Ecological Risk Assessment for the Southampton Island Area of Interest

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by

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Acronyms and Abbreviations

AIS	Automatic Identification System
AOI	Area of Interest
BCB	Bering-Chukchi-Beaufort
CO	Conservation Objective
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CSAS	Canadian Science Advisory Secretariat
CWS	Canadian Wildlife Service
DFO	Fisheries and Oceans Canada
DNA	Deoxyribonucleic Acid
DWT	Deadweight Tonnage
EBSA	Ecologically and Biologically Significant Area
ECCC	Environment and Climate Change Canada
EC-WG	Eastern Canada-West Greenland
ENGO	Environmental Non-Government Organization
ERA	Ecological Risk Assessment
ERAF	Ecological Risk Assessment Framework
ESC	Ecologically Significant Components
HTO	Hunters and Trappers Organization
IMO	International Maritime Organization
IUCN	International Union for Conservation of Nature
kHz	kilohertz
km	kilometre
MARPOL	International Convention for the Prevention of Pollution by Ships
MBES	Multibeam Echosounder
MBS	Migratory Bird Sanctuary
mg/L	milligrams per liter
MPA	Marine Protected Area
MPC	Marine Planning Conservation
MV	Motor Vessel
NE	Northeast
NIS	Non-Indigenous Species
OSPAR	Oslo/Paris Convention for the Protection of the Marine Environment of the Northeast Atlantic
PAH	Polycyclic Aromatic Hydrocarbons
ROV	Remotely Operated Vehicle
RV	Research Vessel
SARA	*Species at Risk Act*
SE	Southeast
SI	Southampton Island
SIMEP	Southampton Island Marine Ecosystem Project
SPL	Sound Pressure Level
TBT	Tributyl-Tin
TC	Transport Canada
UAV	Underwater Autonomous Vehicle
WAF	Water Accommodated Fraction
WWF	World Wildlife Fund

Abstract

Bone, B., Friesen, J., Gagliardi, K., Holst, M., Koski, W.R., Lang, A.L., Moulton, V.D., Penney-Belbin, S., Sharkey, C., and Tucker, A. 2024. Ecological Risk Assessment for the Southampton Island Area of Interest. Can. Tech. Rep. Fish. Aquat. Sci. 3632: xvii + 524 p.

The Southampton Island Area of Interest (SI AOI), located in the Kivalliq Region of Nunavut, is being considered for Marine Protected Area (MPA) designation under the *Oceans Act*. The AOI supports several species of marine mammals and seabirds, marine and anadromous fishes, and important kelp bed and polynya habitat. The area also supports culturally significant activities, including harvesting, for nearby Inuit communities. This ecological risk assessment evaluates the potential risk that human activities pose to the AOI's important species and habitats (i.e., conservation priorities). Activities considered here include those currently occurring or that may occur in the foreseeable future (i.e., within 10 years): shipping and vessel traffic, submarine cables, scientific research, recreation and tourism, and fisheries and harvesting. Risk scores (low, moderate, moderately-high, or high) were assessed semi-quantitatively or qualitatively by investigating the consequence and likelihood of interactions between activities (and their associated stressors) and conservation priorities. Submarine cable installation resulted in a high risk score to sessile benthic invertebrates. Noise disturbance from large moving vessels resulted in moderately-high risk scores to walruses and cetaceans. Habitat alteration from Digby dredge gear resulted in moderately-high risk scores to benthic invertebrates and walruses. DFO and partners will use this document to inform regulatory decisions about which activities should be allowed or mitigated, should an MPA be established.

Résumé

Bone, B., Friesen, J., Gagliardi, K., Holst, M., Koski, W.R., Lang, A.L., Moulton, V.D., Penney-Belbin, S., Sharkey, C., and Tucker, A. 2024. Ecological Risk Assessment for the Southampton Island Area of Interest. Can. Tech. Rep. Fish. Aquat. Sci. 3632: xvii + 524 p.

Le site d'intérêt de l'île Southampton, situé dans la région de Kivalliq, au Nunavut, est envisagé pour la désignation comme zone de protection marine (ZPM) en vertu de la *Loi sur les océans*. Le site d'intérêt abrite plusieurs espèces de mammifères marins et d'oiseaux marins, des poissons marins et anadromes, ainsi que d'importants lits de varech et habitats de polynie. La région soutient également des activités culturelles importantes, y compris la récolte, pour les collectivités inuites voisines. La présente évaluation des risques écologiques porte sur le risque potentiel que les activités humaines posent pour les espèces et habitats importants dans le site d'intérêt (c'est-à-dire les priorités en matière de conservation). Les activités prises en compte ici comprennent celles qui se produisent actuellement ou qui pourraient se produire dans un avenir prévisible (c'est-à-dire d'ici 10 ans) : le trafic maritime et les navires, les câbles sous-marins, la recherche scientifique, les loisirs et le tourisme, ainsi que la pêche et la récolte. Les cotes de risque (faible, modéré, modérément élevé ou élevé) ont été évaluées semi-quantitativement ou qualitativement grâce à l'examen des conséquences et de la probabilité d'interactions entre les activités (et leurs facteurs de stress connexes) et les priorités de conservation. L'installation de câbles sous-marins a donné lieu à une cote de risque élevé pour les invertébrés benthiques sessiles. Les perturbations sonores provenant de grands navires en mouvement ont donné lieu à des cotes de risque modérément élevé pour les morses et les cétacés. La modification de l'habitat par les engins de drague Digby a donné lieu à des cotes de risque modérément élevé pour les invertébrés benthiques et les morses. Pêches et Océans Canada (MPO) et ses partenaires utiliseront ce document pour éclairer les décisions réglementaires concernant les activités qui devraient être autorisées ou atténuées, dans l'éventualité où une ZPM est établie.

1.0 Introduction

The Southampton Island Area of Interest (SI AOI), which was identified in 2019[1], is being considered for designation as a Marine Protected Area (MPA) under Canada's *Oceans Act* (1996). Fisheries and Oceans Canada (DFO) has conducted an ecological risk assessment (ERA) for the SI AOI, which will be needed to advance regulatory decisions (i.e., which activities could be allowed to continue and which should be mitigated or prohibited) should an *Oceans Act* MPA be established. Undertaking an ERA to identify risks to the conservation priorities of an MPA is a fundamental step in the MPA establishment process.

The ERA is a systematic and transparent process for gathering, evaluating, and recording information on the risks posed by human activities to conservation priorities within a study area. Only those human activities that are occurring or may occur in the SI AOI and which could reasonably be mitigated through regulation were considered. The risk assessment for the SI AOI was based on an Ecological Risk Assessment Framework (ERAF) developed by DFO Arctic region, which provides a consistent approach for calculating risk of impact to Arctic ecosystems. This ERA was developed in consideration of a draft Pathways of Effects (PoE) report (Johnson et al. unpublished[2]), a Canadian Science Advisory Secretariat (CSAS) peer-review process that was held on the assessment November 1-3, 2022, as well as a review meeting with local experts from Coral Harbour and Chesterfield Inlet held March 21-24, 2023. The final risk assessment report was developed by DFO's Marine Planning and Conservation (MPC) program and will inform discussions with partners on the regulatory intent and design of a potential future MPA.

1.1 Objectives

Oceans Act MPA regulations are designed to protect a set of site-specific conservation priorities. MPA regulations typically include a general prohibition to prevent removal or harm to species and/or habitats, some form of zoning scheme, activity approval requirements (e.g., for research or commercial tourism), and class exceptions to the general prohibition (e.g., national security, certain low impact fishing activities, etc.).

The ERA for the Southampton Island AOI provides important information about activities that may be allowed to continue and the activities that should be mitigated or prohibited in a potential future MPA. The findings from this assessment will also help to identify activities and associated interactions that may require enhanced management and monitoring post MPA designation.

1.2 Overview of the Southampton Island AOI

The SI AOI is in the Kivalliq Region of Nunavut and is located west of Hudson Strait and between northwestern Hudson Bay and southwestern Foxe Basin (Figure 1-1). The community of Coral Harbour (Salliq) is located on southern SI in South Bay and the community of Chesterfield Inlet (Igluligarjuk) is also located adjacent to the boundaries of the AOI. Three other communities (Naujaat, Baker Lake, and Rankin Inlet) are located near the SI AOI. These five communities can only be accessed by air or vessels that transit the AOI. The AOI boundary represents an area of interest to guide more detailed assessments, with final boundaries of a potential MPA being decided based upon results of those assessments of the area.

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[1] See Loewen et al. (2020b) for an overview of how and why the SI AOI was selected.

[2] Johnson et al. 2019. Pathways of effects modelling for the ecological and biological components of the Southampton Island Area of Interest. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/nnn. vi + xx p.

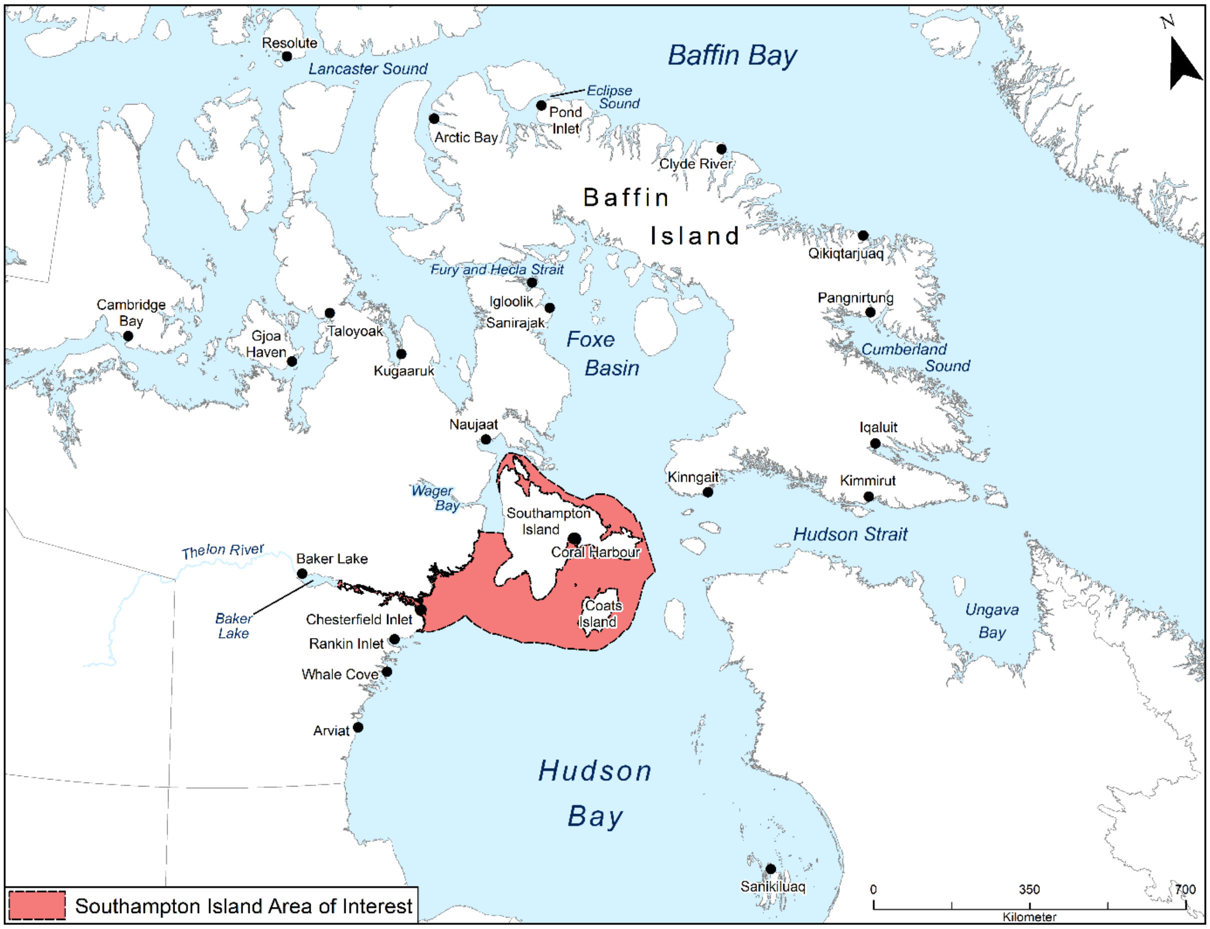

Figure 1-1. Southampton Island AOI, a site being considered for Marine Protected Area designation under the *Oceans Act*. The AOI is located in northern Hudson Bay in the Kivalliq Region, Nunavut.

As described in Loewen et al. (2020a,b) key reasons the area, encompassing the nearshore ocean around Southampton Island and Chesterfield Inlet, was selected as an AOI were because it provides important habitat for several species of marine mammals, seabirds, and marine and anadromous fishes. More specifically, the SI AOI provides valuable migratory habitat for bowhead whale *Balaena mysticetus*, narwhal *Monodon monoceros*, and beluga *Delphinapterus leucas*, as well as feeding and calving areas for a proportion of these marine mammal populations. The AOI hosts aggregation areas for polar bears *Ursus maritimus*, Atlantic walruses *Odobenus rosmarus rosmarus*, and large numbers of seabirds (Cobb 2011). The SI AOI supports large numbers of nesting seabirds during spring and summer, including Thayer's gull *Larus glaucoides thayeri* and thick-billed murre *Uria lomvia*. Marine conservation values within the SI AOI extend into two Migratory Bird Sanctuaries (MBS): the Harry Gibbons (Ikkattuaq) MBS, and the East Bay (Qaqsauqtuuq) MBS. The largest single colony of common eiders *Somateria mollissima* in Nunavut is located in East Bay (Qaqsauqtuuq). In addition, anadromous Arctic char *Salvelinus alpinus* are the most abundant salmonid that is available for subsistence harvesting to Inuit communities living adjacent to the SI AOI. The Roes Welcome Sound polynya is tidal and wind driven, serving as an important corridor for mixing waters from Foxe Basin, as well as a marine mammal and human transportation corridor (Babb et al. 2022; Loewen et al. 2020b). Tidally-driven currents support high benthic primary production, mainly as benthic macroalgae, within Roes Welcome Sound (Goldsmit et al 2021; Filbee-Dexter et al. 2022; Castro de la Guardia et al. 2023). The ERA focuses on these key species and areas within the SI AOI that make the area ecologically unique and rich; see Section 3.0 and the ecological and biophysical overview report (Loewen et al. 2020b) and supplement to the overview report (Loewen et al. 2020a) for additional details on the ecological significance of the AOI.

2.0 Ecological Risk Assessment Overview, Approach, and Scoping

2.1 Overview

The objective of this ERA is to determine the potential risks that human activities (and their associated stressors) pose to the AOI's specific conservation priorities and to provide important information about which activities may be allowed to continue and which activities should be mitigated or prohibited in a potential future MPA. The ERA process began with characterizing both the conservation priorities and relevant human activities in the study area and determining their potential for interaction. A semi-quantitative risk analysis was then conducted by assessing the consequence of potential interactions between each activity/stressor and conservation priorities by estimating the magnitude of each interaction and the degree to which each ecological component is sensitive to the activity/stressor. The estimated level of consequence was then combined with the likelihood (i.e., probability) of the stressor interacting with the conservation priority to determine the overall level of risk (ISO 2009). As information on fisheries potential of hitherto unexploited resources in the SI AOI is currently limited, assessments in Section 9.2 Fisheries and Harvesting used a fully qualitative approach. The aspects outlined above were considered qualitatively and a final risk score (low, moderate, moderately-high, or high) was provided for each assessment in this section.

MPAs are designated to conserve and protect ecological integrity including biodiversity, ecosystem function, productivity, and the special natural features identified for each site, so tolerance for risk within an MPA is lower than for other areas. Thus, the risk scores presented here do not necessarily represent typical assessment of risks for the same activities elsewhere in the ocean.

2.2 Approach

This section includes an overview of the steps taken to complete the risk assessment process for Southampton Island AOI and how each piece fits into the overall process.

1) Background biophysical and ecological overviews of the Southampton Island Area of Interest

Developed by DFO Science

- Ecological and Biophysical Overview of the Southampton Island Ecologically and Biologically Significant Area in support of the identification of an Area of Interest (Loewen et al. 2020b).
- Supplement to the biophysical and ecological overview for Southampton Island (SI) EBSA to include additional areas within the Southampton Island Area of Interest (AOI) (DFO 2020a).
- Identification of Ecological Significance, Potential Conservation Objectives, Knowledge Gaps and Vulnerabilities for the Southampton Island Ecologically and Biologically Significant Area (DFO 2020b).

These reports provided a comprehensive overview of the most current and available scientific information for the area, including information to support the identification of priorities for conservation (i.e., ecologically significant species and community properties, termed Ecologically Significant Components "ESC") and the identification of priority areas. The reports provide a summary of stressors and vulnerabilities within the area, along with suggested conservation objectives (i.e., the stated goals of the potential MPA).

DFO MPC also commissioned a facilitated Inuit Qaujimajatuqangit workshop to help characterize the importance of the area to Inuit. The workshop report complements the DFO Science overview.

- Southampton Island Area of Interest: Assessment Phase Inuit Qaujimajatuqangit Workshop (Idlout 2020)

2) Pathways of Effects Assessment

Developed via external contract (North/South Consultants Inc.) with revisions by DFO (MPC and Science); Spring – Fall 2021

A Pathways of Effects (PoE) report (Johnson et al. unpublished[3]) for the SI AOI was drafted and revised following a peer review process from Spring to Fall 2021. The report was reviewed by an internal DFO working group comprising DFO MPC, Science, and Fisheries Management sector practitioners, and coordinated by CSAS, but was not a formal CSAS peer review (e.g., did not result in the production of science advisory documents). The purpose of the PoE report was to identify existing and potential human activities (e.g., vessel traffic) and global drivers (e.g., climate change), their associated stressors (e.g., vessel strikes, habitat alteration), and the mechanisms (or 'pathways') by which these stressors could cause effects (e.g., injury or direct mortality) to the 'endpoint' level (i.e., ESCs) and then further, to the subcomponent of each ESC (e.g., narwhal or forage fish). ESCs were 'unpacked' into ESC subcomponents to facilitate the exercise. For example, the ESC endpoint "Anadromous fish species and other subsistence foods" includes the Arctic char, beluga, narwhal, Atlantic walrus, bowhead whale, ringed seal *Pusa hispida*, and bearded seal *Erignathus barbartus* subcomponents (Johnson et al. unpublished[3]). PoE assessments represent the first step in an ERA process in that they comprehensively outline all potential pathways through which human activities may affect a study area. In contrast, the next stage identifies which of those pathways pose a potentially measurable impact to the area's ESC subcomponents and examines these in greater detail to inform which activities should be allowed, mitigated, and prohibited in a potential MPA.

3) Development of an Arctic Ecological Risk Assessment Framework

Developed by DFO MPC with input from Science and Fisheries Management (FM); Summer – Fall 2021

While national guidance on ecological risk assessment for the purpose of MPA establishment was evolving at the time, existing draft guidance and a number of other sources such as ecological risk assessments for other *Oceans Act* MPAs, existing Science advice (CSAS findings and other reports), and published literature informed the development of an Arctic Region ERAF.

The DFO Arctic Region ERAF incorporated the likelihood and the consequence of an interaction between and activity/stressor and an ESC subcomponent (see Section 4.0). The consequence was scored by evaluating the exposure and the sensitivity of an ESC subcomponent to a stressor.

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[3] Johnson et al. 2019. Pathways of effects modelling for the ecological and biological components of the Southampton Island Area of Interest. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/nnn. vi + xx p.

Exposure was determined based on spatial (depth, areal) and temporal overlap, and intensity. Sensitivity was based on expected acute and chronic changes and the subcomponent's inherent ability for recovery (i.e., the recovery factors). The output of the risk equation was an overall risk ranking of low, moderate, moderately-high, or high.

4) Ecological Risk Assessment scoping and development of draft risk scores

Developed by DFO MPC with contractor input (LGL Ltd.) January – September 2022

Every interaction identified in the draft SI AOI PoE assessment (Johnson et al. unpublished[4]) underwent an initial qualitative level 1 assessment to determine if the interaction was expected to result in measurable impact to the ESC subcomponent (adapted from O et al. 2015). This determination was based on the best available literature and subject matter expertise of DFO and LGL biologists, inferred from other areas or species where appropriate. Additionally, where there was no spatial or temporal overlap in the occurrence of a human activity and an ESC subcomponent, the interaction did not proceed past a level 1 assessment. The determination of an 'interaction' took into account the exposure pathway being active and assumed some level of measurable impact; where no measurable impact was expected, interactions did not proceed past a level 1 assessment. This process was iterative, and reviewers (see Step 5 below) were also given the opportunity to provide input on the level 1 assessments. In cases where reviewers requested that additional details be provided around this determination, the rationale was outlined in the introductory sections for each activity or sub-activity. Level 1 assessments allow the assessors to improve the efficiency of the process and to focus effort on those interactions that are more likely to require mitigation measures (O et al. 2015). Where an interaction was expected to potentially result in a measurable impact, a semi-quantitative or qualitative level 2 assessment was undertaken following the method outlined in Section 4.0. Some interactions proceeded to a level 2 assessment based on recommendation by SI AOI partner communities. Qualitative level 2 assessments (in Section 9.0 Fisheries and Harvesting) considered the same factors as the semi-quantitative level 2 assessments and only a final risk score was provided for each interaction. Assessments were undertaken in consideration of residual risk, and took into account existing and effective management measures. If evidence existed that current management measures are not effective, consideration of the best available knowledge to this effect was included in the assessment.

In some cases, ESC subcomponents were modified or added (see Table 2-1 and Section 3.0) from the original list outlined in the PoE report (Johnson et al. unpublished[4]). Thayer's gull and barren-ground caribou (*Rangifer tarandus groenlandicus*) were added as ESC subcomponents and "kelp" was replaced with "kelp beds and other macroalgae". "Open water associated with polynyas" was changed to "polynya habitat", and the subcomponents "landfast ice" and "ice edges" were combined into the more inclusive "sea ice", allowing consideration of both landfast and mobile sea ice. Certain 'habitat characteristic' ESC subcomponents identified in the PoE report (i.e., Southward inflow of Arctic Ocean water from Fury and Hecla Strait; Westward inflow of water from the Atlantic Ocean via northern Hudson Strait; Eastward outflow of water to the Atlantic Ocean via southern Hudson Strait; mixing water masses; wind forcing; and deep water formation) were not included in the risk assessment as they are facets of the physical environment and assessments investigated the biotic subcomponents that are associated with these features.

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[4] Johnson et al. 2019. Pathways of effects modelling for the ecological and biological components of the Southampton Island Area of Interest. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/nnn. vi + xx p.

5) CSAS peer review meeting for the draft ERA for the SI AOI (November 1-3, 2022)

Led by DFO CSAS office and based on draft risk assessment

This process included a comprehensive review of the draft ecological risk assessment which included the following activities: shipping and vessel traffic; scientific research; recreation and tourism; and submarine cables. Internal DFO and external subject matter experts were invited to peer review:

1. information used to assess interactions involving ESC subcomponents, and identified stressors in their identified priority areas (i.e., has the most relevant and appropriate information been used and has it been correctly interpreted);
2. resulting risk scores associated with each interaction; and
3. level of uncertainty for each interaction (i.e., has it been appropriately characterized/assessed).

Advice received through the CSAS meeting informed the final ERA for SI AOI.

6) Local expert review workshop for the draft Ecological Risk Assessment for the Southampton Island AOI (March 21-24, 2023)

Led by DFO MPC based on draft risk assessment

The ecological risk assessment is rooted in western science and is not necessarily intuitive to Inuit ways of knowing. Therefore, the review of this assessment by local experts from Coral Harbour and Chesterfield Inlet was accomplished using a workshop format that occurred over four days and investigated where the two "stories of risk" did and did not overlap (see the workshop Record of Discussion for a fulsome overview; DFO 2023a). The workshop included review of the following activities: shipping and vessel traffic; scientific research; recreation and tourism; submarine cables; and directed harvesting. The Aiviit and Aqigiq Hunters and Trappers Organizations (HTOs) nominated two and three experts respectively who participated in the workshop. Confirmation of the ecologies and behaviours of the ESC subcomponents was sought using maps produced during the SI AOI Inuit Qaujimajatuqangit workshop and by sharing the ecological and behavioural assumptions about the ESCs that were incorporated into the assessment (e.g., known sensitivities, distribution, and seasonal occupation). Discussions were focused on interactions of greatest interest to participants as well as interactions with ESC subcomponents on which participants had particular expertise. The framework was discussed at a high level, focusing on the general aspects that were considered in assessments (e.g., spatial and temporal overlap between stressor and ESC, sensitivity of the ESC) and avoiding semantic discussions about definitions. Specific interactions were introduced by summarizing the assessment tables into a few sentences which captured the main points driving the overall risk score; input was solicited on these main points and the overall risk score. In general, there was a great deal of overlap between the "stories of risk" from DFO's draft assessment and from the local experts. Input was incorporated into the final Ecological Risk Assessment for the Southampton Island AOI.

7) Final Ecological Risk Assessment report

Developed by DFO MPC with support from LGL Ltd. and review by DFO Science and FM sectors and external experts

The final ecological risk assessment report for the SI AOI incorporated the various pieces of the risk assessment process (i.e., as outlined above), as well as other knowledge streams and relevant information where available, to provide a comprehensive assessment of those activities which may pose a significant risk to the AOI's ESC subcomponents.

The fishing gear assessments (Section 9.2) were developed during this step as these activities did not have well-defined scenarios like the other activities, and thus required additional investigation and thought as to the assessment approach. Beyond nearshore gillnets used in the Arctic char fishery, none of these gears is in widespread use in the area, and limited baseline information is available regarding the populations of marine resources in the AOI and whether and at what scale they could viably support new fisheries. Despite not being in current widespread use, it was deemed important to assess these gears, as local communities are interested in exploring fisheries potential and want the opportunity to develop fisheries in the area. DFO's CSAS office completed a coordinated review of Section 9.2 by DFO Science and Fisheries Management reviewers with relevant expertise on the assessed species and habitats and those with appropriate knowledge of the gears. In addition, reviews were conducted by colleagues from Environment and Climate Change Canada (ECCC) with relevant knowledge of seabirds.

During this step, additional review was provided by Transport Canada on the interactions regarding Pathogens/non-indigenous species (NIS) introductions via ballast water discharge and biofouling of vessels.

The results herein will be used to inform which activities could be allowed and which activities should be mitigated or prohibited within an *Oceans Act* MPA, should one be established in the area.

Table 2-1. ESCs for SI AOI and their associated ESC subcomponents. ESCs were identified by DFO (2020 a,b) and subcomponents are outlined in Johnson et al. (unpublished[5]). ESC subcomponents were the focus of this risk assessment. Asterisk denotes a subcomponent added or modified from the original list in the PoE report for the risk assessment process (see #4 above). No subcomponents from ESC 1 were assessed.

Ecologically Significant Component (ESC)	Applicable ESC Subcomponents
1. Intersection of several water masses	• Southward inflow of Arctic Ocean water from Fury and Hecla strait • Westward inflow of Arctic Ocean water via northern Hudson strait • Eastward outflow of water to the Atlantic Ocean via southern Hudson Strait • Mixing of water masses • Wind forcing • Deep water formation
2. Winter habitat in Roes Welcome Sound Polynya, including the coastal polynya at the mouth of Chesterfield Inlet	• Phytoplankton • Sea ice* • Polynya habitat* • Kelp beds and other macroalgae*
3. Migration corridor for beluga, bowhead, narwhal, and harp seal	• Beluga • Bowhead • Narwhal • Harp seal
4. Marine mammal (beluga, narwhal, bowhead, and polar bear) seasonal residence (feeding), calving and denning areas	• Beluga • Narwhal • Bowhead • Polar bear
5. Year-round resident marine mammals (walrus, bearded seal, ringed seal, and polar bear) and their prey species	• Walrus • Bearded seal • Ringed seal • Polar bear • Arctic cod • Other forage fish (e.g., capelin) • Benthic invertebrates
6. Anadromous fish species and other subsistence foods	• Arctic char • Marine mammals (beluga, narwhal, bowhead, walrus, bearded seal, ringed seal, harp seal) • Other forage fish (e.g., capelin) • Barren-ground caribou*
7. Seabirds and their prey species	• Common eider • Thayer's gull* • Thick-billed murre • Other seabirds • Arctic cod • Other forage fish (e.g., capelin) • Benthic invertebrates • Zooplankton
8. Macroalgae as habitat	• Kelp beds and other macroalgae*
9. Benthic biodiversity	• Benthic invertebrates • Kelp beds and other macroalgae*

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[5] Johnson et al. 2019. Pathways of effects modelling for the ecological and biological components of the Southampton Island Area of Interest. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/nnn. vi + xx p.

Ecologically Significant Component (ESC)	Applicable ESC Subcomponents
	• Benthic substrate

2.2.1 Conservation Objectives

Oceans Act MPA conservation objectives are statements that describe the desired and measurable state of the conservation priorities to achieve conservation goals. As the conservation objectives for the SI AOI were not yet finalized at the beginning of the ERA process, the risk assessment approach focused on evaluating ESCs by their individual subcomponents (defined in Section 2.2 and listed in Table 2-1). This approach allowed greater flexibility as ESCs inform the development of conservation objectives.

2.2.2 Data Gaps

There is a moderate amount of scientific information available for the natural environment of the SI AOI compared to other regions of the Arctic; however, information is limited for lower trophic level communities (e.g., phytoplankton, zooplankton), macroalgae, benthic invertebrates, forage fish community composition and distribution, and for some marine mammals. While this limitation is acknowledged, the *Oceans Act* and DFO's guiding principles promote the use of a precautionary approach. In the absence of scientific certainty, conservation measures can and should be taken when the best available information suggests risk of serious impact to the environment, and a lack of certainty should not act as a reason to postpone or fail to take action to preserve the marine environment.

The most significant knowledge gaps for the SI AOI are discussed in greater detail by Loewen et al. (2020b) and DFO (2020a, b), and it is recognized that a lack of information specific to this area was a limitation when estimating ecological risks. As marine protection in the SI AOI is further advanced, it is expected that this will create additional support and opportunities for concerted data collection within the area. MPA establishment allows for increased monitoring of components of the conservation objectives, in turn addressing significant data gaps and thresholds that are meant to inform on additional pressures as they arise. In addition, *Oceans Act* MPA management and monitoring plans are living documents that are reviewed and updated on a regular basis. Adaptive co-management would allow plans to change in response to new or changed pressures, and provide opportunity to incorporate measures for species or ecological features that were previously undetected/unidentified. As such, future risk assessments may be more detailed and precise with regards to the risk to the conservation objectives of the area.

For this risk assessment, in cases where there was no or limited direct evidence of impacts of a given stressor to the species or habitats in the SI AOI, evidence from other areas of the Arctic and/or other species was used to inform the development of risk scores. In some instances, the final assessment relied heavily on the experience of subject matter experts as the best available information to support the assessment.

2.2.3 Global Drivers of Environmental Effects

Across the circumpolar Arctic, several global phenomena have been identified which are having a range of impacts on terrestrial, freshwater, and marine ecosystems and habitats. The most significant of these include climate change, ocean acidification, globally-sourced contaminants, and the influx of marine debris from movement of ice and water masses; these "wide-ranging (global) drivers" and their effects in the study area are discussed in greater detail in Johnson et al. (unpublished[6]).

Climate change poses a substantial ecological threat to the AOI as it is driving fundamental change to the biological and physical ecosystem components, such as prey availability and timing of sea ice break-up and formation. While a protection measure in the AOI can prohibit activities that may exacerbate climate change impacts to that region, managing and/or mitigating climate change and its impacts themselves requires action at a global scale. In this assessment, climate change was not assessed as a stand-alone stressor for which to investigate risk. Similarly, the import of globally-sourced contaminants and marine debris are phenomena which require broad coordinated efforts to manage at the international level, beyond the scope of management measures that could be implemented as part of the creation of an *Oceans Act* MPA. As such, these drivers were not considered in this assessment as stand-alone entities for which risk was evaluated.

2.3 Scoping

An important first step of ERA is scoping (Fletcher 2005; Hobday et al. 2011; DFO 2012), which includes defining the spatial and temporal bounds of the assessment, along with the ESC subcomponents and human activities that will be assessed.

2.3.1 Spatial Scope

The geographic extent of this ERA was defined by the SI AOI boundary (Figure 2-2).

The spatial scope of the interactions assessed was not always taken to be the entire AOI and was not consistent among all interactions. The AOI encompasses a large area (93,087 km^2) and different parts of the AOI exhibit different ecologies. This was recognized in Loewen et al. (2020a,b) with the identification of priority areas, which were integral in outlining the ESCs for the SI AOI (Figure 2-3). Thus, the ESCs manifest differently in different parts of the AOI, with the same ESC subcomponents (e.g., Arctic char, beluga) using multiple priority areas in different seasons and for different purposes. Moreover, the intensity of the various stressors resulting from human activities is not spatially or temporally homogenous across the entire AOI. For these reasons, taking the spatial scope of the interactions being assessed to always be the entire AOI could result in a diluted risk level. As the risk assessment will form the foundation for discussions on the regulatory intent of a potential future MPA, diluted risk level results could translate into regulations that would not adequately protect the ESCs. Therefore, many of the interactions assessed were spatially scoped to one of the priority areas, selected according to the priority area in which the ESC subcomponent was most vulnerable and/or in which the stressor (i.e., activity/sub-activity) was densest. The resulting risk scores can be applied to other areas where the ESC occurs, providing a precautionary level of risk to form the basis of discussion around regulations. As existing information on fisheries-related resources is currently limited, assessments in Section 9.0 were not spatially restricted to priority areas.

For greater clarity, the AOI and any future MPA would exist only in the marine environment and not extend past the low water mark. Therefore, features that occur on land but in close proximity to the ocean, such as communities, seabird colonies, and walrus haul-outs, are adjacent to, and within the outer boundaries of, the AOI.

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[6] Johnson et al. 2019. Pathways of effects modelling for the ecological and biological components of the Southampton Island Area of Interest. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/nnn. vi + xx p.

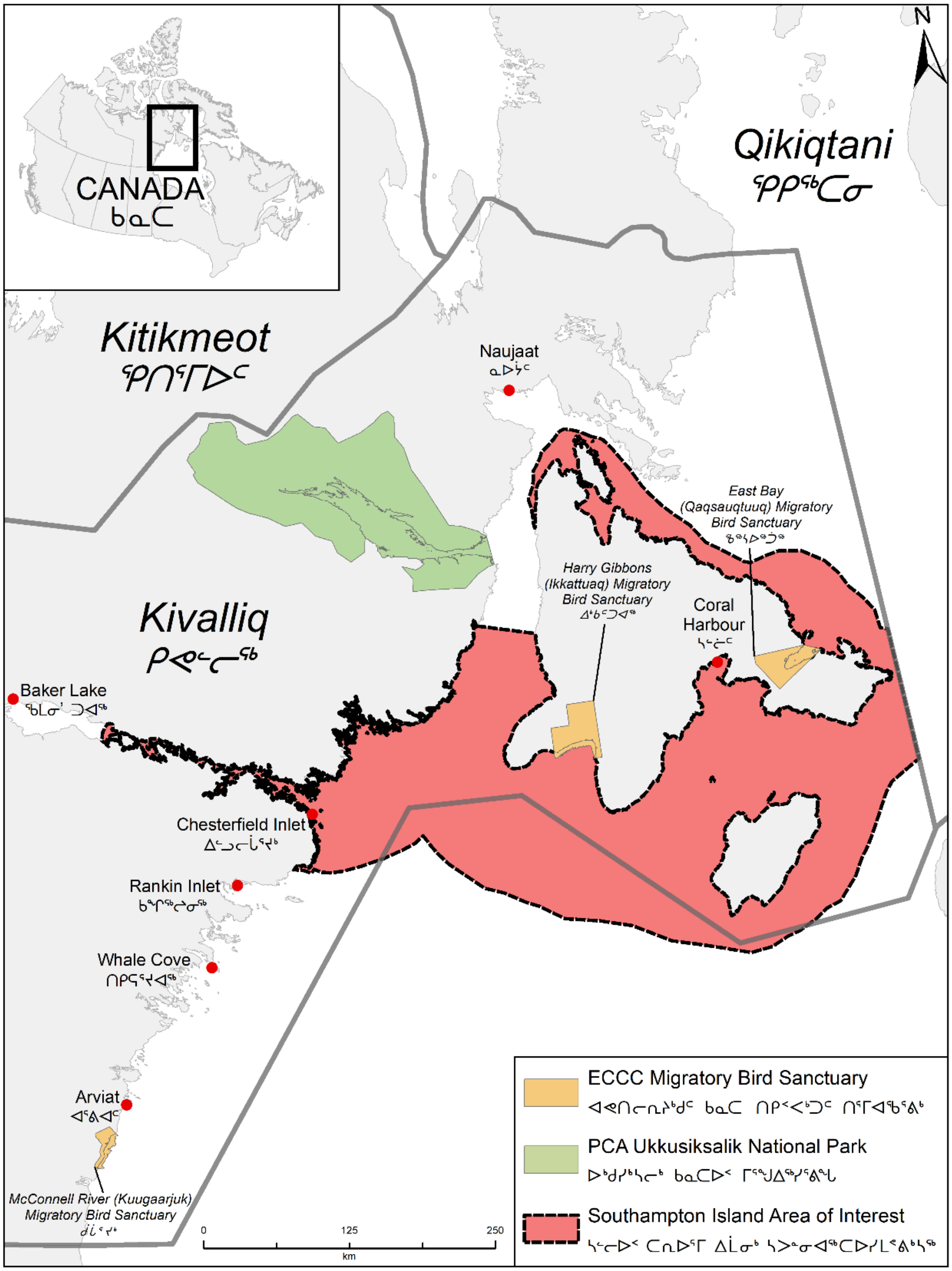
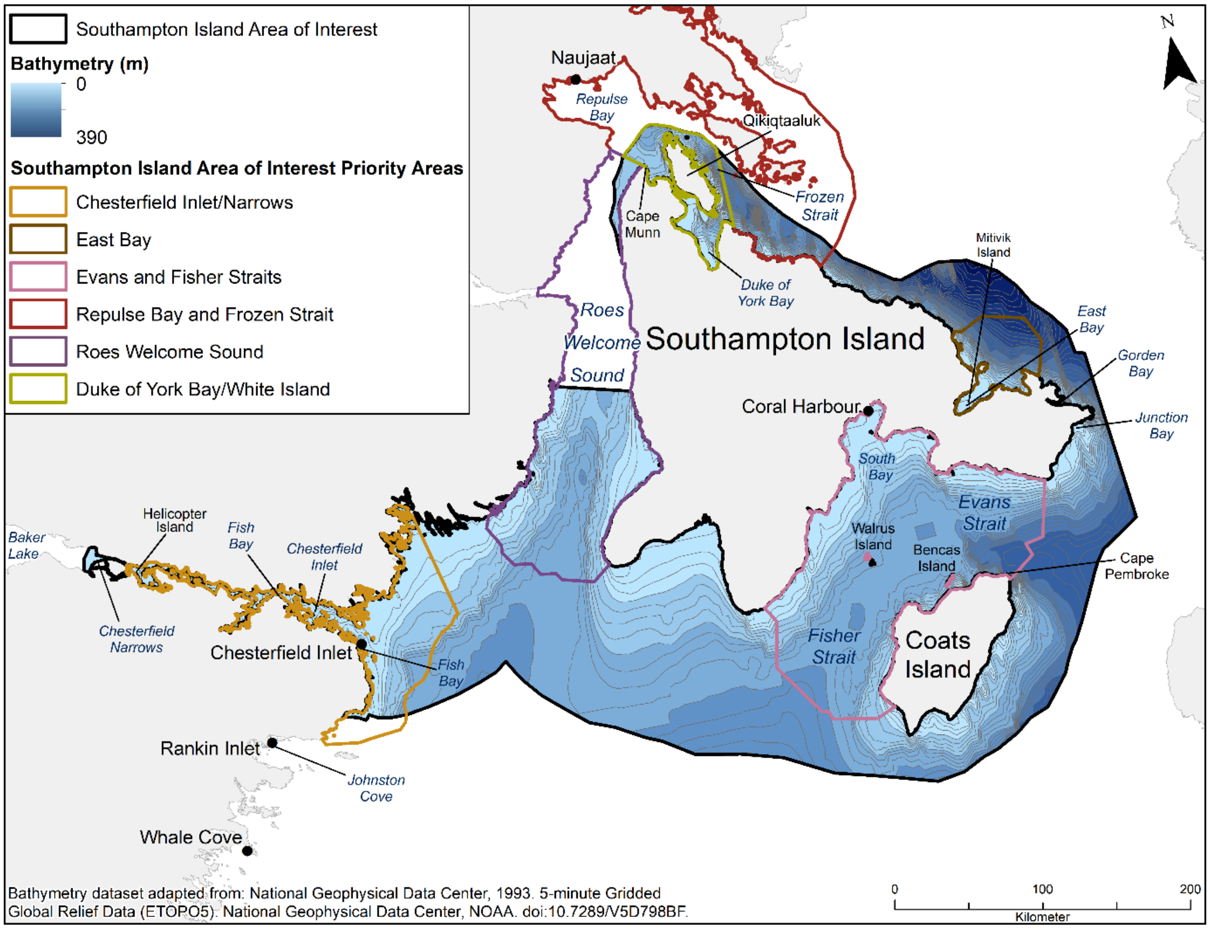


Figure 2-1. Southampton Island AOI and nearby protected areas. Grey line denotes the boundary among the three regions of Nunavut. ECCC = Environment and Climate Change Canada. PCA = Parks Canada Agency.



Bathymetry dataset adapted from: National Geophysical Data Center, 1993. 5-minute Gridded Global Relief Data (ETOPO5). National Geophysical Data Center, NOAA. doi:10.7289/V5D798BF.

Figure 2-2. Priority areas for the Southampton Island AOI, including where they extend outside the AOI boundary: Chesterfield Inlet/Narrows, Roes Welcome Sound, Duke of York Bay extending around White Island, Repulse Bay/Frozen Strait extending to Lyon Inlet, Fisher and Evans Straits, and East Bay. Duke of York Bay and Repulse Bay/Frozen Strait priority areas overlap along the northeast and southeast sides of Qikiqtaaluk. Note: Qikiqtaaluk may be referred to as “White Island” in other publications.

2.3.2 Temporal Scope

Generally, the ERA examines activities that are existing and/or ‘foreseeable’. The temporal bound for a foreseeable activity is 10 years from present, as beyond this the information to support an assessment would be more speculative. Existing activities were assessed at the extent (i.e., level and density) that they currently occur. If there is demonstrated interest in increasing the level of an activity (e.g., a project proposal), these were considered in the assessment. In certain cases, where there were no definite plans for an activity within the 10-year timeframe (including fisheries and harvesting), plausible future scenarios informed the assessments. These assumptions were outlined where relevant in the sections below.

2.3.3 Scoping of Activities

The ERA considers five primary types of activities: 1) shipping and vessel traffic; 2) submarine cables; 3) scientific research (data collection); 4) recreation and tourism; and 5) fisheries and harvesting. These activities were deemed to be within the scope of the assessment and likely to have a measurable impact on one or more ESC subcomponents. The scope of these activities is discussed in detail in their respective sections later in the report. Appendix A provides a tabular summary of all activities/sub-activities and ESC subcomponents which underwent an ERA.

Proxy assessments were used in some instances to increase the efficiency of the risk assessment. Where a stressor manifested from multiple pathways in a similar manner, the assessment of one pathway may cover the other assessment by proxy (e.g., habitat alteration by Digby dredge fishing gear can cover the assessment of habitat alteration by bottom otter trawl fishing gear). The most sensitive species in an assemblage (e.g., pinnipeds, forage fish) were used as a proxy for other assessments in the same assemblage where appropriate. See the overview of ESC subcomponents (Section 3.0) and introductory text for each activity (Sections 5.0-9.0) for additional details on proxy assessments.

Several activities examined in the PoE report (Johnson et al. unpublished[7]) were scoped out of the ERA: hydroelectric development; infrastructure development; mining within the AOI (both terrestrial and marine); and municipal wastes—wastewater, solid waste/litter/debris. Rationale for excluding activities from the ERA is provided in Appendix B.

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[7] Johnson et al. 2019. Pathways of effects modelling for the ecological and biological components of the Southampton Island Area of Interest. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/nnn. vi + xx p.

3.0 Overview of ESC Subcomponents

This section provides brief biological and life history overviews of the ESC subcomponents analyzed in the ecological risk assessment (Table 3-1). For more thorough overviews, see Loewen et al. (2020a,b) and DFO (2020a). This section also discusses the link between the ESC subcomponents and their uses of and distribution in priority areas as well as any clarification on how an ESC subcomponent was considered in the assessment, if necessary. Priority area associations and interaction summary tables are available in Appendix A.

3.1 Beluga Whale

Belugas are a white medium-sized toothed whale, weighing up to 1,500 kg and reaching lengths of 5.5 m (O'Corry-Crowe 2009). They lack a dorsal fin, instead using their dorsal ridge to break through thin ice and are well adapted to cold arctic waters with insulating blubber reaching 15 cm in thickness (O'Corry-Crowe 2009). Belugas are long-lived mammals, reaching up to 80 years of age (Stewart et al. 2006). Belugas that occur in the AOI belong to the Western Hudson Bay stock with the most recent abundance calculations estimating 54,473 individuals (Mathews et al. 2017). Beluga are believed to remain near river mouths in spring to feed on migrating Arctic char *(*GN 2011, 2012). They have also been reported to eat sculpin, Arctic cod (*Boreogadus saida*), Atlantic salmon (*Salmo salar*), capelin (*Mallotus villosus*), sand lance *(Ammodytes* sp.)*,* herring (Clupeidae), and crustaceans (Breton-Honeyman et al. 2016). They generally migrate into the AOI in May/June, with most belugas continuing towards locations along western Hudson Bay. However, some belugas remain in the AOI throughout the summer until they migrate back out in early-late September at which point they are joined by larger numbers returning from western Hudson Bay. During their occupation of the AOI belugas feed and migrate along the southern part of Southampton Island in Fisher and Evans Straits including South Bay, and have been spotted around Duke of York Bay, East Bay, Gorden Bay, and from Junction Bay to Allinataaq Lake (Loewen et al. 2020a, b; Idlout 2020). East Bay, Duke of York Bay, and possibly Roes Welcome Sound are calving grounds for these animals; their gestation is 14-14.5 months long and they generally bear a single calf that takes 2 years to rear (O'Corry-Crowe 2009; Idlout 2020). Priority area associations and interaction summaries available in Table A-1.

3.2 Narwhal

Narwhals are a medium-sized toothed whale, with males characteristically carrying a unique spiraled tusk that can grow to 3 m in length and females tusked in rare instances (Heide-Jørgensen 2018; Garde and Heide-Jørgensen 2022). These marine mammals can grow to 4.5 m in length and 1600 kg in weight and may live for up to 100 years (Garde et al. 2015; Heide-Jørgensen 2018). Narwhals that occur in the AOI belong to the Northern Hudson Bay population with the most recent abundance calculations estimating 19,232 individuals, less abundant than the genetically distinct Baffin Bay population (DFO 2015a; Watt et al. 2020a). Narwhals forage largely on Arctic cod and shrimp, but consume squid (*Teuthida* spp.), capelin, wolffish (*Anarhichas lupus*), sculpins (C*ottoidea* spp.), and skate as well (Heide-Jørgensen et al. 2006). Watt et al. (2013) documented a heavier reliance on benthic prey for narwhals that occur in the AOI than other narwhal populations. They migrate into important feeding areas of Repulse Bay, Lyon Inlet, Duke of York Bay, and Frozen Strait in June and July and out in August and September through Frozen Strait (Idlout 2020; Loewen et al. 2020a, b). Roff et al. (2020) also identified foraging that occurs in the Chesterfield Inlet/Narrows and Fisher and Evans Straits priority areas. Important calving and rearing habitat was identified throughout much of the summer feeding range within the AOI (Higdon 2017). Mating occurs in May-June and calving occurs in June-August with a gestation of 11-15 months, and calves are reared for 1-2 years; female narwhals are believed to calve every 3 years (Heide-Jørgensen and Garde 2011). The Repulse Bay/Frozen Strait priority area is a critical migratory pathway, summer feeding, and calving/rearing area for narwhals. Summer feeding and calving/rearing may occur throughout much of the AOI and has been noted in the Duke of York Bay/White Island and Chesterfield Inlet/Narrows priority areas and extends into the Fisher and Evans Straits priority area. Priority area associations and interaction summaries available in Table A-2.

3.3 Bowhead Whale

Bowhead whales are large, long-lived baleen whales weighing up to 100 tons (100,000 kg) and with a life span estimated at over 200 years (George et al. 1999; George et al. 2021). Populations were depressed due to commercial whaling from the 1500s to early 1900s though estimates now indicate some recovery (COSEWIC 2009; Witting 2014). Whales that occur in the AOI belong to the Eastern Canada-West Greenland population, which is assessed as *special concern* by COSEWIC (COSEWIC 2009) though is not listed under the *Species at Risk Act* (2002). Recent abundance calculations place the population size at 7,660 (Mathews et al. 2017). There is no dietary information for bowhead directly in the AOI, but stomach analyses show they consume calanoid copepods, mysids, and euphausiids (Lowry et al. 2004; Pomerleau et al. 2012). Most individuals migrate westward into the AOI in April and May, through Fisher and Evans Straits, through Roes Welcome Sound and into Repulse Bay, Lyon Inlet, and Frozen Strait, with a return fall migration from September through November (Idlout 2020; Loewen et al. 2020a, b). Some bowheads stay in the AOI all summer to feed, and some areas in Evans Strait and the Duke of York Bay have been observed as calving areas (GN 2012; Higdon 2017). Priority area associations and interaction summaries available in Table A-3.

3.4 Atlantic Walrus

The walrus is one of the largest species of pinniped with limbs developed into flippers, and upper canine teeth that develop into long tusks made of ivory (Higdon et al. 2022). Male and female walruses can reach weights of 1,100 kg and 800 kg, respectively. Walruses that occur in the AOI belong to the Hudson Bay-Davis Strait stock with the most recent abundance calculations estimating 7,100 individuals (Hammill et al. 2016a). Walruses are primarily bottom feeders, foraging in sediments on the ocean floor for mollusks and other invertebrates, primarily in water less than 80 m deep (Fay 1982; Outridge et al. 2003; Dietz et al. 2013). On occasion, larger prey such as seals may be consumed. For example, walruses were observed foraging on thick-billed murres at Coats Island (Mallory et al. 2004). They are considered long-lived mammals and can live for up to 40 years. Walruses are known to have delayed sexual maturation and fairly low reproductive rates, so they are considered vulnerable to environmental changes and over-harvesting (COSEWIC 2006). Walruses occur in the AOI year-round, undertaking primarily local movements around Southampton Island. Known terrestrial haul-out locations within the AOI boundary include islands in Fisher and Evans Straits (i.e., Bencas, Coats, and Walrus Islands) and the south coast of Southampton Island, NW Southampton Island, and Depot Island near Chesterfield Inlet. They are known to occupy mobile pack ice and polynyas in Roes Welcome Sound and at the mouth of Chesterfield Inlet in the winter. Priority area associations and interaction summaries available in Table A-4.

3.5 Ringed, Bearded, and Harp Seal

Ringed seals play an important role in the trophic dynamics of Arctic marine ecosystems, acting as the primary prey of polar bears and through the consumption of marine fish and invertebrates (Lowry et al. 1980; Smith 1987). This species is distributed across the circumpolar Arctic and is closely linked to sea ice (Lowry 2016b; Reeves 1998). Ringed seals in Hudson Bay consume a variety of prey and are known to target marine fishes, such as sand lance and Arctic cod, pelagic invertebrates such as amphipods, and benthic invertebrates such as decapods (Stirling 2005; Chambellant 2010; Amiraux et al. 2023). This species commonly occurs year-round in the AOI, with distribution closely linked to the occurrence of landfast ice (Loewen et al. 2022a). Thus, ringed seals are distributed throughout much of the AOI, including the Roes Welcome Sound area (GN 2011), Duke of York Bay, the eastern and southern coasts of Southampton Island, and along floe edges (GN 2012). A pupping area has been identified near Coral Harbour in Evans Strait (Idlout 2020).

Bearded seal population densities are generally lower throughout their range than that of ringed seals (Stirling et al. 1982; Bengtson et al. 2005; Stephenson and Hartwig 2010) and their distribution is patchy (Smith 1981). Preferred habitat includes areas of open water generally no greater than 100m deep along with mobile ice (Mansfield 1963). Foraging dives targeting benthic prey are facilitated by shallow waters, and moving ice allows a platform for resting, moulting, and birthing young (Kovacs et al. 1996). They are year-round residents of the AOI and move throughout to find their preferred habitat (GN 2012). Bearded seals are benthic-feeding generalists; though dietary information specifically for the SI AOI is not known, they feed on decapods, mollusks, Arctic cod and other fish elsewhere in Hudson Bay and the Northwest Territories (Smith 1981; Dehn et al. 2007; Loewen et al. 2020b). Bearded seals occur in Duke of York Bay and around the northern tip of Southampton Island, and along southern Southampton Island in Fisher and Evans Straits (GN 2012). It has also been reported that they overwinter in South Bay near Coral Harbour and in Roes Welcome Sound (GN 2012; Loewen et al. 2020b).

Harp seals (*Pagophilus groenlandicus*) are migratory and generally found in the Hudson Bay complex and other Arctic locations only during the open-water period, with those that occupy Hudson Bay remaining there from early June to early October (Collins 1983; Stewart and Barber 2010). They overwinter in the Gulf of St Lawrence and Newfoundland, migrating north in spring as the sea ice retreats (Mansfield 1963). Harp seal diets are variable and include more than 100 species of invertebrates and fish, with some of the more important being polar and Arctic cod, capelin, amphipods, and euphausiids (Mansfield 1963; Reijnders et al. 1993). During summer they occur in low numbers in Fisher and Evans Straits along the south coast of Southampton Island as far west as southern Roes Welcome Sound (Sergeant 1965, 1976; Collins 1983; Stewart and Lockhart 2005) and into Chesterfield Inlet in fall (Idlout 2020). Harp seals make up a very small proportion of the total number of harvested seals in and near the AOI (DFO 2023a) and important areas for harp seal generally overlap with those identified for ringed and bearded seals. In addition, unlike ringed and bearded seals, harp seals do not pup or mate in the AOI. Therefore, assessments of ringed and bearded seals will adequately represent the phocids that occur in the AOI and dedicated interactions for harp seals were not included. Priority area associations and interaction summaries available in Table A-5.

3.6 Marine and Anadromous Fishes (Arctic Char, Arctic Cod, and Other Forage Fish)

Arctic char, as well as Arctic cod and other forage fish species (e.g., capelin), are important in the diets of higher trophic level species, including marine mammals and seabirds (Loewen et al. 2020b). Arctic char are important subsistence harvest species for the communities adjacent to and in the vicinity of the AOI and are targeted in commercial fisheries by those communities.

Arctic char are generally diadromous fish (migratory between fresh and salt waters) with elongate and moderately laterally compressed bodies that can attain total lengths of 100 cm, with great variation in morphology and colour (Coad and Reist 2018). Though non-diadromous, lake resident forms are known in the AOI, Arctic char typically migrate from freshwater systems into the marine environment in June where they remain throughout the open water period to feed (GN 2012). Arctic char forage on smaller fish, including Arctic cod, capelin, and sand lance, and invertebrates (primarily amphipods) throughout the open water period, returning in August to freshwater lakes to spawn and overwinter (GN 2012; Coad and Reist 2018; Loewen et al. 2020b). Arctic char generally occupy nearshore environments when in marine waters, with tagging indicating a preference to remain within 1,500 m of the coastline (Moore et al. 2016). Arctic char are known to occur throughout the AOI with higher densities noted in the Chesterfield Inlet/Narrows and Repulse Bay/Frozen Strait priority areas and minimal occurrences along the west coast of Southampton Island in Roes Welcome Sound (GN 2012; Loewen et al. 2020b).

Arctic cod are a small-bodied benthopelagic fish in the family Gadidae, with adults generally around 25 cm and up to 40cm in total length (Coad and Reist 2018). They are ubiquitous throughout the Canadian Arctic, occupying coastal and offshore waters, and areas without sea ice, though they rely on sea ice for spawning and rearing at their early life history stages (Coad and Reist 2018). Arctic cod spawn under the sea ice and on the sea-bed with a peak in January and February (Coad and Reist 2018). As Arctic cod are reliant on sea ice for habitat it is noted that changing environmental conditions leading to decreasing sea ice cover will likely impact Arctic cod populations and distribution (Hop et al. 1997; Gaston and Elliott 2014). They play a particularly important role in Arctic marine food webs, transferring energy from their main diet of ice-associated copepods and amphipods to higher trophic level species (Bain et at. 1977; Hop et al. 1997; Coad and Reist 2018; Idlout 2020). For example, a change in the diet of thick-billed murre from primarily Arctic cod to capelin (1981-2013), coinciding with a reduction in summer sea ice, resulted in a decline in chick growth rates (Gaston and Elliott 2014). This species is abundant in coastal areas off of Southampton and Coats Islands and in particular Fisher and Evans Straits, though it is noted that the distributions of marine fishes, including Arctic cod, are not well characterized for the AOI (Loewen et al. 2020a, b).

Other forage fish in the AOI include capelin and sand lance, with a full list of known marine fishes and distribution maps provided in Loewen et al. (2020b). Forage fish play an important role in the transfer of energy between lower and higher trophic levels, critical in the diets of other fish, seabirds, and marine mammals (Coad and Reist 2018; Idlout 2020). Capelin are an important forage species during their spawning season (generally June-August) in North Atlantic waters (Gulka et al. 2017) and have been noted in the stomachs of belugas and narwhals and along with sand lance in the stomachs of thick-billed murre and Arctic char (Watt et al. 2013; Gaston and Elliott 2014; DFO 2020a; Loewen et al. 2020b). As environmental conditions including sea ice extent and open water period change due to the warming climate, a shift has been seen in the diets of higher trophic level organisms such as seabirds, with capelin displacing Arctic cod as the primary component of the diet (Gaston and Elliott 2014). As conditions continue to change, the dominant forage fish species consumed by higher trophic level predators may shift to sub-Arctic associated species such as capelin, as it has done in thick-billed murre (Gaston and Elliott 2014). Though Arctic cod are a forage fish they have been identified as a separate ESC subcomponent and will not be included in the other forage fish subcomponent. In most cases, considering the importance of Arctic cod as a forage species and the relative lack of information for other forage fish in the AOI, other forage fish were assessed by proxy through the assessment on Arctic cod. The distribution of other forage fish is poorly described in the AOI. However, there are records of sand lance and capelin in the Fisher and

Evans Straits and Chesterfield Inlet/Narrows priority areas, with capelin also noted in Roes Welcome Sound. Priority area associations and interaction summaries available in Table A-6.

3.7 Polar Bear

Polar bears have a circumpolar distribution in ice-covered Arctic waters and occur in low densities throughout their range (DeMaster and Stirling 1981; Stirling 2009). They are highly dependent on sea ice as a platform used for hunting and feeding, ranging widely during periods of ice cover to find prey, retreating to land during the open water period where they fast until the ice returns (Stirling 2009). Polar bears inhabiting the Southampton Island area belong to the Foxe Basin subpopulation and though bears show seasonal and annual home range fidelity, studies suggest that some mixing of bears from Hudson Strait, Hudson Bay, and Foxe Basin occurs in the Southampton Island area (Sahanatien et al. 2015; Viengkone et al. 2016, 2018). The current size of the Foxe Basin subpopulation is estimated to be ~ 2,585 individual bears (Stapleton et al. 2016). Ringed seals make up a large proportion of polar bear diets in Foxe Basin, however other species of seal, walrus, seabirds, seabird eggs, and bowhead whales are also consumed (Galicia et al. 2016). Bowhead whale carcasses washed ashore may contribute important seasonal foraging opportunity in the summer when bears would otherwise be fasting (Galicia et al. 2016). The AOI provides foraging habitat for polar bears and denning habitat is located on land adjacent to the AOI. Dens have been noted near East Bay and along the northern coast of Southampton Island (Florko et al. 2020), near the Repulse Bay/Frozen Strait and Duke of York Bay/White Island priority areas. In winter and spring bears are usually found at the interface between open water and ice - in areas such as mobile pack ice and along the floe edge - where hunting success is greater (Stirling 2009). Though foraging behaviour is variable, some bears on Southampton Island occupy the landfast ice in Fisher and Evans Straits until breakup, then cross the island to East Bay or migrate north along the coast (Iverson et al. 2014). Bears also occupy the floe edge in Frozen Strait in spring, moving to coastal areas in summer (GN 2012; Loewen et al. 2020b). Priority area associations and interaction summaries available in Table A-7.

3.8 Sea Ice and Polynya Habitat

Sea ice influences many ecosystem processes in the Arctic, providing spawning (e.g., Arctic cod) and pupping habitat (e.g., ringed seal), hunting and resting platforms (e.g., polar bears), dictating migratory routes and timing (e.g., thick-billed murres), and affecting inputs such as light and freshwater (Coad and Reist 2018; Loewen et al. 2020b; Bruneau et al. 2021; Patterson et al. 2021; Gupta et al. 2022). Sea ice around Southampton Island is annual and with the exception of polynyas, waters of the AOI are ice-covered during winter and ice-free in the summer (Loewen et al. 2020b). Though local variations are present, ice break-up generally begins in late June moving towards ice-free in August, with ice formation beginning in November and ice-coverage nearly complete by December (Loewen et al. 2020b). Mobile pack ice may comprise up to 90% of the sea ice in the Hudson Bay complex and is similarly dominant in the AOI, with landfast ice occurring along the shores of Southampton Island (Loewen et al. 2020b; Gupta et al. 2022). Considering the above, the ESC subcomponent “landfast ice” as identified in the PoE report was changed to the more inclusive “sea ice” for the risk assessment, allowing consideration of both landfast and mobile sea ice. Additionally, an ice bridge forms approximately every four years just south of Wager Bay which may contribute to the formation of the Roes Welcome Sound polynya and provides a transportation pathway for Inuit and wildlife from the mainland to Southampton Island (Babb et al. 2021). Roes Welcome Sound was chosen as the priority area for the sea ice assessments due to its importance in sea ice formation and the intermittent presence of the ice arch (Loewen et al. 2020b; Bruneau et al. 2021; Babb et al. 2022).

Sea ice will be assessed independently and as a component of polynya habitat, as discussed below.

Polynyas are areas of persistent open water and/or thin sea ice where otherwise thicker ice cover would be expected (DFO 2020a; Bruneau et al. 2021) and are ecologically important areas hosting increased primary productivity and feeding opportunities by higher trophic level organisms (Stirling and Cleator 1981; Loewen et al. 2020b). Polynyas are classified as either latent heat (i.e., ice is continually removed from an area by wind or currents) or sensible heat (i.e., ice formation is inhibited by the presence of warm water at depth) according to the dominant process involved in its formation, though they can involve influence from both factors (Morales Maqueda et al. 2004; Bruneau et al. 2021). In this risk assessment polynyas will be treated as habitat that includes the open water area and the sea ice in and surrounding the polynya, considering three ESC subcomponents as identified in the PoE report: open water associated with polynyas, ice-edge, and sea ice (changed from the less inclusive term landfast ice, see above). As such, a new ESC subcomponent, polynya habitat, was added to the list identified in the PoE report. The Roes Welcome Sound polynya, its benthic and primary productivity, and the higher trophic levels it supports are the primary reason that Roes Welcome Sound was chosen as a priority area for the AOI (DFO 2020a). This polynya is formed primarily due to the continuous movement of ice away from the landfast ice edge via wind. There is also a coastal polynya that occurs along the western coast of Hudson Bay, the northern edge of which extends into the Chesterfield Inlet/Narrows priority area, and smaller polynyas in Repulse Bay/Frozen Strait priority area (DFO 2020a; Bruneau et al. 2021). This polynya is primarily formed due to turbulence in the area from strong water currents. Available AIS data (Maerospace 2020) indicates that vessel traffic is low in all priority areas during winter when polynyas occur, though vessel traffic density is higher in Chesterfield Inlet/Narrows throughout the rest of the year and more likely to overlap with polynya habitat. Therefore, assessments on polynya habitat will be conducted in the Chesterfield Inlet/Narrows priority area and used as a proxy for polynya habitat in Roes Welcome Sound and Repulse Bay/Frozen Strait. Priority area associations and interaction summaries available in Table A-8.

3.9 Kelp Beds and Other Macroalgae

Kelp beds and other macroalgae provide structural complexity to the benthos and are important habitats for benthic and epibenthic species (Ordines et al. 2011; Teagle et al. 2017). Fish and invertebrates rely on macroalgal habitat for critical stages of their life cycle, including recruitment, feeding, growth, and reproduction (Ordines and Massuti 2009). Thus, by hosting lower trophic level species macroalgal beds support higher trophic level feeding as well. Seabirds and migratory birds, such as common eider (and the black guillemot), forage for organisms that are supported by macroalgal habitat (Keats et al. 1993; Idlout 2020). Kelp detritus also contributes significantly to marine food webs, providing a significant proportion of carbon in suspension feeders and indirectly supporting higher trophic levels (Dunton and Schell 1987; Duggins et al. 1989; Krumhansl and Scheibling 2012).

Kelp species common in the AOI include *Saccharina latissima*, *S. longicruris* (found to be the same species as *S. latissima), Agarum clathratum*, Laminaria *solidungula*, and *Alaria esculenta* occurring at water depths from 5 to 50 m (Loewen et al. 2020b; DFO 2020a; Filbee-Dexter et al. 2022). Other macroalgal species are also present; for example, the coralline algae *Lithothamnion* sp. occurs in the Chesterfield Inlet/Narrows priority area (Misiuk and Aitken 2020) and the brown alga *Saccorhiza dermatodea* and dulse *Palmaria palmata* occur in Roes Welcome Sound and Fisher and Evans Straits, respectively (Filbee-Dexter et al. 2022). A total of 132 species of benthic algae have been documented throughout the greater Hudson Bay Complex (Lee 1980). Though it is acknowledged that other macroalgal species may form biogenic habitats in the AOI, the importance of kelp in particular is noted (DFO 2020a; Loewen et al. 2020b; Filbee-Dexter et al. 2022); therefore, the interactions involving this ESC subcomponent will focus on kelp. Kelp abundance in the Eastern Canadian Arctic and western Greenland is significantly influenced by the ice cover, substrate, salinity, and water depth, with higher densities at 10 and 15 m compared with 5 m (Krause-Jensen et al 2012; Filbee-Dexter et al. 2022). Around Southampton Island, kelp depth extent is strongly and positively correlated with the number of open water days with daylight, and kelp cover reaches a maximum at around 20 m depth (Castro de la Guardia et al. 2023). Roes Welcome Sound, Chesterfield Inlet/Narrows, Fisher and Evans Straits, and Repulse Bay/Frozen Strait are priority areas identified as having high densities of kelp, though it occurs throughout much of the nearshore habitat of the AOI (DFO 2020a,b; Idlout 2020; Filbee-Dexter et al. 2022). Priority area associations and interaction summaries available in Table A-9.

3.10 Phytoplankton and Zooplankton

Phytoplankton primary production is at the base of the marine food web and is a key driver of zooplankton and ichthyoplankton dynamics (Svensen et al. 2019) while zooplankton are critical links to higher trophic level consumers such as macroinvertebrates, fish, seabirds, and marine mammals (Loewen et al. 2020b). Phytoplankton occur in the euphotic zone of the water column with sea ice playing a large role in light availability; the euphotic zone is restricted to the upper approximately 50 m in Hudson Bay near Southampton Island (Matthes et al. 2021). Similar to other oceanic Canadian waters, depending on bloom stage, Arctic waters are dominated by diatoms and dinoflagellates (Archambault et al. 2010). Since many species of zooplankton consume phytoplankton, they are tightly coupled to the strong seasonality in primary production and shifts in timing or abundance can rapidly affect populations (Grainger 1959). When environmental conditions, including light levels, water column mixing, and sea ice cover, change in the spring, phytoplankton communities increase in number (Matthes et al. 2021), referred to as a bloom. As zooplankton are highly responsive to food availability and feed on phytoplankton, the numbers of zooplankton typically increase in response to the spring phytoplankton bloom (Grainger 1959; Estrada et al. 2012; Svensen et al. 2019; Matthes et al. 2021). The reaction of zooplankton is dependent on the species type (Grainger 1959), and in some cases zooplankton numbers may increase only in the summer with a second peak occurring in the fall (Svensen et al. 2019). Phytoplankton likely occur in all priority areas and throughout the AOI with conditions such as light levels and sea ice cover influencing their density in a given location at various times of the year. There are multiple areas throughout the AOI that have been identified for their high primary productivity, including Frozen Strait (Kitching 2022), Roes Welcome Sound (Matthes et al. 2021; Kitching 2022), the northwestern coastal polynya that includes the mouth of Chesterfield Inlet (Matthes et al. 2021).

Vessels at rest near Chesterfield Inlet are a concern raised by the community and therefore the risk from disturbance from artificial light on zooplankton was assessed in the Chesterfield Inlet/Narrows priority area. Vessels are known to remain at rest for prolonged periods during the open water period from late July through mid-October (Maerospace 2020), corresponding to longer periods of darkness from August onwards. It is anticipated that any management measure that would be implemented to protect an area of high primary productivity would also confer benefits to the zooplanktonic grazers. Considering the information outlined above, phytoplankton were assessed and will act as a proxy for the assessment of zooplankton for each discharges sub-activity. Priority area associations and interaction summaries available in Table A-10.

3.11 Benthic Invertebrates

A number of factors influence the distribution and abundance of benthic organisms, including substrate type, water depth, sea ice scouring, physical and chemical properties of the water column, and food availability (Cusson et al. 2007; Loewen et al. 2020b). Among Canada's marine ecoregions, Hudson Bay is among several hotspots of biodiversity for marine benthic invertebrates (Wei et al. 2020). Though sampling has been fairly limited, at least 430 taxa have been identified within or near the AOI with amphipods, polychaetes, gastropods, hydrozoans, and bryozoans demonstrating higher diversity among major taxa (Loewen et al. 2020a, b). Benthic invertebrates are expected to occur throughout the AOI, with certain areas expected to be more diverse or productive; Roes Welcome Sound polynya has been identified as having potentially high benthic richness due to pelagic-benthic coupling (Kenchington et al. 2011). In an assessment of epifaunal communities throughout Hudson Bay, Pierrejean et al. (2020) documented high diversity and biomass at stations within or adjacent to the southern boundaries of the AOI associated with mixed substrate or located near polynyas. Misiuk and Aitken (2020) combined historical and contemporary data to investigate the benthic community over a small area near Chesterfield Inlet. The authors defined distinct benthic environments via a combination of presence of benthic organisms and substrate texture; common organisms included barnacles *Balanus balanus*, sea urchins *Strongylocentrus droebachiensis*, and sponges. As the benthic invertebrate community throughout the AOI is not well characterized and the availability of information regarding possible effects on benthic invertebrates is inconsistent among stressors, assessments considered numerous different species. As benthic invertebrates are a noted concern of members of the community of Chesterfield Inlet and vessel traffic density is high in the region relative to some other portions of the AOI, the majority of interactions were assessed in this priority area.

Corals and sponges, notable as important taxa contributing to biogenic habitat for many other species of invertebrates and fish, have been identified in the AOI (Misiuk and Aitken 2020; Pierrejean et al. 2020). Considering their importance to ecosystem function where they occur, known susceptibility to anthropogenic stressors (DFO 2015b; Montagna and Girard 2020), and limited ability for recovery (Henry and Hart 2005; Girard et al. 2018), as well as the evidence that cable installation has limited negative impacts on mobile benthic invertebrate species (Andrulewicz et al. 2003; Kogan et al. 2006), corals and sponges were chosen as the representative benthic invertebrates for the assessment on habitat alteration/removal due to the installation of submarine cables. It should be noted that some laboratory evidence exists that the dominant coral type in the AOI, soft corals, are less vulnerable to disturbance than sea pens or gorgonian corals (Henry et al. 2003). Priority area associations and interaction summaries available in Table A-11.

3.12 Marine Birds (Thick-billed Murre, Thayer's Gull, Common Eider)

It is estimated that thick-billed murres are the most abundant marine bird species in the Canadian Arctic with 30,000 nesting pairs on Coats Island alone (Gaston et al. 2012). While most colonies in the Canadian Arctic appear stable (Gaston et al. 2012), there are declining trends for this species in some Arctic regions (e.g., Greenland; Merkel et al. 2014). They occur in the AOI from mid-May to October, foraging in marine waters from two sub-colonies at Coats Island (Mallory et al. 2018; Patterson et al. 2021). These birds—most originating from a single colony near Cape Pembroke on Coats Island—feed primarily on Arctic cod, capelin, and marine invertebrates, undertaking foraging dives as deep as 92 m (Elliott et al. 2009). Gaston and Elliott (2014) described a shift in diet from 1981-2013 from Arctic cod to capelin, resulting in lower chick growth rates. In August and September, adult murres undergo a post-breeding moult where they become flightless and are thus particularly vulnerable. Along with the use of Fisher and Evans Straits for feeding and brood-rearing, thick-billed murre feed in Roes Welcome Sound priority area during late summer (DFO 2020a; Patterson et al. 2022). Foraging ranges around the colonies have been identified as important habitat to support these colonies (Mallory et al. 2019). No other priority areas have been identified as important for this species.

Thayer's gull (a subspecies of Iceland gull) occur in the SI AOI from mid-May to early-October, wintering on the west coast of North America (DFO 2020a; Goudie et al. 2020). They breed in colonies of 50-100 nests on coastal cliffs and are known to have colonies on White Island and the NE coasts of Southampton Island (DFO 2020a). Thayer's gull forage over open water among pack ice or close to shore and on beaches (Richards and Gaston 2018) pulling their prey from the ocean surface without landing, and feed predominantly on fish, mussels, snails, large zooplankton, carrion, fish remains, plants, and berries. They may winter at the edges of polynyas and along coasts (DFO 2020a). Thayer's gull feed and brood-rear in the Duke of York Bay/White Island area, and presumably near colonies on the NE coast of Southampton Island which may include the East Bay priority area. No other priority areas have been identified as important for this species. There are several other gull species that nest in the region and thus rely on the marine environment in the AOI, including glaucous gulls *L. hyperboreus*, herring gulls *L. argentatus*, and Sabine's gulls *Xena sabini* (Stenhouse and Robertson 2005; Baak et al. 2021a; Baak et al. 2021b).

Common eider are a large bodied sea duck that occur seasonally in the AOI from mid-June to September (Loewen et al. 2020b). The largest Eider colony in the Canadian Arctic occurs in East Bay and they inhabit coastal areas in the northern portion of the AOI (DFO 2020a). Shortly after hatching, the young leave the nest to forage in the marine environment, attended by the adult female (Goudie et al. 2000). Common eider feed on mollusks, gastropods, and crustaceans that occur in inshore coastal waters less than 10 meters deep (Cramp 1980). Common eider forage and brood-rear in the East Bay priority area; no other priority areas have been identified as important for this species. The East Bay common eider population has declined in recent years due to avian cholera (Descamps et al. 2012; Henri et al. 2018) and polar bear predation (Iverson et al. 2014).

Other seabirds was also identified as an ESC subcomponent in the PoE report. No assessments were undertaken directly on species beyond the three mentioned above; risks to other seabirds may be inferred from the assessments on common eider, thick-billed murre, and Thayer's gull. See appropriate scoping rationale throughout Sections 5-9 for additional details. Priority area associations and interaction summaries available in Table A-12.

Table 3-1. Summary of ESC subcomponents assessed in the Southampton Island Area of Interest ecological risk assessment.

ESC (Refer to Table 2-1)	ESC Subcomponent	General Distribution	Timing	Key Habitat	Life History Events/Importance	Reference(s)
8,9	Macroalgae	Coastal regions between 5-50 m depth	Occurs in AOI year-round	Rocky sediments, and also soft sediments (i.e., sand/clay) with few cobbles. Highest densities at 10 and 15 m compared with 5 m. Important areas identified within/near Chesterfield Inlet and southern Southampton Island during Inuit Qaujimajatuqangit workshop. Also in Roes Welcome Sound and Frozen Strait.	Relatively short growing season (open-water period in summer)	Krause-Jensen et al. 2012; Carvalho et al. 2019; Idlout 2020; DFO 2020a; Filbee-Dexter et al. 2022
2	Phytoplankton	Occurs throughout AOI	Occurs in AOI year-round	Photic zone (generally limited to upper 80 m in the Arctic)	Highly productive spring bloom in Repulse Bay and Frozen Strait, Roes Welcome Sound, and Chesterfield Inlet.	Loewen et al. 2020b; Matthes et al. 2021; Kitching 2022
7	Zooplankton	Occurs throughout AOI	Occurs in AOI year-round	Throughout water column	Abundance increases with onset of phytoplankton bloom	Loewen et al. 2020b
5,7,9	Benthic invertebrates	Occur throughout AOI	Occur in AOI year-round	Benthic substrate and kelp beds; Pierrejean et al. (2020) documented high diversity and biomass at stations associated with mixed substrate or located near polynyas.	Strong pelagic-benthic coupling in the region; organic (plankton) material sinks to seabed in the fall	Lapoussière et al. 2013; Carvalho et al. 2019; Loewen et al. 2020b; Pierrejean et al. 2020
5,6,7	Other forage fish	Occur throughout AOI	Occurs in AOI year-round	Throughout water column; Chesterfield Inlet region is important habitat for marine and anadromous forage fish, including as feeding grounds and a migration corridor	Seasonal migrations to spawning/feeding grounds, depending on species and life stage	DFO 2020a; Loewen et al. 2020a, b

ESC (Refer to Table 2-1)	ESC Subcomponent	General Distribution	Timing	Key Habitat	Life History Events/Importance	Reference(s)
5,6,7	Arctic char	Shallow coastal waters with patchy distribution; do not occur along west coast of SI	Mainly occurs in coastal waters during summer (June-August)	Coastal waters within 1,500 m from shore	Feeding in AOI during open-water period in summer; spawn in rivers	Moore et al. 2016; Loewen et al. 2020a, b; DFO 2020a
5,7	Arctic cod	Occurs throughout AOI; most records appear to be off of Southampton and Coats islands, in particular Evans Strait	Occurs in AOI year-round	Coastal and deep waters, ice edges, upwellings, polynyas, nearshore areas, flaw lead features, coastal areas	Eggs and larvae concentrate under the sea ice	Loewen et al. 2020a, b; DFO 2020a
7	Common eider	Thought to occur in northern portion of the AOI; coastal areas; reoccurring polynyas; marine waters <20 m depth	Occurs in AOI from mid-June to September	East Bay	Nesting, brood-rearing, summer feeding	DFO 2020a; Goudie et al. 2020; Loewen et al. 2020b
7	Thayer’s gull	Occurs at least within the northern portion of the AOI; coastal areas; open waters among pack ice	Occurs in AOI from mid-May to early-October	Breeding colonies in the Duke of York Bay/White Island area, and along the northeast portion of Southampton Island which may include East Bay	Nesting, brood-rearing, feeding	Loewen et al. 2020b; Snell et al. 2020
7	Thick-billed murre	Occurs in the southern, western, and eastern portions of the AOI; cliffs; rocky coasts; open waters among sea ice	Occurs in AOI from mid-May to October; present at nesting cliffs on Coats Island from mid-May through July	Nesting cliffs on Coats Island	Nesting, brood-rearing, feeding, flightless moulting, migration	DFO 2020a; Patterson et al. 2021; Loewen et al. 2020b
5,6	Ringed seal	Occurs throughout AOI	Occurs in AOI year-round	Large bays and shorelines of SI where landfast ice occurs and along floe edges	Ice provides platform for pupping, nursing, resting, and moulting. Ringed seals establish breathing holes and lairs. Breeding/foraging also occur in AOI.	Idlout 2020; Loewen et al. 2020b

ESC (Refer to Table 2-1)	ESC Subcomponent	General Distribution	Timing	Key Habitat	Life History Events/Importance	Reference(s)
5,6	Bearded seal	Prefers a combination of moving ice and open water over areas typically <100 m deep	Occurs in AOI year-round	Occurs at northern tip of SI at Cape Munn and in Duke of York Bay, along southern SI and throughout Evans Strait. Likely occur in Roes Welcome Sound polynya.	Ice provides platform for pupping, nursing, resting, and moulting. Breeding/foraging also occur in AOI.	Idlout 2020; Loewen et al. 2020b
3,6	Harp seal	Open-water areas of the AOI	Open-water period	Found along the south coast of SI as far west as southern Roes Welcome Sound and mouth of Chesterfield Inlet. South Bay and possibly Repulse Bay.	Presumably foraging	Idlout 2020; Loewen et al. 2020a, b
5,6	Walrus	Tends to remain in areas where food is most abundant and in water less than 80 m deep.	Occurs in AOI year-round	Bencas, Coats and walrus islands with other haul-out sites on S/NW coasts of SI. Chesterfield Inlet and Roes Welcome Sound area, and the floe edge along the S and E coasts of SI provide winter habitat. Foraging in Fisher/Evans Straits.	Foraging, calving, nursing, mating, and haul-out sites.	Idlout 2020; Loewen et al. 2020a, b
3,4,6	Beluga	AOI is primarily used as a migratory corridor for moving to and from summering areas along western Hudson Bay coast. Small numbers remain in AOI during summer.	Migrate into the AOI in May and June and occur there during summer, with migration out of the AOI beginning in early to late September. Fall migration from Hudson Bay through AOI,	Duke of York Bay, East Bay, Gorden Bay, and from Junction Bay to Allinataaq Lake and in South Bay along southern Southampton Island. Occur near rivers.	Foraging, moulting, migration, calving, and nursing.	Idlout 2020; Loewen et al. 2020a, b

ESC (Refer to Table 2-1)	ESC Subcomponent	General Distribution	Timing	Key Habitat	Life History Events/Importance	Reference(s)
			October through December			
3,4,6	Narwhal	Northern portion of AOI	Migrate into Repulse Bay in June and July and out in August and September through Frozen Strait.	Repulse Bay, Frozen Strait and nearby waters; north coast of SI.	Feeding, calving, migration	Idlout 2020; Loewen et al. 2020a, b
3,4,6	Bowhead whale	Occurs throughout AOI	Westward migration in April and May; summer; with fall migration September through November.	Duke of York Bay and areas around White Island, Repulse Bay, Frozen Strait, Evans Strait.	Feeding, calving, nursing, migration	Idlout 2020; Loewen et al. 2020a, b
4,5	Polar bear	Occurs throughout AOI	Occurs in AOI year-round, but majority of individuals occur on land during the ice-free period in summer	Landfast ice, mobile ice	Hunt seals on ice	Loewen et al. 2020a, b; DFO 2020a
6	Barren-ground caribou	Focal assessment area is Chesterfield Inlet within the AOI.	Barren-ground caribou cross open water of Chesterfield Inlet during summer migration (between July-September).	Traditional crossing points situated at peninsulas, islands, or other natural shoreline features, that minimize open water traverse.	Long-distance migratory movements of barren-ground caribou typically occur during ice-covered periods, though later summer movements require they swim or wade lakes and rivers at optimal fording sites. Barren-ground caribou frequently circumvent large open water bodies or utilize traditional crossing locations.	Williams and Gunn 1982; Leblond et al. 2016

ESC (Refer to Table 2-1)	ESC Subcomponent	General Distribution	Timing	Key Habitat	Life History Events/Importance	Reference(s)
2	Polynya habitat	Polynyas are open areas of water surrounded by ice, but one side can also be adjacent to the coast (e.g., Western Hudson Bay Polynya).	Polynyas typically form in December and merge with surrounding open water in summer, starting in late June	Open water, ice edges, landfast ice, mobile pack ice	Support increased productivity and foraging birds and marine mammals; also provide overwintering areas for birds and marine mammals	Stirling 1980; Arrigo and van Dijken 2004; Loewen et al. 2020b; DFO 2020a
2	Sea ice	Landfast ice occurs along shorelines; also pack ice throughout AOI	Throughout AOI from fall through late spring; melts during summer	Landfast ice, ice edges, moving pack ice	Pupping/resting habitat for seals, platform to forage and den for polar bears	Loewen et al. 2020b; DFO 2020a

4.0 Methods

Every interaction identified in the draft SI AOI PoE assessment (Johnson et al. unpublished[8]) underwent an initial qualitative level 1 assessment to determine if the interaction was expected to result in measurable impact to the ESC subcomponent. This determination was based on the best available literature and subject matter expertise of DFO and LGL biologists, and inferred from other areas or species where appropriate; where no measurable impact was expected interactions did not proceed past a level 1 assessment. Additionally, where there was no spatial or temporal overlap in the occurrence of a human activity and an ESC subcomponent, the interaction did not proceed to a level 2 assessment. This process was iterative and reviewers were also given the opportunity to provide input on the level 1 assessments. In cases where reviewers requested that additional details be provided around this determination, the rationale was outlined in the introductory sections for each activity or sub-activity. Level 1 assessments allow the assessors to improve the efficiency of the process and to focus effort on those interactions that are more likely to require mitigation measures (O et al. 2015). Where an interaction was expected to potentially result in measurable impact, a semi-quantitative or qualitative level 2 assessment was undertaken following the method outlined below. Some interactions resulted in a level 2 assessment based on recommendation by SI AOI partner communities. Qualitative level 2 assessments considered the same factors as the semi-quantitative level 2 assessments and only a final risk score was provided for each interaction. Assessments were undertaken in consideration of residual risk, taking into account existing and effective management measures. If evidence existed that current management measures are not effective, consideration of the best available knowledge to this effect was included in the assessment.

A risk statement was completed for each interaction that underwent a level 2 assessment following this general structure: “If an interaction occurs involving [ESC subcomponent] and [stressor] due to [human activity/sub-activity] the consequences could result in a [negative ecological impact]”. The risk statement focuses the scope of the assessment and orients the reader. Additional details beyond the general stated outline were included where appropriate. For example, if a spatial scope other than the AOI was used (e.g., a priority area), or if the interaction investigated a subset of an activity (e.g., an interaction that investigated a sub-set of vessel traffic, such as Zodiacs/motorboats).

4.1 Overall Risk Equation

Risk = *Consequence* × *Likelihood*
Where: *Consequence* = *Exposure* × *Sensitivity*

Risk for each interaction was assessed by calculating the product of *likelihood* and *consequence*, following international standards (ISO 2009) and other DFO regional ecological risk assessments (Aker et al. 2014; Koropatnick et al. 2023). Each factor was assessed and a rationale was provided to ensure the work is transparent and feedback could be targeted and incorporated efficiently. Each factor (e.g., *areal overlap*, *likelihood*, *expected acute change*; Table 4-1) was assessed using the best available information, from quantitative to qualitative. Inuit Qaujimajatuqangit informed the assessments wherever possible. Geographic Information Systems (GIS) analysis was used to help define the exposure factors, particularly areal and temporal overlap, and intensity.

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[8] Johnson et al. 2019. Pathways of effects modelling for the ecological and biological components of the Southampton Island Area of Interest. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/nnn. vi + xx p.

Table 4-1. Risk factor definitions used in the ecological risk assessment for the Southampton Island Area of Interest.

Risk Factor	Definition
Exposure	Intensity x Temporal x Spatial (Areal x Depth)
Intensity	Persistence or density of the stressor. Focused on current information and/or frequency of the activity (unless assessing a defined hypothetical future scenario).
Temporal	The overlap between the occurrence of the stressor and the occurrence of the ESC subcomponent (when present in the AOI or priority area) measured over the course of one year.
Spatial	Areal x Depth
Areal	2-dimensional spatial overlap between the ESC subcomponent and stressor. The overlap considered the subcomponent's distribution in the AOI or restricted spatial scope (i.e., priority area).
Depth	Vertical overlap between ESC subcomponent and stressor, taking into account terrain barriers.
Sensitivity	(Expected Acute change + Expected Chronic change) x Recovery factors
Acute change	Expected short-term harm (mortality or behavioural impacts) to the ESC subcomponent from the stressor. Effects considered the population as a whole within the AOI or within the restricted spatial scope identified.
Chronic change	Expected long-term harm to the ESC subcomponent from the stressor including indirect effects (e.g., effects to reproductive capacity, chronic toxicity, habitat fragmentation). Effects considered the population as a whole within the AOI or within the restricted spatial scope identified.
Recovery factors	Set of attributes that reflect the ESC subcomponent's (species or habitat) ability to recover from acute/chronic effects (e.g., fecundity, age at maturity, population status, connectivity, resilience).
Consequence	Exposure x Sensitivity = Binned score
Likelihood	Probability that the stressor will interact with the ESC subcomponent, considering the expected effect of the interaction based on existing data (where available) and consideration of existing management measures.
Output (overall risk)	*Consequence* and *Likelihood* plotted on the risk matrix to produce a total risk score (green = low, yellow = moderate, orange = moderately-high, red = high). The risk ranking is linked to mitigation and management measures to consider where appropriate.
Uncertainty	An uncertainty score on a 5-point qualitative scale assigned based on the amount of scientific information available, and its specificity to the area, for the interaction for the *Exposure*, *Sensitivity*, and *Likelihood* factors. Rationale was provided and it was identified if the information used is only available from other areas. Note that uncertainty does not explicitly modify the risk assessment score.

4.2 Consequence

Consequence = Exposure × Sensitivity
Where: *Exposure = Intensity × Temporal × Areal × Depth*
And: Sensitivity = (Expected Acute Change + Expected Chronic Change) × Recovery Factors

The *exposure* factor characterized the overlap in space and time between the ESC subcomponent and the stressor. *Exposure* is a product of four factors: *intensity* (scored from 1-3), *temporal* (scored from 1-4), *areal* (scored from 1-3), and *depth* (scored from 1-3). The *exposure* scales (Table 4-2) are applicable to conservation priorities designated as either species or habitats.

The *intensity* factor characterized the persistence or density of the stressor, focused on current frequency and information (unless assessing a defined hypothetical future scenario). Persistence referred to the persistence of the stressor (e.g., heavy fuel oil), not of the effect (e.g., depressed fecundity), which is covered in the acute and chronic change scores.

The *temporal* factor characterized the overlap between the stressor and the ESC subcomponent over the course of the year. The *temporal* factor was assessed against the time period the ESC subcomponent spends in the AOI. For example, assessing the temporal overlap between a seasonal activity (four months) and a year-round resident (12 months) would result in a temporal score of 2. Assessing the temporal overlap between a seasonal activity (4 months) and a seasonal resident (4 months) where they both occur in the same timeframe resulted in a *temporal* score of 4.

The *areal* factor measured the 2-dimensional overlap between the occurrence of the stressor and the distribution of the ESC subcomponent in the AOI or in a more restricted spatial score (i.e., a priority area) where identified.

The *depth* factor measured the overlap between ESC subcomponent and stressor on the y-axis (i.e., vertically), taking into account terrain barriers. A depth score of 3 was the default for interactions that take place on a 2-dimensional plane. The *depth* factor was included to provide the ability to consider the mitigating effects of water depth, and a default score of 3, with interactions occurring at depth scoring lower than a 3, offers this possibility. For example, generally, an ESC would be impacted less severely in deeper water than shallower water for a stressor that occurs at the water's surface.

Table 4-2. Scales used to score the *exposure* factor. Adapted from Clarke Murray et al. 2016 and Koropatnick et al. 2023.

Risk Factor	**Score**			
	1	**2**	**3**	**4**
Intensity	The stressor occurs at low density (e.g., effort, number of events, amount) and/or demonstrates low persistence.	The stressor occurs at moderate density (e.g., effort, number of events, amount) and/or demonstrates moderate persistence.	The stressor occurs at high density (e.g., effort, number of events, amount) and/or demonstrates high persistence	N/A
Temporal overlap	There is very little overlap between when the stressor occurs in the assessment area and when the ESC subcomponent is present.	There is some overlap between when the stressor occurs in the assessment area and when the ESC subcomponent is present. For example, 25-50% overlap.	There is a large amount of overlap between when the stressor occurs in the assessment area and when the ESC subcomponent is present. For example, 50-75% overlap.	There is complete or near complete overlap between when the stressor occurs in the assessment area and when the ESC subcomponent is present.
Areal overlap	The area of overlap is a few restricted locations within the ESC subcomponent range in the assessment area. For example, when the stressor occurs at a single point source or location where the ESC subcomponent also occurs.	The area of overlap is localized, and a small proportion of the total ESC subcomponent range in the assessment area. For example, when a stressor overlaps the ESC subcomponent distribution in a bay or inlet that is part of the ESC subcomponent distribution.	The area of overlap is a widespread area, a large proportion of the ESC subcomponent range, in multiple locations or the entire assessment area.	N/A
Depth overlap	The stressor occurs over a small portion of the depth range of the ESC subcomponent within the assessment area or the depth range of the stressor is not considered primary habitat.	The stressor occurs over a moderate portion of the depth range of the ESC subcomponent or the depth range can be considered a combination of primary and secondary habitats for the ESC subcomponent in the assessment area.	The depth overlap between the ESC subcomponent and stressor covers the entire depth range of the ESC subcomponent in the assessment area or covers a large portion of primary ESC subcomponent habitat(s).	N/A

The four *exposure* factor scores were multiplied to provide a raw *exposure* score ranging from 1-108 and were subsequently binned from 1-5 (Table 4-3). The binned *exposure* score was multiplied with the *sensitivity* score and binned to produce a *consequence* score from 1-5.

Table 4-3. Scoring rubric for the *exposure* factor. Raw scores were generated by multiplying the respective scores from each of the four *exposure* factors (i.e., *temporal*, *depth*, *intensity*, and *areal*); see Table 4-2. Adapted from O et al. 2015 and Koropatnick et al. 2023.

Raw exposure score	Binned exposure score
1 2 3 4	1
6 8 9 12	2
16 18 24	3
27 36 48 54	4
72 81 108	5

The *sensitivity* factor considered the expected acute and chronic change to the ESC subcomponent from the stressor along with the subcomponent's inherent ability to recover from disturbance, reflected by the recovery factors. Acute and chronic change scales (Table 4-4) and recovery factors (Table 4-5) were developed separately for ESC subcomponents classified as species or habitats. Expected acute and chronic change were applied considering the population unit chosen for assessment, either within the AOI or within a more restricted spatial scope (i.e., priority area), where identified. For species, scoring of the *expected acute change* factor considered the severity of the effect to the individual and proportion of the assessment area population affected, relating the potential for change to population-wide effects. Scoring of the *expected chronic change* factor for species considered the sensitivity of the ESC subcomponent to long-term harm and the proportion of the population affected, and captured indirect effects including food-chain effects, chronic toxicity, reproductive effects (e.g., fertility, birth defects, eggshell thinning), and population level changes in growth rate, fecundity, and productivity, where applicable. For habitats, scoring of the *expected acute change* factor considered the severity of the effect at a localized scale (e.g., one coral colony or one kelp bed) and proportion of assessment area habitat affected, relating back to the habitat's function in the ecosystem. Scoring of the *expected chronic change* factor for habitats considered change to long-term viability of the habitat as it relates to its function in the ecosystem. Effects that last beyond the acute phase or are a result of the acute phase were considered, as well as indirect effects including chronic toxicity, the effects of fragmentation, and habitat-wide changes in growth rate and productivity, where appropriate. Each of the recovery factors was scored using the best available knowledge. If insufficient knowledge was available to score a recovery factor, the factor was excluded from the calculation.

Table 4-4. Scales used to score the *expected acute change* and *expected chronic change* for Species and Habitats. Adapted from O et al. 2015 and Koropatnick et al. 2023.

Risk Factor	**Score**		
	1	**2**	**3**
Species			
Acute change	Insignificant or undetectable change to the ESC subcomponent mortality rates against background variability and/or limited behavioural impacts.	Expected measurable change to the ESC subcomponent mortality rates against background variability and/or moderate behavioural impacts.	Expected significant source of mortality and/or significant behavioural impacts.
Chronic change	Insignificant or undetectable change to overall fitness (e.g., via changes in geographic range/ genetic structure/ reproductive capacity) compared with background variability, with no impact on population dynamics.	Expected measurable change to overall fitness (e.g., via changes in geographic range/ genetic structure/ reproductive capacity) compared with background variability, with possible impact on population dynamics.	Expected significant change to overall fitness (e.g., via changes in geographic range/ genetic structure/ reproductive capacity) compared with background variability, with expected impact on population dynamics.
Habitat			
Acute change	Insignificant or undetectable change to habitat function in the ecosystem (e.g., as habitat or nursery) at the localized scale over an acute timeframe. Consider acute loss of area and/or fragmentation as it relates to ecosystem function.	Expected measurable change to habitat function in the ecosystem (e.g., as habitat or nursery) at the localized scale over an acute timeframe. Consider acute loss of area and/or fragmentation as it relates to ecosystem function.	Expected significant change to habitat function in the ecosystem (e.g., as habitat or nursery) at the localized scale over an acute timeframe. Consider acute loss of area and/or fragmentation as it relates to ecosystem function.
Chronic change	Insignificant or undetectable change to long-term viability of the habitat as it relates to its function in the ecosystem. Consider effects that last beyond the acute phase.	Expected measurable change to long-term viability of the habitat across its range as it relates to its function in the ecosystem. Consider effects that last beyond the acute phase.	Expected significant change to long-term viability of the habitat as it relates to its function in the ecosystem. Consider effects that last beyond the acute phase.

Table 4-5. Scales used to score recovery factors for Species and Habitats. Final recovery factors score was obtained by calculating the arithmetic mean of all scored factors to one decimal place. Adapted from Hobday et al. 2007, Astles et al. 2009, Samhouri and Levin 2012, and O et al. 2015.

Risk Factor	Score		
Recovery factors (species)	**1**	**2**	**3**
Fecundity: the population-wide average number of offspring produced by a female each year.	High	Moderate	Low
Early life stage mortality: provides an indication of the level of mortality that may be expected for offspring in the first stages of life.	Low	Moderate	High
Recruitment pattern: ability of a species to successfully add individuals to the population. Populations with sporadic and infrequent recruitment success are often long-lived and thus may be expected to have a lower ability to recover.	High level of recruitment	Moderate level of recruitment	Low level of recruitment
Natural mortality rate: instantaneous mortality rate; populations with naturally higher instantaneous mortality rates likely have higher recovery rates.	High	Moderate	Low
Age at maturity: best estimate of the population-wide average age at maturity.	<2 years	2-4 years	>4 years
Life stages affected: the life stage(s) affected by a stressor; if stressor affects individuals before they have the opportunity to reproduce, recovery is likely to be inhibited.	Not affected or only mature stages	Only immature stages	All stages
Population connectivity: realized exchange with other populations based on spatial patchiness of distribution, degree of isolation, and potential dispersal capability.	Regular	Occasional	Negligible
Population status: as described by the best available knowledge (COSEWIC/SARA/IUCN classification/Inuit Qaujimajatuqangit).	Stable or increasing sustainably	Declining unsustainably	Declined/at a critical level
Recovery factors (habitat)	**1**	**2**	**3**
Growth rate (biogenic)/**rate of structural rebuilding** (abiotic): individual capacity to return to pre-disturbance size (e.g., growth rate of one coral colony or one kelp plant)	High	Moderate	Low
Resistance: the ability to withstand physical or biological disturbance. Consider the physical characteristics of the habitat.	High	Moderate	Low
Regenerative potential: population-wide capacity to return to pre-disturbance state. Consider spatial patchiness of distribution, exchange with other habitat areas, dispersal capability.	High	Moderate	Low
External stress: the combined effect of other stressors. Other additional stressors may inhibit recovery.	Low	Moderate	High

Expected acute and chronic change scores were added and the sum multiplied by the overall recovery factors score to produce a raw *sensitivity* score from 2 to 18. The raw *sensitivity* score was binned to produce a *sensitivity* score from 1 to 5 using quintiles (Table 4-6).

Table 4-6. Scoring rubric for the *sensitivity* parameter. *Sensitivity* is a combination of *expected acute change* and *expected chronic change* and the inherent ability of the ESC subcomponent to recover from disturbance, reflected by the recovery factors. Adapted from O et al. (2015).

Raw sensitivity score	Binned sensitivity score
2 – 4.8	1
4.9 – 6.5	2
6.6 – 8.4	3
8.5 – 11.5	4
11.6 - 18	5

The *exposure* score and *sensitivity* score were multiplied to produce a *consequence* score from 1 to 25 (Table 4-7). *Consequence* scores were subsequently binned into five categories. *Consequence* scores were binned in consideration of a combination of the exposure and sensitivity factors (i.e., any combination of “very high” sensitivity with “moderate” or greater exposure resulted in a “very high” *consequence*. *Consequence* categories were plotted on a risk matrix with *likelihood* in order to determine the overall risk level (Figure 4-1).

Table 4-7. Scoring rubric for the *consequence* parameter. Adapted from Koropatnick et al. 2023.

Exposure score	Sensitivity score	Consequence score	Binned consequence category
1 (Negligible)	1 (Very low)	1	Negligible
1 (Negligible)	2 (Low)	2	Negligible
2 (Low)	1 (Very low)	2	Negligible
1 (Negligible)	3 (Moderate)	3	Negligible
3 (Moderate)	1 (Very low)	3	Negligible
1 (Negligible)	4 (High)	4	Low
4 (High)	1 (Very low)	4	Low
2 (Low)	2 (Low)	4	Low
1 (Negligible)	5 (Very high)	5	Low
5 (Very high)	1 (Very low)	5	Low
2 (Low)	3 (Moderate)	6	Moderate
3 (Moderate)	2 (Low)	6	Moderate
2 (Low)	4 (High)	8	Moderate
4 (High)	2 (Low)	8	Moderate
3 (Moderate)	3 (Moderate)	9	Moderate

Exposure score	Sensitivity score	Consequence score	Binned consequence category
5 (Very high)	2 (Low)	10	High
2 (Low)	5 (Very high)	10	High
3 (Moderate)	4 (High)	12	High
4 (High)	3 (Moderate)	12	High
5 (Very high)	3 (Moderate)	15	High
3 (Moderate)	5 (Very high)	15	Very high
4 (High)	4 (High)	16	Very high
4 (High)	5 (Very high)	20	Very high
5 (Very high)	4 (High)	20	Very high
5 (Very high)	5 (Very high)	25	Very high

4.3 Likelihood

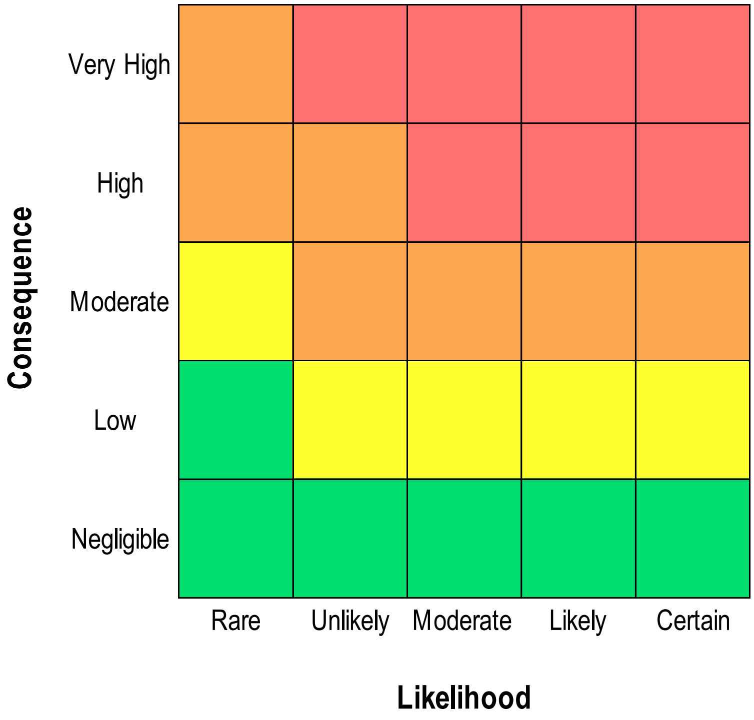
Likelihood was defined as the probability that the stressor will interact with the ESC subcomponent, and considered the expected effect of the interaction (i.e., there had to be a minimum level of effect for a level 2 assessment to occur e.g., artificial light bathing the benthic substrate did not constitute an interaction that required a level 2 assessment). *Likelihood* was determined based on the best available information, existing management measures, and subject matter expertise. For routine events (e.g., vessel traffic) the sub-activity was assumed to be occurring (i.e., likelihood of noise disturbance to a marine mammal was evaluated based on the assumption that a vessel was in the area and producing noise). For accidental events (e.g., a vessel strike on a marine mammal), *likelihood* was scored based on the probability of the event itself (i.e., the probability of a strike). All categories could be equally applied to current or potential future activities (e.g., if the sub-activity occurs in the future, an interaction will occur in most circumstances; Table 4-8). *Observed frequency* referred to current activities and was described using best available knowledge (e.g., expert opinion, quantitative data). *Potential frequency* referred to activities that may occur in the foreseeable future (i.e., within 10 years).

Note that a lack of overlap (i.e., temporal or spatial) was not considered to lower the *likelihood* score. A lack of spatial or temporal overlap was identified in the level 1 assessments and, where appropriate, contributed to the decision not to undertake a level 2 assessment. A restricted spatial or temporal overlap was considered while evaluating the exposure factors.

Table 4-8. Scale used to score the *likelihood* factor. All categories could be equally applied to current or potential future activities (e.g., if the sub-activity occurs in the future, an interaction will occur in most circumstances). Adapted from Koropatnick et al. 2023.

Likelihood	Observed or Potential Frequency
Certain (5)	Interaction is occurring or will occur **if** stressor is present in future
Likely (4)	Interaction will occur in most circumstances
Moderate (3)	Interaction may occur in some but not all circumstances
Unlikely (2)	Interaction is unlikely to occur
Rare (1)	Interaction may occur only in exceptional circumstances or almost never happens

Likelihood was plotted on a risk matrix (Figure 4-1) with *consequence* to produce an overall risk score.



	Rare	Unlikely	Moderate	Likely	Certain
Very High	🟧	🟥	🟥	🟥	🟥
High	🟧	🟧	🟥	🟥	🟥
Moderate	🟨	🟧	🟧	🟧	🟧
Low	🟩	🟨	🟨	🟨	🟨
Negligible	🟩	🟩	🟩	🟩	🟩

Figure 4-1. Overall risk output matrix. Overall risk was calculated by plotting the *likelihood* and *consequence* factors. Adapted from Koropatnick et al. 2023.

4.4 Risk Determination

Risk results plotted on the overall risk output matrix (Figure 4-1) are interpreted using the risk tolerance matrix (Figure 4-2) to inform potential need for additional management measures (i.e., beyond those that may already be in place; additional management may include mitigation measures, zoning, and final boundary determination). Activities where the risk result lands in the *Acceptable* zone have an acceptable level of risk and do not require additional management, or treatment, measures. Activities where the risk result lands in the *May be Tolerable* zone require consideration of treatment measures that could reduce the risk to as close to the *Acceptable* zone as reasonably practicable. Whereas ecological factors influence risk levels calculated during risk assessment, non-ecological factors (e.g., operational feasibility, socio-economics) may influence the degree of risk reduction that is reasonably practicable, and therefore what level of risk within this zone is ultimately tolerated. Activities where the risk result lands in the *Incompatible* zone require treatment measures to reduce the level of risk down to the *May be Tolerable* zone (at a minimum), aiming to reduce the risk as close to the *Acceptable* zone as is reasonably practicable based on non-ecological factors. If treatment measures cannot reduce an activity's risk level to below the *Intolerable* risk threshold, then the activity that poses the risk must be prohibited.

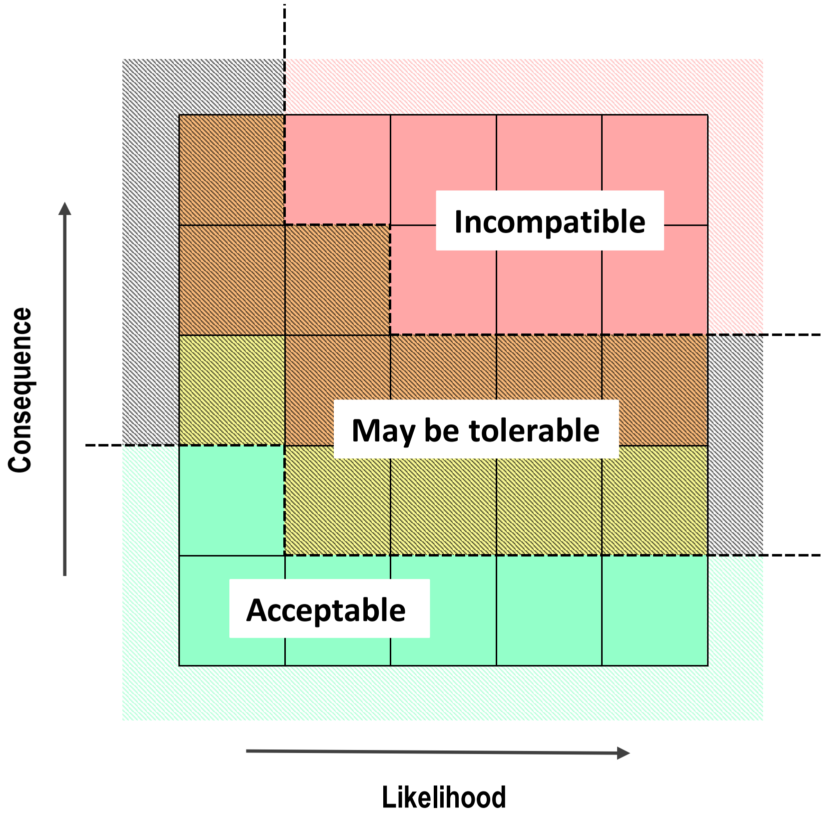


Figure 4-2. Risk tolerance matrix. Risk results plotted on the overall risk output matrix are interpreted using the risk tolerance matrix

The zones of the risk tolerance matrix are the starting point for discussions related to management measures and do not represent the final decision about management of activities in a potential MPA. Factors such as consistency with the *Nunavut Agreement*, social and economic considerations, consultations with affected communities and stakeholders, and the precautionary approach, are considered when pursuing potential management measures based on the results of this ecological risk assessment.

It is worth reiterating that MPAs are designated to conserve and protect ecological integrity including biodiversity, ecosystem function, productivity, and the special natural features identified for each site, so tolerance for risk within an MPA is lower than for other areas. Thus, the risk scores presented here may differ from assessment of risks for the same activities elsewhere in the ocean.

4.5 Uncertainty

Uncertainty was evaluated for each assessment using a qualitative 5-point scale (Table 4-9). Uncertainty scores were assigned to each of the *exposure*, *sensitivity*, and *likelihood* factors; each score was accompanied by a brief rationale justifying the choice.

Table 4-9. Uncertainty scoring scale. Adapted from O et al. (2015).

Uncertainty		
Category	**Score**	**Description**
Very low uncertainty (very high certainty)	1	Extensive peer-reviewed scientific information or data specific to the area including long-term relevant datasets.
Low uncertainty (high certainty)	2	Substantial scientific information or recent data specific to the area. This could include both peer-reviewed and non-peer reviewed sources.
Moderate uncertainty (moderate certainty)	3	Moderate amount of scientific information mainly from non-peer reviewed sources and firsthand, unsystematic or opportunistic observations. This could include both scientific information and expert opinion. This may include older data from the area and may also include information not specific to the area.
High uncertainty (low certainty)	4	Little scientific information but expert opinion relevant to the topic and area.
Very high uncertainty (very low certainty)	5	Little or no scientific information. Expert opinion based on knowledge.

5.0 Shipping and Vessel Traffic

Marine transportation is vital to many activities that occur in the Canadian Arctic, such as the provision of goods to communities and resource extraction. Shipping and vessel traffic may negatively affect the marine environment through numerous pathways of effect as a result of vessel presence (e.g., underwater noise, vessel strikes, and disturbance through visual cues) and through discharged substances (e.g., ballast water) (Jagerbrand et al. 2019; Hannah et al. 2020). Vessel traffic has been increasing over the last two decades in the Canadian Arctic and the trend is expected to continue, mirroring the decline in sea ice extent and seasonal duration due to climate change and increased industrial interest in the Canadian Arctic (Dawson et al. 2018).

Each of the assessments associated with vessel traffic take into consideration vessel traffic patterns and timing within the AOI to the extent possible. Based on an analysis of Automatic Identification System (AIS) data for the period 2012-2019, seven different primary types of vessels have been documented within the study area including bulk carriers, icebreakers, military/patrol vessels, cargo/supply vessels, oil/chemical tankers, passenger/pleasure vessels, and tugs (Maerospace 2020). Shipping primarily occurs during July through October for larger commercial vessels. As noted above, shipping and vessel traffic has been increasing over time in the Canadian Arctic (Dawson et al. 2018) and a similar trend is demonstrated in the AOI (see Figures 5-2 to 5-9, adapted from Maerospace 2020). Vessel traffic is not distributed evenly throughout the AOI; the majority of the vessel traffic occurs through Fisher and Evans Straits and in Chesterfield Inlet (Figure 5-10), largely to service the Meadowbank mine complex located near Baker Lake. Most of the corresponding AIS data—the positional information received by satellites from a vessel's onboard AIS transmitters—occur during a four-month period of the year which suggests seasonal behaviour. However, AIS data do not perfectly represent vessel traffic trends due to inherent limitations such as the location of the AOI (i.e., potentially "spotty" satellite coverage in higher latitudes) and inconsistent AIS reporting by vessels (e.g., only vessels that have active AIS will be captured, including most large vessels and some smaller vessels that voluntarily transmit AIS; vessels report AIS with varying frequency; some vessels may turn off AIS transmitters; AIS pings may be masked out due to signal collision when a satellite is receiving too many AIS signals simultaneously; inaccurate AIS reporting). The AIS dataset underwent thorough processing which has a greater degree of accuracy when compared to an unprocessed dataset (i.e., “raw” or “unscrubbed” AIS datasets where perceived anomalies are not removed). Processing removed perceived AIS anomalies for various reasons including: behavioural anomalies (i.e., occurrences where “expected” behaviour is not met, e.g., doppelgangers [vessels transmitting inaccurate MMSI]); intrinsic anomalies (i.e., a message field of an AIS record containing an invalid value making the record potentially invalid); and contextual anomalies (i.e., comparing reported AIS data through independent, third party data sources such as ship registry information). This processed dataset contained one percent of the total amount of AIS data available during the time period.

Although processing of AIS data is necessary to produce a more accurate dataset, it is not a perfect system and will not yield perfect results. Due to the limitations discussed above, Maerospace advised that it would likely be inaccurate to predict vessel tracks and “trips” by connecting sequential AIS data of an individual vessel. Therefore, the density of AIS data was used in the vessel traffic analyses as the best available option to identify general trends of large vessel traffic in the AOI. Local boat traffic from communities within the AOI is largely undocumented by AIS data. However, we have assumed that local boat traffic would occur during the open-water period.

This section will assist with predicting risks from any large vessel traffic associated with, for instance, submarine cable laying vessels, seismic survey vessels (exclusive of noise from airgun arrays), vessels conducting research activities, and cruise ships. Icebreaking is assessed separately (see Section 5.2). Stressors from icebreakers underway through open water are not expected to differ from other large vessels and they will be investigated together in this section.

It is important to note that assessments have been conducted considering the recent density and extent of vessel traffic in the AOI (Maerospace 2020) and any future increases in vessel traffic may result in different levels of risk. As vessel traffic continues to evolve in a potential future MPA, adaptive management measures may be implemented in discussion with the MPA co-management partners and as described in an MPA management plan. Due to the relatively low absolute density of vessel traffic in the AOI at present, a new or expanded activity, such as mining, may lead to a noticeable increase in shipping through or adjacent to the AOI (Dawson et al. 2018). Additionally, it should be noted that relative to other areas that experience shipping and vessel traffic and for which biological effects literature is largely based, the AOI receives a low density of vessel traffic.

5.1 Vessel Underway

The risk assessment for vessels underway focuses on four primary PoE: noise disturbance, vessel strikes, habitat alteration/removal, and water displacement. As noted earlier, vessels (with available AIS data) are typically present in the AOI during July to October and occasionally during June or November (Maerospace 2020). Figure 5-1 shows the location of available vessel AIS data relative to the SI AOI.

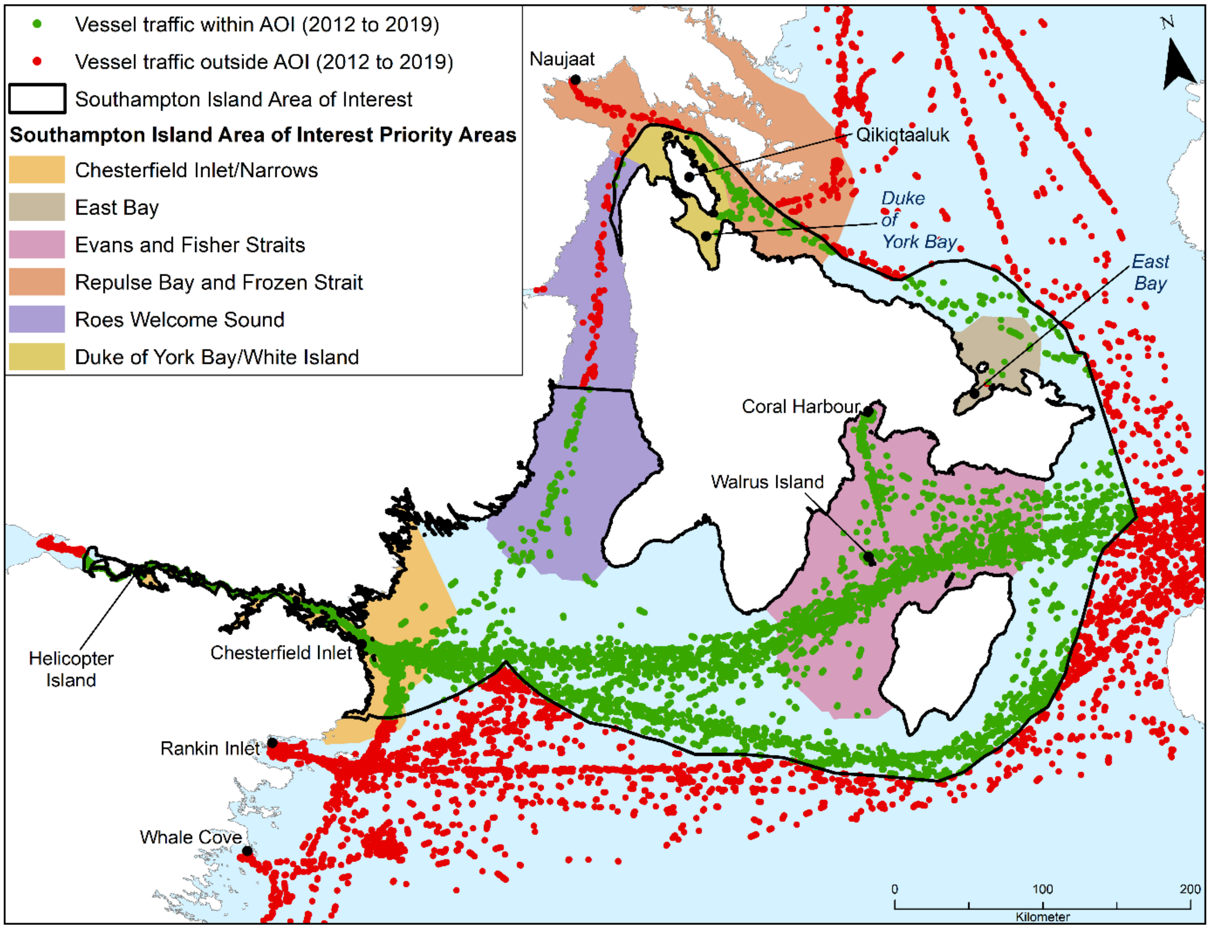


Figure 5-1. Locations of vessels with available AIS data relative to the Southampton Island AOI and priority areas (data from 2012-2019; adapted from Maerospace 2020). Duke of York Bay/White Island and Repulse Bay/Frozen Strait priority areas overlap along the northeast and southeast sides of Qikiqtaaluk. Note: Qikiqtaaluk may be referred to as “White Island” in other publications.

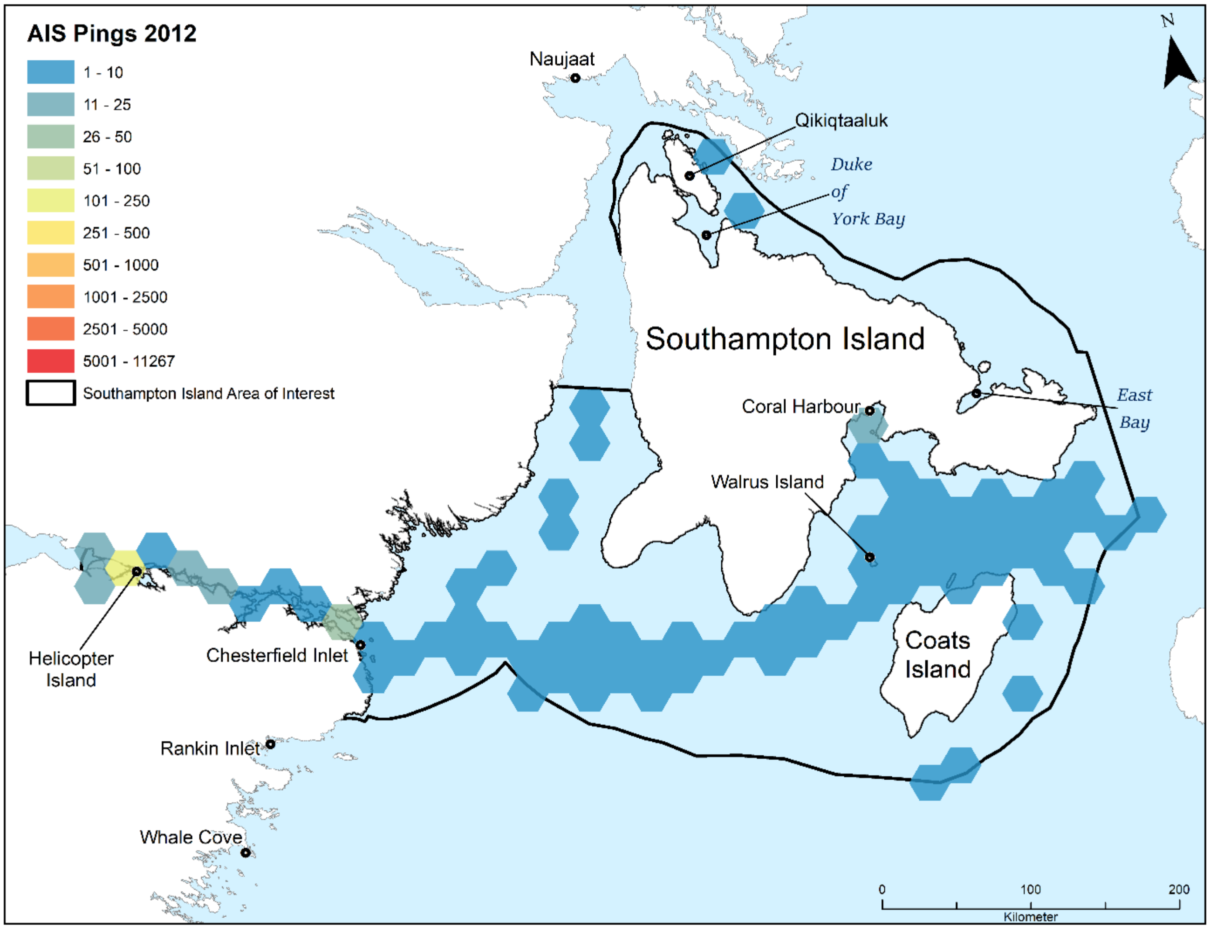


Figure 5-2. Tessellated heatmap of vessel traffic density within the Southampton Island AOI using AIS data from 2012 (adapted from Maerospace 2020). Hexagonal grid cells are 500 km^2.

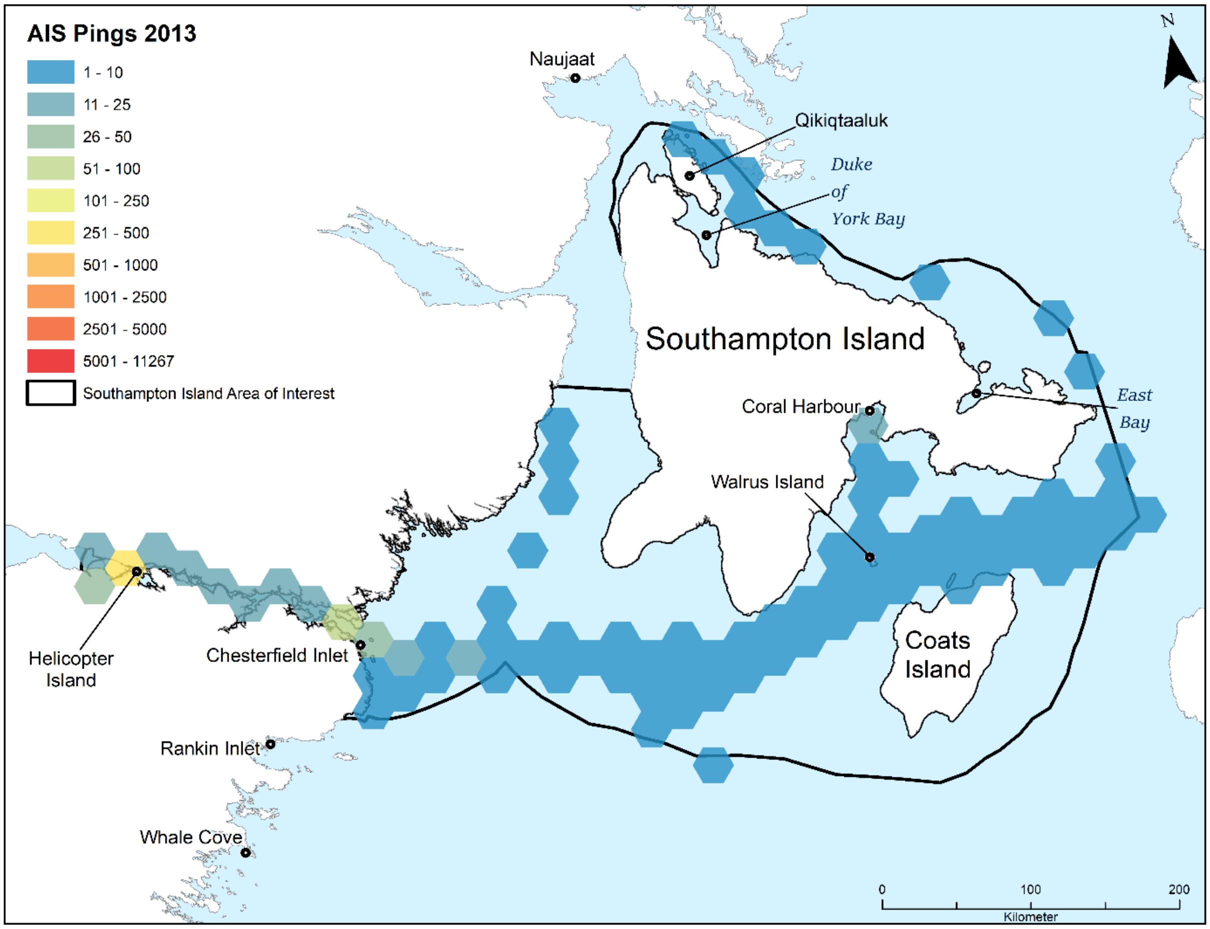


Figure 5-3. Tessellated heatmap of vessel traffic density within the Southampton Island AOI using AIS data from 2013 (adapted from Maerospace 2020). Hexagonal grid cells are 500 km^2.

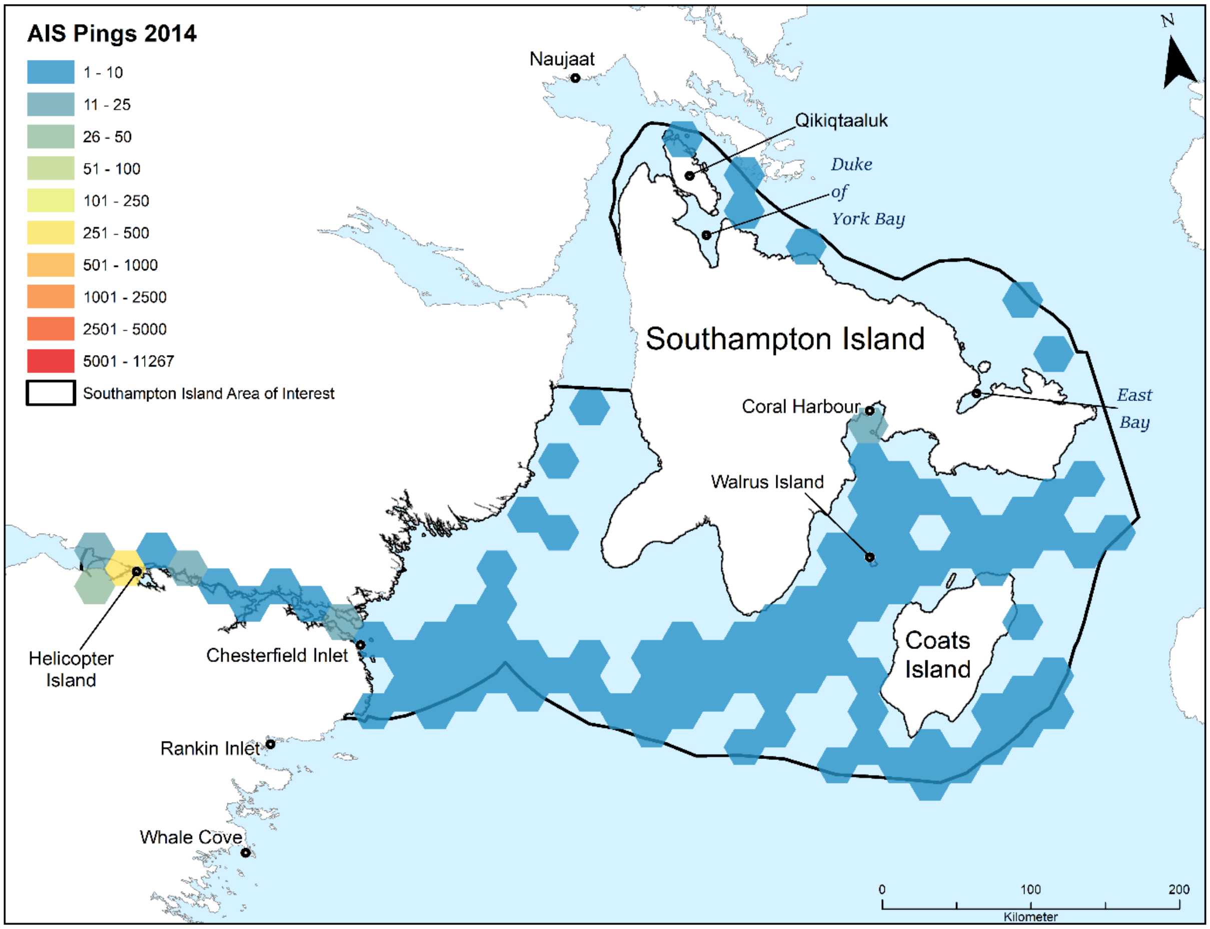


Figure 5-4. Tessellated heatmap of vessel traffic density within the Southampton Island AOI using AIS data from 2014 (adapted from Maerospace 2020). Hexagonal grid cells are 500 km^2.

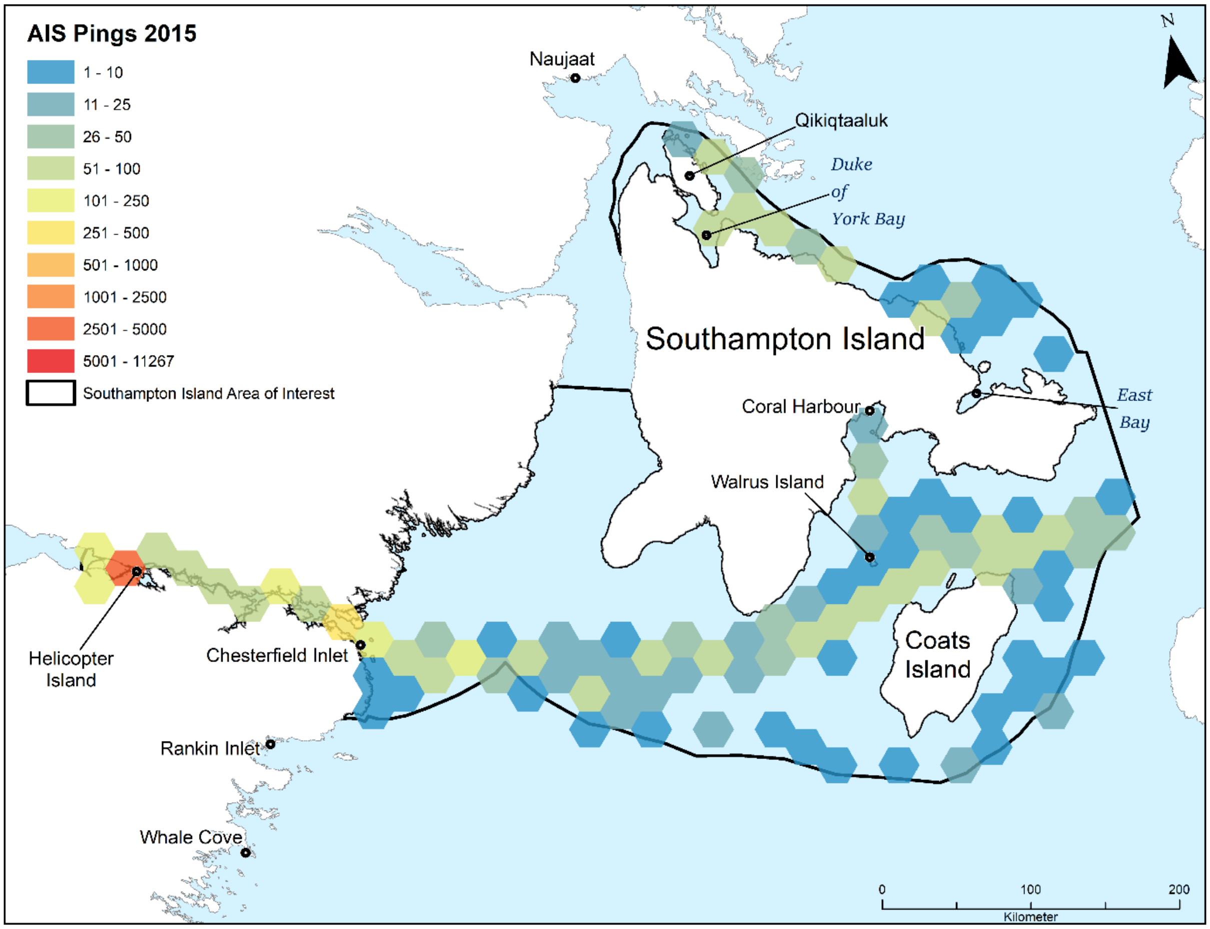


Figure 5-5. Tessellated heatmap of vessel traffic density within the Southampton Island AOI using AIS data from 2015 (adapted from Maerospace 2020). Hexagonal grid cells are 500 km^2.

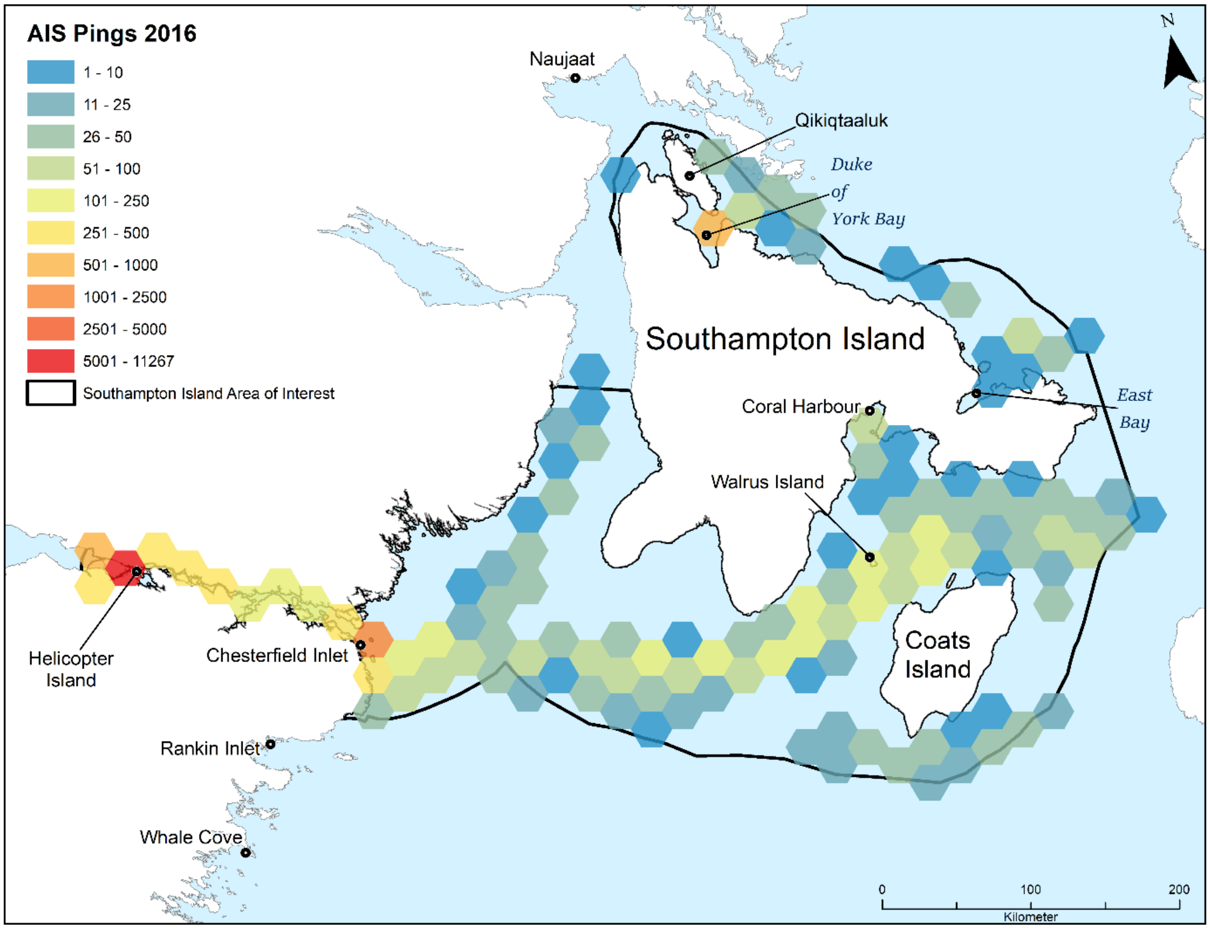


Figure 5-6. Tessellated heatmap of vessel traffic density within the Southampton Island AOI using AIS data from 2016 (adapted from Maerospace 2020). Hexagonal grid cells are 500 km^2.

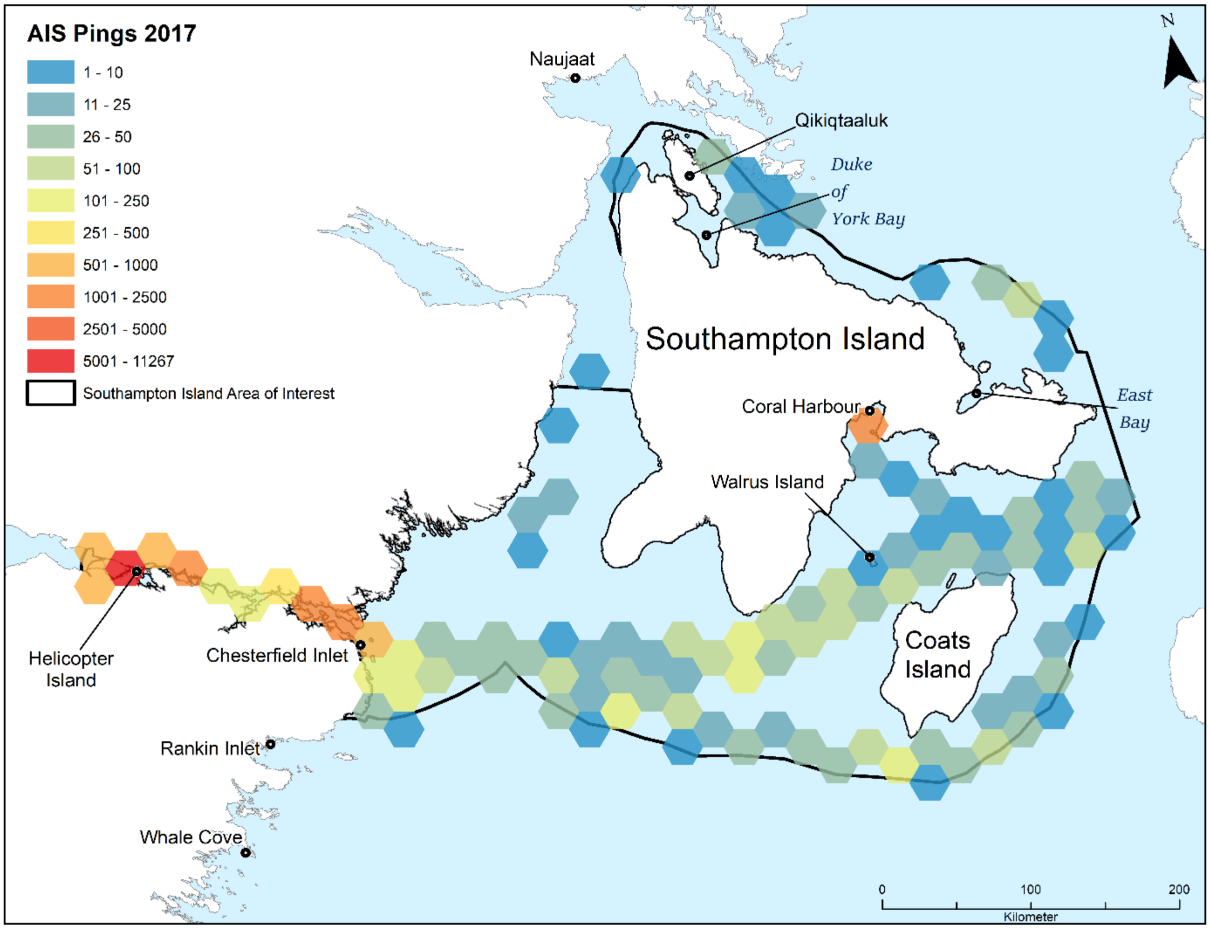


Figure 5-7. Tessellated heatmap of vessel traffic density within the Southampton Island AOI using AIS data from 2017 (adapted from Maerospace 2020). Hexagonal grid cells are 500 km^2.

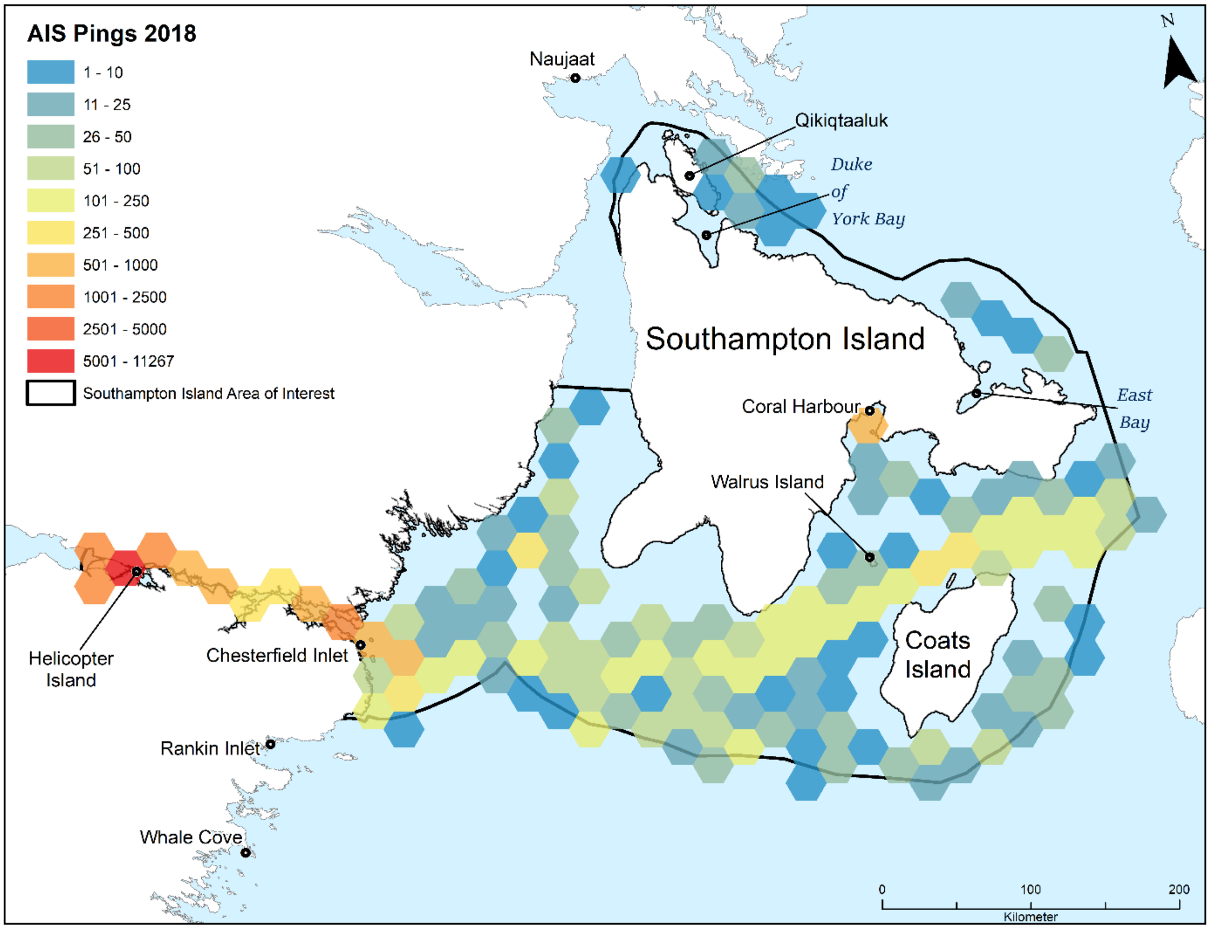


Figure 5-8. Tessellated heatmap of vessel traffic density within the Southampton Island AOI using AIS data from 2018 (adapted from Maerospace 2020). Hexagonal grid cells are 500 km^2.

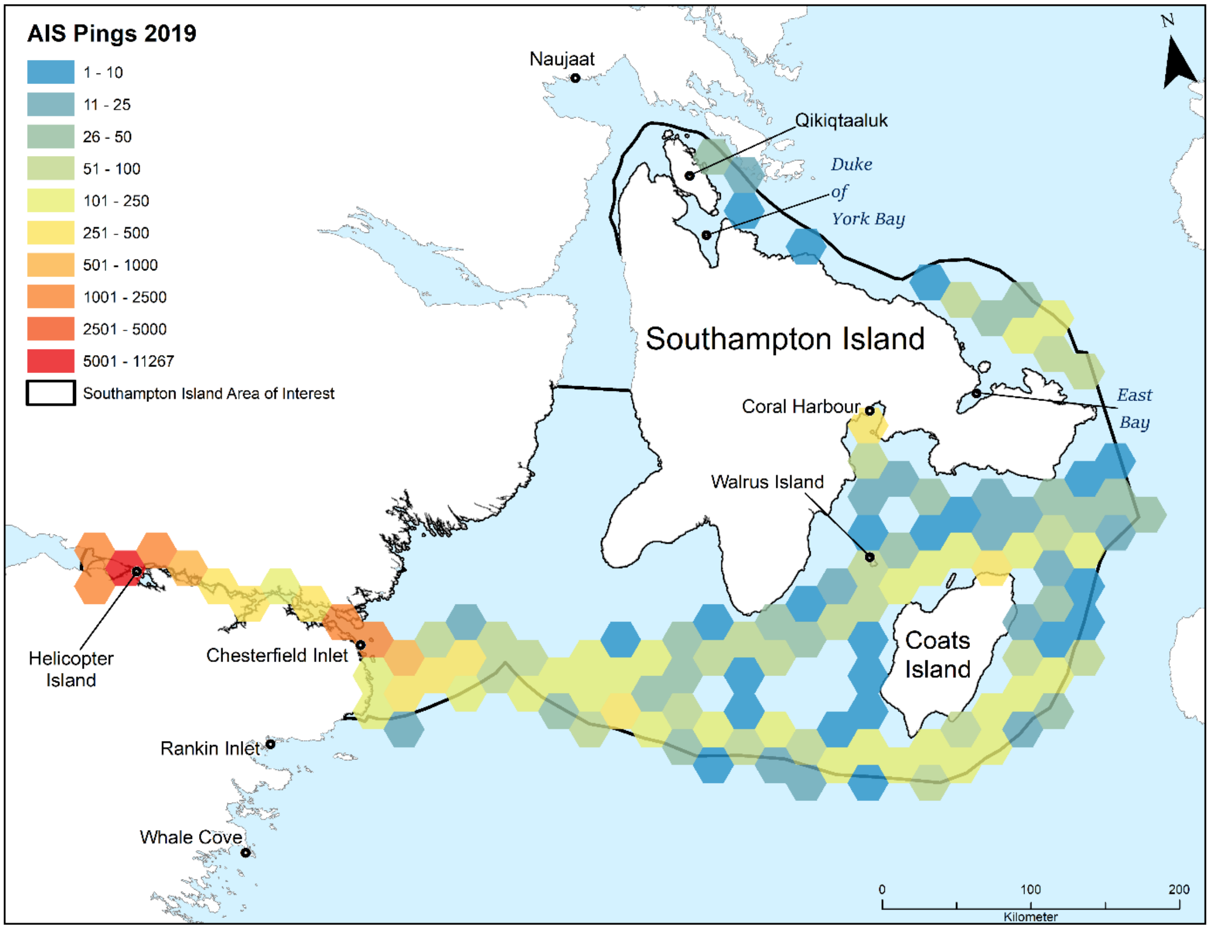


Figure 5-9. Tessellated heatmap of vessel traffic density within the Southampton Island AOI using AIS data from 2019 (adapted from Maerospace 2020). Hexagonal grid cells are 500 km^2.

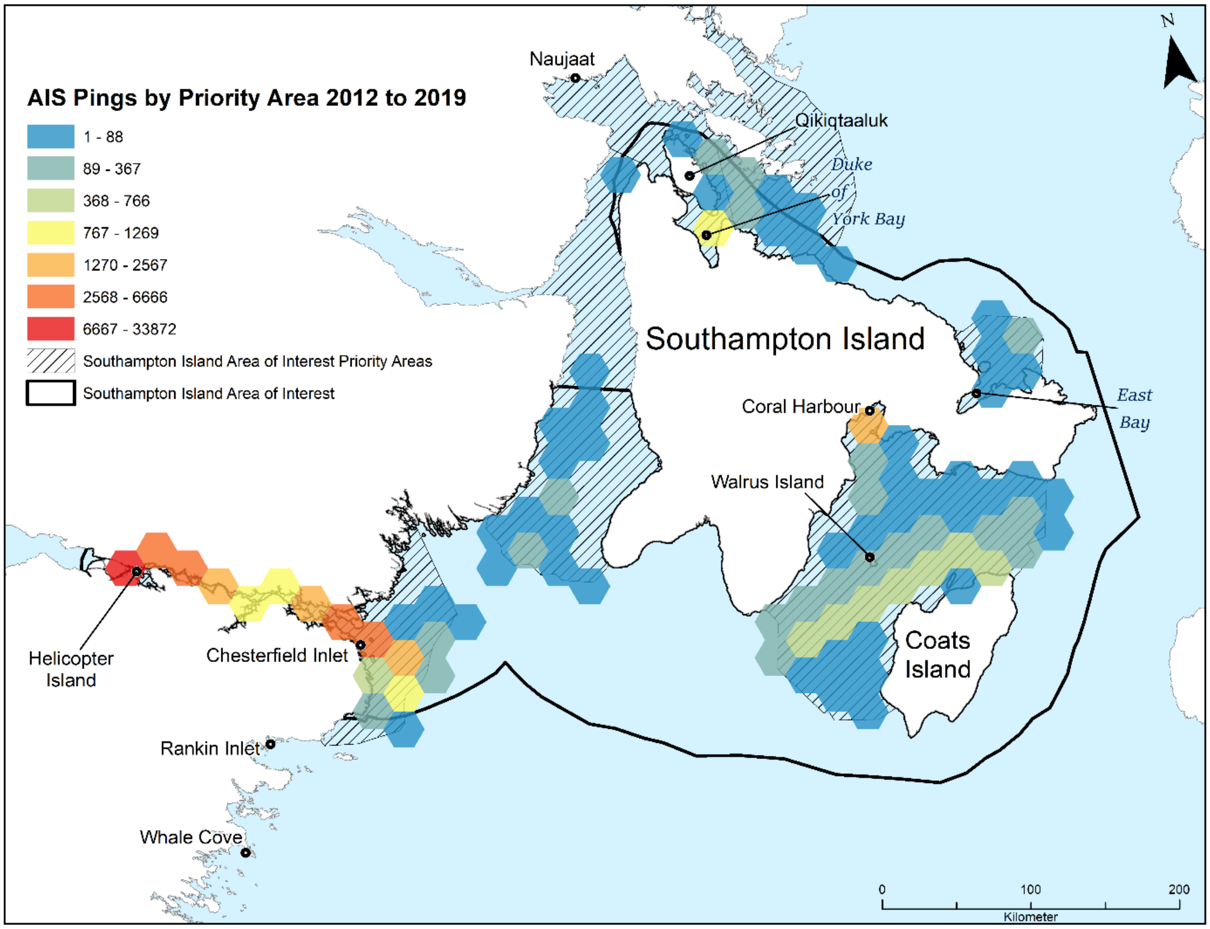


Figure 5-10. Tessellated heatmap of vessel traffic density within the Southampton Island AOI using AIS data from 2012-2019 (adapted from Maerospace 2020). Data display is restricted to priority areas (see Figure 2-3).

5.1.1 Noise Disturbance

Noise generated from vessels has the potential to disturb marine fauna, including marine mammals, birds, fish, and invertebrates. Marine mammals use sound to communicate and navigate, while foraging, and during reproductive activities, and have been demonstrated to exhibit a broad range of responses to vessel noise (e.g., Richardson et al. 1995a; Southall et al. 2009, 2019; Erbe et al. 2019); therefore, all marine mammal ESC subcomponents were assessed (Table 5-1). In addition, concern has been expressed during community engagement sessions that barren-ground caribou may be disturbed by passing vessel traffic (DFO unpublished[9]); as such barren-ground caribou were assessed. Fishes and, to some extent, invertebrates may use sound for similar purposes, including communication with conspecifics, seeking prey, avoiding predators, habitat selection, navigation, mating, and other social interactions (Hawkins and Popper 2017). Fishes in the family Gadidae are known to use sound for communication and reproduction (Rowe and Hutchings 2004, 2006, 2008) and have demonstrated some sensitivity to vessel noise (Stanley et al. 2017); as such, Arctic cod was selected for assessment. As Arctic cod are forage fish, they serve as a proxy assessment for other forage fish (e.g., capelin). Though there is little directed research on the effects of noise specifically on Arctic char, research on other salmonids (i.e., Atlantic salmon) indicates that they have less sensitive hearing than many other marine fish species and that sound may not play a large role in their behaviours (e.g., Hawkins and Johnstone 1976; Harding et al. 2016; Popper and Hawkins 2019). However, they may be able to perceive particle motion (Bolgan et al. 2016, 2018) and as this pathway considers all commercial vessel traffic (i.e., it is expected to have the greatest spatial and temporal overlap of the pathways that investigate vessel-produced noise), an assessment on Arctic char has been included here to be precautionary. Seabird disturbance by vessel activity (presumably a combination of vessel noise and visual cues) has been documented (Fliessbach et al. 2019). Compared to murres and gulls, common eider have been described as more sensitive to disturbance from vessels (Garthe and Hüppop 2004; Fliessbach et al. 2019); therefore, common eider was selected for assessment and acted as a proxy for other seabird ESC subcomponents. As it is difficult to differentiate between the influences of visual cues and noise on seabird disturbance, the common eider assessment considers both pathways.

Table 5-1. Vessels Underway − Noise Disturbance: ESC Subcomponents and Priority Areas Assessed.

ESC Subcomponent	Priority Area	Assessed by Proxy
Common eider	East Bay	
Thayer’s gull		Via common eider
Thick-billed murre		Via common eider
Arctic char	Chesterfield Inlet/Narrows	
Arctic cod	Fisher and Evans Straits	
Other forage fish		Via Arctic cod
Ringed seal	Fisher and Evans Straits	
Bearded seal	Fisher and Evans Straits	
Walrus	Fisher and Evans Straits	
Narwhal	Repulse Bay/Frozen Strait	
Beluga	East Bay	
Bowhead whale	Fisher and Evans Straits	
Barren-ground caribou	Chesterfield Inlet/Narrows	

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[9] DFO. 2019. Community confirmation engagement report: Marine Protected Area process in Kivalliq and Southampton Island proposed Area of Interest. 27 p.

Risk Statement: If an interaction occurs involving common eiders and noise disturbance due to a vessel underway through open water the consequence could result in a negative impact on the common eider population in the East Bay priority area.

Table 5-2. Common eider – Vessel Underway (East Bay) – Noise Disturbance.

Risk Factor	Score	Rationale
Exposure	1 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 2 = 2 (Raw Score)
Intensity	1	It should be noted that relative to other areas that experience shipping and vessel traffic, and for which biological effects literature is largely based, the AOI receives a low density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9). The East Bay priority area experiences a low density of vessel traffic relative to other priority areas (see Figures 5-1 and 5-10) representing <1% of total AIS data within the AOI from 2012-2019. Therefore, intensity was scored as 1.
Temporal	1	Common eiders are present in the East Bay priority area from mid-June to September. Adult males depart on their moult migration in July (Abraham and Finney 1986). Eggs hatch in July and the flightless females rear their precocial broods in marine and intertidal waters. Groups of females and young are present until late September (Abraham and Finney 1986), primarily foraging on benthic invertebrates in waters <20 m deep (Goudie et al. 2020). Vessels are typically present in the East Bay priority area during October and very occasionally in September, though they are not present throughout that entire period. There is very little overlap between when vessels occur in the East Bay priority area and when common eiders are present in marine waters there, resulting in a score of 1.
Spatial	2	Spatial = Areal x Depth = 1 x 2 = 2
Areal	1	Common eider females and broods are expected to be distributed in intertidal and marine waters, primarily <20 m deep, within the East Bay priority area. Due to navigational constraints, vessel activity in shallow water is expected to be minimal. The long distance effects of vessel traffic or vessel noise on seabirds are unknown, and there are no established thresholds for behavioural disturbance to seabirds (Halliday et al. 2022). Vessels may cause local displacement of common eiders at least 210-250 m from the birds (Schwemmer et al. 2011; Fliessbach et al. 2019). Considering the information above, the area of overlap between eider broods and vessels is expected to be limited to a few restricted locations within the common eider distribution in the priority area; resulting in a score of 1.
Depth	2	Common eider flight altitude (over water) is similar to that of the height above the water line of a sea-going vessel's superstructure. This species typically dives to a depth of <20 m, which is similar to the draught of a sea-going vessel. Depending on the size of the vessel, the potential for noise disturbance due to a vessel underway covers a moderate portion of the depth range of common eider in the East Bay priority area, resulting in a score of 2.
Sensitivity	2 (binned)	Sensitivity = (Acute change + Chronic Change) x Recovery Factors = (1 + 1) x 2.6 = 5.2
Acute Change	1	Seabirds approached by vessels may respond by flying away, diving under the sea surface, or increasing alertness, all of which reduce the amount of time engaged in feeding, resting, or mating, potentially reducing survival and reproductive success

Risk Factor	Score	Rationale
		and affect population dynamics (Schwemmer et al. 2011; Fliessbach et al. 2019). Noise disturbance from vessels would be expected to cause displacement of common eiders when vessels approach within 210-250 m (Schwemmer et al. 2011; Fliessbach et al. 2019). Noise disturbance is not known to cause mortality in sea ducks. Considering the current low density of vessel traffic in the priority area, noise disturbance from this stressor would be expected to result in an insignificant or undetectable change in common eider behaviour and mortality rates against background variability. Thus, a score of 1 was assigned.
Chronic Change	1	A small proportion of common eiders could be affected by noise disturbance from vessels underway in the East Bay priority area, as this species is known to be affected by this stressor (Schwemmer et al. 2011; Fliessbach et al. 2019). However, the low frequency of vessels passing through the priority area would be unlikely to cause repeated effects and, therefore, chronic change in the common eider population. As a result, it is expected that there would be an insignificant or undetectable change to overall fitness and no impact on population dynamics, resulting in a score of 1.
Recovery Factors	2.6	Recovery factors = mean of the factors listed below. Fecundity: 2 (Three to five eggs laid per year; nesting success 0-40% [Goudie et al. 2020]). Early life stage mortality**:** 3 (90-95% in first year [Goudie et al. 2020]). Recruitment pattern**:** 3 (Probability: 0.17-0.47 [Nicol-Harper et al. 2021]). Natural mortality rate**:** 3 (13% [Goudie et al. 2020]). Age at maturity**:** 2 (≥4 years [Goudie et al. 2020]). Life stages affected**:** 3 (All life stages could potentially occur in the East Bay priority area [Goudie et al. 2020]). Population connectivity**:** 3 (High degree of fine-scale spatial population genetic structuring [Talbot et al. 2015]). Population status**:** 2 (Common eider is listed as *near threatened* by the International Union for the Conservation of Nature (IUCN) [BirdLife International 2018a] but is not listed under SARA or COSEWIC. However, the population may be declining due to increased polar bear predation in the East Bay priority area [Loewen et al. 2020b]). Also, avian cholera has the potential to cause mass mortality and significantly impact the East Bay population [Descamps et al. 2012]).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 1 x 2 = Negligible
Likelihood	3	Noise disturbance from a vessel underway is likely dependent on a vessel approaching within 250 m of eiders, on the behavioural state of the individual eiders, and on the eiders' previous experience with vessel noise. An interaction may occur in some but not all circumstances.
Overall Risk	Low Risk	No additional management measures need to be considered at this time. However, vessels should observe minimum set-back distances from at-sea concentrations of common eiders as prescribed by ECCC-CWS (Canadian Wildlife Service). A 15 km buffer around breeding colonies was recommended by Mallory and Fontaine (2004).
Uncertainty		
Exposure	3	There is a moderate amount of scientific information available regarding the abundance and distribution of common eiders in the East Bay priority area and general vessel traffic patterns are known. There is some literature that exists from other areas that has investigated the distance at which eiders may be disturbed by vessels.
Sensitivity	3	There is a moderate amount of scientific information on the sensitivity of common eiders to noise disturbance from vessels in other areas (Fliessbach et al. 2019).

Risk Factor	Score	Rationale
Likelihood	3	There is a moderate amount of scientific information on the likelihood of common eiders reacting to noise from vessels and of the likelihood of vessels approaching close enough to cause a reaction.

Risk Statement: If an interaction occurs involving Arctic char and noise and vibration disturbance due to a vessel underway through open water the consequence could result in a negative impact on Arctic char populations in the Chesterfield Inlet/Narrows priority area.

Table 5-3. Arctic Char – Vessel Underway (Chesterfield Inlet/Narrows) – Noise and Vibration Disturbance.

Risk Factor	Score	Rationale
Exposure	3 (binned)	Exposure = Intensity x Temporal x Spatial = 2 x 3 x 3 = 18 (raw score)
Intensity	2	It should be noted that relative to other areas that experience shipping and vessel in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low absolute density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Chesterfield Inlet/Narrows priority area experiences a high density of vessel traffic relative to other portions of the AOI (see Figures 5-1 and 5-10) representing 61% of total AIS data within the AOI from 2012-2019. The intensity of vessel traffic and the resulting stressor is not uniform, and the density would be higher in areas of higher vessel traffic (e.g., near regular anchorage areas at Helicopter Island or near Chesterfield Inlet). Considering the above, intensity was scored as a 2.
Temporal	3	Arctic char primarily occur in coastal waters during summer (June-August). Vessels are typically present in the priority area during July to September, and occasionally during June (Maerospace 2020), though they may not be present throughout that entire period. Thus, there is expected to be a large amount of overlap between when vessels and Arctic char are present, resulting in a score of 3.
Spatial	3	Spatial = Areal x Depth = 1 x 3 = 3
Areal	1	Arctic char are expected to occur in the coastal waters of the Chesterfield Inlet/Narrows priority area (GN 2012; Idlout 2020; Loewen et al. 2020a, b), generally within 1,500 m from shore (Moore et al. 2016). Although sound propagates underwater beyond the path of the vessel, due to navigational constraints in nearshore waters, overlap is expected to be a few restricted locations within the Arctic char range in the priority area. Therefore, a score of 1 was assigned.
Depth	3	Arctic char are distributed in shallow coastal waters. Noise and/or vibrations from a vessel underway could propagate throughout the entire water column in shallow waters, thus covering the entire depth range of Arctic char in the Chesterfield Inlet/Narrows priority area and resulting in a score of 3.
Sensitivity	2 (binned)	Sensitivity = (Acute change + Chronic Change) x Recovery Factors = (1 + 1) x 2.5 = 5.0
Acute Change	1	Fish use sound to communicate, avoid predators, select habitat, and for mating behaviour (Popper and Hawkins 2019). Noise can impact fish behaviour, physiology, and hearing (Popper and Hawkins 2019), and can mask natural

Risk Factor	Score	Rationale
		sounds and decrease communication space (e.g., Stanley et al. 2017; Pine et al. 2018). The swim bladder of Arctic char is not involved in hearing but is sensitive to particle motion; therefore, Arctic char are less sensitive to sound than other fish that have swim bladders (Popper and Hawkins 2019), but they may be sensitive to vibration. Salmonids are only sensitive to a narrow band of frequencies (Popper and Hawkins 2019). Studies have shown changes in behaviour of salmonids exposed to noise (e.g., Knudsen et al. 1992), but most studies examining impacts of noise on fish have mainly been conducted on fish in laboratories, not free-ranging animals in natural conditions. Vibrations, like sound, have the potential to interfere with fish communication and behaviour (Hawkins et al. 2021). The possible impacts of vessel noise on char, especially during their fall migratory period, is a noted concern from residents of Chesterfield Inlet (Idlout 2020). Although there could be limited behavioural impacts such as avoidance by Arctic char, due to the low absolute level of vessel traffic in the Chesterfield Inlet/Narrows priority area and the fact that sounds/vibrations emitted by moving vessels are transitory, it is expected that there would be an insignificant or undetectable change to Arctic char mortality rates against background variability and limited behavioural impacts, resulting in a score of 1.
Chronic Change	1	Noise (as well as vibrations) can impact fish behaviour, physiology, and hearing (Popper and Hawkins 2019), and can mask natural sounds and decrease communication space (e.g., Stanley et al. 2017; Pine et al. 2018). If critical life functions, such as spawning success (e.g., de Jong et al. 2018, 2020) are compromised by sound or avoidance responses result from sound, fitness consequences could result (Slabbekoorn et al. 2010). However, Arctic char do not spawn in the marine environment where vessel sounds would occur. There is a risk that vessel noise/vibrations could mask Arctic char sounds and interfere with the production and detection of important acoustic signals or cause behavioural changes, such as avoidance. Although long-term effects associated with prolonged avoidance are possible, this has not been shown to occur in naturally occurring environments where fish are able to swim away from loud source sources. Based on the low density of vessel traffic and transitory nature of the sound/vibrations, no detectable changes to overall fitness or population dynamics are expected, resulting in a score of 1.
Recovery Factors	2.5	Recovery factors = mean of the factors listed below. Fecundity: 2 (Fecundity declines with latitude, but Arctic char spawn several times throughout their life [Coad and Reist 2018]). Early life stage mortality: 3 (High mortality likely associated with environmental factors, as well as density-dependent factors [Coad and Reist 2018]). Recruitment pattern: 2 (Anadromous Arctic char are not as long lived as lake-dwelling populations but may live 20+ years and spawn multiple times throughout their lives [Coad and Reist 2018]). Natural mortality rate: 2 (Mean annual mortality for Canadian anadromous populations is 30-45%, for age classes 6-15 years [Coad and Reist 2018]). Age at maturity: 3 (Age at maturity is 3-10 years [Coad and Reist 2018]). Life stages affected: 3 (All stages). Population connectivity: 3 (Discrete stocks/populations occur in rivers and lakes [Coad and Reist 2018]). Population status: 2 (IUCN classification is *least concern* [Freyhof and Kottelat 2008], but many discrete stocks exist, and the population trends are unknown).
Consequence	3 (binned)	Consequence = Exposure x Sensitivity = 3 x 2 = Moderate

Risk Factor	Score	Rationale
Likelihood	2	An interaction has the potential to occur when Arctic char and a vessel are present at the same time within the Chesterfield Inlet/Narrows priority area and within close enough proximity for the vessel noise/vibration to cause a disturbance to the animal. However, salmonids, including Arctic char, are less sensitive to noise than other fishes (Hawkins and Popper 2019), and impacts will depend on the behavioural state of the animal as well as distance to the vessel. Therefore, a score of 2 was assigned.
Overall Risk	Moderately-High Risk	Additional management measures should be considered, such as reducing vessel speed within areas identified as generally important for Arctic char and as important for Arctic char feeding and fishing. The Aiviit Hunters and Trappers Organization (HTO) suggested a halt to shipping during the Arctic char migration run, which occurs from mid-August to the beginning of September (DFO unpublished[10]).
Uncertainty		
Exposure	5	How noise/vibration would impact Arctic char over different spatial scales is uncertain. Some details exist about the general coastal distribution of Arctic char though no investigation has occurred specifically in the Chesterfield Inlet/Narrows priority area. General vessel traffic patterns are known. Thus, the uncertainty is very high.
Sensitivity	4	The impacts of anthropogenic noise on fish, including Arctic char, are not well understood, in particular how particle motion rather than sound pressure, may affect their behaviour and physiology (Popper and Hawkins 2018). Also, there are knowledge gaps regarding impacts of vibration on fish (Hawkins et al. 2021). In addition, most studies on fish hearing and sound production have focused on laboratory experiments, and results may differ if experiments were conducted in natural settings (Popper and Hawkins 2019). Thus, the uncertainty is high.
Likelihood	4	Research is needed on the response of Arctic char to vessel noise/vibration, though some literature exists on the responses of other fish to this stressor. Since little scientific information is available on the topic and existing literature is from other areas, the uncertainty is high.

Risk Statement: If an interaction occurs involving Arctic cod and noise disturbance due to a vessel underway through open water the consequence could result in a negative impact on Arctic cod populations in the Fisher and Evans Straits priority area.

Table 5-4. Arctic Cod – Vessel Underway (Fisher and Evans Straits) – Noise Disturbance.

Risk Factor	Score	Rationale
Exposure	3 (binned)	Exposure = Intensity x Temporal x Spatial (Depth x Areal) = 2 x 2 x 6 = 24 (raw score)
Intensity	2	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Fisher and Evans Straits priority area experiences a higher density of vessel traffic relative to other

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[10] DFO. 2019. Community confirmation engagement report: Marine Protected Area process in Kivalliq and Southampton Island proposed Area of Interest. 27 p.

Risk Factor	Score	Rationale
		priority areas except Chesterfield Inlet/Narrows (see Figures 5-1 and 5-10), representing 9.5% of total AIS data within the AOI from 2012-2019. Therefore, an intensity score of 2 was assigned.
Temporal	2	Arctic cod are expected to occur in the area year-round. Vessels are typically present in the priority area during July to October, and very occasionally during June and November (Maerospace 2020), though they may not be present throughout that entire period. There is an approximate temporal overlap of 33-50% between when vessels and Arctic cod may be present, resulting in a score of 2.
Spatial	6	Spatial = Areal x Depth = 2 x 3 = 6
Areal	2	A ubiquitous species, Arctic cod occupy coastal and offshore waters in areas with and without sea ice and are expected to be widespread throughout the Arctic Ocean (Coad and Reist 2018). Based on Loewen et al. (2020a), most records for Arctic cod within the AOI are for Evans Strait though Loewen et al. (2020b) also noted the occurrence of Arctic cod around small islands in Fisher Strait. Based on available AIS data, vessel activity (see Figures 5-1 and 5-10) is typically focused along two primary paths that occur north and south of Coats Island, with underwater sound propagating beyond the vessel track. Therefore, regular vessel activity could overlap with a small proportion of the total Arctic cod range in the priority area, resulting in a score of 2.
Depth	3	Arctic cod are widespread across the circumpolar Arctic, but they occur at different depths throughout the water column based on factors such as life history stage (e.g., Geoffroy et al. 2016), seasonal diet (e.g., Majewski et al. 2016), and light regime (e.g., Benoit et al. 2010). Eggs and larvae concentrate under the sea ice. Noise from a vessel underway could propagate throughout the entire water column and is expected to cover the entire depth range of Arctic cod in the Fisher and Evans Straits priority area. This results in a score of 3.
Sensitivity	1 (binned)	Sensitivity = (Acute change + Chronic Change) x Recovery Factors = (1 + 1) x 1.9 = 3.8
Acute Change	1	As with all members of the Gadidae family, Arctic cod have swim bladders positioned close to their ears, their hearing is more sensitive to a wider range of frequencies compared to other fish species that do not have a swim bladder; however, they are less sensitive than fish that have swim bladders linked to their ears (Popper and Hawkins 2019). Gadids are sensitive to sound pressure as well as particle motion, giving them the ability to locate sound sources and discriminate sounds against background noise (Popper and Hawkins 2019). Gadids can hear frequencies up to 500 Hz (Popper and Hawkins 2019), which overlap with the low frequencies typically emitted by large vessels; they also produce sounds (Riera et al. 2018). Fish use sound to communicate, avoid predators, select habitat, and for mating behaviour (see Popper and Hawkins 2019). Noise can impact fish behaviour, physiology, and hearing (Popper and Hawkins 2019), it can mask natural sounds and decrease communication space (e.g., Stanley et al. 2017; Pine et al. 2018), and impact spawning success (e.g., de Jong et al. 2018, 2020). Several studies have shown changes in behaviour and physiology of gadids exposed to noise, including reduced spawning success (e.g., Nedelec et al. 2015; Sierra-Flores et al. 2015; Ivanova et al. 2020), but most studies have been conducted on fish in laboratories, not free-ranging animals in natural conditions. Although there could be limited behavioural impacts (e.g., avoidance) by Arctic cod, due to the overall low level of vessel traffic in the Fisher and Evans Straits priority area and the fact that sounds emitted by moving vessels are transitory, it is expected that there would be an insignificant or

Risk Factor	Score	Rationale
		undetectable change to Arctic cod mortality rates against background variability and limited behavioural impacts. Thus, a score of 1 was assigned.
Chronic Change	1	Noise can impact fish behaviour, physiology, and hearing (Popper and Hawkins 2019), and can mask natural sounds and decrease communication space (e.g., Stanley et al. 2017; Pine et al. 2018). If critical life functions, such as spawning success (e.g., de Jong et al. 2018, 2020) are compromised by sound or avoidance responses result from sound, fitness consequences could result (Slabbekoorn et al. 2010). There is a risk that vessel noise could mask gadid sounds and interfere with the production and detection of important acoustic signals or cause behavioural changes (e.g., avoidance), possibly leading to further impacts (e.g., interruptions to spawning behaviour). Although long-term effects associated with reduced spawning success and prolonged avoidance are possible, this has not been shown to occur in naturally occurring environments where fish are able to swim away from loud sources. Based on the relatively low density of vessel traffic and transitory nature of the sounds, no detectable changes to overall fitness or population dynamics are expected, resulting in a score of 1.
Recovery Factors	1.9	Recovery factors = mean of the factors listed below. Fecundity: 2 (Spawn only once in their lifetime with a relatively low number of eggs; between 9,000 to 21,000 eggs are produced, with an average of 11,900 per female [Cohen et al. 1990]). Early life stage mortality: 3 (R-selected species with high mortality [Coad and Reist 2018]). Recruitment pattern: 2 (Increased recruitment expected with climate change [LeBlanc et al. 2019]). Natural mortality rate: 1 (Mortality is high [Coad and Reist 2018]). Age at maturity: 2 (2-3 years for males and 3-4 years for females [Coad and Reist 2018]). Life stages affected: 3 (All life stages could potentially occur in the area). Population connectivity: 1 (Arctic cod range widely throughout the Arctic). Population status: 1 (IUCN classification is *least concern* [Fernandes et al. 2015], but population trend is unknown. Abundant in Arctic marine waters [Coad and Reist 2018]).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 3 x 1 = Negligible
Likelihood	3	An interaction has the potential to occur when Arctic cod and a vessel are present at the same time within the priority area and within close enough proximity for the vessel noise to cause a disturbance to the animal. Gadids are relatively sensitive to sound and depending on the behavioural state of the animal and the distance to the vessel, an interaction may occur in some but not all circumstances.
Overall Risk	Low Risk	No additional management measures need to be considered at this time.
Uncertainty		
Exposure	4	How noise would impact Arctic cod over different spatial scales is uncertain. General information exists regarding the distribution of Arctic cod, as well as some information specific to the priority area, though it is limited. General vessel traffic patterns are known. Thus, the uncertainty is high.
Sensitivity	4	The impacts of anthropogenic noise on fish, including Arctic cod, are not well understood, in particular how particle motion rather than sound pressure, may affect their behaviour and physiology (Popper and Hawkins 2018). In addition, most studies on fish hearing and sound production have focused on laboratory experiments, and results may differ if experiments were conducted in natural

Risk Factor	Score	Rationale
		settings (Popper and Hawkins 2019). However, gadids have received more focus on this topic than other fishes. Thus, the uncertainty is high.
Likelihood	4	Research is needed on the response of Arctic cod to vessel noise. However, literature exists on the responses of other gadids to noise disturbance in other areas. Since little scientific information is available is available on the topic and assumptions were made from other areas, the uncertainty is high.

Risk Statement: If an interaction occurs involving ringed seals and noise from a vessel underway through open water the consequence could result in a negative impact on the ringed seal population in the Fisher and Evans Straits priority area.

Table 5-5. Ringed Seal – Vessel Underway (Fisher and Evans Straits) – Noise Disturbance.

Risk Factor	Score	Rationale
Exposure	3 (binned)	Exposure = Intensity x Temporal x Spatial = 2 x 2 x 6 = 24 (raw score)
Intensity	2	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Fisher and Evans Straits priority area experiences a higher density of vessel traffic relative to other priority areas except Chesterfield Inlet/Narrows (see Figures 5-1 and 5-10), representing 9.5% of total AIS data within the AOI from 2012-2019. Therefore, an intensity score of 2 was assigned.
Temporal	2	Ringed seals are expected to occur in the priority area year-round (Idlout 2020; Loewen et al. 2020b). Vessels are typically present in the priority area during July to October, and very occasionally during June and November (Maerospace 2020), though they may not be present throughout that entire period. There is an approximate temporal overlap of 33-50% between when vessels and ringed seals may be present, resulting in a score of 2.
Spatial	6	Spatial = Areal x Depth = 2 x 3 = 6
Areal	2	Ringed seals are expected to be widely distributed throughout the priority area (but during the ice-covered season more prevalent in areas of fast-ice with water depths >3 m). Based on available AIS data, vessel activity (see Figures 5-1 and 5-10) is typically focused along two primary paths that occur north and south of Coats Island, with underwater sound propagating beyond the vessel track. Therefore, regular vessel activity could overlap with a small proportion of ringed seal distribution within the priority area, resulting in a score of 2.
Depth	3	The maximum dive depth for ringed seals is >500 m (Ogloff et al. 2021). Depending on where vessel transits occur in the priority area, ringed seals may be found throughout the water column. Sound levels from vessel traffic are expected to reach the maximum dive depth of ringed seals at levels which may influence their behaviour, resulting in a score of 3.
Sensitivity	1 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (1+1) × 2.3 = 4.6

Risk Factor	Score	Rationale
Acute Change	1	Ringed seals can hear vessel noise. Sounds produced from transiting vessels are not predicted to cause hearing damage or mortality. Given that sounds important to ringed seals are predominantly at much higher frequencies than shipping noise, and given the temporary nature of vessel sounds, it is unlikely that masking would affect ringed seals. Few authors have described the responses of phocids to vessels, and most of the available information concerns pinnipeds hauled out on land or ice. Ringed seals hauled out on ice pans often showed short-term escape reactions when a ship came within 250-500 m (Brueggeman et al. 1992). However, during the open-water season in the Beaufort Sea, ringed seals are commonly observed close to vessels (e.g., Harris et al. 1997, 1998, 2001, 2007, 2009). Several Hunter and Trapper Committee members in the Inuvialuit Settlement Region in the Beaufort Sea indicated that during seal hunting, they often create underwater noise to attract ringed seals to their boat, noting that seals are “curious”. When in the water (vs. hauled out), seals appear less responsive to approaching vessels. Some seals will approach a vessel out of apparent curiosity, including noisy vessels such as those operating airgun arrays (Moulton and Lawson 2002). Suryan and Harvey (1999) reported that Pacific harbour seals (*Phoca vitulina richardsi*) commonly left the shore when powerboat operators approached to observe them. These seals apparently detected a powerboat at a mean distance of 264 m and left their haul-out sites when boats approached to within 144 m. Harbour seals hauled out on floating ice in fjords in Disenchantment Bay, Alaska were more likely to enter the water when a cruise ship approached within 500 m (Jansen et al. 2010). Seals that were approached as close as 100 m were 25 times more likely to enter the water than those approached at 500 m. Cruise ships that approached directly vs. abeam resulted in more seals entering the water. Based on available information, some seals are likely to avoid approaching vessels by a few hundreds of metres while some curious seals may swim toward them. Given that ringed seal displacement is considered temporary and in a small area, and that behavioural impacts are variable, the impact of noise from a vessel underway on ringed seal behaviour at the population level is considered insignificant or undetectable, resulting in a score of 1.
Chronic Change	1	Ringed seals are known to exhibit localized and temporary avoidance of vessels, though responses are variable (see *Acute Change*, above); however, noise from a vessel underway is not expected to affect the overall fitness of the population. Furthermore, vessel transits in open water are not anticipated to occur during spring when ringed seals give birth, nurse pups, and undergo mating. Chronic change in overall fitness of ringed seals in the priority area is ranked as insignificant or undetectable, resulting in a score of 1.
Recovery Factors	2.3	Recovery factors = mean of the factors listed below. Fecundity: 3 (Females typically give birth to one pup a year). Early life stage mortality: 2 (Mortality could increase in the future as climate change affects the amount and suitability of ice required for important life functions [pupping, nursing; Reeves et al. 1992]). Recruitment pattern: 2 (Recruitment is variable depending on prevailing environmental conditions [Ferguson et al. 2005; Stirling 2005; Chambellant et al. 2010]). Natural mortality rate: 3 (Mortality rates have been reported low in adult ringed seals with survivorship of 0.89 for age 6+ seals. Survivorship of age 0+ seals is reported to be much lower [0.59] [Smith 1975; Reimer et al. 2019]).

Risk Factor	Score	Rationale
		Age at maturity: 3 (Best estimate of the population-wide average age at maturity is 4-7 years old [in most areas; can range from 3-9; see COSEWIC 2019]). Life stages affected: 3 (All stages). Population connectivity: 1 (Ringed seals in the Canadian Arctic are known to move extensively to different arctic regions, regularly making annual journeys that are 1,000s of kilometers). Population status: 1 (Ringed seals are considered *special concern* by COSEWIC [2019] and are not listed under SARA. The COSEWIC [2019] report does not offer insight into population trend. Ringed seals are listed as *threatened* in the USA [related to potential habitat loss], *least concern* in Greenland, no listing in Russia, and *least concern* by IUCN).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 3 x 1 = Negligible
Likelihood	3	An interaction has the potential to occur when ringed seals and a transiting vessel are present at the same time within the priority area and within close enough proximity for the vessel noise to cause a disturbance to the animal(s). Ringed seals are known to display variable responses to vessel noise (e.g., Moulton and Lawson 2002). Depending on the behavioural state of the animal and the distance to the vessel, an interaction may occur in some but not all circumstances.
Overall Risk	Low Risk	No additional management actions need to be considered at this time.
Uncertainty		
Exposure	4	There is some information about ringed seal distribution and numbers for the Fisher and Evans Straits priority area and general traffic patterns are known. Since exposure assumptions (i.e., distances at which disturbance occurs) were based primarily on ringed seal literature from other areas and on limited shipping data, the uncertainty is high.
Sensitivity	3	Certain aspects of ringed seal biology and their response to transiting vessels have been reported in other areas of the arctic. There is a moderate amount of scientific information available on the topic as well as expert opinion; thus, the uncertainty is moderate.
Likelihood	4	Available information, not specific to the priority area, indicates that some ringed seals will exhibit a temporary behavioural response to vessels underway. Since assumptions were based primarily on ringed seal literature from other areas and there is limited vessel traffic information for the priority area, the uncertainty is high.

Risk Statement: If an interaction occurs involving bearded seals and noise from a vessel underway through open water the consequence could result in a negative impact on the bearded seal population in the Fisher and Evans Straits priority area.

Table 5-6. Bearded Seal – Vessel Underway (Fisher and Evans Straits) – Noise Disturbance.

Risk Factor	Score	Rationale
Exposure	3 (binned)	Exposure = Intensity x Temporal x Spatial = 2 x 2 x 6 = 24 (raw score)
Intensity	2	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel

Risk Factor	Score	Rationale
		traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Fisher and Evans Straits priority area experiences a higher density of vessel traffic relative to other priority areas except Chesterfield Inlet/Narrows (see Figures 5-1 and 5-10), representing 9.5% of total AIS data within the AOI from 2012-2019. Therefore, an intensity score of 2 was assigned.
Temporal	2	Bearded seals are presumably present in the priority area year-round (Idlout 2020); bearded seals are known to occur in Evans Strait (Loewen et al. 2020b). Vessels are typically present in the priority area during July to October, and very occasionally during June and November (Maerospace 2020), though they may not be present throughout that entire period. There is an approximate temporal overlap of 33-50% between when vessels and bearded seals may be present, resulting in a score of 2.
Spatial	6	Spatial = Areal x Depth = 2 x 3 = 6
Areal	2	Bearded seals are expected to be widely distributed (in low densities) throughout the priority area given that water depths are generally <100 m (Loewen et al. 2020b). Based on available AIS data, vessel activity (see Figures 5-1 and 5-10) is typically focused along two primary paths that occur north and south of Coats Island, with underwater sound propagating beyond the vessel track. Therefore, regular vessel activity could overlap with a small proportion of bearded seal distribution within the priority area, resulting in a score of 2.
Depth	3	Foraging bearded seals typically dive to depths of <100 m, up to about 500 m (NOAA 2022a). Depending on where vessel transits occur in the priority area, bearded seals may be found throughout the water column. Noise from vessel traffic is expected to reach the maximum dive depth of bearded seals at levels which may influence their behaviour, resulting in a score of 3.
Sensitivity	1 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (1+1) × 2.4 = 4.8
Acute Change	1	Bearded seals can hear vessel noise (Sills et al. 2020). Sounds produced from transiting vessels are not predicted to cause hearing damage or mortality. The potential for masking from vessel noise is somewhat reduced given that the dominant frequencies in bearded seal calls fall mostly outside the range of those associated with noise generated by shipping traffic. Few authors have described the responses of phocids to vessels, and most of the available information concerns pinnipeds hauled out on land or ice. During the open water season in the Beaufort Sea, bearded (and ringed) seals are commonly observed close to vessels (e.g., Harris et al. 1997, 1998, 2001, 2007, 2009). In places where boat traffic is heavy, there have been cases where seals have habituated to vessel disturbance. In England, harbour and grey seals at some haul-out sites appear to have habituated to close approaches by tour boats (Bonner 1982). When in the water (vs. hauled out), seals appear less responsive to approaching vessels. Some seals, including bearded seals, will approach a vessel out of apparent curiosity, including noisy vessels such as those operating airgun arrays (Harris et al. 2001; Moulton and Lawson 2002). Harwood et al. (2005) noted the behaviour of two bearded seals in the Canadian Beaufort Sea from a research vessel; one seal swam away and the other swam alongside the vessel. Suryan and Harvey (1999) reported that Pacific harbour seals commonly left the shore when powerboat operators approached to observe them. These seals apparently detected a powerboat at a mean distance of 264 m, and seals left their haul-out sites when boats approached to within 144 m. Harbour seals hauled out on floating ice in fjords in Disenchantment Bay, Alaska, were more likely to

Risk Factor	Score	Rationale
		enter the water when a cruise ship approached within 500 m (Jansen et al. 2010). Seals that were approached as close as 100 m were 25x more likely to enter the water than those approached at 500 m. Cruise ships that approached directly vs. abeam of hauled out seals resulted in more seals entering the water. Based on available information, some bearded seals are likely to avoid approaching vessels by a few 100s of metres. Given that bearded seal displacement is considered temporary and localized, and that behavioural impacts are variable, the impact of noise from a vessel underway on bearded seal behaviour at the population level is considered insignificant or undetectable resulting in a score of 1.
Chronic Change	1	Bearded seals are known to exhibit localized and temporary avoidance of vessels (see *Acute Change*, above) though responses are variable; however, noise from a vessel underway is not expected to affect the overall fitness of the population. Furthermore, vessel transits in open water are not anticipated to occur during spring when bearded seals give birth, nurse pups, and undergo mating. Chronic change in overall fitness of bearded seals in the priority area is ranked as insignificant or undetectable, resulting in a score of 1.
Recovery Factors	2.4	Recovery factors = mean of the factors listed below. Fecundity: 3 (Females typically give birth to one pup a year). Early life stage mortality: 2 (Mortality could increase in the future as climate change affects the amount and suitability of ice required for important life functions [pupping, nursing; Reeves et al. 1992]). Recruitment pattern: Unknown; excluded from analysis. Natural mortality rate: Unknown; excluded from analysis. Age at maturity: 3 (In general, bearded seals attain sexual maturity at 5-6 years old for females and 6-7 for males [Cameron et al. 2010; Kovacs 2016]; however, some females in the Arctic have been found to attain sexual maturity between 3-7 years of age [Andersen et al. 1999]). Life stages affected: 3 (All stages may be affected). Population connectivity: Unknown; excluded from analysis (It is unknown if bearded seals in the AOI remain there year-round or undertake seasonal movements in and out of the region). Population status: 1 (Bearded seals are considered *data deficient* by COSEWIC [2021] and are not listed under SARA. Bearded seals are listed as *threatened* in the USA [related to potential habitat loss], *not threatened* in Greenland, and *least concern* by IUCN).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 3 x 1 = Negligible
Likelihood	3	An interaction has the potential to occur when bearded seals and a transiting vessel are present at the same time within the priority area and within close enough proximity for the vessel noise to cause a disturbance to the animal(s). Bearded seals are known to display variable responses to vessel noise (e.g., Moulton and Lawson 2002). Depending on the behavioural state of the animal and the distance to the vessel, an interaction may occur in some but not all circumstances.
Overall Risk	Low Risk	No additional management measures need to be considered at this time.
Uncertainty		
Exposure	4	There is little to no information about bearded seal distribution and numbers from the priority area. General traffic patterns are known. Since exposure assumptions (i.e., distances at which disturbance occurs) were based primarily on bearded seal

Risk Factor	Score	Rationale
		literature from other areas and there is little scientific information available on the topic, the uncertainty is high.
Sensitivity	4	Certain aspects of bearded seal biology and their response to transiting vessels have been reported in other areas of the arctic; however, little is known about the impacts of noise disturbance. Since assumptions were based primarily on bearded seal literature from other areas and there is little scientific information available on the topic, the uncertainty is high.
Likelihood	4	Available information, not specific to the study area, indicates that some bearded seals will exhibit a temporary behavioural response to vessels underway. Since assumptions were based primarily on bearded seal literature from other areas and there is little scientific information available on the topic, the uncertainty is high.

Risk Statement: If an interaction occurs involving walruses and noise from a vessel underway through open water the consequence could result in a negative impact on the walrus population in the Fisher and Evans Straits priority area.

Table 5-7. Walrus – Vessel Underway (Fisher and Evans Straits) – Noise Disturbance.

Risk Factor	Score	Rationale
Exposure	3 (binned)	Exposure = Intensity x Temporal x Spatial = 2 x 2 x 6 = 24 (Raw score)
Intensity	2	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Fisher and Evans Straits priority area experiences a higher density of vessel traffic relative to other priority areas except Chesterfield Inlet/Narrows (see Figures 5-1 and 5-10), representing 9.5% of total AIS data within the AOI from 2012-2019. Therefore, an intensity score of 2 was assigned.
Temporal	2	Based on scientific studies and current Inuit Qaujimajatuqangit, walruses occur in the Fisher and Evans Straits priority area year-round (Idlout 2020; Loewen et al. 2020b). Vessels are typically present in the priority area during July to October, and very occasionally during June and November (Maerospace 2020), though they are not present throughout that entire period. Considering the above, there is an approximate temporal overlap of 33-50% between vessel traffic occurrence and the time walruses are present, resulting in a score of 2.
Spatial	6	Spatial = Areal x Depth = 2 x 3 = 6
Areal	2	Walruses are relatively sedentary in summer (Stewart 2008), tending to remain in areas where their food is most abundant and in water less than 80 m deep (Fay 1982; Reeves et al. 2002; Dehn et al. 2007; Lowry 2016a; COSEWIC 2017). The priority area provides walrus foraging habitat, calving areas, and key haul-out sites (on Walrus, Bencas, and Coats Islands). Based on available AIS data, vessel activity (see Figures 5-1 and 5-10) is typically focused along two primary paths that occur north and south of Coats Island, with underwater sound propagating beyond the vessel track. Therefore, regular vessel activity could overlap with a small proportion walrus habitat, and a score of 2 was assigned.

Risk Factor	Score	Rationale
Depth	3	Walrus typically feed in waters <80 m deep but sometimes feed in waters up to 200 m (Fay 1982; Outridge et al. 2003; COSEWIC 2017). Sounds produced by moving vessels would be detectable and may elicit a response at all water depths where walrus occur, resulting in a score of 3.
Sensitivity	3 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (2+2) × 2.1 = 8.4
Acute Change	2	Important walrus haul-out sites, calving, and foraging habitat occur in the Fisher and Evans Straits priority area. Most studies on walrus response to vessels are for Pacific walruses and it is assumed disturbance reactions may be similar for Atlantic walruses (DFO 2019a). Research indicates that when operating a small vessel (e.g., Zodiac or skiff), walruses at a terrestrial haul-outs will be disturbed and enter the water when small vessels are within 400 m (Born et al. 1995). Salter (1979) reported that on six approaches to a terrestrial haul-out via Zodiac, walruses were only disturbed when the vessel was within 1.8 km of the haul-out site. However, noise from outboard motors may be more disturbing than sounds from a diesel engine (Fay et al. 1984). Animals from hunted populations are typically more skittish around small boats compared to non-hunted populations (see Malme et al. 1989; Born et al. 1995; Higdon et al. 2022). Non-hunted populations in Svalbard were not significantly disturbed when tourist boats approached haul-out sites (with a single exception resulting in a large number of walruses entering the water) (Øren et al. 2018; Higdon et al. 2022). Born et al. (1995) noted that non-hunted populations could be approached within 10 to 20 m when the walruses were drowsy. At Round Island, Alaska walruses have been observed during disturbances over several years. During 44 potential boat disturbance events (primarily tour boats) in 2008, walruses raised their heads in response to two boats, re-oriented in response to three boats, and dispersed when disturbed by 11 boats; during 28 other events, walruses did not react (Okonek et al. 2008). Similarly, for 43 potential boat disturbances in 2007, walruses had no response during 27 events; head raises occurred on four occasions, and dispersal occurred on 12 occasions (Okonek et al. 2007). An apparent correlation between increased noise during the yellowfin sole fishery and observed declines in numbers of walruses using haul-outs in northern Bristol Bay, Alaska led to the establishment in 1990 of protection zones around the walrus islands (see Wilson and Evans 2009). Additionally, indigenous hunters in Bristol Bay were concerned that noise from fishing activities disturbed walruses and made it more difficult to hunt them (Wilson and Evans 2009). If walruses disperse from haul-out sites, young animals can be injured or killed during these evacuations (Fischbach et al. 2009). Walruses have also been documented abandoning haul-out sites after a disturbance for a short period of time (3-4 days; Mansfield and St. Aubin 1991). Marine mammal monitoring studies (2006-2010) in the Chukchi (and Beaufort) Sea have revealed that Pacific walruses were regularly detected in open-water (at distances ranging from < 10-3000 m) from both monitoring and geophysical source vessels (Funk et al. 2013). Behavioural data indicated that walrus generally exhibited no to minor responses (e.g., look) to both types of vessels even in areas where received sound levels were estimated as >160 dB re 1 µPa rms. There is little information on small vessel disturbances to walrus in water, however, McFarland and Aerts (2015) recorded walrus being disturbed (diving, changing course, and/or speed) when icebreakers came within 500 m of the observed walruses. This suggests that walrus response to vessels in open water may be minor.

Risk Factor	Score	Rationale
		Walruses at haul-out sites or on sea ice often react to disturbance such as loud sounds or a visual stimulus from a vessel by entering the water (Salter 1979; Brueggeman 1993). Though disturbance-induced mortality to adult walruses is not known, young animals can be injured or killed during these evacuations (Fischbach et al. 2009). Thus, changes to the health or survival of individual walruses are plausible and behavioural impacts are expected if walrus (particularly at haul-out sites) are exposed to sounds produced by a moving vessel. Thus, a score of 2 was assigned.
Chronic Change	2	Disturbance may cause indirect impacts including interruption of foraging and social interactions (e.g., interference of mother-offspring communication or insufficient nursing of calves) and increased stress and energy expenditure (Born et al. 1995). Additionally, walruses may abandon haul-out sites after repeated exposure that may cause a shift in distribution away from preferred feeding areas (Johnson et al. 1989; Born et al. 1995), which would result in a loss of important habitat and a change in geographic range. Although the current absolute density of vessel traffic is low, haul-out abandonment is plausible given repeated disturbance, resulting in a score of 2. To note regarding habituation: Stewart et al. (2012) generally found that evidence of walrus habituation to noise disturbance from vessels and aircraft has not been sufficiently supported. Additionally, observations for walrus haul-out disturbance behaviour from one area may not be transferable to another. For example, since walruses in Canada are hunted, they tend to be more sensitive to human presence compared to other areas where they are not (Higdon et al. 2022). Øren et al. (2018) looked at the effects of tourist visitations on haul-out dynamics and site use by walruses in Svalbard, Norway and found that tourists on land and boats near the haul-out sites did not disturb walrus haul-out behaviour significantly at any of the sites, with a single exception. This perhaps suggests that habituation occurred; however, it has been suggested that this is due to the fact that walruses are not hunted in this area (Higdon et al. 2022). At Round Island, Alaska long-term datasets have suggested that Pacific walruses have not habituated to disturbance from both boats and aircraft as reactions have remained similar over a 20+ year monitoring period (DFO 2019a; Higdon et al. 2022). Habituation may therefore not occur consistently among Pacific and Atlantic walruses, populations, or individuals. Since there is potential for walruses to experience chronic stress whether they were to habituate or not in response to ship noise (Stewart et al. 2012) and since walruses in the Southampton Island AOI may respond differently to sound given that they are hunted for subsistence, the possibility of habituation was not incorporated into the risk score calculations.
Recovery Factors	2.1	Recovery factors = mean of the factors listed below. Fecundity: 3 (Adult female walrus have 1 calf every 3 years [Garlich-Miller and Stewart 1999]). Early life stage mortality: 1 (The data are sparse but the population structure and relatively high proportion of juveniles in the population suggests low mortality in all juvenile stages [Fay et al. 1997]). Recruitment pattern: 1 (Although annual recruitment is low by some standards, recruitment seems to be consistent among years and because walrus are long lived [40 years; Kovacs and Lydersen 2006], a single female produces a lot of young over her lifetime]). Natural mortality rate: 3 (The data are sparse but the population structure and relatively high proportion of juveniles in the population suggests low mortality in all life stages [Fay et al. 1997]). Age at maturity: 3 (Average age at sexual maturity of females is 7 years [Garlich-Miller and Stewart 1999]).

Risk Factor	Score	Rationale
		<u>Life stages affected</u>: 3 (All life stages may be affected]. <u>Population connectivity</u>: 2 (Studies suggest that there is some interchange among Canadian Arctic walrus populations [Stewart 2008; Charette et al. 2020; Loewen et al. 2020b]). <u>Population status</u>: 1 (COSEWIC [2017] lists walruses as *special concern* due to threats associated with global warming. The Hudson Bay-Davis Strait stock has increased from a minimum of 3,900 in 1986 to approximately 7,000 and the authors suggest that walruses remain abundant in the Southampton Island area (Hammill et al. 2016a).
Consequence	3 (binned)	Consequence = Exposure x Sensitivity = 3 x 3 = Moderate
Likelihood	4	Given the documented responses of walruses to disturbance from vessel noise (see *Acute Change*, above), if a vessel were to enter the priority area and approach close enough to groups or individuals an interaction would occur in most circumstances. This results in a likelihood score of 4.
Overall Risk	Moderately-High Risk	Additional management measures should be considered, such as limiting vessel activities during important times of the year for walruses and enforcing set-back distances to haul-out sites in the Fisher and Evans Straits priority area.
Uncertainty		
Exposure	4	General vessel traffic patterns are known. Information exists on important walrus habitat and distribution in the priority area. Some information exists from other areas on distances at which walruses may be disturbed from vessel noise, though limited information exists for the AOI. Uncertainty is considered high.
Sensitivity	3	Certain aspects of walrus biology and their response to transiting vessels have been reported in other areas of the Arctic, although there is virtually no information on noise disturbance for walruses in open water. Since there is some scientific information available on the topic and assumptions were based primarily on walrus literature from other areas, the uncertainty is moderate
Likelihood	3	Available information, not specific to the priority area or AOI, indicates that walruses do exhibit measurable behavioural changes to vessel noise, but the response can be variable. Since assumptions were based on walrus literature from other areas of the Arctic, the uncertainty is moderate.

Risk Statement: If an interaction occurs involving narwhals and noise from a vessel underway through open water the consequence could result in a negative impact on the narwhal population in the Repulse Bay and Frozen Strait priority area.

Table 5-8. Narwhal – Vessel Underway (Repulse Bay and Frozen Strait) – Noise Disturbance.

Risk Factor	Score	Rationale
Exposure	3 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 2 x 9 = 18 (raw score)
Intensity	1	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low absolute density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Repulse Bay/Frozen Strait priority area experiences a low density of vessel traffic relative to other

Risk Factor	Score	Rationale
		priority areas (see Figures 5-1 and 5-10) representing <1% of total AIS data within the AOI from 2012-2019. Therefore, a score of 1 was assigned.
Temporal	2	Narwhals migrate into Repulse Bay in June and July and out in August and September through Frozen Strait (Westdal et al. 2010). Vessels are typically present in the Repulse Bay/Frozen Strait priority area mainly during September and October, and occasionally in August, though they may not be present throughout that entire period. Thus, there is some overlap between when vessels occur in the priority area and when narwhals are present, resulting in a score of 2.
Spatial	9	Spatial = Areal x Depth = 3 x 3 = 9
Areal	3	Narwhal preferred habitats are leads in landfast or pack ice (Koski and Davis 1994; Kovacs et al. 2011). Repulse Bay and nearby waters provides important summering habitat for narwhals where they are known to feed and calve (Idlout 2020; Loewen et al. 2020b). Narwhals migrate through Frozen Strait en route to Repulse Bay during spring/early summer break-up and en route to Hudson Strait prior to freeze-up in the fall. Noise disturbance extends beyond the immediate vessel path (Finley et al. 1990; Heide-Jørgensen et al. 2021). Thus, vessel activity could overlap with a large proportion of narwhal distribution within the priority area resulting in a score of 3.
Depth	3	Sounds produced by moving vessels would be detectable and may elicit a response at all water depths where narwhals might be feeding, which typically is <500 m (Heide-Jørgensen and Dietz 1995; Laidre et al. 2003). Thus, a score of 3 was assigned.
Sensitivity	3 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (2+1) × 2.5 = 7.5
Acute Change	2	Direct mortality to narwhals would not be expected to occur because of exposure to sounds produced by a vessel underway. However, a recent study found that when captured and released, narwhals experience extreme cardiovascular stress (Williams et al. 2017). It is possible that similar effects may be experienced when exposed to other anthropogenic activities, including vessel noise. Finley et al. (1990) found that narwhals exhibited avoidance behaviour at distances of 35 to 50 km when exposed to vessel noise from active icebreaking. Heide-Jørgensen et al. (2021) also demonstrated behavioural disturbances, recording avoidance reactions and changes in swimming speed to vessel noise at distances of at least 10 km; maximum detection or reaction ranges could not be determined due to the fjord system where the study took place. The authors also suggested a lack of acute physiological or physical impacts when exposed to an air gun, which produces sounds louder than those produced by a transiting vessel alone. Re-examination of these results highlighted possible impacts to feeding behaviour, indicated by decreased buzzing activity and a lack of deep (>350 m) dives (NAMMCO 2022a). The energetic costs of avoidance behaviour from anthropogenic disturbance, including vessel noise, is suggested to be higher during important feeding times, with lost foraging opportunity demonstrating a larger impact than increased locomotion costs associated with avoidance (NAMMCO 2022a). Monitoring results related to shipping for Baffinland's iron ore mine documented short-term avoidance behaviour of narwhal from vessels, though it is suggested that impacts would be negligible at a distance beyond several kilometers as at this distance the noise would be inaudible to narwhal (Golder 2021; Sweeney et al. 2022). Considering the information included above, moderate behavioural impacts to vessel noise are expected and a score of 2 was assigned.
Chronic Change	1	Narwhals rely on acoustic communication for critical life functions (Shapiro 2006) and are known to react to underwater vessel noise produced multiple kilometers

Risk Factor	Score	Rationale
		away by altering swim speed, direction, and behaviour (Finley et al. 1990; Heide-Jørgensen et al. 2021; NAMMCO 2022a). Though research on chronic effects of vessel noise on narwhal is limited (Erbe et al. 2019; Halliday et al. 2022), an increase in consistent vessel traffic has been suggested as the cause of a decrease in narwhal numbers in Eclipse Sound, Nunavut (NAMMCO 2022a; QIA 2022) also reflected in external comments provided in response to Baffinland's summary report on marine mammal monitoring studies (Appendix F, Golder 2021). This assertion is refuted by Baffinland's monitoring summary report which suggest climate change as a possible explanation for changes in population distribution (Golder 2021). Heide-Jørgensen et al. (2015, 2021) note that as narwhals have defined migratory routes and high site fidelity, they are vulnerable to displacement. The energetic costs of avoidance behaviour from anthropogenic disturbance, including vessel noise, is suggested to be higher during important feeding times, with lost foraging opportunity demonstrating a larger impact than increased locomotion costs associated with avoidance (NAMMCO 2022a), suggesting possible impacts to body condition from repeated disturbances. It is plausible that given their apparent sensitivity to disturbance from vessel noise narwhals may experience chronic impacts such as displacement or decreased foraging in certain contexts, however, given the low density of vessel traffic present in the priority area chronic change was scored as 1.
Recovery Factors	2.5	Recovery factors = mean of the factors listed below. Fecundity: 3 (Adult female narwhals have a calf about every 3 years [Garde et al. 2015]). Early life stage mortality: 2 (Few data on first year mortality of narwhal calves are available. Koski and Davis [1994] estimated that 17% of calves died when between 1 and 13 months of age; this is lower than for many other marine mammal species]). Recruitment pattern: 2 (Although annual recruitment is low by some standards, recruitment seems to be consistent among years and because narwhals are long lived [80 years; Garde et al. 2015], a single female can produce a lot of young over her lifetime]). Natural mortality rate: 3 (The data are sparse but the stable population size with the removals by subsistence hunters suggests low mortality in all life stages). Age at maturity: 3 (Age at sexual maturity of females is 6-9 years and older for males [Garde et al. 2015]). Life stages affected: 3 (All life stages except for newborn calves are likely to be affected. An adult female accompanied by a yearling was seen in the AOI [Carlyle et al. 2021]). Population connectivity: 3 (Studies suggest that there is limited interchange among Canadian Arctic narwhal populations [Westdal et al. 2010; Heide-Jørgensen et al. 2013a; Doniol-Valcroze et al. 2020]). Population status: 1 (IUCN classifies narwhals as *least concern* [Lowry et al. 2017]. The last COSEWIC assessment is outdated [from 2004]. Narwhal populations are considered stable [Furgal and Laing 2012; Lowry et al. 2017]).
Consequence	3 (binned)	Consequence = Exposure x Sensitivity = 3 x 3 = Moderate
Likelihood	4	Given the sensitivity of narwhal to disturbance from noise (Finley et al. 1990; Heide-Jørgensen et al. 2021, NAMMCO 2022a), if a vessel were to enter the priority area and approach close enough to groups or individuals an interaction would occur in most circumstances. This results in a likelihood score of 4.

Risk Factor	Score	Rationale
Overall Risk	Moderately-High Risk	Additional management measures should be considered, such as limiting vessel activities during important times of the year for narwhal in the Repulse Bay/Frozen Strait priority area.
Uncertainty		
Exposure	4	General vessel traffic patterns are known. Some information exists from other areas on distances at which narwhals may be disturbed from vessel noise, though no information exists for the AOI. There is some information on narwhal distribution and temporal occurrence in the priority areas. Uncertainty is considered high.
Sensitivity	4	Certain aspects of narwhal biology and their response to transiting vessels have been reported in other areas of the arctic; however, little is known about the impacts of noise disturbance. Since assumptions were based primarily on narwhal literature from other areas and there is limited scientific information available on the topic, the uncertainty is high.
Likelihood	4	Available information, not specific to the priority area or AOI, indicates that narwhals do exhibit measurable behavioural changes to vessel noise, but the response can be variable. Since assumptions were based on narwhal literature from other areas and there is little scientific information available on the topic, the uncertainty is high.

Risk Statement: If an interaction occurs involving belugas and noise from a vessel underway through open water the consequence could result in a negative impact on the beluga population in the East Bay priority area.

Table 5-9. Beluga – Vessel Underway (East Bay) – Noise Disturbance.

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 2 x 6 = 12 (raw score)
Intensity	1	It should be noted that relative to other areas that experience shipping and vessel traffic and for which biological effects literature is largely based, the AOI receives a low density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9). The East Bay priority area experiences a low density of vessel traffic relative to other priority areas (see Figures 5-1 and 5-10) representing <1% of total AIS data within the AOI from 2012-2019. Therefore, intensity was scored as 1.
Temporal	2	Belugas are expected to migrate into the AOI and presumably the East Bay priority area in May and June and occur in the priority area during summer, with migration out of the priority area beginning in early to late September (Loewen et al. 2020b). Vessels are typically present in the East Bay priority area during October and very occasionally in September, though they are not present throughout that entire period (Maerospace 2020). Thus, there is some overlap between when vessels occur in the priority area and when belugas are present, resulting in a score of 2.
Spatial	9	Spatial = Areal x Depth = 2 x 3 = 6
Areal	2	There is expected to be limited spatial overlap between vessel traffic (and associated noise) and beluga occurrence in the East Bay priority area. Belugas migrate into the priority area in spring/early summer, congregate in the shallow

Risk Factor	Score	Rationale
		waters of East Bay during summer, and migrate out of East Bay by end of September. Available AIS data indicate that vessels occur in the northern portion of the East Bay priority area. Noise disturbance extends beyond the immediate vessel path (Finley et al. 1990; Heide-Jørgensen et al. 2021). A small proportion of beluga habitat in the East Bay priority area could overlap with the occurrence of a vessel, for a score of 2.
Depth	3	Beluga regularly forage at depths of 100s of metres (Martin et al. 1998; Watt et al. 2016), with some dives to depths greater than 800 m (Heide-Jørgensen et al. 1998; Richard et al. 2001). Sounds produced by moving vessels would be detectable and may elicit a response at all water depths where belugas occur. This results in a score of 3.
Sensitivity	3 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (2+1) × 2.4 = 7.2
Acute Change	2	Direct mortality to belugas would not be expected to occur because of exposure to sounds produced by a vessel underway. Beluga responses to vessels are variable, ranging from tolerance to extreme sensitivity, depending on the whale's activity and experience, its habitat, and boat type and behaviour (Fraker 1978; Richardson et al. 1995a). In Bristol Bay, Alaska, belugas have been seen feeding among hundreds of salmon fishing boats (Frost et al. 1984). Stewart et al. (1982) reported that the whales were more responsive to outboard motorboats than to other vessels, and Kleinenberg et al. (1964) noted that they sometimes stopped feeding and moved out of an area in response to motorboats. However, Fish and Vania (1971) reported that feeding belugas were not displaced when harassed by motorboats. Belugas that are hunted from motorboats generally return each summer to estuarine concentration areas, even though hunting causes short-term displacement (e.g., Fraker 1980; Seaman and Burns 1981; Burns and Seaman 1985; Caron and Smith 1990). In upper Cook Inlet, Alaska they do not avoid vessels (Markowitz and McGuire 2007). They have also been shown to be tolerant of frequent passages by large vessels traveling in consistent directions in the St. Lawrence River, the Beaufort Sea, and Cook Inlet, Alaska (e.g., Fraker 1977b; Burns and Seaman 1985; Pippard 1985). However, flight from fast and erratically moving boats is often observed. Small-scale dispersal of belugas has been observed when small ships approach within 2.5 km (Fraker 1977a, 1978). In the Mackenzie estuary in 1976, Fraker (1977a) noted that belugas swam rapidly away to about 2.5 km from loaded barges that were being pushed by tugs; the change in whale distribution persisted at least 3 hours but <30 hours. In Kugmallit Bay, beluga responses were variable; some animals moved away from a vessel that approached to within 400 m, whereas whales that were apparently feeding did not respond to a tug that passed ~400 m away (Fraker 1978). Similarly, whales accompanied by calves moved away in apparent response to a vessel 1.5-3 km away, whereas those that were apparently feeding did not respond to a vessel ~1.5 km away (Fraker 1978). Harwood et al. (2005) also suggested that belugas in deep-water regions of the Canadian Beaufort Sea avoided vessels. Belugas may be more sensitive to ship noise when in leads during spring than at other times (Burns and Seaman 1985). In June 1981, a group of 250 whales encountered two anchored drillships and three supply vessels while moving west in the main lead seaward of the landfast ice north of Kugmallit Bay. At a distance of 1 km from the first drillship, the whales milled briefly, then turned toward the ice and swam around the ship, keeping a distance of ~1 km. When a supply vessel

Risk Factor	Score	Rationale
		began moving ~3 km away, they abruptly turned into the ice and swam under it, passing within 100 m of a stationary supply vessel. Similar avoidance of a moving supply vessel in ice leads was noted on the next day in two groups of whales 1-2 km from the vessel. Although belugas in the St. Lawrence River occasionally show positive reactions to ecotourism boats by approaching and investigating, one study found that they surface less frequently, swim faster, and group together in the presence of boats (Blane and Jaakson 1994). The degree of disturbance varied with the number and speeds of the approaching vessels, the activity and age of the whales (young belugas were less likely to respond than adults), and location (Blane 1990; Blane and Jaakson 1994). Feeding or traveling belugas were less likely to react, but when they did, responses were typically stronger. Blane (1990) cautioned that beluga use of high-traffic areas should not be interpreted as a lack of disturbance effects, although some habituation to boats is likely. Caron and Sergeant (1988) noted that a decrease in beluga numbers coincided with an increase in boat activity in one part of the St. Lawrence River, but no causative relationship could be established. Declines in abundance and possibly reduced reproductive success have been reported for dolphins disturbed by tourism vessels (Bejder 2005; Bejder et al. 2006). Lerczak et al. (2000) tagged belugas in the Susitna delta during the summers of 1994 and 1995 and observed that belugas appeared to recover quickly from vessel disturbance; even when being incidentally harassed or intentionally pursued by small boats with outboard motors, they never left the immediate study area. If the pursuit vessel stopped, whales approached to within ~100 m after ~15 minutes, and if the engines were turned off the whales approached closely or passed underneath. Lesage et al. (1999) examined the effect of vessel noise on belugas in the St. Lawrence River estuary, Québec. They used controlled experiments to record surface behaviour and vocalizations before, during, and after the passing of two different types of vessels—an outboard motorboat moving rapidly and erratically on an unpredictable course, and a ferry moving regularly and slowly on a predictable route. Belugas changed their vocalizations in response to both vessels, using higher frequencies, greater redundancy (more calls emitted in a series), and a lower calling rate, which persisted for longer during exposure to the ferry than to the motorboat. Investigators attempting to record beluga whale vocalizations off Norway found them to be surprisingly silent most of the time, during 72% of the recordings when the whales were known to be in the vicinity (Karlsen et al. 2002). The researchers suggested that the relative silence of this usually vocal species could be attributed to the presence of the research vessel in an area not accustomed to vessel traffic. Belugas have been observed to stay near the shoreline when large ships arrived (BIM 2012). Some residents have noticed that belugas seem to have become accustomed to ships and now ignore them (BIM 2012). This observation is supported by studies in the St. Lawrence River, Beaufort Sea, and Cook Inlet (e.g., Fraker 1977a; Burns and Seaman 1985; Pippard, 1985), which suggest that some beluga populations may become habituated to vessel noise and traffic—particularly frequent passages by large vessels travelling in consistent directions. Considering the above, moderate behavioural impacts are expected and a score of 2 was assigned.
Chronic Change	1	Belugas are known to react to underwater vessel noise produced multiple kilometers away by altering swim speed, direction, and behaviour (see *Acute Change*, above). Research on chronic effects of vessel noise on beluga is very

Risk Factor	Score	Rationale
		limited (Erbe et al. 2019; Halliday et al. 2022). It is plausible that given beluga apparent sensitivity to disturbance from vessel noise in some situations, beluga may experience chronic impacts in certain contexts. However, given the low density of vessel traffic present in the priority area chronic change was scored as a 1.
Recovery Factors	2.4	Recovery factors = mean of the factors listed below. Fecundity: 3 (Adult female belugas have 1 calf every 3 years [Sergeant 1973; Matthews and Ferguson 2015]). Early life stage mortality: Unknown; excluded from analyses (There are no data on mortality rates in juvenile belugas). Recruitment pattern: 2 (Although annual recruitment is low by some standards, belugas live to be about 70 years old assuming a single growth layer is formed in their teeth in a year [Waugh et al. 2018: Vos et al. 2020]. The maximum longevity may be 100 years [Harwood 2002]. Because of their longevity, a single female could produce a lot of young over her lifetime even if they become reproductively senescent at 35-40 years old, as suggested by Hobbs et al. [2015] and Ellis et al. [2018]). Natural mortality rate: 3 (The natural mortality rate of belugas must be low if they live to ~70 years old. Ice entrapments of belugas are known to recur in the Canadian High Arctic and in northern Foxe Basin [Smith and Sjare 1990]. Polar bears and Inuit hunters take advantage of these incidents to harvest belugas. The proportion of mortality in these situations that is attributable to predation is not well documented and remains debatable [Kilabuk 1998]. Age at maturity: 3 (Average age at sexual maturity of female beluga is 6-14 years [COSEWIC 2020]). Life stages affected: 3 (It is likely that all life stages of belugas will be affected). Population connectivity: 2 (The Western Hudson Bay population that occurs in the AOI overlaps with the Eastern Hudson Bay and Ungava Bay beluga populations in Hudson Strait during winter). Population status: 1 (IUCN classifies the beluga whale as *near threatened*. COSEWIC [2020] lists the Western Hudson Bay population that occurs in the AOI as *least concern*]).
Consequence	3 (binned)	Consequence = Exposure x Sensitivity = 2 x 3 = Moderate
Likelihood	3	Given the sensitivity of beluga to disturbance from noise in some situations but not in others (see *Acute Change*, above), if a vessel were to enter the priority area and approach close enough to groups or individuals an interaction would occur in some but not all cases. This results in a likelihood score of 3.
Overall Risk	Moderately-High Risk	Additional management measures should be considered, such as limiting vessel activities during important times of the year for belugas in the East Bay priority area.
Uncertainty		
Exposure	4	General vessel traffic patterns are known. Some information exists from other areas on distances at which belugas may be disturbed from vessel noise, though no information exists for the AOI.There is some information on beluga distribution and temporal occurrence in the priority area. Uncertainty is considered high.
Sensitivity	3	Certain aspects of beluga biology and their response to transiting vessels have been reported in other areas of the arctic and in the St. Lawrence River; there is considerable literature relative to some other marine mammal species. Since assumptions were based primarily on beluga literature from other areas, the uncertainty is moderate.

Risk Factor	Score	Rationale
Likelihood	3	Available information, not specific to the priority area or AOI, indicates that belugas can exhibit measurable behavioural changes to vessel noise, but the response can be variable. Since assumptions were based on beluga literature from other areas, the uncertainty is moderate.

Risk Statement: If an interaction occurs involving bowheads and noise from a vessel underway through open water the consequence could result in a negative impact on the bowhead population in the Fisher and Evans Straits priority area.

Table 5-10. Bowhead Whale – Vessel Underway (Fisher and Evans Straits) – Noise Disturbance.

Risk Factor	Score	Rationale
Exposure	4 (binned)	Exposure = Intensity x Temporal x Spatial = 2 x 3 x 9 = 54 (raw score)
Intensity	2	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Fisher and Evans Straits priority area experiences a higher density of vessel traffic relative to other priority areas except Chesterfield Inlet/Narrows (see Figures 5-1 and 5-10), representing 9.5% of total AIS data within the AOI from 2012-2019. Therefore, an intensity score of 2 was assigned.
Temporal	3	Based on scientific studies and current Inuit Qaujimajatuqangit, bowheads occur in the Fisher and Evans Straits priority area from April to November but primarily occur there during summer to feed (Idlout 2020; Loewen et al. 2020b). Vessels are typically present in the priority area during July to October, and very occasionally during June and November (Maerospace 2020), though they may not be present throughout that entire period. Considering the above, there is an approximate temporal overlap of 50-75% between vessel traffic occurrence and the time bowhead whales are present, resulting in a score of 3.
Spatial	9	Spatial = Areal x Depth = 3 x 3 = 9
Areal	3	Bowhead whales are expected to primarily occur in the Fisher and Evans Straits priority area during the summer and can occur throughout the priority area. Nearshore areas around SE Southampton Island in Evans Strait are known calving and nursery grounds (DFO 2020a; Idlout 2020; Loewen et al. 2020b). Based on available AIS data, vessel activity (see Figures 5-1 and 5-10) is typically focused along two primary paths that occur north and south of Coats Island. Noise disturbance extends beyond the immediate vessel path (Finley et al. 1990; Heide-Jørgensen et al. 2021). The areal overlap of a vessel underway (and associated vessel noise) with bowheads within the Fisher and Evans Straits priority area could be widespread, resulting in a score of 3.
Depth	3	Bowheads in the eastern Canadian Arctic routinely conduct foraging dives >100 m with maximum depths exceeding 650 m (Fortune et al. 2020). Sounds produced by moving vessels would be detectable and may elicit a response at all water depths where bowheads might occur including foraging dives. This results in a score of 3.

Risk Factor	Score	Rationale
Sensitivity	3 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (2+1) × 2.3 = 6.9
Acute Change	2	The Fisher and Evans Straits priority area is considered important summering habitat for bowheads where they forage; the nearshore waters of SE Southampton Island in Evans Strait are calving/nursing grounds (see Figure 26 in DFO 2020). Bowhead whale responses to industrial activity, including shipping, are variable; as with other cetaceans, they appear to depend on the whale's activity, its habitat, and the type of industrial activity. Bowheads begin to avoid approaching vessels at distances of 4 km or greater, where received levels are as low as 84 dB re 1 μPa (Richardson et al. 1995a). If a vessel approaches within several hundred metres, the avoidance response usually is conspicuous: the whale may increase its swimming speed, attempt to out-swim the vessel or change direction to swim perpendicularly away from the vessel's path, or decrease its time at the surface (Richardson et al. 1985a, b, 1995a; Richardson and Malme 1993). Koski and Johnson (1987) reported that bowheads 1-2 km from a supply vessel swam rapidly away to distances of 4-6 km from the vessel track; displaced individuals returned to feeding locations within one day. If the vessel travels slowly, bowhead whales often are more tolerant, and may show little or no reaction, even when the vessel is within several hundred metres (e.g., Richardson and Finley 1989; Wartzok et al. 1989). This is especially so when the vessel is not directed toward the whale and when there are no sudden changes in direction or engine speed (Wartzok et al. 1989; Richardson et al. 1995a). Wartzok et al. (1989) noted that bowheads often approached small ships within 100-500 m when the vessel was not moving toward them. Bowhead whales engaged in social interactions or mating may be less responsive than other bowheads (Wartzok et al. 1989). Also, bowheads engaged in foraging seem less responsive to anthropogenic noise. Although louder than noise from moving vessels alone, airgun arrays have produced variable results as well. Bowhead whale communication is altered up to 100 km from the array and ceases when 10-20 km from the array. However, some whales continue feeding when 1-2 km from the array (NAMMCO 2022a). Considering the information above, moderate behavioural impacts are expected and a score of 2 was assigned.
Chronic Change	1	Bowheads will sometimes respond to underwater vessel noise produced multiple kilometers away by altering swim speed, direction, and behaviour (see *Acute Change*, above). Research on chronic effects of vessel noise on marine mammals is limited (Erbe et al. 2019; Halliday et al. 2022). Though it is plausible that given known bowhead disturbance response from vessels bowheads may experience chronic impacts in certain contexts, given the current low level of vessel traffic in the area chronic change was scored as a 1.
Recovery Factors	2.3	Recovery factors = mean of the factors listed below. Fecundity: 3 (Adult female bowheads have 1 calf every 3-4 years [Miller et al. 1992; Koski et al. 1993; Tarpley et al. 2016, 2021]). Early life stage mortality: Unknown; excluded from consideration (There are no data on mortality rates in juvenile bowheads). Recruitment pattern: 1 (Although annual recruitment is low by some standards, bowhead pregnancies seem to be determined by the health of the prospective mother to maximize survival of the calf [W. Koski, pers. comm., 2022]. Because bowheads live to be about 200 years old, a single female produces a lot of young over her lifetime [Tarpley et al. 2016, 2021]). Natural mortality rate: 3 (The mortality rate of adult bowheads is extremely low, possibly the lowest of any animal. Survival has been estimated as 0.984 [0.948-1.00; Zeh et al. 2002] to 0.996 [0.976-1.00, Givens et al. 2018]).

Risk Factor	Score	Rationale
		<u>Age at maturity</u>: 3 (Average age at sexual maturity of female bowheads is about 25 years [Koski et al. 1993; George et al. 1999] and appears to have declined in recent years [Tarpley et al. 2021]). <u>Life stages affected</u>: 3 (Bowheads move away from vessels and other sound sources when they are within a few kilometers, but their long-term distribution is not likely to be affected by vessel activities or other anthropogenic activities [Richardson et al. 1995a; Wursig and Koski 2021]. <u>Population connectivity</u>: 2 (The Eastern Canada-West Greenland (EC-WG) population of bowhead whales occur in the AOI. Until recently, the geographic distributions of the EC-WG and Bering-Chukchi-Beaufort (BCB) bowhead populations were significantly different so that there was little or no overlap between the populations [Zeh et al. 1995]. With the opening of the NW passage resulting from climate change, interchange between these two populations is possible, as suggested by a sighting of two satellite tagged bowheads from the two populations in the same general area in the High Arctic [Heide-Jørgensen et al. 2011]). <u>Population status</u>: 1 (IUCN classifies the EC-WG bowhead whale population as *least concern* [Cooke and Reeves 2018]. COSEWIC (2009) classifies them as *threatened*; however, that status report is out of date and is currently being reviewed. Recent surveys indicate that the population has increased since commercial overharvesting ended in the early 1900s. They may have increased to the point where this population has reached the carrying capacity of their habitat, based on sightings of skinny whales and apparent natural mortality in Cumberland Sound [Young et al. 2019] and recent cases of apparent natural mortality in other areas [DFO unpublished data]).
Consequence	4 (binned)	Consequence = Exposure x Sensitivity = 4 x 3 = High
Likelihood	2	Given the documented responses of bowheads to disturbance from vessel noise (see *Acute Change*, above) and the type of vessel traffic that transits the area (i.e., large vessels travelling a consistent path and not directed at the whales), if a vessel were to enter the priority area and approach close enough to groups or individuals an interaction would be unlikely. This results in a likelihood score of 2.
Overall Risk	Moderately-High Risk	Additional management measures should be considered, such as limiting vessel activities during important times of the year for bowhead whales in the Fisher and Evans Straits priority area.
Uncertainty		
Exposure	4	General vessel traffic patterns in the priority area are known. There is some information on bowhead distribution and temporal occurrence in the priority area. Some information exists from other areas on distances at which bowheads may be disturbed from vessel noise, though no information exists for the AOI. Uncertainty is considered high.
Sensitivity	4	Certain aspects of bowhead biology and their response to transiting vessels have been reported in other areas of the arctic. Since assumptions were based primarily on bowhead literature from other areas and there is some scientific information available on the topic, the uncertainty is moderate
Likelihood	4	Available information, not specific to the priority area or AOI, indicates that bowheads do exhibit measurable behavioural changes to vessel noise, but the response can be variable. Since assumptions were based on bowhead literature from other areas, the uncertainty is moderate.

Risk Statement: If an interaction occurs involving barren-ground caribou and noise disturbance due to a vessel underway the consequence could result in a negative impact on the barren-ground caribou population in the Chesterfield Inlet/Narrows priority area.

Table 5-11. Barren-ground Caribou – Vessel Underway (Chesterfield Inlet/Narrows) – Noise Disturbance.

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 2 x 3 x 1 = 6 (raw score)
Intensity	2	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low absolute density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Chesterfield Inlet/Narrows priority area experiences a high density of vessel traffic relative to other portions of the AOI (see Figures 5-1 and 5-10) representing 61% of total AIS data within the AOI from 2012-2019. The intensity of vessel traffic and the resulting stressor is not uniform, and the density would be higher in areas of higher vessel traffic (e.g., near regular anchorage areas at Helicopter Island or near Chesterfield Inlet). This results in a score of 2.
Temporal	3	During the summer and early fall, barren-ground caribou may be migrating across the Thelon River and small groups may cross the Chesterfield Inlet/Narrows priority area. Vessels are typically present in the priority area during July to September, and occasionally during June (Maerospace 2020), though they may not be present throughout that entire period. Thus, there is expected to be a large amount of overlap between when vessels and caribou are present, resulting in a score of 3.
Spatial	1	Spatial = Areal x Depth = 1 x 1 = 1
Areal	1	Barren-ground caribou are known to migrate across the Thelon River, and small groups may cross Chesterfield Inlet/Narrows. However, few crossing points are expected to occur within the Chesterfield Inlet/Narrows priority area. Barren-ground caribou could occur on land alongside Chesterfield Inlet/Narrows. The area of overlap would occur in a few restricted locations of the total barren-ground caribou range, resulting in a score of 1.
Depth	1	Vessel noise would be audible throughout the water column, but barren-ground caribou spend the majority of their time on land, where noise levels from a moving vessel are much quieter because sound does not transmit as efficiently in air as it does in water. If barren-ground caribou were to occur in the water (e.g., during migration), the animal's head and ears would be above the water surface most of the time and vessel sounds would not be as loud as they would be if the animal were submerged. The stressor would occur over a small portion of the depth range of barren-ground caribou within the Chesterfield Inlet/Narrows priority area, resulting in a score of 1.
Sensitivity	1 (binned)	Sensitivity= (Acute change + Chronic Change) × Recovery Factors = (1+1) x 2.1 = 4.2
Acute Change	1	Considerable research has been conducted on the effects of noise disturbance on barren-ground and woodland caribou ecotypes. Studies have focused

Risk Factor	Score	Rationale
		primarily on direct animal response to high-intensity noise profiles from low-level military jets, propeller-driven aircraft (fixed-wing and helicopter), and noise associated with industrial development (e.g., mining, seismic, and petroleum extraction; see Maier et al. 1998; Harrington and Veitch 1991; Bradshaw et al. 1997). In general, impacts of noise on barren-ground caribou resulted in variable types of disturbance with varying temporal lag effects relative to pre-disturbance behaviour. One consistent finding of effects research on barren-ground caribou (and other northern ungulates, e.g., muskox and moose) is that females with calves, and calves themselves, are more sensitive to disturbance than other herd members (Vistnes and Nellemann 2007). There are no known studies involving effects of shipping-related noise on barren-ground caribou. It is presumed animals would habituate to low-frequency in-air vessel noise (i.e., diesel engine drone) over time. Unlike rapid-onset, low altitude aircraft noise disturbance, barren-ground caribou would likely return to baseline behaviour shortly after initial response to shipping-related noise. Individuals may exhibit altered movements, feeding activity, and/or exposure near the shoreline at select locations along the Chesterfield Inlet/Narrows priority area, such as potential barren-ground caribou crossing points. In these instances, animal stress (i.e., startle response) as a result of visual cues of approaching vessel would likely dominate any effects from noise. Local knowledge suggests that in some cases localized displacement may occur but that caribou would return to the area within the day (DFO 2023a). In summary, no changes in the health of individual barren-ground caribou would be expected if they heard noise produced by moving vessels, although it could cause the animal stress. Insignificant or undetectable changes to mortality rates against background variability and/or limited behavioural impacts are expected, resulting in a score of 1.
Chronic Change	1	Community members from Chesterfield Inlet have reported changes in barren-ground caribou seasonal movements across Chesterfield Inlet/Narrows during the-ice free season (DFO unpublished[11]). During consultations, this change was attributed to noise disturbance from shipping activity. However, based on the available disturbance studies, and the limited number of vessel passes in the open water season, it seems unlikely that there would be a population level effect from noise disturbance or that large numbers of barren-ground caribou would be prevented from swimming across the Chesterfield Inlet/Narrows due to vessel noise. Barren-ground caribou are unlikely to significantly change their behaviour or distribution when they hear sounds from moving vessels. Thus, it is expected that there would be an insignificant or undetectable change to overall fitness in barren-ground caribou occurring in the Chesterfield Inlet/Narrows priority area compared with background variability, with no impact on population dynamics. Thus, a score of 1 was assigned.
Recovery Factors	2.1	Recovery factors = mean of the factors listed below. <u>Fecundity:</u> 2 (Barren-ground caribou females may give birth to a single calf in early June. In general, annual pregnancy rates are ≥80% and twinning is rare. [Parker 1972; Thomas and Barry 1990a]). <u>Early life stage mortality:</u> 2 (Barren-ground caribou calves experience variable mortality dependent on environmental conditions. In addition to wolf and raptor densities near calving areas, female caribou forage and milk production

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[11] DFO. 2019. Community confirmation engagement report: Marine Protected Area process in Kivalliq and Southampton Island proposed Area of Interest. 27 p.

Risk Factor	Score	Rationale
		influences calf growth rate, such that underweight calves have a reduced chance of survival [Couturier et al. 2009]). Recruitment pattern: 2 (Barren-ground caribou have a moderate level of recruitment due to a reproductive lifespan of about 12 years and only about 50% of the calves living through their first year of life [Bergerud 1978]). Natural mortality rate: 2 (Adult caribou have a relatively low annual mortality rate, averaging ~15% for females between 3 and 10 years of age [*n* = 1284; Thomas and Barry 1990b]. In general, females have longer life spans than males, some reaching over 15 years. Males typically incur higher predation and live less than 10 years in the wild due to physiological stress associated with the rutting period. Life expectancy of barren-ground caribou is further reduced by hunting pressure [i.e., proximity to communities] and wolf population size [Klaczek et al. 2016]). Age at maturity: 2 (Under the most favorable conditions, earliest age at sexual maturity for females is 2 years with most females not reproducing until 3 years of age [Dauphiné 1976]. Males reach sexual maturity as early as 2 years of age. Life stages affected: 3 (All life stages may be affected). Population connectivity: 2 (The Lorillard herd encompasses the Chesterfield Inlet and Thelon River area east of Baker Lake and its range overlaps with the Qamanirjuaq, Ahiak and Wager Bay herds [COSEWIC 2020]. Studies suggest that there is interchange between arctic and subarctic barren-ground caribou subpopulations, but the degree is unknown, particularly for yearling males, given the reliance on female collared animals to derive demographic parameters [Nagy et al. 2011]). Population status: 2 (The barren-ground caribou Designatable Unit was assessed for the first time by COSEWIC as *threatened* in November 2016. Status met the criteria for *endangered* due to a reduction in numbers of ≥50%; however, *threatened* was recommended because, overall, the population did not appear to be facing imminent extinction at time of assessment [COSEWIC 2020]. Regionally, the Lorillard subpopulation is considered robust, but herd demographics are considered data deficient given the most recent population estimate of 41,000 animals in 2002 [Nagy et al. 2011]).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 2 x 1 = Negligible
Likelihood	3	Interactions between moving vessels and barren-ground caribou may occur when caribou and vessels are in the vicinity. Barren-ground caribou would receive limited noise while in the water, as they tend to keep their head and ears above the water surface, though disturbance has been noted by community members. Thus, an interaction may occur in some but not all circumstances.
Overall Risk	Low Risk	No additional management actions need to be considered at this time.
Uncertainty		
Exposure	5	General vessel traffic patterns are known in the priority area. There is some information about the number of animals or locations where barren-ground caribou cross the Chesterfield Inlet/Narrows priority area, though the distances at which disturbance may occur from moving vessels are not known. Uncertainty is very high.
Sensitivity	4	Although there is some information on disturbance by aircraft on barren-ground caribou, there is a lack of information on potential impacts of vessel sounds on barren-ground caribou. Community members in Chesterfield Inlet and Baker Lake have noted disturbance on caribou from vessels in the area.

Risk Factor	Score	Rationale
Likelihood	4	Barren-ground caribou could potentially be disturbed by vessel noise, as noted by community members in Chesterfield Inlet and Baker Lake but more information on responses of barren-ground caribou to vessel noise is required.

5.1.2 Vessel Strikes

There is some potential that cetaceans, seals, and walruses may be struck by a transiting vessel and experience injury and/or mortality (e.g., Schoeman et al. 2020). However, given the low density of vessel traffic in the AOI and the greater susceptibility of large whales compared with smaller, more agile marine mammals, only bowhead whale are expected to be at risk from this stressor in open water and were assessed (Table 5-12). Ringed and bearded seal pups, which are born in spring when vessels would not typically be operating in open water, are vulnerable from icebreaking activities and were assessed in Section 5.2.2 (Icebreaking). Common eiders are known to be susceptible to this stressor (Kingsley 2006) and were assessed and serve as a proxy for other seabirds.

Table 5-12. Vessels Underway − Vessel Strikes: ESC Subcomponents and Priority Areas Assessed.

ESC Subcomponent	Priority Area	Assessed by Proxy
Common eider	East Bay	
Other seabirds		Via common eider
Bowhead Whale	Fisher and Evans Straits	

Risk Statement: If an interaction occurs involving common eiders and collisions with a moving vessel the consequence could result in a negative impact on the common eider population in the East Bay priority area.

Table 5-13. Common eider – Vessel Underway (East Bay) – Vessel Strikes.

Risk Factor	Score	Rationale
Exposure	1 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 2 = 2 (raw score)
Intensity	1	It should be noted that relative to other areas that experience shipping and vessel traffic and for which biological effects literature is largely based, the AOI receives a low density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9). The East Bay priority area experiences a low density of vessel traffic relative to other priority areas (see Figures 5-1 and 5-10) representing <1% of total AIS data within the AOI from 2012-2019. Therefore, intensity was scored as 1.
Temporal	1	Common eiders are present in the East Bay priority area from mid-June to September. Adult males depart on their moult migration in July (Abraham and Finney 1986). Eggs hatch in July and the flightless females rear their precocial broods in marine and intertidal waters. Groups of females and young are present until late September (Abraham and Finney 1986). Adult females and young would be expected to complete growth of their flight feathers in September and have the potential to strike vessels while in flight in poor visibility (fog or darkness) (Merkel and Johansen 2011; Day et al. 2017). Vessels are typically present in the East Bay priority area during October and very occasionally in September, though they are not present throughout that entire period. Thus, there is very little overlap

Risk Factor	Score	Rationale
		between when vessels occur in the East Bay priority area and when volant common eiders are present, resulting in a score of 1.
Spatial	2	Spatial = Areal x Depth = 1 x 2 = 2
Areal	1	Common eider females and broods are expected to be distributed in intertidal and marine waters, primarily <20 m deep (Goudie et al. 2020), within the East Bay priority area. Also, vessel activity in shallow water is expected to be minimal due to navigational constraints. The area of overlap between eider broods and vessels is expected to be limited to a few restricted locations within the common eider distribution range in the priority area, resulting in a score of 1.
Depth	2	Common eider flight altitude (over water) is similar to that of the height of a sea-going vessel's superstructure above the water line, though they can fly at higher altitudes. This species typically dives to a depth of 4 m, which is similar to the draught of a sea-going vessel. Depending on the size of the vessel, the potential for collision covers a moderate portion of the depth range of common eider in the East Bay priority area, resulting in a score of 2.
Sensitivity	2 (binned)	Sensitivity = (Acute change + Chronic Change) x Recovery Factors = (1 + 1) x 2.6 = 5.2
Acute Change	1	Many marine birds demonstrate attraction to light, which can cause them to fly towards and collide with the source, resulting in injury and/or mortality (Dick and Donaldson 1978; Black 2005; Merkel and Johansen 2011). While collisions are unlikely during the day and when visibility is adequate, the risk increases substantially at night (due to attraction to light) and when visibility is poor (i.e., in rain or foggy conditions; Merkel and Johansen 2011; Ronconi et al. 2015). It has been suggested that the tendency for common eiders to fly low over water and rarely fly over land make them especially susceptible to collisions with vessels, particularly in coastal areas (Merkel and Johansen 2011). In west Greenland single events have resulted in mortality to hundreds—and occasionally thousands—of common eiders due to entire flocks flying into fishing vessels; similar events have occurred in the Southern Ocean (Ryan 1991; Black 2005). However, during an international workshop on this issue, a Canadian participant reported that collisions with vessels were not known as a significant source of common eider mortality in Canada (Kingsley 2006). This was reflected in a risk assessment of northwest Atlantic seabirds using expert opinion which ranked light pollution as lower risk than fisheries bycatch, oil pollution, offshore wind turbines, and marine debris (Lieske et al. 2019). Considering the information above and the low density of vessel traffic in the priority area, collisions with vessels underway is expected to result in an insignificant or undetectable change to the common eider mortality rates against background variability (Merkel and Johansen 2011; Day et al. 2017), resulting in a score of 1.
Chronic Change	1	A small proportion of common eiders could be affected by strikes with vessels underway in the East Bay priority area (Abraham and Finney 1986; Merkel and Johansen 2011; Day et al. 2017). However, the low frequency of vessels passing through the priority area would be unlikely to cause repeated effects or, therefore, chronic change in the common eider population. As a result, there would be an insignificant or undetectable change to overall fitness and no impact on population dynamics, resulting in a score of 1.
Recovery Factors	2.6	Recovery factors = mean of the factors listed below. Fecundity: 2 (Three to five eggs laid per year [Goudie et al. 2020]).

Risk Factor	Score	Rationale
		<u>Early life stage mortality</u>**:** 3 (90-95% in first year [Goudie et al. 2020]). <u>Recruitment pattern</u>**:** 3 (Probability: 0.17-0.47 [Nicol-Harper et al. 2021]). <u>Natural mortality rate</u>**:** 3 (13% [Goudie et al. 2020]). <u>Age at maturity</u>**:** 2 (≥4 years [Goudie et al. 2020]). <u>Life stages affected</u>**:** 3 (All life stages could potentially occur in the East Bay priority area [Goudie et al. 2020]). <u>Population connectivity</u>**:** 3 (High degree of fine-scale spatial population genetic structuring [Talbot et al. 2015]). <u>Population status</u>**:** 2 (Common eider is listed as *near threatened* by IUCN [BirdLife International 2018a] but is not listed under SARA or COSEWIC. However, the population may be declining due to increased polar bear predation in the East Bay priority area [Loewen et al. 2020b]). Also, avian cholera has the potential to cause mass mortality and significantly impact the East Bay population [Descamps et al. 2012]).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 1 x 2 = Negligible
Likelihood	1	The attraction of seabirds to artificial light is well documented. However, collisions have predominantly been recorded at night or in reduced visibility (Kingsley 2006), and do not occur in every circumstance in which vessels and common eider interact; additionally, this stressor is not well known in Canada (Kingsley 2006; Lieske et al. 2019). Considering this information, an interaction is expected to occur only in exceptional circumstances and a score of 1 was assigned.
Overall Risk	Low Risk	No additional management measures need to be considered at this time. However, vessels should observe minimum set-back distances from at-sea concentrations of common eiders as prescribed by ECCC-CWS. A 15 km buffer around breeding colonies was recommended by Mallory and Fontaine (2004).
Uncertainty		
Exposure	3	There is a moderate amount of scientific information available regarding the abundance and distribution of common eiders in the East Bay priority area and general vessel traffic patterns are known in the priority area.
Sensitivity	3	There is a moderate amount of scientific information on the susceptibility of common eiders to vessel strikes (Abraham and Finney 1986; Merkel and Johansen 2011; Day et al. 2017), though this exists from other area.
Likelihood	3	There is a moderate amount of scientific information on the likelihood of common eiders striking vessels (Abraham and Finney 1986; Merkel and Johansen 2011; Day et al. 2017), though this exists from other areas.

Risk Statement: If an interaction occurs involving bowhead whales and a vessel underway resulting in a collision the consequence could result in a negative impact on bowhead whales in the Fisher and Evans Straits priority area.

Table 5-14. Bowhead Whale – Vessel Underway (Fisher and Evans Straits) – Vessel Strikes.

Risk Factor	Score	Rationale
Exposure	3 (binned)	Exposure = Intensity x Temporal x Spatial = 2 x 3 x 4 = 24 (raw score)
Intensity	2	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker,

Risk Factor	Score	Rationale
		passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Fisher and Evans Straits priority area experiences a higher density of vessel traffic relative to other priority areas except Chesterfield Inlet/Narrows (see Figures 5-1 and 5-10), representing 9.5% of total AIS data within the AOI from 2012-2019. Therefore, an intensity score of 2 was assigned.
Temporal	3	Based on scientific studies and current Inuit Qaujimajatuqangit, bowheads occur in the Fisher and Evans Straits priority area from April to November but primarily occur there during summer (Idlout 2020; Loewen et al. 2020b). Vessels are typically present in the priority area during July to October, and very occasionally during June and November (Maerospace 2020), though they may not be present throughout that entire period. Considering the above, there is an approximate temporal overlap of 50-75% between vessel traffic occurrence and the time bowhead whales are present, resulting in a score of 3.
Spatial	4	Spatial = Areal x Depth = 2 x 2 = 4
Areal	2	Bowhead whales are expected to primarily occur in the Fisher and Evans Straits priority area during the summer and can occur throughout the priority area. Nearshore areas around SE Southampton Island in Evans Strait are known calving and nursery grounds (DFO 2020; Idlout 2020; Loewen et al. 2020b). Based on available AIS data, vessel activity (see Figures 5-1 and 5-10) is typically focused along two primary paths that occur north and south of Coats Island. Though laboratory hydrodynamic experiments suggest the lethal zone extends beyond the actual physical boundaries of the ship (extending 1-2 x the draft depth, and horizontally extending an additional ½ beam width beyond the sides of the vessel; Silber et al. 2010), a collision can only occur within close proximity to the vessel path. Therefore, areal overlap is a small portion of total range within the priority area and a score of 2 was assigned.
Depth	2	Though bowhead whales undertake foraging dives (e.g., Fortune et al. 2020), they spend a considerable amount of time at or near the water surface. Vessel strikes would be limited to the upper portion of the water depth range where this species occurs. The stressor occurs over a moderate portion of the depth range of bowhead whales, resulting in a score of 2.
Sensitivity	1 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (1 + 1) x 2.3 = 4.6
Acute Change	1	The Fisher and Evans Straits priority area is considered important summering habitat for bowheads where they forage; the nearshore waters of SE Southampton Island in Evans Strait are calving/nursing grounds (see Figure 26 in DFO 2020). Available information indicates that bowheads would avoid vessels underway, maintaining distances that would prevent ship strikes (see Moulton et al. 2012 for a review). Although strikes are possible, George et al. (1994) reported that only a small percentage (~1%) of bowheads in the BCB seas stock had scars from collisions with propellers. While nearly all species of large whale have been victims of collisions with ships (Laist et al. 2001; Glass et al. 2008), right whales (*Eubalaena* spp.) are especially vulnerable, likely because of certain characteristic behaviours during which they may be less aware of their surroundings. These behaviours include surface active group activity (individuals interacting at the surface with frequent physical contact); skim feeding (swimming slowly at the surface with mouth open); and logging (resting motionlessly at the surface), an activity frequently observed in nursing mothers (Knowlton 1997). In contrast, bowhead whales are not noted for their surface activity in groups; they rest at the

Risk Factor	Score	Rationale
		surface and only occasionally skim feed at or near the surface (e.g., Thomas et al. 2002). Bowheads are expected to have little difficulty avoiding oncoming ships, which would be detectable many kilometers away in the Fisher and Evans Straits priority area. Mortality rates of bowhead whales due to ship strikes are expected to be undetectable relative to background variability, resulting in a score of 1.
Chronic Change	1	As described above, available evidence indicates that bowhead whales readily move away from approaching vessels and the risk of injury/mortality from a vessel underway in Fisher and Evans Straits priority area is low. There is no expected change to the overall fitness of bowheads due to ship strikes compared to background variability based on current vessel traffic levels, resulting in a score of 1.
Recovery Factors	2.3	Recovery factors = mean of the factors listed below. Fecundity: 3 (Adult female bowheads have 1 calf every 3-4 years [Miller et al. 1992; Koski et al. 1993; Tarpley et al. 2016, 2021]). Early life stage mortality: Unknown; excluded from consideration (There are no data on mortality rates in juvenile bowheads). Recruitment pattern: 1 (Although annual recruitment is low by some standards, bowhead pregnancies seem to be determined by the health of the prospective mother to maximize survival of the calf [W. Koski, pers. comm., 2022]. Because bowheads live to be about 200 years old, a single female produces a lot of young over her lifetime [Tarpley et al. 2016, 2021]). Natural mortality rate: 3 (The mortality rate of adult bowheads is extremely low, possibly the lowest of any animal. Survival has been estimated as 0.984 [0.948-1.00; Zeh et al. 2002] to 0.996 [0.976-1.00, Givens et al. 2018]). Age at maturity: 3 (Average age at sexual maturity of female bowheads is about 25 years [Koski et al. 1993; George et al. 1999] and appears to have declined in recent years [Tarpley et al. 2021]). Life stages affected: 3 (Bowheads move away from vessels and other sound sources when they are within a few kilometers, but their long-term distribution is not likely to be affected by vessel activities or other anthropogenic activities [Richardson et al. 1995a; Wursig and Koski 2021]. However, because bowhead swimming speeds are low [4-4.5 km/hr; Rugh 1990; Koski et al. 2002], it is assumed that all life stages could be susceptible to being struck and injured or killed by fast moving vessels]). Population connectivity: 2 (The EC-WG population of bowhead whales occur in the AOI. Until recently, the geographic distributions of the EC-WG and BCB bowhead populations were significantly different so that there was little or no overlap between the populations [Zeh et al. 1995]. With the opening of the NW passage resulting from climate change, interchange between these two populations is possible, as suggested by a sighting of two satellite tagged bowheads from the two populations in the same general area in the High Arctic [Heide-Jørgensen et al. 2011]). Population status: 1 (IUCN classifies the EC-WG bowhead whale population as *least concern* [Cooke and Reeves 2018]. COSEWIC [2009] classifies them as *threatened*; however, that status report is out of date and is currently being reviewed. Recent surveys indicate that the population has increased since commercial overharvesting ended in the early 1900s. They may have increased to the point where this population has reached the carrying capacity of their habitat, based on sightings of skinny whales and apparent natural mortality in Cumberland Sound [Young et al. 2019] and recent cases of apparent natural mortality in other areas [DFO unpublished data]).
Consequence	1	Consequence = Exposure x Sensitivity = 3 × 1

Risk Factor	Score	Rationale
		= Negligible
Likelihood	2	Although bowhead whales may be more susceptible to a ship strike in areas of open water than other Arctic cetaceans, the typical behaviour and ability of bowheads to avoid oncoming vessels in the Fisher and Evans Straits priority area considerably reduces the likelihood of an interaction. An interaction is unlikely to occur.
Overall Risk	Low Risk	Additional management do not need to be considered. Precautionary measures could include vessel speed reductions, particularly if, in the future, shipping levels in the Fisher and Evans Straits priority area increase.
Uncertainty		
Exposure	4	General vessel traffic patterns are known for the priority area, as are general times and areas of bowhead occupation. The mechanics of a vessel strike on large whales have been described generally (e.g., distance from vessel, depth at which it may occur). No investigation of this interaction has occurred in the priority area.
Sensitivity	3	Some information from other areas of the Arctic exists on this stressor. A moderate amount of scientific information is available, though information is not specific to the AOI.
Likelihood	4	Some published information exists on bowhead behaviour and response to shipping in other areas of the Arctic.

5.1.3 Habitat Alteration/Removal

For vessels underway in open water, habitat alteration refers to the increased suspended sediment load from wakes and propeller wash when vessels pass through shallow waters. Effects on turbidity, water temperature, and water column destratification have been noted in areas with consistent large vessel traffic (e.g., Lindholm et al. 2001), with environmental and vessel-related factors, including successive vessel passages, contributing to sediment suspension (Smart et al. 1985; Gabel et al. 2017 and references therein); due to the comparatively low level of vessel traffic in the AOI, increased suspended sediment load is not expected to reach a level where it would impact most ESC subcomponents. However, residents of Chesterfield Inlet have observed that commercial vessel traffic is disturbing the sediment in the Chesterfield Inlet channel, with Fish Bay and Helicopter Island having been affected (DFO unpublished[12]). As such, assessments were conducted for other forage fish, benthic invertebrates, and kelp beds/other macroalgae (Table 5-15). Propeller wash and vessel wake (i.e., water displacement causing an increased suspended sediment load) were assessed together for interactions with macroalgae in this section; there is not a separate assessment in Section 5.1.4.

Table 5-15. Vessels Underway − Habitat Alteration/Removal: ESC Subcomponents and Priority Areas Assessed.

ESC Subcomponent	Priority Area or AOI	Assessed by Proxy
Other forage fish	Chesterfield Inlet/Narrows	-
Kelp beds and other macroalgae	Chesterfield Inlet/Narrows	-
Benthic Invertebrates	Chesterfield Inlet/Narrows	-

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[12] DFO. 2019. Community confirmation engagement report: Marine Protected Area process in Kivalliq and Southampton Island proposed Area of Interest. 27 p.

Risk Statement: If an interaction occurs involving forage fish and habitat alteration (by increased suspended sediment load from vessel wake and propeller wash) due to a vessel underway the consequence could result in a negative impact on forage fish populations in the Chesterfield Inlet/Narrows priority area.

Table 5-16. Other forage fish – Vessel Underway (Chesterfield Inlet/Narrows) – Habitat Alteration (Sedimentation from Vessel Wake and Propeller Wash).

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 2 x 4 = 8 (raw score)
Intensity	1	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low absolute density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS data indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Chesterfield Inlet/Narrows priority area experiences a high density of vessel traffic relative to other portions of the AOI (see Figures 5-1 and 5-10) representing 61% of total AIS data within the AOI from 2012-2019. The intensity of vessel traffic and the resulting stressor is not uniform, and the density would be higher in areas of higher vessel traffic (e.g., near regular anchorage areas at Helicopter Island or near Chesterfield Inlet). Although the relative density of AIS data is higher in this priority area, the baseline environmental conditions are regularly expected to generate elevated levels of suspended sediment (see *Acute Change*, below). Due to these baseline conditions, it is expected that the level of suspended sediment created by the current level of vessel traffic would lead to a minimal increase in density of suspended sediment in the water column. The persistence of elevated levels of suspended sediment in the water column from this stressor is expected to be low, as disturbed suspended sediment in the water column reaches background levels on the order of hours (Yang et al. 2004) and the tidal cycles of the area are nearly constant. Therefore, intensity was scored as 1.
Temporal	2	Forage fish may be present in the Chesterfield Inlet/Narrows priority area year-round. Vessels are typically present in the priority area during July to September, and occasionally during June (Maerospace 2020), though they are not present throughout that entire period. This results in an approximate temporal overlap of 33-50% between vessel traffic occurrence and during the time other forage fish may be present, resulting in a score of 2.
Spatial	4	Spatial = Areal x Depth = 2 x 3 = 4
Areal	2	Other forage fish are anticipated to occur throughout the Chesterfield Inlet/Narrows priority area. According to the shipping management plan produced by the Meadowbank mine (Agnico Eagle 2022) and sailing instructions produced by the Canadian Hydrographic Service (2022), vessels travelling through Chesterfield Inlet follow a restricted path in the deepest area of the channel. However, a plume of suspended sediment is able to extend beyond the immediate path of a vessel due to water circulation. Based on vessel traffic patterns in the priority area (see Figure 5-10), increased suspended sediment from vessel wake and propeller wash would be expected to overlap a small proportion of the forage fish range in the assessment area resulting in a score of 2.

Risk Factor	Score	Rationale
Depth	2	Other forage fish may occur throughout the water column in the priority area. Suspended sediment load generally increases with depth, with greater increases near the substrate, and sediment originating from the substrate may only reach the lower column even in high current velocities (Yang et al. 2004). Considering the baseline environmental conditions in the estuary, suspended sediment from vessel traffic is unlikely to lead to habitat alteration in the upper water column. Therefore, it is expected that a moderate portion of forage fish depth range would be impacted, resulting in a score of 2.
Sensitivity	1 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (1 + 1) x 1.7 = 3.4
Acute Change	1	Chesterfield Inlet is a 200 km-long estuary that undergoes semi-diurnal tidal cycles with a tidal range of 3.4 m at spring tide and 1.5 m at neap tide (Roff et al. 1980; GoC 2023). Due largely to the form of the estuary and tidal influence, current velocities reach 4.5 knots on the flood and 7 knots on the ebb tide (Dohler 2007), leading to dynamic conditions in the area (Roff et al. 1980). Though studies of the suspended sediment load between slack tide (i.e., baseline) and flood tide in Chesterfield Inlet/narrows are unknown, long estuaries with high tidal action are known to significantly positively influence suspended sediment load (Uncles et al. 2002; Yang et al. 2004) and some consistent elevated level of suspended sediment is expected in the priority area. Therefore, it is expected that biota in the priority area are regularly exposed to elevated levels of suspended sediment in the natural conditions of the estuary, and the discussion on biological effects will consider this baseline. The potential biological effects of increased suspended sediment loads are complex and involve multiple confounding factors such as a change in light levels (Airoldi et al. 2003) and further compounded by the natural and critical process of sediment flux in aquatic ecosystems (Barry et al. 2003). Increased suspended sediment load is more likely to result in sub-lethal than lethal effects as fish are able to move away from areas of increased concentration (Kjelland et al. 2015). During community consultations for the AOI, community members indicated that shipping is disturbing the sediment in the Chesterfield Inlet channel near Fish Bay and Helicopter Island (DFO unpublished[13]). Sedimentation and the resultant turbidity can affect spawning areas, primary productivity, and benthic biota, and may cause physiological stress or mortality in fish (Mahtab et al. 2005). Turbidity has been shown to affect the feeding behaviour of fish in marine waters (Airoldi 2003; Leahy et al. 2011). Acute increases of suspended sediments may cause alarm reactions in fish, such as increased swimming behaviour and relocation to undisturbed areas, which may disrupt schooling behaviour (Wilber and Clarke 2001). Laboratory suspended sediment exposure studies indicated that for some species, increased sedimentation may decrease hatching success (e.g., white perch [*Morone americana*], striped bass [*Morone saxatilis*]) and/or larval survival (e.g., striped bass, American shad [*Alosa sapidissima*]), while others are tolerant and experience no significant effects (e.g., blueback herring [*Alosa aestivalis*], alewife [*Alosa pseudoharengu*]) (Auld and Schubel 1978). However, direct evidence of effects on adult fish are scarce (Airoldi et al. 2003) and there is evidence that fishes that exist in more turbid environments are more resistant to the negative effects of increased suspended sediment load (e.g., fishes that live in estuaries near the sediment-water interface; Wilber and Clarke 2001). Given the existing environmental conditions and the current low level of vessel traffic, habitat alteration via increased sedimentation from vessel wake/propeller wash as vessels

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[13] DFO. 2019. Community confirmation engagement report: Marine Protected Area process in Kivalliq and Southampton Island proposed Area of Interest. 27 p.

Risk Factor	Score	Rationale
		transit through the Chesterfield Inlet/Narrows priority area may result in limited behavioural changes but would not be expected to result in detectable changes to mortality rates against background variability of other forage fish species. Thus, a score of 1 was assigned.
Chronic Change	1	Chesterfield Inlet is a dynamic environment with high tidal range and current velocities, and the baseline conditions are expected to regularly include elevated levels of suspended sediment (see *Acute Change*, above), which should be noted when considering the following examples. The passage of large vessels can increase suspended sediment concentrations several times greater than natural background levels; large vessel transits in Hillsborough Bay, Florida were observed to cause suspended sediments to increase by five times the background level, up to 250 mg/L, with increased sedimentation lasting for up to 8 h (Wilber and Clarke 2001). Depending on water currents, demersal adhesive eggs of forage fish species may be subject to increased sedimentation for up to several days following sediment disturbance from anthropogenic activities, while demersal semi-buoyant eggs and pelagic eggs would likely experience shorter exposure windows (Wilber and Clarke 2001). Egg development of Atlantic herring (*Clupea harengus*), a coastal egg-releasing species, was not affected by suspended sediment dosages of 300 and 500 mg/L for one day (Wilber and Clarke 2001). If persistent increased sedimentation negatively impacts feeding success for juvenile fish, it may affect mortality, year-class strength, recruitment, and overall body condition (Wilber and Clarke 2001). Depending on the species and their tolerance to turbidity, long-term sedimentation may cause fish to alter their feeding strategies (Wilber and Clarke 2001). Chronic exposure to increased sedimentation can decrease respiration efficiency and result in changes in blood chemistry; at high concentrations of suspended sediment, fine particles may coat a fishes' respiratory epithelia and large particles may become trapped in gill lamellae, which may reduce or block gas exchange with or the passage of water, possibly to the point of asphyxiation (Wilber and Clarke 2001). Considering the baseline environmental conditions expected in the priority area and current low level of vessel traffic, a measurable change to overall fitness and population dynamics of forage fish species from this stressor is not expected within the Chesterfield Inlet/Narrows priority area. Thus, a score of 1 was assigned.
Recovery Factors	1.6	Knowledge of other forage fish communities is limited for the AOI; however, species observed in the Hudson Bay, Hudson Strait, and/or Foxe Basin regions may occur in the AOI, including Atlantic poacher (*Leptagonus decagonus*), fish doctor (*Garra rufa*), Arctic alligatorfish (*Aspidophoroides olrikii*), Atlantic herring, capelin, sculpins *(Cottidae* spp.*),* lumpfish (*Cyclopterus lumpus)* and lumpsuckers (*Cyclopteridae* spp.), cods *(Gadidae* spp.*),* sticklebacks *(Gasterosteidae* spp.), snailfishes (*Liparidae* spp.), burbot (*Lota lota*), eelblennies *(Stichaeidae* spp.), Arctic shanny (*Stichaeus punctatus)*, eelpout (*Lycodes* sp.), *r*ainbow smelt *(Osmerus mordax)*, American plaice *(Hippoglossoides platessoides*), halibut, skates, cisco (*Coregonus artedi)*, whitefishes *(Salmonidae* spp.*),* and redfishes (*Sebastes* spp.) (Loewen et al. 2020a). Due to ecological importance (e.g., keystone species in marine ecosystems), capelin and sand lances were identified as the representative other forage fish species for the AOI. These species were used for the determination of Recovery Factors, with scores and rationale provided for the most sensitive species for each Factor (where information was available). There have been no dedicated baseline studies for the Chesterfield Inlet/Narrows priority area; therefore, information is provided here for the AOI to represent the priority area. Recovery factors = mean of the factors listed below.

Risk Factor	Score	Rationale
		Fecundity: 1 (A female capelin can deposit 6000-12,000 eggs during a single spawning event [Oceana 2022]. A female sand lance can produce up to 22,904 eggs [Coad and Reist 2018]). Early life stage mortality: 3 (The eggs and/or larvae of capelin and sand lances are important food sources for predators in the marine ecosystem [DFO 2021a; Coad and Reist 2018]). Recruitment pattern: 1 (Capelin have short lifespans of five to six years [Oceana 2022] and sand lances may live up 9-10 years [Coad and Reist 2018]. Both species have relatively high recruitment). Natural mortality rate: 1 (Sand lances are a key species in marine ecosystems; they and their eggs are important food sources in the marine food web and are heavily preyed upon [Coad and Reist 2018]. Capelin are a keystone prey species and experiences high post-spawning mortality [DFO 2021a]). Age at maturity: 1 (Sand lances and capelin reach maturity at approximately 1-2 years and 2-3 years, respectively [Coad and Reist 2018]). Life stages affected: 3 (All life stages could potentially occur in the AOI and could thus be affected). Population connectivity: Unknown; excluded from consideration. Population status: 1 (Capelin are listed as *least concern* on the IUCN Red List and Northern sand lance is listed as *not evaluated* [Smith-Veniz et al. 2015; Herdson and Priede 2010]).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 2 x 1 = Negligible
Likelihood	2	Habitat alteration due to increased sedimentation from vessel wake and propellor wash could occur during summer/fall when vessels transit through the Chesterfield Inlet/Narrows priority area. An interaction may occur with other forage fish species that are intolerant of increased sedimentation but may not occur for tolerant species. However, given the expected elevated baseline levels of suspended sediment in and around the mouth of Chesterfield Inlet due to the dynamic tidal environment (see *Acute Change*), additional suspended sediment to a level that would cause measurable impacts in forage fish is unlikely to occur. A score of 2 was assigned.
Overall Risk	Low Risk	No additional management measures need to be considered at this time.
Uncertainty		
Exposure	4	Little is known of other forage fish community composition, abundance, or distribution for the Chesterfield Inlet/Narrows priority area. General vessel traffic patterns are known for the priority area. Thus, uncertainty is high.
Sensitivity	5	The extent, duration, and concentration/rates of sedimentation induced by vessel passage (vessel wake/propeller wash) is uncertain, as are the effects of sedimentation on Arctic forage fish. There is some scientific information available relating to forage fish for sedimentation caused by human activities in other parts of the world; however, most studies have been laboratory-based (e.g., Auld and Schubel 1978; Wilber and Clarke 2001) and are not necessarily reflective of exposure in the natural environment. This assessment was conducted on representative forage fish species and examples were drawn as such; however, the assemblage includes numerous species and the assessment may not be accurate for all. Thus, uncertainty is very high.
Likelihood	5	Little research has been conducted on how Arctic forage fish respond to increased sedimentation and turbidity. This assessment encompasses a broad group of forage fish and may not be accurate for all.

Risk Statement: If an interaction occurs involving kelp beds/other macroalgae and habitat alteration (by increased suspended sediment load from vessel wake and propeller wash) due to a vessel underway the consequence could result in a negative impact on the ecosystem function of kelp bed/other macroalgae habitat in the Chesterfield Inlet/Narrows priority area.

Table 5-17. Kelp beds and other macroalgae – Vessel Underway (Chesterfield Inlet/Narrows) – Habitat Alteration (Sedimentation from Vessel Wake and Propeller Wash).

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 2 x 3 = 6 (raw score)
Intensity	1	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low absolute density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS data indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Chesterfield Inlet/Narrows priority area experiences a high density of vessel traffic relative to other portions of the AOI (see Figures 5-1 and 5-10) representing 61% of total AIS data within the AOI from 2012-2019. The intensity of vessel traffic and the resulting stressor is not uniform, and the density would be higher in areas of higher vessel traffic (e.g., near regular anchorage areas at Helicopter Island or near Chesterfield Inlet). Although the relative density of AIS data is higher in this priority area, the baseline environmental conditions are regularly expected to generate elevated levels of suspended sediment (see *Acute Change*, below). Due to these baseline conditions, it is expected that the level of suspended sediment created by the current level of vessel traffic would lead to a minimal increase in density of suspended sediment in the water column. The persistence of elevated levels of suspended sediment in the water column from this stressor is expected to be low, as disturbed suspended sediment in the water column reaches background levels on the order of hours (Yang et al. 2004) and the tidal cycles of the area are nearly constant. Therefore, intensity was scored as 1.
Temporal	2	Macroalgae are present in the Chesterfield Inlet/Narrows priority area year-round, though photosynthetic activity, important in advance of the growth phase which largely occurs under ice (Chapman and Lindley 1980), is restricted to the ice-free season. Vessels are typically present in the priority area during July to September, and occasionally during June (Maerospace 2020), though they may not be present throughout that entire period. Considering the above, there is an approximate temporal overlap of 33-50% between when vessels and macroalgae are present, resulting in a score of 2.
Spatial	3	Spatial = Areal x Depth = 1 x 3 = 3
Areal	1	Macroalgae typically occurs in water depths between 5-50 m in the AOI, with higher densities at 10 and 15 m compared with 5 m (Krause-Jensen et al. 2012; Filbee-Dexter et al. 2022). According to the shipping management plan produced by the Meadowbank mine (Agnico Eagle 2022) and sailing instructions produced by the Canadian Hydrographic Service (2022), vessels travelling through Chesterfield Inlet follow a path in the deepest area of the channel. Based on vessel traffic patterns in the priority area (see Figure 5-10), increased suspended sediment from vessel wake and propeller wash would be expected to

Risk Factor	Score	Rationale
		overlap a few restricted locations of the macroalgae range in the priority area. Thus, a score of 1 was assigned.
Depth	3	Macroalgae inhabit surficial seabed substrate. Suspended sediment load generally increases with depth, with greater increases near the substrate, and sediment originating from the substrate may only reach the lower column even in high current velocities (Yang et al. 2004). Therefore, habitat alteration via increased suspended sediment from vessel wake and propeller wash would be expected to occur mainly near the substrate and overlap the entire depth range of macroalgae in the Chesterfield Inlet/Narrows priority area, resulting in a score of 3.
Sensitivity	2 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (1 + 2) x 2.0 = 6.0
Acute Change	1	Chesterfield Inlet is a 200 km-long estuary that undergoes semi-diurnal tidal cycles with a tidal range of 3.4 m at spring tide and 1.5 m at neap tide (Roff et al. 1980; GoC 2023). Due largely to the form of the estuary and tidal influence, current velocities reach 4.5 knots on the flood and 7 knots on the ebb tide (Dohler 2007), leading to dynamic conditions in the area (Roff et al. 1980). Though studies of the suspended sediment load between slack tide (i.e., baseline) and flood tide in Chesterfield Inlet/narrows are unknown, long estuaries with high tidal action are known to significantly positively influence suspended sediment load (Uncles et al. 2002; Yang et al. 2004) and some consistent elevated level of suspended sediment is expected in the priority area. Therefore, it is expected that biota in the priority area are regularly exposed to elevated levels of suspended sediment in the natural conditions of the estuary. Sediment disturbance from vessel traffic is a noted concern of individuals from the community of Chesterfield Inlet (DFO unpublished[14]). Suspended sediment can decrease available light for macroalgae affecting productivity (Aumack et al. 2007), and resettled sediment can cause smothering or inhibit substrate attachment (Traiger and Konar 2017). Some species are intolerant of increased sedimentation, such as the kelp *Nereocystis luetkeana*, while others thrive, albeit with potentially shorter growing seasons, such as the kelp *Saccharina latissima* (Traiger and Konar 2017). Considering the baseline environmental conditions and the low current level of vessel traffic in the area acute loss or fragmentation of kelp bed habitat from this stressor is not expected, resulting in a score 1.
Chronic Change	2	Chesterfield inlet is a dynamic environment with high tidal range and current velocities, and the baseline conditions are expected to regularly include elevated levels of suspended sediment (see *Acute Change*, above), which should be noted when considering the following examples. Kelp distribution, abundance, and species composition vary with sedimentation, substrate type, wave exposure, temperature, and light (Traiger and Konar 2017). The passage of large vessels can increase suspended sediment concentrations several times greater than natural background levels; large vessel transits in Hillsborough Bay, Florida were observed to cause suspended sediments to increase by five times the background level, up to 250 mg/L, with increased sedimentation lasting for up to 8 h (Wilber and Clarke 2001). The community structure of Arctic kelp beds could be altered to favour species with sediment tolerant gametophytes, such as *Saccharina latissima*, if the ecosystem experienced long-term increased sedimentation rates, such as from increased glacial melt (e.g., Traiger and Konar 2017) or frequent vessel traffic. Aumack et al. (2007) demonstrated a strong correlation between decreased light levels and suspended sediment load in an Arctic kelp bed, suggesting that productivity and growth would likely be negatively impacted.

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[14] DFO. 2019. Community confirmation engagement report: Marine Protected Area process in Kivalliq and Southampton Island proposed Area of Interest. 27 p.

Risk Factor	Score	Rationale
		Reproductive success may also be affected by long-term increases in turbidity by decreasing settlement success of gametophytes (Airoldi 2003), although this was not found to be the case during laboratory studies with *S. latissima* and *Nereocystis luetkeana* (Traiger and Konar 2017). Balata et al. (2007) and Spurkland and Iken (2011) observed decreased macroalgal diversity and kelp recruitment in areas with high increases in sedimentation rates during field studies off the coasts of Tuscany and Alaska, respectively. Relating to kelp's ability to function as habitat, although invertebrate species richness was not significantly affected by suspended sediment load it was related to a change in species composition and a shift in the dominant taxonomic groups (Ronowicz et al. 2018). Therefore, considering the baseline environmental conditions and although the current level of vessel traffic is low, possible effects related to decreased productivity, decreased recruitment success, and a change in habitat function could result in a change to long-term viability of the habitat within the priority area, resulting in a score of 2.
Recovery Factors	2.0	At least 19 species/taxonomic groups of macroalgae have been documented to occur within or near the AOI (DFO 2020; Loewen et al. 2020a, b; Filbee-Dexter et al. 2022). At least 8 species/taxonomic groups have been reported for the Chesterfield Inlet/Narrows priority area. Of these macroalgae, three kelp species, *Laminaria solidungula*, edible kelp (*Alaria esculenta*), and sugar kelp (*Saccharina latissima*) are among the most abundant in the AOI, creating extensive kelp forests reaching up to 3-4 m in height and spreading several kilometers from shore (Filbee-Dexter et al. 2022; DFO 2020; Loewen et al. 2020b). *L. solidungula* is an Arctic endemic species (Roleda 2016). Biomasses of up to 34 kg/m^2 were observed for these kelp forests in the AOI, the highest ever reported for the eastern Canadian Arctic (Filbee-Dexter et al. 2022). Other types of macroalgae also occur amongst these kelp species, including coralline encrusting algae, and are important to create the structural complexity beneficial to its inhabitants (Wharton and Mann 1981; Christie et al. 1998; Steen et al. 2016; Misiuk and Aitken 2020). Habitat recovery factors were used. Recovery factors = mean of the factors listed below. <u>Growth rate (biogenic)/rate of structural rebuilding (abiotic)</u>: 1 (kelp sporophyte growth rates are high compared to other organisms [Mann 1973]). <u>Resistance:</u> 3 (Kelp can easily be disturbed physically, known to break apart during physical duress such as sample collection [Mundy 2020]. A change in ecosystem structure, such as an increase in urchin populations [e.g., Filbee-Dexter and Scheibling 2014] can lead to rapid and extensive defoliation of kelp). <u>Regenerative potential:</u> 2 (The regeneration of kelp forests after destructive events highly depends on the strength and duration of the event(s). Different clearing experiments in the northern Atlantic have shown that a full kelp regrowth can be observed after 1-3 years when environmental pressures are removed [Scheibling 1986; Christie et al. 1998; Steen et al. 2016]. However, fully grown kelp forests also host a great variety of understorey algae along with many fish and invertebrates, that can take over 5 years to recolonize the habitat [Wharton and Mann 1981; Christie et al. 1998; Steen et al. 2016]. In the Arctic, many authors have concurred that coastal recovery processes should be much slower than in temperate waters [Dunton et al. 1982; Conlan 2005; Keck et al. 2020]. Several experiments and measurements done in the Beaufort Sea's Boulder Patch have shown that following a major disturbance on the site, it could take more than a decade for the sessile community, including kelp, to fully recover [Konar 2013; Bonsell and Dunton 2021]). <u>External stress:</u> 2 (Climate change and warming waters add to stress [e.g., Filbee-Dexter et al. 2020]).
Consequence	2	Consequence = Exposure x Sensitivity

Risk Factor	Score	Rationale
	(binned)	= 2 x 2 = Low
Likelihood	2	Habitat alteration due to increased sedimentation from vessel wake and propeller wash could occur during summer/fall when vessels transit through the Chesterfield Inlet/Narrows priority area. An interaction may occur with macroalgae species that are intolerant of increased sedimentation but may not occur for tolerant species. However, given the expected elevated baseline levels of suspended sediment in and around the mouth of Chesterfield Inlet due to the dynamic tidal environment (see *Acute Change*), additional suspended sediment to a level that would cause measurable impacts in kelp beds is unlikely to occur.
Overall Risk	Moderate Risk	Additional management measures may be considered, such as the development of a sedimentation study and minimizing permissible vessel traffic in shallow portions of the Chesterfield Inlet/Narrows priority area, particularly in habitats identified as important kelp areas (see areas identified during an Inuit Qaujimajatuqangit workshop in February 2020 [Idlout 2020]).
Uncertainty		
Exposure	4	Macroalgal documentation in the priority area is limited (e.g., DFO 2020; Loewen et al. 2020a, b), although macroalgae and coastal kelp beds have been identified near the mouth of Chesterfield Inlet and it is known that the Western Hudson Bay Coastline EBSA features dense coastal kelp beds and macroalgae (DFO 2020). The extent, duration, and concentration/rates of sedimentation induced by vessel passage (vessel wake/propellor wash) is uncertain, and
Sensitivity	3	Studies exist investigating the effects of sedimentation on kelp in other regions (e.g., Airoldi 2003 and references therein), though relatively few studies have examined the effects of sedimentation on Arctic macroalgae. Life history information is generally limited for macroalgae species that occur in/near the priority area.
Likelihood	4	Research is needed on how different species of Arctic macroalgae respond to increased sedimentation and turbidity.

Risk Statement: If an interaction occurs involving benthic invertebrates and habitat alteration (by increased suspended sediment load from vessel wake and propeller wash) due to a vessel underway the consequence could result in a negative impact on benthic invertebrate populations in the Chesterfield Inlet/Narrows priority area.

Table 5-18. Benthic invertebrates – Vessel Underway (Chesterfield Inlet/Narrows) – Habitat Alteration (Sedimentation from Vessel Wake and Propeller Wash).

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 2 x 3 = 6 (raw score)
Intensity	1	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low absolute density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS data indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Chesterfield Inlet/Narrows priority area experiences a high density of vessel traffic relative to other portions of the AOI (see Figures 5-1 and 5-10) representing 61% of total AIS data within the AOI from 2012-2019. The intensity of vessel traffic and the resulting stressor is not

Risk Factor	Score	Rationale
		uniform, and the density would be higher in areas of higher vessel traffic (e.g., near regular anchorage areas at Helicopter Island or near Chesterfield Inlet). Although the relative density of AIS data is higher in this priority area, the baseline environmental conditions are regularly expected to generate elevated levels of suspended sediment (see *Acute Change*, below). Due to these baseline conditions, it is expected that the level of suspended sediment created by the current level of vessel traffic would lead to a minimal increase in density of suspended sediment in the water column. The persistence of elevated levels of suspended sediment in the water column from this stressor is expected to be low, as disturbed suspended sediment in the water column reaches background levels on the order of hours (Yang et al. 2004) and the tidal cycles of the area are nearly constant. Therefore, intensity was scored as 1.
Temporal	2	Benthic invertebrates are present in the Chesterfield Inlet/Narrows priority area year-round. Vessels are typically present in the priority area during July to September, and occasionally during June (Maerospace 2020), though they may not be present throughout that entire period. There is an approximate temporal overlap of 33-50% between when vessels and benthic invertebrates may be present, resulting in a score of 2.
Spatial	3	Spatial = Areal x Depth = 1 x 3 = 3
Areal	1	Benthic invertebrates are anticipated to occur throughout the Chesterfield Inlet/Narrows priority area. According to the shipping management plan produced by the Meadowbank mine (Agnico Eagle 2022) and sailing instructions produced by the Canadian Hydrographic Service (2022), vessels travelling through Chesterfield Inlet follow a path in the deepest area of the channel. Based on vessel traffic patterns in the priority area (see Figure 5-10), increased suspended sediment from vessel wake and propeller wash would be expected to overlap a small proportion of the benthic invertebrate range in the priority area. This results in a score of 1.
Depth	3	Benthic invertebrates inhabit the seabed. Suspended sediment load generally increases with depth, with greater increases near the substrate, and sediment originating from the substrate may only reach the lower column even in high current velocities (Yang et al. 2004). Therefore, habitat alteration via suspended sediment from vessel wake and propeller wash would occur mainly near the substrate and overlap the entire depth range of benthic invertebrates in the Chesterfield Inlet/Narrows priority area, resulting in a score of 3.
Sensitivity	1 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (1 + 1) x 2.3 = 4.6
Acute Change	1	Chesterfield Inlet is a 200 km-long estuary that undergoes semi-diurnal tidal cycles with a tidal range of 3.4 m at spring tide and 1.5 m at neap tide (Roff et al. 1980; GoC 2023). Due largely to the form of the estuary and tidal influence, current velocities reach 4.5 knots on the flood and 7 knots on the ebb tide (Dohler 2007), leading to dynamic conditions in the area (Roff et al. 1980). Though studies of the suspended sediment load between slack tide (i.e., baseline) and flood tide in Chesterfield Inlet/narrows are unknown, long estuaries with high tidal action are known to significantly positively influence suspended sediment load (Uncles et al. 2002; Yang et al. 2004) and some consistent elevated level of suspended sediment is expected in the priority area. Therefore, it is expected that biota in the priority area are regularly exposed to elevated levels of suspended sediment in the natural conditions of the estuary.

Risk Factor	Score	Rationale
		Benthic invertebrates inhabiting the seabed in nearshore locations that experience regular, natural disturbance (e.g., wind, wave, and tidal action) are likely adapted to physical disruptions (Wilber and Clarke 2001; Hinchey et al. 2006; Broad et al. 2020) and would be expected to experience minimal effects from increased sedimentation from vessel wake and propeller wash. More pronounced effects would be expected in benthic habitats that normally experience little in the way of natural disturbance, particularly in areas with predominantly mud/clay substrates (Broad et al. 2020) such as portions of Chesterfield Inlet/Narrows (see Figure 17 in DFO 2020; Misiuk and Aitken 2020). Additionally, impacts of increased suspended sediment load vary by benthic invertebrate species and taxonomic group. The passage of large vessels can increase suspended sediment concentrations several times greater than natural background levels; large vessel transits in Hillsborough Bay, Florida were observed to cause suspended sediments to increase by five times the background level, up to 250 mg/L, with increased sedimentation lasting for up to 8 h (Wilber and Clarke 2001). Though these levels of increased suspended sediment load may not be relevant to the current vessel traffic densities in the AOI, effects on benthic invertebrates from this stressor have been demonstrated in various contexts and situations. Sediment disturbance from vessel traffic is a noted concern of individuals from the community of Chesterfield Inlet (DFO unpublished[15]). Though enough re-suspension to cause burial is not expected with the current level of vessel traffic in the AOI, benthic biota may be smothered by the settling of suspended sediments (e.g., World Wildlife Fund [WWF] 2020). The effects of burial differ by taxonomic group, and burial depth and sediment composition are important; negative effects have been demonstrated in some polychaete worms and amphipods, whereas bivalve and gastropod molluscs, other polychaete worms, and some corals are able to migrate through or remove sediments (Maurer et al. 1981; Hinchey et al. 2006; Brooke et al. 2009; Bolam 2011). Multiple studies have investigated the effects of elevated suspended sediment load on cold-water corals. Williamson and authors (2011) introduced a non-photosynthetic coral (*Leptogorgia virgulata*) to sediment levels up to 20,000 mg/L continuously for 14 days without any demonstrable tissue loss and an increase in polyp activity (i.e., indicative of feeding behaviour). The study also showed that control levels of sediment (i.e., 0 mg/L) demonstrated tissue loss, with the authors suggesting that some corals may operate more efficiently in areas with some baseline level of suspended sediment. Many species of corals exhibit an outer mucus coating which functions in defense and feeding and can be used to expel or ingest sediments (Stafford-Smith and Ormond 1992; Bessell-Browne et al. 2017). Though cilial movement enacts an energetic cost, it is estimated to be a limited portion (i.e., <0.1%) of the energy budget (Shapiro et al. 2014). Sponges, as filter-feeding organisms, may be more susceptible to the effects of increased sediment load. Particles can reduce the pumping efficiency and filtering capacity of some species (Bell et al. 2015; Grant et al. 2019) and interfere with feeding activities (Strehlow et al. 2017). However, sponges also exhibit certain abilities to limit impacts from suspended sediment including mucus production, cessation of pumping, and expulsion of particles (Strehlow et al. 2017). Repeated exposures would likely interfere with long-term viability (Tompkins-Macdonald and Leys 2008) and it is plausible that higher one-time sediment depositions (i.e., partial or complete burial) could cause acute detrimental effects. If sediment

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[15] DFO. 2019. Community confirmation engagement report: Marine Protected Area process in Kivalliq and Southampton Island proposed Area of Interest. 27 p.

Risk Factor	Score	Rationale
		suspension/turbidity affected oxygen concentrations or the exchange of organic carbon, the distribution of benthic biota may be impacted (Hinchey et al. 2006; WWF 2020). Increased suspended sediment/turbidity may affect filter feeding benthic biota, such as causing a decrease or complete stop in filter feeding pumping rates of some sponge species (Grant et al. 2019). Given the baseline environmental conditions and the current low level of vessel traffic, habitat alteration via increased sedimentation from vessel traffic through the Chesterfield Inlet/Narrows priority area would not be expected to result in detectable changes to mortality rates of benthic invertebrate species, resulting in a score of 1.
Chronic Change	1	Chesterfield Inlet/Narrows priority area is a dynamic environment with high tidal range and current velocities, and the baseline conditions are expected to regularly include elevated levels of suspended sediment (see *Acute Change*, above), which should be noted when considering the following examples. The passage of large vessels can increase suspended sediment concentrations several times greater than natural background levels; large vessel transits in Hillsborough Bay, Florida were observed to cause suspended sediments to increase by five times the background level, up to 250 mg/L, with increased sedimentation lasting for up to 8 h (Wilber and Clarke 2001). Though the levels of increased suspended sediment load may not be relevant to the current vessel traffic densities in the AOI, effects on benthic invertebrates from this stressor have been demonstrated in various contexts and situations. Habitat smothering by sedimentation may impact the spawning or feeding behaviour of benthic taxa (Ragnarsson et al. 2016). Persistent sedimentation of the benthic habitat may reduce primary and/or secondary productivity or alter community dynamics towards species more tolerant of such disturbance and may require lengthy periods for ecosystem recovery (Hinchey et al. 2006; Broad et al. 2020; WWF 2020). No juvenile benthic invertebrate taxa were found to exhibit adaptation to high sedimentation rates from inorganic discharges released by three glaciers in Kongsfjord, Svalbard (Fetzer et al. 2002). Wlodarska-Kowalczuk et al. (2005) studied the response of macrofauna inhabiting soft-bottom sediments to increased sedimentation from chronic glacial disturbance in Kongsfjord and observed decreased biomass, mean body size, and species diversity and evenness nearest the glacier. Repeated exposures to elevated suspended sediment loads would likely interfere with long-term viability of filter-feeding sponges (Tompkins-Macdonald and Leys 2008). In contrast, other taxa or contexts have revealed limited or no impacts on benthic invertebrates from increased suspended sediment load. Multiple studies have demonstrated that cold-water corals are able ingest or remove settled sediment without noted negative impacts (Stafford-Smith and Ormond 1992; Larsson and Purser 2011; Williamson et al. 2011; Bessell-Browne et a. 2017). Young oligochaetes were exclusively located near a glacier at the fjord mouth and juvenile suspension-feeding bivalves experienced little in the way of disturbance from glacial discharge (Fetzer et al. 2002). Though variation in observed impacts does exist, multiple studies suggest that estuarine species routinely exposed to elevated suspended sediment loads are naturally more tolerant of periodic pulses due to physiological and behavioural adaptations (McFarland and Petticord 1980; Wilber and Clarke 2001; Miller et al. 2002; Hinchey et al. 2006). Though negative impacts from increased suspended sediment load have been documented on benthic invertebrates in some situations, given the dynamic baseline conditions present in the priority area and the low current level of vessel

Risk Factor	Score	Rationale
		traffic, it is not expected that this stressor would result in a measurable change to overall fitness for benthic invertebrate species. This results in a chronic change score of 1.
Recovery Factors	2.3	At least 430 benthic invertebrate species have been identified within or near the AOI, including corals (e.g., the soft coral *G. rubiformis*), sponges, sea stars, brittle stars, sea urchins, bivalves, cephalopods, crinoids, gastropods, holothuroids (sea cucumbers), hydrozoans, amphipods, cumaceans, decapods, euphausiids, isopods, Leptostracans, ostracods, sea spiders, polychaetes, barnacles, and chitons (DFO 2020; Loewen et al. 2020a, b; Misiuk and Aitken 2020). Corals and sponges are the most sensitive benthic invertebrate groups identified for the priority area and were used for the determination of Recovery Factors. There have been limited benthic invertebrate studies for the Chesterfield Inlet/Narrows priority area (e.g., GN 2010; Misiuk and Aitken 2020; Pierrejean et al. 2020). Recovery factors = mean of the factors listed below. Fecundity: 1 (*Geodia phlegraei* sponges from the North Atlantic were observed to produce ~16 million oocytes/sponge and ~30 billion spermatozoa/sponge [Koutsouveli et al. 2020]. It is currently unknown whether *Geodia* sponges occur in the AOI, but the information presented here may be generally used for the Porifera Phylum reported for the AOI). Early life stage mortality: 3 (During four years of observations in water depths >650 m in the Gulf of Maine, the deep-water gorgonian coral experienced high mortality during its early benthic stage, possibly due to biological disturbance, such as by suspension-feeding brittle stars, and limited food supply [Lacharité and Metaxas 2013]. Larvae of the cold-water coral *Lophelia pertusa* had an average survival rate of 60% during three months of laboratory observations and a maximum longevity of one year [Strömberg and Larsson 2017]. Although neither of these species have been reported for the AOI (Loewen et al. 2020a), their habitat conditions may be considered analogous to those of the AOI and the information presented here is applied in a precautionary manner for species within the AOI, for which no specific early life stage mortality information could be found). Recruitment pattern: 2 (Of two deep-water gorgonian corals observed in the Gulf of Maine, the broadcast spawner *P. resedaeformis* had high recruit abundance while the brooder spawner *Paragorgia arborea* had few recruits [Lacharité and Metaxas 2013]. The life span and rates of asexual and sexual reproduction in the soft coral *G. rubiformis* are unknown; however, asexual reproduction can be stimulated by physical disturbance [Henry et al. 2003; Iken et al. 2012]. The lifespan of *Geodia* spp. sponges is unknown, but they are likely to be slow growing [Last et al. 2019]. Although the corals *P. resedaeformis* and *P. arborea* and *Geodia* sponges have not been reported for the AOI, the information provided here has been applied for the AOI, for which no specific information could be found). Natural mortality rate: Unknown; excluded from consideration. Age at maturity: Unknown (DFO 2015b); excluded from consideration. Life stages affected: 3 (All life stages are expected to be affected). Population connectivity: Unknown; excluded from consideration. Population status: Unknown (the population size of the soft coral *soft c* is unknown [Boutillier et al. 2019] and corals/sponges are not considered under Sara or COSEWIC; excluded from consideration).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 2 x 1 = Negligible
Likelihood	2	Habitat alteration due to increased sedimentation from vessel wake and propeller wash could occur during summer/fall when vessels transit through the Chesterfield

Risk Factor	Score	Rationale
		Inlet/Narrows priority area. An interaction may occur with benthic invertebrate species that are intolerant of increased sedimentation but may not occur for tolerant species. However, given the expected elevated baseline levels of suspended sediment in and around the mouth of Chesterfield Inlet due to the dynamic tidal environment (see *Acute Change*), additional suspended sediment to a level that would cause measurable impacts in benthic invertebrates is unlikely to occur.
Overall Risk	Low Risk	No additional management measures need to be considered at this time.
Uncertainty		
Exposure	5	The extent, duration, and concentration/rates of sedimentation induced by vessel passage (vessel wake/propeller wash) is uncertain. Benthic invertebrate distribution is poorly studied in the area though general vessel traffic patterns are known.
Sensitivity	5	Limited information is available for benthic community diversity and abundance for the Chesterfield Inlet/Narrows priority area (DFO 2020). Life history information is generally limited for sensitive benthic invertebrate species that may occur within the priority area. This assessment was conducted on representative benthic invertebrate species and examples were drawn as such; however, the assemblage includes numerous species and the assessment may not be accurate for all. Some studies exist regarding Arctic sedimentation, though in different contexts (i.e., glacial sedimentation rather than the extent of impacts from vessel passage; Slattery and Bockus 1997; Wlodarska-Kowalczuk et al. 2005). Uncertainty is very high.
Likelihood	5	Research is needed on how different species of Arctic benthic invertebrates respond to increased sedimentation and turbidity.

5.1.4 Water Displacement

Water displacement from a moving vessel is not expected to result in a measurable impact to marine fishes, marine mammals, or planktonic organisms. Likewise, adult seabirds are not expected to be affected by a vessel wake. It is possible that walruses or other pinnipeds at haul-out sites could be impacted by vessel-generated waves, though documented cases of negative impacts are not known in the AOI and it is not identified in recent threat assessments on walrus by COSEWIC (2017) and Higdon et al. (2022); therefore, it is not expected to result in measurable impacts to pinniped populations and was not assessed. There is some potential for the wake of a vessel to affect nests of seabirds which may occur along low-lying areas of shoreline adjacent to a ship track. Due to their nest site selection behaviour, common eiders were assessed for this stressor and act as a proxy for other seabirds that may nest in close proximity to marine waters (Table 5-19). Typical nesting habitat for thick-billed murre and Thayer's gull consists of rocky cliffs and these species are not expected to be affected by this stressor.

Table 5-19. Vessels Underway – Water Displacement: ESC Subcomponents and Priority Areas Assessed.

ESC Subcomponent	Priority Area or AOI	Assessed by Proxy
Common eider	East Bay	
Other seabirds		Via common eider

Risk Statement: If an interaction occurs involving common eider nests and water displacement due to a vessel underway the consequence could result in a negative impact on the common eider population in the East Bay priority area.

Table 5-20. Common eider (Nests) – Vessel Underway (East Bay) – Water Displacement.

Risk Factor	Score	Rationale
Exposure	1 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 1 = 1 (raw score)
Intensity	1	It should be noted that relative to other areas that experience shipping and vessel traffic and for which biological effects literature is largely based, the AOI receives a low density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS data indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9). The East Bay priority area experiences a low density of vessel traffic relative to other priority areas (see Figures 5-1 and 5-10) representing <1% of total AIS data within the AOI from 2012-2019. Therefore, intensity was scored as 1.
Temporal	1	Common eiders are present in the East Bay priority area from mid-June to September. Adult males depart on their moult migration in July (Abraham and Finney 1986). Eggs hatch in July and the flightless females rear their precocial broods in marine and intertidal waters. Groups of females and young are present until late-September (Abraham and Finney 1986). Common eiders nesting along shorelines are present in the East Bay priority area from mid-June to mid-October and eggs would be present in nests from the end of June until late July (Goudie et al. 2020). Vessels are typically present in the East Bay priority area during October and very occasionally in September, though they are not present throughout that entire period. There is very little overlap between when vessels occur in the East Bay priority area and when common eider eggs are present in nests, resulting in a score of 1.
Spatial	1	Spatial = Areal x Depth = 1 x 1 = 1
Areal	1	Nests near the high tide mark are expected to be sporadically distributed in appropriate microhabitat within the East Bay priority area. Vessel wake would be spatially limited to shorelines within a few hundred metres of the vessel. Also, due to navigational constraints vessel activity in close proximity of the shoreline is expected to be minimal. The area of overlap between nests and where vessel wakes are expected to reach would be restricted to a few locations within the common eider nesting range in the East Bay priority area, resulting in a score of 1.
Depth	1	A small proportion of common eider nests are placed near the high tide mark with the remainder placed well above the high tide mark. Vessel wake would occur just above sea level, and, if coinciding with high tide, would overlap only those nests placed very close to the high tide mark. Vessel wake at high tide occurs over a small portion of the depth range of common eider nesting habitat within the East Bay priority area, resulting in a score of 1.
Sensitivity	1 (binned)	Sensitivity = (Acute change + Chronic Change) x Recovery Factors = (1 + 1) x 2.4 = 4.8
Acute Change	1	Inundation from vessel wakes at high tide would cause nest failure in eider nests. However, it is expected that only a small proportion of common eider nests in the East Bay priority area would be located just above the high-tide line, following nesting behaviour demonstrated at other colonies (Goudie et al. 2020). As a result, water displacement is expected to result in an insignificant or undetectable change to the common eider mortality rates against background variability in the East Bay priority area. A score of 1 was assigned.
Chronic Change	1	A small proportion of nests could be affected by water displacement via vessel wake in the East Bay priority area. However, the low frequency of vessels passing through the priority area suggests that shoreline exposure to repeated vessel

Risk Factor	Score	Rationale
		wakes is unlikely. As a result, there would be an insignificant or undetectable change to overall fitness and no impact on population dynamics in the common eider nesting population in the East Bay priority area, resulting in a score of 1.
Recovery Factors	2.4	Fecundity: 2 (Three to five eggs laid per year [Goudie et al. 2020]). Early life stage mortality**:** 3 (90-95% in first year [Goudie et al. 2020]). Recruitment pattern**:** 3 (Probability: 0.17-0.47 [Nicol-Harper et al. 2021]). Natural mortality rate**:** 3 (13% [Goudie et al. 2020]). Age at maturity**:** 2 (≥4 years [Goudie et al. 2020]). Life stages affected**:** 2 (All life stages could potentially occur in the East Bay priority area [Goudie et al. 2020], though, as noted above, adults would not be affected by nest inundation). Population connectivity**:** 2 (High degree of fine-scale spatial population genetic structuring [Talbot et al. 2015]). Population status**:** 2 (Common eider is listed as *near threatened* by IUCN [BirdLife International 2018a] but is not listed under SARA or COSEWIC. However, the population may be declining due to increased polar bear predation in the East Bay priority area [Loewen et al. 2020b]). Also, avian cholera has the potential to cause mass mortality and significantly impact the East Bay population [Descamps et al. 2012]).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 1 x 1 = Negligible
Likelihood	5	In the event of a vessel wake contacting a common eider nest an interaction will occur; thus, a score of 5 was assigned.
Overall Risk	Low Risk	No additional management measures need to be considered at this time. However, vessels should observe minimum set-back distances from nesting common eiders as prescribed by ECCC-CWS. A 15 km buffer around breeding colonies was recommended by Mallory and Fontaine (2004).
Uncertainty		
Exposure	3	There is a moderate amount of scientific information available regarding the abundance and distribution of common eider nesting in the East Bay priority area. General vessel traffic patterns are known in the priority area. Uncertainty is moderate.
Sensitivity	4	There is little scientific information on the sensitivity on common eider nests to inundation in the East Bay priority area due to water displacement from vessels underway, though some literature exists from other areas (Boersma et al. 2002; Boyd et al. 2015).
Likelihood	3	There is a moderate amount of scientific information on the likelihood of common eider nest inundation due to wakes from vessels underway (Abraham and Finney 1986; Boersma et al. 2002; Boyd et al. 2015), though this exists for other areas.

5.2 Icebreaking

Icebreakers are special-purpose ships that clear passages through sea ice by ramming forward into the ice, reversing, and repeating the process. Icebreaking can also be undertaken by other types of vessels that have reinforced hulls and are classified to operate in Arctic waters; hereafter, “icebreakers” will refer to any vessel that is capable of icebreaking. Icebreaking operations can potentially disturb marine fauna and local communities via noise and the path of open water and altered ice left astern (Arctic Council 2009; Qikiqtani Inuit Association 2021). Icebreaking and its stressors can differ from those of other vessel types since icebreakers typically produce louder and more variable sounds and icebreaking would allow access to the AOI throughout a greater portion of the year (Halliday et al. 2020). The noise disturbance, habitat alteration/removal, and vessel strikes pathways are expected to manifest differently when an icebreaker is actively icebreaking, which is the focus of this section. Although icebreaking is a very rare event in the AOI (see below) it is a concern of partner communities (Idlout 2020) and in other communities where it is a more regular occurrence (Qikiqtani Inuit Association 2021) and was therefore included in this risk assessment.

From May 2012 to October 2019, eight different icebreakers representing 9,763 AIS pings were recorded in the SI AOI (Maerospace 2020; Figure 5-11). However, icebreakers may be present in an area and not be actively icebreaking so presence does not provide a solid indication of icebreaking trends. Additionally, icebreaking has been identified as only very rarely occurring in the AOI and is not a regularly scheduled occurrence (DFO 2024). In order to get a better indication of where icebreaking may have occurred, additional analyses were undertaken to identify the spatiotemporal characteristics of icebreakers by overlaying AIS data with Canadian Ice Service (CIS) weekly regional ice charts. This revealed that 10.6% of AIS icebreaker pings overlapped with sea ice occurrence (Figure 5-12). This refined dataset reveals that no potential icebreaking in the AOI occurred outside of June to November, with the majority of co-occurrence in the spring shoulder season, particularly June (i.e., 83% of AIS data; adapted from Maerospace 2020). This trend also held for AIS data within priority areas with potential icebreaking occurring in the Fisher and Evans Straits, Roes Welcome Sound, and Frozen Strait/Repulse Bay priority areas (Figure 5-12). The amount of vessel traffic, including icebreakers, is projected to increase in the Hudson Bay Complex and SI AOI in response to changing ice conditions related to climate change and increased industrial activity and tourism.

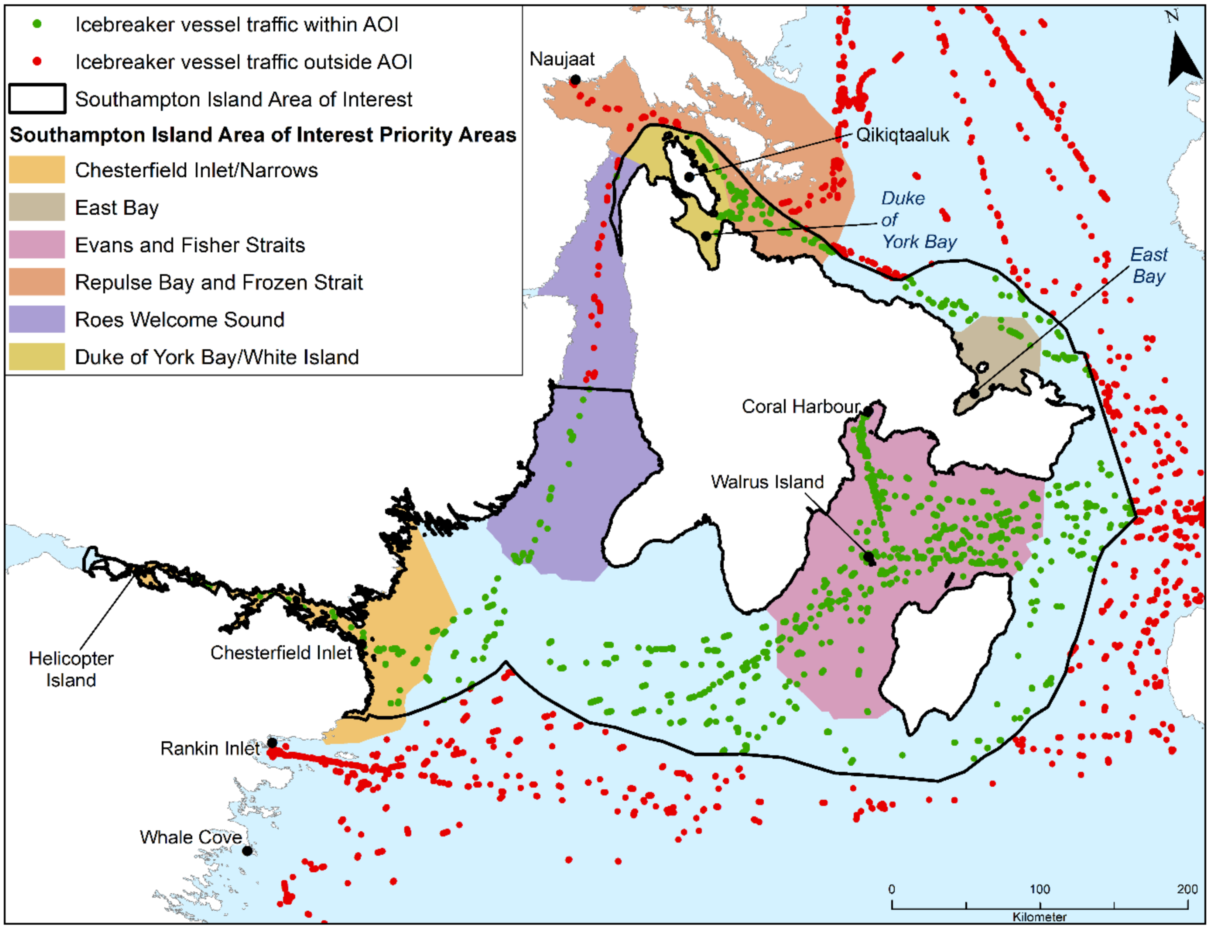

Figure 5-11. Locations of icebreakers with available AIS data relative to the Southampton Island AOI and priority areas (data from 2012-2019; adapted from Maerospace 2020). Note: the presence of an icebreaker does not necessarily indicate active icebreaking. Duke of York Bay/White Island and Repulse Bay/Frozen Strait priority areas overlap along the northeast and southeast sides of Qikiqtaaluk. Note: Qikiqtaaluk may be referred to as “White Island” in other publications.

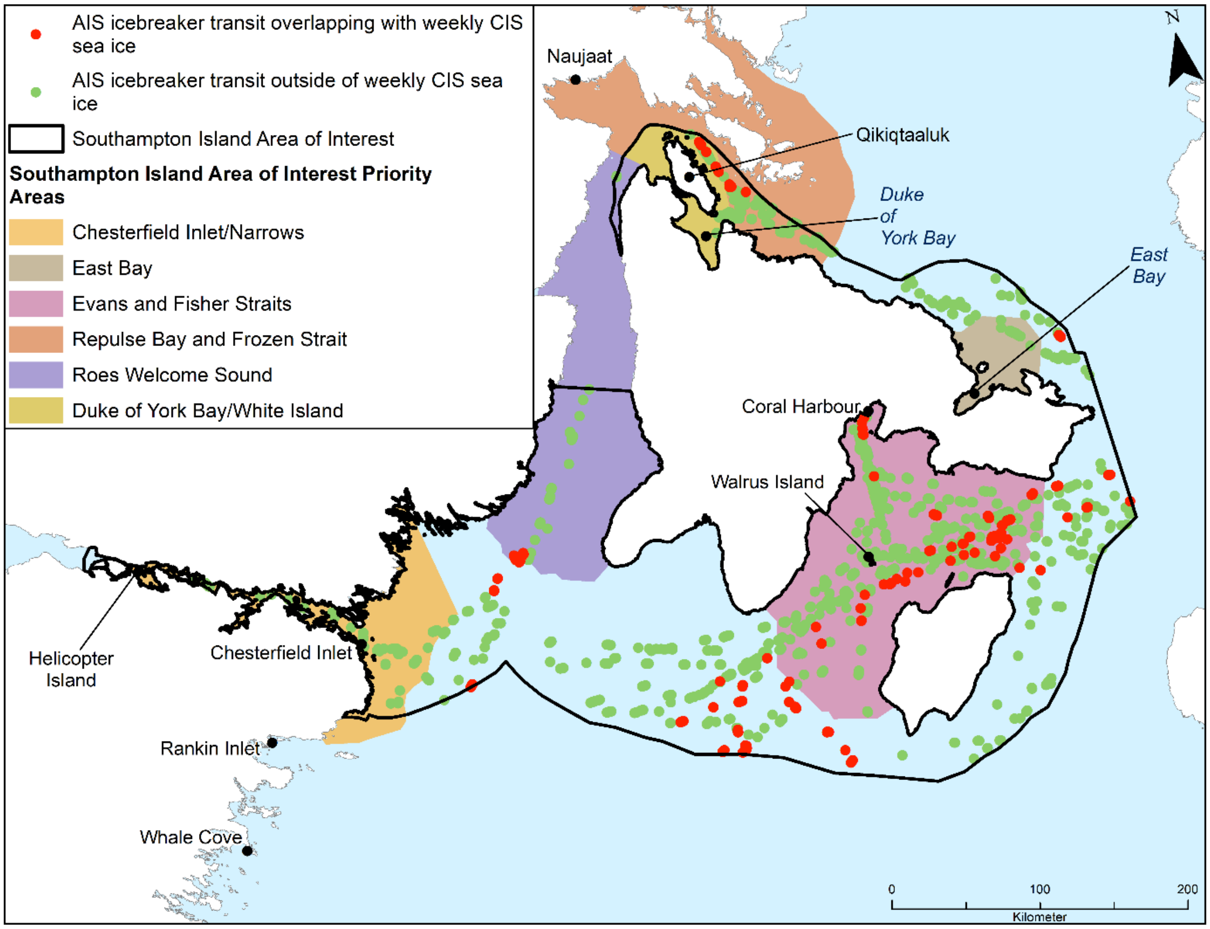

Figure 5-12. AIS icebreaker data (green dots; adapted from Maerospace 2020) overlapping with Canadian Ice Service (CIS) weekly regional sea ice data, 2012-2019. Red dots indicate overlap. Note: icebreaker presence overlapping with weekly regional sea ice does not necessarily indicate active icebreaking. Duke of York Bay/White Island and Repulse Bay/Frozen Strait priority areas overlap along the northeast and southeast sides of Qikiqtaaluk. Note: Qikiqtaaluk may be referred to as "White Island" in other publications.

5.2.1 Noise Disturbance

In addition to the noise produced by a vessel underway (i.e., from engines, propellers, and wave action), icebreaking produces more variable sounds with often higher sound levels because of the vessel hull colliding with ice. Some icebreakers are also equipped with bubbler systems that aid in clearing ice in the vessel's path and create additional noise (Arctic Council 2009). The response of marine mammals to icebreaking varies greatly, with narwhals and belugas demonstrating large-scale avoidance, whereas seals and polar bears exhibit limited behavioural responses (Finley et al. 1990; Lesage et al. 1990; Smultea et al. 2010; Huntington et al. 2015; Lomac-Macnair et al. 2019; Halliday et al. 2020; Stewart et al. 2020). Each marine mammal ESC subcomponent were assessed (Table 5-21). Likewise, Arctic cod were assessed because of their known response to vessel noise (Stanley et al. 2017). Other forage fish (e.g., capelin) were assessed by proxy through the Arctic cod assessment. Arctic Char were not assessed as they are not expected to be in marine waters during the winter or shoulder seasons, spending this time in freshwater bodies. Studies on the effects of icebreaking on seabirds are lacking, particularly with respect to their response to icebreaker noise, but they are known to be disturbed by vessel activity (presumably a combination of vessel noise and visual cues) (Fliessbach et al. 2019). Compared to murres and gulls, common eider have been described as more sensitive to disturbance from vessels (Garthe and Hüppop 2004; Fliessbach et al. 2019); therefore, common eider were selected for assessment and serve as a proxy for other seabirds.

Table 5-21. Icebreaking – Noise Disturbance: ESC Subcomponents and Priority Areas Assessed.

ESC Subcomponent	**Priority Area or AOI**	**Assessed by Proxy**
Common eider	East Bay	
Other seabirds		Via common eider
Arctic cod	Fisher and Evans Straits	
Other forage fish		Via Arctic cod
Ringed seal	Fisher and Evans Straits	
Bearded seal	Fisher and Evans Straits	
Walrus	Fisher and Evans Straits	
Narwhal	Repulse Bay/Frozen Strait	
Beluga	East Bay	
Bowhead whale	Fisher and Evans Straits	
Polar bear	Fisher and Evans Straits	

Risk Statement: If an interaction occurs involving common eiders and noise disturbance due to icebreaking the consequence could result in a negative impact on the common eider population in the East Bay priority area.

Table 5-22. Common eider – Icebreaking (East Bay) – Noise Disturbance.

Risk Factor	Score	Rationale
Exposure	1 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 2 = 2 (raw score)
Intensity	1	Currently, active icebreaking is rare in the AOI and only occurs in the shoulder seasons (DFO 2024). Indeed, overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was not recorded in the priority area from 2012-2019 (adapted from Maerospace 2020). Therefore, an intensity score of 1 was assigned. This assessment considers noise produced by active icebreaking, including noise produced by vessels during regular operation (i.e., from engines, propellers, and wave action) and the hull colliding with ice. Noise disturbance from vessels underway (including icebreakers that are not actively icebreaking) and vessels at rest is considered in Sections 5.1.1 and 5.3.1, respectively.
Temporal	1	Common eiders are present in the East Bay priority area from mid-June to September (Abraham and Finney 1986). Adult males depart on their moult migration in July. Eggs hatch in July and the flightless females rear their precocial broods in the marine and intertidal waters of East Bay. Groups of females and young are present until late-September (Abraham and Finney 1986), primarily foraging on benthic invertebrates in waters <20 m deep (Goudie et al. 2020). Ice break-up in the priority area begins in April or May, but pack ice is blown in and out of East Bay through July (Mallory et al. 2019). Freeze-up begins in mid-October with the formation of landfast ice. Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was not recorded in the priority area from 2012-2019 (adapted from Maerospace 2020). In addition, the eiders depart when ice begins to form in the fall. Consequently, there is very little

Risk Factor	Score	Rationale
		overlap between when icebreaking occurs in the East Bay priority area and when common eiders are present in marine waters, resulting in a score of 1.
Spatial	2	Spatial = Areal x Depth = 1 x 2 = 2
Areal	1	Eider females and broods are expected to be distributed in intertidal and marine waters within the East Bay priority area (Abraham and Finney 1986), primarily <20 m deep (Goudie et al. 2020). Noise disturbance to seabirds from icebreaking is unstudied (Halliday et al. 2022). Vessels underway that are not icebreaking causes local displacement of eiders at least 210-250 m from the birds (Schwemmer et al. 2011; Fliessbach et al. 2019). Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was not recorded in the priority area from 2012-2019 (adapted from Maerospace 2020) and vessel tracks, regardless of vessel type, are generally towards the northern extent of the priority area (see Figure 5-1 and Figure 5-12). Consequently, the area of overlap between eider broods and icebreaking vessels is expected to be limited to a few restricted locations within the common eider distribution in the priority area; resulting in a score of 1.
Depth	2	Common eider flight altitude (over water) is similar to that of the height above the water line of a sea-going icebreaker's superstructure. This species most commonly dives to a depth of 4 m, which is similar to the draught of a sea-going vessel and sound would propagate deeper. Depending on the size of the vessel, the potential for noise disturbance due to icebreaking covers a moderate portion of the depth range of common eider in the East Bay priority area, resulting in a score of 2.
Sensitivity	2 (binned)	Sensitivity = (Acute change + Chronic Change) x Recovery Factors = (1 + 1) x 2.6 = 5.2
Acute Change	1	The effect on sea ducks of noise due to icebreaking is unknown, whether above or below the surface. Underwater hearing of birds is thought to be less sensitive than in air, since the increased pressure associated with diving constricts their middle ear (Dooling and Therrien 2012). In other sea duck species, the in-air hearing sensitivity is greatest between 1.5 and 3 kHz (Crowell 2016). Common eider dive duration is short, so noise from icebreaking is unlikely to interact with eiders under water. In-air noise disturbance due to vessels underway that are not icebreaking causes local displacement. Noise disturbance is not known to cause mortality in sea ducks. Considering the current low density of active icebreaking in the priority area, noise disturbance from icebreaking would be expected to result in an insignificant or undetectable change in common eider behaviour and mortality rates against background variability. Thus, a score of 1 was assigned.
Chronic Change	1	The low frequency of icebreaking in the priority area would be unlikely to cause repeated effects and, therefore, chronic change in the common eider population. As a result, an insignificant or undetectable change to overall fitness and no impact on population dynamics are expected, resulting in a sore of 1.
Recovery Factors	2.6	Recovery factors = mean of the factors listed below. Fecundity: 2 (Three to five eggs laid per year; nesting success 0-40% [Goudie et al. 2020]). Early life stage mortality**:** 3 (90-95% in first year [Goudie et al. 2020]). Recruitment pattern**:** 3 (Probability: 0.17-0.47 [Nicol-Harper et al. 2021]). Natural mortality rate**:** 3 (13% [Goudie et al. 2020]). Age at maturity**:** 2 (≥4 years [Goudie et al. 2020]). Life stages affected**:** 3 (All life stages could potentially occur in the East Bay priority area [Goudie et al. 2020]).

Risk Factor	Score	Rationale
		Population connectivity**:** 3 (High degree of fine-scale spatial population genetic structuring [Talbot et al. 2015]). Population status**:** 2 (Common eider is listed as *near threatened* by IUCN [BirdLife International 2018a] but is not listed under SARA or COSEWIC. However, the population may be declining due to increased polar bear predation in the East Bay priority area [Loewen et al. 2020b]). Also, avian cholera has the potential to cause mass mortality and significantly impact the East Bay population [Descamps et al. 2012]).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 1 x 2 = Negligible
Likelihood	3	An interaction has the potential to occur when common eiders and an icebreaking vessel are present at the same time within the East Bay priority area and within close enough proximity for the vessel noise to cause a disturbance to the animal. Depending on the behavioural state of the animal, its prior experience with vessels, and the distance to the vessel, an interaction may occur in some but not all circumstances. Thus, a score of 3 was assigned.
Overall Risk	Low Risk	No additional management measures need to be considered at this time. However, icebreaking vessels should observe minimum set-back distances from at-sea concentrations of common eiders as prescribed by ECCC-CWS. A 15 km buffer around breeding colonies was recommended by Mallory and Fontaine (2004).
Uncertainty		
Exposure	3	There is a moderate amount of scientific information available regarding the abundance, distribution, and timing of common eiders in the East Bay priority area that suggests. General patterns of icebreaking are known in the AOI, though additional investigation is needed to determine the fine-scale patterns by vessel trip. Uncertainty is moderate.
Sensitivity	5	There is no scientific information on the sensitivity of common eiders or other sea ducks to noise disturbance from icebreaking. As a result, uncertainty is very high.
Likelihood	3	There is a moderate amount of scientific information on the likelihood of common eiders reacting to noise from vessel and of the likelihood of icebreakers approaching close enough to cause a reaction (e.g., Abraham and Finney 1986; Fliessbach et al. 2019), though it is from other areas. Additional investigation is needed particular to icebreaking.

Risk Statement: If an interaction occurs involving Arctic cod and noise disturbance due icebreaking the consequence could result in a negative impact on Arctic cod populations in the Fisher and Evans Straits priority area.

Table 5-23. Arctic cod – Icebreaking (Fisher and Evans Straits) – Noise Disturbance.

Risk Factor	Score	Rationale
Exposure	1 (binned)	Exposure = Intensity x Temporal x Spatial (Depth x Areal) = 1 x 1 x 3 = 3 (raw score)
Intensity	1	Currently, active icebreaking is rare in the AOI and only occurs in the shoulder seasons (DFO 2024). Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was recorded in the priority area approximately every other year from 2012-2019 (adapted from Maerospace 2020). Therefore, an intensity score of 1 was assigned. This assessment considers noise produced by active icebreaking, including noise produced by vessels during regular operation (i.e., from engines, propellers, and

Risk Factor	Score	Rationale
		wave action) and the hull colliding with ice. Noise disturbance from vessels underway (including icebreakers that are not actively icebreaking) and vessels at rest is considered in Sections 5.1.1 and 5.3.1, respectively.
Temporal	1	Arctic cod are expected to occur in the area year-round. Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was recorded in the priority area approximately every two years from 2012-2019. The majority of overlap occurred during June (82% of total AIS data) with the remainder spread among July, August, and November (adapted from Maerospace 2020). Therefore, there is very little overlap between when active icebreaking may occur and Arctic cod may be present, resulting in a score of 1.
Spatial	3	Spatial = Areal x Depth = 1 x 3 = 3
Areal	1	A ubiquitous species, Arctic cod occupy coastal and offshore waters in areas with and without sea ice and are expected to be widespread throughout the Arctic Ocean (Coad and Reist 2018). Based on Loewen et al. (2020a), most records for Arctic cod within the AOI are for Evans Strait though Loewen et al. (2020b) also noted the occurrence of Arctic cod around small islands in Fisher Strait. Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking, was recorded in the priority area from 2012-2019. This accounted for 32% of AIS data throughout the entire AOI though is still a low absolute number (adapted from Maerospace 2020). Icebreaker tracks follow a consistent route through the priority area (Figure 5-12). Underwater noise would propagate beyond the vessel track. Considering the above, overlap is expected to occur at few restricted locations and a score of 1.
Depth	3	Arctic cod are widespread across the circumpolar Arctic, but they occur at different depths throughout the water column based on factors such as life history stage (e.g., Geoffroy et al. 2016), seasonal diet (e.g., Majewski et al. 2016), and light regime (e.g., Benoit et al. 2010). Eggs and larvae concentrate under the sea ice. Sounds produced by icebreaker activity are loud (Roth et al. 2013) and are expected to reach depth occupied by Arctic cod throughout the Fisher and Evans Straits priority area, resulting in a score of 3.
Sensitivity	1 (binned)	Sensitivity = (Acute change + Chronic Change) x Recovery Factors = (1 + 1) x 1.9 = 3.8
Acute Change	1	There are currently no known studies on the direct effects of icebreaker noise on Arctic cod; however, there are studies demonstrating their known sensitivity to noise from vessels underway. This information was used for this assessment since the effects would be expected to be similar or stronger due to icebreakers generally producing louder and more variable noise. As with all members of the Gadidae family, Arctic cod have swim bladders positioned close to their ears, their hearing is more sensitive to a wider range of frequencies compared to other fish species that do not have a swim bladder; however, they are less sensitive than fish that have swim bladders linked to their ears (Popper and Hawkins 2019). Gadids are sensitive to sound pressure as well as particle motion, giving them the ability to locate sound sources and discriminate sounds against background noise (Popper and Hawkins 2019). Gadids can hear frequencies up to 500 Hz (Popper and Hawkins 2019), which overlap with the low frequencies typically emitted by large vessels; they also produce sounds (Riera et al. 2018). Fish use sound to communicate, avoid predators, select habitat, and for mating behaviour (see Popper and Hawkins 2019). Noise can impact fish behaviour, physiology, and hearing (Popper and Hawkins 2019), and can mask natural sounds and decrease communication space (e.g., Stanley et al. 2017; Pine et al. 2018). Several studies have shown

Risk Factor	Score	Rationale
		changes in behaviour and physiology of gadids exposed to noise, including reduced spawning success (e.g., Nedelec et al. 2015; Sierra-Flores et al. 2015; Ivanova et al. 2020), but most studies have been conducted on fish in laboratories, not free-ranging animals in natural conditions. Although there could be limited behavioural impacts (e.g., avoidance) by Arctic cod, due to the overall low level of icebreaking traffic in the Fisher and Evans Straits priority area and the fact that sounds emitted by icebreakers are transitory, it is expected that there would be an insignificant or undetectable change to Arctic cod mortality rates against background variability and limited behavioural impacts resulting in a score of 1.
Chronic Change	1	Noise can impact fish behaviour, physiology, and hearing (Popper and Hawkins 2019), and can mask natural sounds and decrease communication space (e.g., Stanley et al. 2017; Pine et al. 2018). There is a risk that icebreaking sounds could mask Gadid sounds and interfere with the production and detection of important acoustic signals or cause behavioural changes such as avoidance, possibly leading to further impacts such as interruptions to spawning behaviour. If critical life functions, such as spawning success (e.g., de Jong et al. 2018, 2020) are compromised by sound or avoidance responses result from sound, fitness consequences could result (Slabbekoorn et al. 2010). Although long-term effects associated with reduced spawning success and prolonged avoidance are possible, this has not been shown to occur in naturally occurring environments where fish are able to swim away from loud source sources. Based on the low density of icebreaking traffic and transitory nature of the sounds, no detectable changes to overall fitness or population dynamics are expected. Thus, a score of 1 was assigned.
Recovery Factors	1.9	Recovery factors = mean of the factors listed below. <u>Fecundity</u>: 2 (Spawn only once in their lifetime with a relatively low number of eggs; between 9,000 to 21,000 eggs are produced, with an average of 11,900 per female [Cohen et al. 1990]). <u>Early life stage mortality</u>: 3 (R-selected species with high mortality [Coad and Reist 2018]). <u>Recruitment pattern</u>: 2 (Increased recruitment expected with climate change [LeBlanc et al. 2019]). <u>Natural mortality rate</u>: 1 (Mortality is high [Coad and Reist 2018]). <u>Age at maturity</u>: 2 (2-3 years for males and 3-4 years for females [Coad and Reist 2018]). <u>Life stages affected</u>: 3 (All life stages could potentially occur in the area). <u>Population connectivity</u>: 1 (Arctic cod range widely throughout the Arctic). <u>Population status</u>: 1 (IUCN classification is *least concern* [Fernandes et al. 2015], but population trend is unknown. Abundant in Arctic marine waters [Coad and Reist 2018]).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 1 x 1 = Negligible
Likelihood	3	An interaction has the potential to occur when an icebreaker is actively icebreaking in close enough proximity to cause a disturbance to the animal. Arctic cod are sensitive to noise as it can impact their behaviour, physiology, and hearing (Popper and Hawkins 2019), and can mask natural sounds and decrease communication space (e.g., Stanley et al. 2017; Pine et al. 2018). Depending on the behavioural state of the animal and the distance to the icebreaker, an interaction may occur in some but not all circumstances.
Overall Risk	Low Risk	No additional management measures need to be considered at this time.
Uncertainty		

Risk Factor	Score	Rationale
Exposure	4	How noise would affect individuals and populations over different spatial scales is uncertain. General patterns of icebreaking are known in the AOI, though additional investigation is needed to determine the fine-scale patterns by vessel trip. General information exists regarding the distribution of Arctic cod, as well as some information specific to the priority area, though it is limited. Uncertainty is high.
Sensitivity	4	The impacts of anthropogenic noise, such as icebreaking, on fish (including Arctic cod) are not well understood, in particular how particle motion rather than sound pressure, may affect their behaviour and physiology (Popper and Hawkins 2018). Thus, how potential impacts may affect individuals and populations over different spatial and temporal scales is uncertain. In addition, most studies on fish hearing and sound production have focused on laboratory experiments, and results may differ if experiments were conducted in natural settings (Popper and Hawkins 2019). Thus, the uncertainty is high.
Likelihood	4	Research is needed on the response of Arctic cod to icebreaking. However, the responses of other gadids to noise disturbance from vessels has been studied in other areas. Thus, the uncertainty is high.

Risk Statement: If an interaction occurs involving ringed seals and noise disturbance due to icebreaking the consequence could result in a negative impact on the ringed seal population in the Fishers and Evans Straits priority area.

Table 5-24. Ringed Seal – Icebreaking (Fisher and Evans Straits) – Noise Disturbance.

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 6 = 6 (raw score)
Intensity	1	Currently, active icebreaking is rare in the AOI and only occurs in the shoulder seasons (DFO 2024). Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was recorded in the priority area approximately every other year from 2012-2019 (adapted from Maerospace 2020). Therefore, an intensity score of 1 was assigned. This assessment considers noise produced by active icebreaking, including noise produced by vessels during regular operation (i.e., from engines, propellers, and wave action) and the hull colliding with ice. Noise disturbance from vessels underway (including icebreakers that are not actively icebreaking) and vessels at rest is considered in Sections 5.1.1 and 5.3.1, respectively.
Temporal	1	Ringed seals are expected to occur in the priority area year-round (Idlout 2020; Loewen et al. 2020b). Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was recorded in the priority area approximately every two years from 2012-2019. The majority of overlap occurred during June (82% of total AIS data) with the remainder spread among July, August, and November (adapted from Maerospace 2020). Therefore, there is very little overlap between when active icebreaking may occur and ringed seals may be present, resulting in a score of 1.
Spatial	6	Spatial = Areal x Depth = 2 x 3 = 6
Areal	2	Ringed seals are expected to be widely distributed throughout the priority area (but during the ice-covered season more prevalent in areas of fast-ice with water depths >3 m). Overlap between icebreaker AIS data and sea ice cover, as a

Risk Factor	Score	Rationale
		proxy for active icebreaking taking place, was recorded in the priority area from 2012-2019. This accounted for 32% of AIS data throughout the entire AOI though is still a low absolute number (adapted from Maerospace 2020). Icebreaker tracks follow a consistent route through the priority area (Figure 5-12). Underwater sound would propagate beyond the vessel track. Therefore, icebreaking activity could overlap with a small proportion of ringed seal distribution within the priority area, resulting in a score of 2.
Depth	3	The maximum dive depth for ringed seals is >500 m (Ogloff et al. 2021). Depending on where icebreaker transits occur in the priority area, ringed seals may be found throughout the water column. Sound levels from icebreaking are loud (Roth et al. 2013) and would be detectable and may elicit a response at all water depths where ringed seals occur in the priority area, including when hauled out, resulting in a score of 3.
Sensitivity	1 (binned)	Sensitivity= (Acute change + Chronic Change) × Recovery Factors = (1+1) × 2.3 = 4.6
Acute Change	1	Ringed seals can hear vessel and icebreaking noise. Sounds produced during icebreaking are not predicted to cause hearing damage or mortality. Given that sounds important to ringed seals are predominantly at much higher frequencies than shipping and icebreaking noise, and given the intermittent nature of icebreaking sounds, it is unlikely that masking would affect ringed seals. Based on available scientific literature investigating ringed seals on ice adjacent to an icebreaker, some ringed seals are likely to avoid the icebreaker when it is breaking ice by ~1 km whereas seals may occur within a few tens of metres of an icebreaker when the vessels are not actively breaking ice (Brueggeman et al. 1992; Brewer et al. 1993). Given that ringed seals are expected to be widely dispersed in the priority area and that displacement is considered temporary and in a small area (see Alliston 1980, 1981; Lomac-MacNair et al. 2019), the impact of icebreaking noise on ringed seal behaviour at the population level is considered insignificant or undetectable, resulting in a score of 1.
Chronic Change	1	Ringed seals are known to exhibit localized and temporary avoidance of icebreakers and other vessels and there is some evidence that demonstrates at least temporary separation of Caspian seal mothers from pups during icebreaking (Wilson et al. 2017). However, icebreaking density is currently low, the ringed seal population is expected to be widespread and icebreaking is not anticipated to occur during spring when ringed seals give birth, nurse pups, and undergo mating and are presumed to be more sensitive (pups are weaned before ice break-up; Chambellant 2010). Chronic change in overall fitness of ringed seals in the priority area is ranked as insignificant or undetectable, resulting in a score of 1
Recovery Factors:	2.3	Recovery factors = mean of the factors listed below. Fecundity: 3 (Females typically give birth to one pup a year). Early life stage mortality: 2 (Mortality could increase in the future as climate change affects the amount and suitability of ice required for important life functions [pupping, nursing; Reeves et al. 1992]). Recruitment pattern: 2 (Recruitment is variable depending on prevailing environmental conditions [Ferguson et al. 2005; Stirling 2005; Chambellant et al. 2010]). Natural mortality rate: 3 (Mortality rates have been reported low in adult ringed seals with survivorship of 0.89 for age 6+ seals. Survivorship of age 0+ seals is reported to be much lower [0.59] [Smith 1975; Reimer et al. 2019]). Age at maturity: 3 (Best estimate of the population-wide average age at maturity is 4-7 years old [in most areas; can range from 3-9; see COSEWIC 2019]).

Risk Factor	Score	Rationale
		Life stages affected: 3 (All stages). Population connectivity: 1 (Ringed seals in the Canadian Arctic are known to move extensively to different arctic regions, regularly making annual journeys that are 1,000s of kilometers). Population status: 1 (Ringed seals are considered *special concern* by COSEWIC [2019] and are not listed under SARA. The COSEWIC [2019] report does not offer insight into population trend. Ringed seals are listed as *threatened* in the USA [related to potential habitat loss], *least concern* in Greenland, no listing in Russia, and *least concern* by IUCN).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 2 × 1 =Negligible
Likelihood	3	An interaction has the potential to occur when an icebreaker is actively icebreaking in close enough proximity to cause a disturbance to the animal. Ringed seals may be sensitive to noise and this stressor has elicited varying responses. Depending on the behavioural state of the animal and the distance to the vessel, an interaction may occur in some but not all circumstances. Thus, a score of 3 was assigned.
Overall Risk	Low Risk	No additional management measures need to be considered at this time.
Uncertainty		
Exposure	4	General patterns of icebreaking are known in the AOI, though additional investigation is needed to determine the fine-scale patterns by vessel trip. Some information exists on the general distribution of ringed seals, including in the priority area. Uncertainty is high.
Sensitivity	4	Certain aspects of ringed seals biology and their response to icebreakers have been reported in other areas of the arctic, which provides adequate information for assessing likely behavioural response. However, since assumptions were based primarily on ringed seal literature from other areas and there is limited scientific information available on the topic, the uncertainty is high.
Likelihood	4	Ringed seal responses to icebreakers have been reported in other areas of the arctic, which provides some information for assessing likely behavioural response. Additional investigation is needed for the AOI. Uncertainty is high.

Risk Statement: If an interaction occurs involving bearded seals and noise disturbance due to icebreaking the consequence could result in a negative impact on the bearded seal population in the Fishers and Evans Straits priority area.

Table 5-25. Bearded Seal – Icebreaking (Fisher and Evans Straits) – Noise Disturbance.

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 6 = 6 (raw score)
Intensity	1	Currently, active icebreaking is rare in the AOI and only occurs in the shoulder seasons (DFO 2024). Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was recorded in the priority area approximately every other year from 2012-2019 (adapted from Maerospace 2020). Therefore, an intensity score of 1 was assigned. This assessment considers noise produced by active icebreaking, including noise produced by vessels during regular operation (i.e., from engines, propellers, and wave action) and the hull colliding with ice. Noise disturbance

Risk Factor	Score	Rationale
		from vessels underway (including icebreakers that are not actively icebreaking) and vessels at rest is considered in Sections 5.1.1 and 5.3.1, respectively.
Temporal	1	Bearded seals are expected to occur in the priority area year-round (Idlout 2020; Loewen et al. 2020b). Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was recorded in the priority area approximately every two years from 2012-2019. The majority of overlap occurred during June (82% of total AIS data) with the remainder spread among July, August, and November (adapted from Maerospace 2020). Therefore, there is very little overlap between when active icebreaking may occur and bearded seals may be present, resulting in a score of 1.
Spatial	6	Spatial = Areal x Depth = 2 x 3 = 6
Areal	2	Bearded seals are expected to be widely distributed (in low densities) throughout the priority area given that water depths are generally <100 m (Loewen et al. 2020b). Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was recorded in the priority area from 2012-2019. This accounted for 32% of AIS data throughout the entire AOI though is still a low absolute number (adapted from Maerospace 2020). Icebreaker tracks follow a consistent route through the priority area (Figure 5-12). Underwater sound would propagate beyond the vessel track. Therefore, icebreaking activity could overlap with a small proportion of bearded seal distribution within the priority area, resulting in a score of 2.
Depth	3	Foraging bearded seals typically dive to depths of <100 m, up to about 500 m (NOAA 2022a). Depending on where icebreaker transits occur in the priority area, bearded seals may be found throughout the water column. Sound levels from icebreaking are loud (Roth et al. 2013) and would be detectable and may elicit a response at all water depths where bearded seals occur in the priority area, including when hauled out, resulting in a score of 3.
Sensitivity	1 (binned)	Sensitivity = (Acute change + Chronic Change) × Recovery Factors = (1+1) × 2.4 = 4.8
Acute Change	1	Bearded seals can hear vessel and icebreaking noise (Sills et al. 2020). Sounds produced during icebreaking are not predicted to cause hearing damage or mortality. The potential for masking during icebreaking is somewhat reduced given that the dominant frequencies in bearded seal calls are predominantly at higher frequencies than the dominant frequencies of shipping noise. Bearded seals on pack ice approached by an icebreaker typically dove into the water within ~0.9 km of the vessel but tended to be less responsive when the same ship was underway in open water (Brueggeman et al. 1992). Very similar findings were reported by Lomac-MacNair et al. (2019) off NW Greenland; bearded seals dove into the water when an icebreaker approached within 600 m with no observed dives at distances >800 m. During a seismic monitoring program off NE Greenland in which the seismic vessel was escorted by an icebreaker, three bearded seals were observed on ice floes at 300 m, 368 m, and 400 m from an active airgun array; these seals did not show any overt reaction to the icebreaking vessel or airgun arrays other than looking toward the vessel (T. Lang, pers. comm., 2011). Similarly, two bearded seals observed on ice floes as close as 400 m and 500 m to the seismic vessel during periods when the airgun array was inactive did not exhibit an overt reaction to the vessels; the only noticeable change in behaviour was the seals looked toward the vessel. Given that bearded seals are expected to occur in low densities in the priority area and in close proximity to areas of open water and that displacement is

Risk Factor	Score	Rationale
		considered temporary and likely to occur in a small area (e.g., Lomac-MacNair et al. 2019), the impact of icebreaking noise on bearded seal behaviour is considered insignificant or undetectable. Thus, a score of 1 was assigned.
Chronic Change	1	Bearded seals are known to exhibit localized and temporary avoidance of icebreakers and other vessels and there is some evidence that demonstrates at least temporary separation of Caspian seal mothers from pups during icebreaking (Wilson et al. 2017). However, icebreaking density is currently low, the bearded seal population is expected to occur at low density, and icebreaking is not anticipated to occur during spring when ringed seals give birth, nurse pups, and undergo mating and are presumed to be more sensitive (Cameron et al. 2010). Chronic change in overall fitness of ringed seals in the priority area is ranked as insignificant or undetectable, resulting in a score of 1.
Recovery Factors:	2.4	Recovery factors = mean of the factors listed below. Fecundity: 3 (Females typically give birth to one pup a year). Early life stage mortality: 2 (Mortality could increase in the future as climate change affects the amount and suitability of ice required for important life functions [pupping, nursing; Reeves et al. 1992]). Recruitment pattern: Unknown; excluded from analysis. Natural mortality rate: Unknown; excluded from analysis. Age at maturity: 3 (In general, bearded seals attain sexual maturity at 5-6 years old for females and 6-7 for males [Cameron et al. 2010; Kovacs 2016]; however, some females in the Arctic have been found to attain sexual maturity between 3-7 years of age [Andersen et al. 1999]). Life stages affected: 3 (All stages may be affected). Population connectivity: Unknown; excluded from analysis (It is unknown if bearded seals in the AOI remain there year-round or undertake seasonal movements in and out of the region). Population status: 1 (Bearded seals are considered *data deficient* by COSEWIC [2021] and are not listed under SARA. Bearded seals are listed as *threatened* in the USA [related to potential habitat loss], *not threatened* in Greenland, and *least concern* by IUCN).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 2 × 1 =Negligible
Likelihood	3	An interaction has the potential to occur when an icebreaker is actively icebreaking in close enough proximity to cause a disturbance to the animal. Bearded seals may be sensitive to noise and this stressor has elicited varying responses. Depending on the behavioural state of the animal and the distance to the vessel, an interaction may occur in some but not all circumstances.
Overall Risk	Low Risk	No additional management measures need to be considered at this time.
Uncertainty		
Exposure	4	General patterns of icebreaking are known in the AOI, though additional investigation is needed to determine the fine-scale patterns by vessel trip. Some information exists on the general distribution of bearded seals, though it is limited in the priority area. Uncertainty is high.
Sensitivity	4	Certain aspects of bearded seals biology and their response to icebreakers have been reported in other areas of the arctic, which provides some information for assessing likely behavioural response. However, since assumptions were based primarily on bearded seal literature from other areas and there is limited scientific information available on the topic, the uncertainty is high.

Risk Factor	Score	Rationale
Likelihood	4	Bearded seal responses to icebreakers have been reported in other areas of the arctic, which provides some information for assessing likely behavioural response. Additional investigation is needed for the AOI. Uncertainty is high.

Risk Statement: If an interaction occurs involving walruses and noise disturbance due to ice breaking the consequence could result in a negative impact on the walrus population in the Fisher and Evans Straits priority area.

Table 5-26. Walrus – Icebreaking (Fisher and Evans Straits) – Noise Disturbance.

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 6 = 6 (raw score)
Intensity	1	Currently, active icebreaking is rare in the AOI and only occurs in the shoulder seasons (DFO 2024). Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was recorded in the priority area approximately every other year from 2012-2019 (adapted from Maerospace 2020). Therefore, an intensity score of 1 was assigned. This assessment considers noise produced by active icebreaking, including noise produced by vessels during regular operation (i.e., from engines, propellers, and wave action) and the hull colliding with ice. Noise disturbance from vessels underway (including icebreakers that are not actively icebreaking) and vessels at rest is considered in Sections 5.1.1 and 5.3.1, respectively.
Temporal	1	Based on scientific studies and current Inuit Qaujimajatuqangit, walruses occur in the Fisher and Evans Straits priority area year-round (Idlout 2020; Loewen et al. 2020b). Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was recorded in the priority area approximately every two years from 2012-2019. The majority of overlap occurred during June (82% of total AIS data) with the remainder spread among July, August, and November (adapted from Maerospace 2020). Therefore, there is very little overlap between when active icebreaking may occur and walruses may be present, resulting in a score of 1.
Spatial	6	Spatial = Areal x Depth = 2 x 3 = 6
Areal	2	Walruses are relatively sedentary in summer (Stewart 2008), tending to remain in areas where their food is most abundant and in water less than 80 m deep (Fay 1982; Reeves et al. 2002; Dehn et al. 2007; Lowry 2016a; COSEWIC 2017). The priority area provides walrus foraging habitat, calving areas, and key terrestrial haul-out sites (on Walrus, Bencas, and Coats Islands). During winter, walruses occur off the floe edge along the south and east coasts of Southampton Island and in late spring and summer, walruses use the floating pack ice of Evans Strait (Loewen et al. 2020b). Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was recorded in the priority area from 2012-2019. This accounted for 32% of AIS data throughout the entire AOI though is still a low absolute number (adapted from Maerospace 2020). Icebreaker tracks follow a consistent route through the priority area (Figure 5-12). Underwater sound would propagate beyond the vessel track. Therefore, icebreaking activity could overlap with a small proportion of walrus distribution within the priority area, resulting in a score of 2.

Risk Factor	Score	Rationale
Depth	3	Walrus typically feed in waters <80 m deep but sometimes feed in waters up to 200 m (Fay 1982, Outridge et al. 2003; COSEWIC 2017). Sounds produced by icebreakers are loud (Roth et al. 2013) and would be detectable and may elicit a response at all water depths where walruses occur in the priority area, including when hauled out, resulting in a score of 3.
Sensitivity	2 (binned)	Sensitivity = (Acute change + Chronic Change) × Recovery Factors = (2+1) × 2.1 = 6.3
Acute Change	2	Important walrus haul-out sites, calving, and foraging habitat occur in the Fisher and Evans Straits priority area. Walruses at haul-out sites or on sea ice often react to disturbance such as loud sounds or a visual stimulus from a vessel by entering the water (Salter 1979; Brueggeman 1993). Young animals can be injured or killed during these evacuations (Fischbach et al. 2009). Walruses may also change course of direction or speed underwater within 500 m of an icebreaker vessel (DFO 2019a). Walruses have also been documented abandoning haul-out sites after a disturbance for a short period of time (3-4 days; Mansfield and St. Aubin 1991). Thus, changes to the health or survival of individual walruses are plausible and behavioural impacts are expected if they are exposed to sounds produced by a moving vessel, resulting in a score of 2.
Chronic Change	1	Disturbance may cause indirect impacts including interruption of foraging and social interactions (e.g., interference of mother-offspring communication or insufficient nursing of calves) and increased stress and energy expenditure (Born et al. 1995). Additionally, walruses may abandon haul-out sites after repeated exposure and may shift distribution away from preferred feeding areas (Johnson et al. 1989; Born et al. 1995), which would result in a loss of important habitat and a change in geographic range. However, since the current density of icebreaking traffic is low, it is unlikely that detectable change to overall fitness compared to background variability will occur, resulting in a score of 1. To note regarding habituation: Stewart et al. (2012) generally found that evidence of walrus habituation to noise disturbance from vessels and aircraft has not been sufficiently supported. Additionally, observations for walrus haul-out disturbance behaviour from one area may not be transferable to another. For example, since walruses in Canada are hunted, they tend to be more sensitive to human presence compared to other areas where they are not (Higdon et al. 2022). Øren et al. (2018) looked at the effects of tourist visitations on haul-out dynamics and site use by walruses in Svalbard, Norway and found that tourists on land and boats near the haul-out sites did not disturb walrus haul-out behaviour significantly at any of the sites, with a single exception. This perhaps suggests that habituation occurred; however, it has been suggested that this is due to the fact that walruses are not hunted in this area (Higdon et al. 2022). At Round Island, Alaska, long-term datasets have suggested that Pacific walruses have not habituated to disturbance from both boats and aircraft as reactions have remained similar over a 20+ year monitoring period (DFO 2019a; Higdon et al. 2022). Habituation may therefore not occur consistently among Pacific and Atlantic walruses, populations, or individuals. Since there is potential for walruses to experience chronic stress whether they were to habituate or not in response to ship noise (Stewart et al. 2012) and since walruses in the Southampton Island AOI may respond differently to sound given that they are hunted for subsistence, the possibility of habituation was not incorporated into the risk score calculations.
Recovery Factors:	2.1	Recovery factors = mean of the factors listed below.

Risk Factor	Score	Rationale
		Fecundity: 3 (Adult female walrus have 1 calf every 3 years [Garlich-Miller and Stewart 1999]). Early life stage mortality: 1 (The data are sparse but the population structure and relatively high proportion of juveniles in the population suggests low mortality in all juvenile stages [Fay et al. 1997]). Recruitment pattern: 1 (Although annual recruitment is low by some standards, recruitment seems to be consistent among years and because walrus are long lived [40 years; Kovacs and Lydersen 2006], a single female produces a lot of young over her lifetime]). Natural mortality rate: 3 (The data are sparse but the population structure and relatively high proportion of juveniles in the population suggests low mortality in all life stages [Fay et al. 1997]). Age at maturity: 3 (Average age at sexual maturity of females is 7 years [Garlich-Miller and Stewart 1999]). Life stages affected: 3 (All walruses may be affected). Population connectivity: 2 (Studies suggest that there is some interchange among Canadian Arctic walrus populations [Stewart 2008; Charette et al. 2020; Loewen et al. 2020b]). Population status: 1 (COSEWIC [2017] lists walruses as *special concern* due to threats associated with global warming. The Hudson Bay-Davis Strait stock has increased from a minimum of 3,900 in 1986 to approximately 7,000 and the authors suggest that walruses remain abundant in the Southampton Island area [Hammill et al. 2016a]).
Consequence	2 (binned)	Consequence = Exposure x Sensitivity = 2 × 2 = Low
Likelihood	4	An interaction has the potential to occur when an icebreaker is actively ice breaking in close enough proximity to a walrus. Walruses have shown measurable responses to this stressor. Though dependent on the behavioural state of the animal and the distance to the vessel, an interaction is likely to occur.
Overall Risk	Moderate Risk	Additional management measures should be considered, such as limiting ice breaking activities during important times of the year for walruses and having minimum setback distances from hauled out walruses (on ice) in the Fisher and Evans Straits priority area.
Uncertainty		
Exposure	4	General patterns of icebreaking are known in the AOI, though additional investigation is needed to determine the fine-scale patterns by vessel trip. Information exists on the known haul-out sites and distribution of walruses in the priority area. Uncertainty is high.
Sensitivity	4	Certain aspects of walrus biology and their response to anthropogenic noise have been reported in other areas of the Arctic, which provides some information for assessing likely behavioural response, although there is little information particularly related to icebreakers. Since there has been little to no observations of walruses in water, and since assumptions were based primarily on walrus literature from other areas, the uncertainty is high.
Likelihood	4	Walrus responses to icebreakers have been reported in other areas of the arctic, which provides some information for assessing likely behavioural response. Additional investigation is needed for the AOI. Uncertainty is high.

Risk Statement: If an interaction occurs involving narwhals and noise disturbance due to icebreaking the consequence could result in a negative impact on the narwhal population in the Repulse Bay and Frozen Strait priority area.

Table 5-27. Narwhal – Icebreaking (Repulse Bay and Frozen Strait) – Noise Disturbance.

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 6 = 6 (raw score)
Intensity	1	Currently, active icebreaking is rare in the AOI and only occurs in the shoulder seasons (DFO 2024). Indeed, overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was only recorded for one trip—in September 2015—in the priority area from 2012-2019 (adapted from Maerospace 2020). Therefore, an intensity score of 1 was assigned. This assessment considers noise produced by active icebreaking, including noise produced by vessels during regular operation (i.e., from engines, propellers, and wave action) and the hull colliding with ice. Noise disturbance from vessels underway (including icebreakers that are not actively icebreaking) and vessels at rest is considered in Sections 5.1.1 and 5.3.1, respectively.
Temporal	1	Narwhals migrate into Repulse Bay in June and July and out in August and September through Frozen Strait (Westdal et al. 2010). Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was only recorded for one trip—in September 2015—in the priority area from 2012-2019 (adapted from Maerospace 2020). Therefore, there is very little overlap between when active icebreaking may occur and narwhals may be present, resulting in a score of 1.
Spatial	6	Spatial = Areal x Depth = 2 x 3 = 6
Areal	2	Narwhal preferred habitats are leads in landfast or pack ice and are seldom found in areas of fast-ice (Koski and Davis 1994; Kovacs et al. 2011). Narwhals migrate through Frozen Strait en route to Repulse Bay during spring/early summer break-up and en route to Hudson Strait prior to freeze-up in the fall. Sea ice in Frozen Strait is some of the first to be reduced in the area with much melt occurring by late June/early July. Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was only recorded for one trip—in September 2015—in the priority area from 2012-2019 (adapted from Maerospace 2020). It is assumed that icebreaker navigation would follow a consistent route through the priority area. Noise disturbance extends beyond the immediate vessel track (Finley et al. 1990; Heide-Jørgensen et al. 2021), with Finley et al. (1990) demonstrating that narwhals exhibit avoidance behaviour at distances of 35 to 50 km when exposed to vessel noise from active icebreaking. Considering the above, the area of overlap would be in a small proportion of the narwhal range in the priority area, resulting in a score of 2.
Depth	3	Sounds produced by icebreakers are loud (Roth et al. 2013) and would be detectable and may elicit a response at all water depths where narwhals might be feeding, which typically is <500 m (Heide-Jørgensen and Dietz 1995; Laidre et al. 2003). This results in a score of 3.
Sensitivity	3 (binned)	Sensitivity= (Acute change + Chronic Change) × Recovery Factors = (2+1) × 2.5 = 7.5

Risk Factor	Score	Rationale
Acute Change	2	Direct mortality to narwhals would not be expected to occur because of exposure to sounds produced by an icebreaking vessel. A recent study found that when captured and released, narwhals experience extreme cardiovascular stress. (Williams et al. 2017). This might also be experienced when subjected to loud noise or other anthropogenic activities. Narwhals are known to exhibit a strong behavioural response to icebreaking activity but have been documented to return to areas of icebreaking (LGL Ltd. and Greeneridge 1986; Finley et al. 1990). Finley et al. (1990) found that narwhals exhibited avoidance behaviour at distances of 35 to 50 km when exposed to vessel noise from active icebreaking. Heide-Jørgensen et al. (2021) also demonstrated behavioural disturbances, recording avoidance reactions and changes in swimming speed to vessel noise at distances of at least 10 km; maximum detection or reaction ranges could not be determined due to the fjord system where the study took place. The authors also suggested a lack of acute physiological or physical impacts when exposed to an air gun, which produces sounds louder than those produced by a transiting vessel alone. Monitoring results related to shipping for Baffinland's iron ore mine documented short-term avoidance behaviour of narwhal from vessels, though it is suggested that impacts would be negligible at a distance beyond several kilometers as at this distance the noise would be inaudible to narwhal (Golder 2021; Sweeney et al. 2022). Re-examination of these results highlighted possible impacts to feeding behaviour, indicated by decreased buzzing activity and a lack of deep (>350 m) dives (NAMMCO 2022a). The energetic costs of avoidance behaviour from anthropogenic disturbance, including vessel noise, is suggested to be higher during important feeding times, with lost foraging opportunity demonstrating a larger impact than increased locomotion costs associated with avoidance (NAMMCO 2022a). This report also highlighted that disturbance from icebreaking can cause impacts at a greater distance than transiting vessels (up to 35 km vs. 25 km, respectively) and suggested a buffer of 35 km between icebreaking activities and important habitat. Considering the information included above, moderate behavioural impacts to icebreaking noise are expected and a score of 2 was assigned.
Chronic Change	1	Narwhals rely on acoustic communication for critical life functions (Shapiro 2006) and are known to react to underwater vessel noise produced multiple kilometers away by altering swim speed, direction, and behaviour (Finley et al. 1990; Heide-Jørgensen et al. 2021; NAMMCO 2022a). Though research on chronic effects of vessel noise on narwhals is limited (Erbe et al. 2019; Halliday et al. 2022), an increase in consistent vessel traffic has been suggested as the cause of a decrease in narwhal numbers in Eclipse Sound, Nunavut (NAMMCO 2022a; QIA 2022) also reflected in external comments provided in response to Baffinland's summary report on marine mammal monitoring studies (Appendix F, Golder 2021). This assertion is refuted by Baffinland's monitoring summary report which suggests climate change as a possible explanation for changes in population distribution (Golder 2021). Heide-Jørgensen et al. (2015, 2021) note that as narwhals have defined migratory routes and high site fidelity, they are vulnerable to displacement. The energetic costs of avoidance behaviour from anthropogenic disturbance, including vessel noise, is suggested to be higher during important feeding times, with lost foraging opportunity demonstrating a larger impact than increased locomotion costs associated with avoidance (NAMMCO 2022a), suggesting possible impacts to body condition from repeated disturbances. It is plausible that given their apparent sensitivity to disturbance from vessel noise narwhal may experience chronic impacts such as displacement or decreased foraging in certain contexts, however, given the low density of icebreaking present in the priority area chronic change was scored as 1.

Risk Factor	Score	Rationale
Recovery Factors:	2.5	Recovery factors = mean of the factors listed below. Fecundity: 3 (Adult female narwhals have a calf about every 3 years [Garde et al. 2015]). Early life stage mortality: 2 (Few data on first year mortality of narwhal calves are available. Koski and Davis [1994] estimated that 17% of calves died when between 1 and 13 months of age; this is lower than for many other marine mammal species]). Recruitment pattern: 2 (Although annual recruitment is low by some standards, recruitment seems to be consistent among years and because narwhals are long lived [80 years; Garde et al. 2015], a single female can produce a lot of young over her lifetime]). Natural mortality rate: 3 (The data are sparse but the stable population size with the removals by subsistence hunters suggests low mortality in all life stages). Age at maturity: 3 (Age at sexual maturity of females is 6-9 years and older for males [Garde et al. 2015]). Life stages affected: 3 (All life stages except for newborn calves are likely to be affected. An adult female accompanied by a yearling was seen in the AOI [Carlyle et al. 2021]). Population connectivity: 3 (Studies suggest that there is limited interchange among Canadian Arctic narwhal populations [Westdal et al. 2010; Heide-Jørgensen et al. 2013a; Doniol-Valcroze et al. 2020]). Population status: 1 (IUCN classifies narwhals as *least concern* [Lowry et al. 2017]. The last COSEWIC assessment is outdated [from 2004]. Narwhal populations are considered stable [Furgal and Laing 2012; Lowry et al. 2017]).
Consequence	3 (binned)	Consequence = Exposure x Sensitivity = 3 × 3 = Moderate
Likelihood	4	An interaction has the potential to occur when an icebreaker is actively ice breaking in close enough proximity to a narwhal. Narwhals are sensitive to noise and have demonstrated measurable responses to this stressor. Though dependent on the behavioural state of the animal and the distance to the vessel, an interaction is likely to occur.
Overall Risk	Moderately -High Risk	Additional management measures should be considered, such as limiting icebreaking activities during important times of the year for narwhals in the Repulse Bay/Frozen Strait priority area.
Uncertainty		
Exposure	4	General patterns of icebreaking are known in the AOI, though additional investigation is needed to determine the fine-scale patterns by vessel trip. Information exists on the timing and migratory routes of narwhals in this area. Uncertainty is high.
Sensitivity	4	Certain aspects of narwhal biology and their response to icebreakers have been reported in other areas of the arctic, which provides some information for assessing likely behavioural response. However, since assumptions were based primarily on narwhal literature from other areas and there is limited scientific information available on the topic, the uncertainty is high.
Likelihood	4	Narwhal responses to icebreakers have been reported in other areas of the arctic, which provides some information for assessing likely behavioural response. Additional investigation is needed for the AOI. Uncertainty is high.

Risk Statement: If an interaction occurs involving belugas and noise disturbance due to icebreaking the consequence could result in a negative impact on the beluga population in the East Bay priority area.

Table 5-28. Beluga – Icebreaking (East Bay) – Noise Disturbance.

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 6 = 6 (raw score)
Intensity	1	Currently, active icebreaking is rare in the AOI and only occurs in the shoulder seasons (DFO 2024). Indeed, overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was not recorded in the priority area from 2012-2019 (adapted from Maerospace 2020). Therefore, an intensity score of 1 was assigned. This assessment considers noise produced by active icebreaking, including noise produced by vessels during regular operation (i.e., from engines, propellers, and wave action) and the hull colliding with ice. Noise disturbance from vessels underway (including icebreakers that are not actively icebreaking) and vessels at rest is considered in Sections 5.1.1 and 5.3.1, respectively.
Temporal	1	Belugas are expected to migrate into the AOI and presumably the East Bay priority area in May and June and occur in the priority area during summer, with migration out of the priority area beginning in early to late September (Loewen et al. 2020b). Ice break-up in the priority area begins in April or May, but pack ice is blown in and out of East Bay through July (Mallory et al. 2019). Freeze-up begins in mid-October with the formation of landfast ice. Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was not recorded in the priority area from 2012-2019 (adapted from Maerospace 2020). Consequently, there is very little overlap between when icebreaking occurs in the East Bay priority area and when belugas may be present, for a score of 1.
Spatial	6	Spatial = Areal x Depth = 2 x 3 = 6
Areal	2	Belugas migrate into the priority area in spring/early summer, congregate in the shallow waters of East Bay during summer, and migrate out of East Bay by end of September. Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was not recorded in the priority area from 2012-2019 (adapted from Maerospace 2020) and vessel tracks, regardless of vessel type, are generally towards the northern extent of the priority area (see Figure 5-1 and Figure 5-12). However, the area affected by this stressor extends beyond the track of the vessel, as belugas have demonstrated strong avoidance reactions when icebreakers were 35-50 km away (Finley et al. 1990). Therefore, a small proportion of beluga habitat in the East Bay priority area could overlap with the occurrence of an icebreaker, for a score of 2.
Depth	3	Beluga regularly forage at depths of 100s of metres (Martin et al. 1998; Watt et al. 2016), with some dives to depths greater than 800 m (Heide-Jørgensen et al. 1998; Richard et al. 2001). Icebreaking produces loud noises (Roth et al. 2013) and sounds produced by icebreaker cavitation may elicit a response at all depths used by belugas for feeding, resulting in a score of 3.
Sensitivity	3 (binned)	Sensitivity = (Acute change + Chronic Change) × Recovery Factors = (2+1) × 2.4 = 7.2

Risk Factor	Score	Rationale
Acute Change	2	The most comprehensive study of beluga responses to icebreaking ships was undertaken during June in each of 1982, 1983, and 1984 in Lancaster Sound (LGL Ltd. And Greeneridge 1986; Finley et al. 1990). In each study year, the icebreaking ore carrier *MV Arctic* (20,000 DWT) was accompanied by icebreakers, the *CCGS John A. MacDonald* (1982, 1983) or the *CCGS Louis St. Laurent* (1984), as it moved through Lancaster Sound en route to Admiralty Inlet. Belugas at fast-ice edges waiting to continue their migration to summering areas responded to approaching vessels by fleeing at speeds of up to 20 km/h from distances of 20-80 km, abandoning normal group structure, and modifying vocal behaviour and/or emitting alarm calls. Strong avoidance reactions occurred when ships were 35-50 km away (Finley et al. 1990). At those distances, received sound levels were barely above typical levels of natural background noise. In 1982, after the *MV Arctic* had travelled 48 km into the fast-ice from the ice edge and 43 hours had passed, the belugas returned and resumed apparently normal activities along the ice edge, although the ship was still audible to them. However, in 1983, beluga distribution along the ice edge and offshore appeared to return to normal only >60 hours after the ships had passed and were >45-50 km into the ice (Finley et al. 1990). Similar displacement observations were reported during a later study by Cosens and Dueck (1988). Noise disturbance from icebreaking would not be expected to result in direct mortality of belugas in the East Bay priority area. If icebreaking occurs during spring or fall migration, there could be moderate to severe, albeit temporary, behavioural impacts. This results in a score of 2.
Chronic Change	1	Belugas are known to exhibit a strong behavioural response to icebreaking activity but have been documented to return to areas of icebreaking (LGL Ltd. And Greeneridge 1986; Finley et al. 1990). There is little documentation on the chronic effects that vessel-related and icebreaking noise has on belugas, though it is reasonable to assume that changes in distribution could occur with repeated exposures over time in some circumstances. However, given the current low density of icebreaking in the priority area chronic change was scored as 1.
Recovery Factors:	2.4	Recovery factors = mean of the factors listed below. Fecundity: 3 (Adult female belugas have 1 calf every 3 years [Sergeant 1973; Matthews and Ferguson 2015]). Early life stage mortality: Unknown; excluded from analyses (There are no data on mortality rates in juvenile belugas). Recruitment pattern: 2 (Although annual recruitment is low by some standards, belugas live to be about 70 years old assuming a single growth layer is formed in their teeth in a year [Waugh et al. 2018: Vos et al. 2020]. The maximum longevity may be 100 years [Harwood 2002]. Because of their longevity, a single female could produce a lot of young over her lifetime even if they become reproductively senescent at 35-40 years old, as suggested by Hobbs et al. [2015] and Ellis et al. [2018]). Natural mortality rate: 3 (The natural mortality rate of belugas must be low if they live to ~70 years old. Ice entrapments of belugas are known to recur in the Canadian High Arctic and in northern Foxe Basin [Smith and Sjare 1990]. Polar bears and Inuit hunters take advantage of these incidents to harvest belugas. The proportion of mortality in these situations that is attributable to predation is not well documented and remains debatable [Kilabuk 1998]. Age at maturity: 3 (Average age at sexual maturity of female beluga is 6-14 years [COSEWIC 2020]).

Risk Factor	Score	Rationale
		Life stages affected: 3 (It is likely that all life stages of belugas will be affected). Population connectivity: 2 (The Western Hudson Bay population that occurs in the AOI overlaps with the Eastern Hudson Bay and Ungava Bay beluga populations in Hudson Strait during winter.) Population status: 1 (IUCN classifies the beluga whale as *near threatened*. COSEWIC [2020] lists the Western Hudson Bay population that occurs in the AOI as *least concern*]).
Consequence	3 (binned)	Consequence = Exposure x Sensitivity = 2 × 3 = Moderate
Likelihood	4	An interaction has the potential to occur when an icebreaker is actively ice breaking in close enough proximity to a beluga. Belugas are sensitive to noise and have demonstrated measurable responses to this stressor. Though dependent on the behavioural state of the animal and the distance to the vessel, an interaction is likely to occur.
Overall Risk	Moderately -High Risk	Additional management measures should be considered, such as limiting icebreaking activity in the East Bay priority area during important times of year, including when beluga are migrating into the area.
Uncertainty		
Exposure	4	General patterns of icebreaking are known in the AOI, though additional investigation is needed to determine the fine-scale patterns by vessel trip. Information exists on the occupancy of belugas in this area. Uncertainty is high.
Sensitivity	4	Certain aspects of beluga biology and their response to icebreakers have been reported in other areas of the arctic, which provides some information for assessing likely behavioural response. However, since assumptions were based primarily on literature from other areas and there is limited scientific information available on the topic, the uncertainty is high.
Likelihood	4	Beluga responses to icebreakers have been reported in other areas of the arctic, which provides some information for assessing likely behavioural response. Additional investigation is needed for the AOI. Uncertainty is high.

Risk Statement: If an interaction occurs involving bowhead whales and noise disturbance due to icebreaking the consequence could result in a negative impact on the bowhead population in the Fisher and Evans Straits priority area.

Table 5-29. Bowhead Whale – Icebreaking (Fisher and Evans Straits) – Noise Disturbance.

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 6 = 6 (raw score)
Intensity	1	Currently, active icebreaking is rare in the AOI and only occurs in the shoulder seasons (DFO 2024). Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was recorded in the priority area approximately every other year from 2012-2019 (adapted from Maerospace 2020). Therefore, an intensity score of 1 was assigned. This assessment considers noise produced by active icebreaking, including noise produced by vessels during regular operation (i.e., from engines, propellers, and wave action) and the hull colliding with ice. Noise disturbance

Risk Factor	Score	Rationale
		from vessels underway (including icebreakers that are not actively icebreaking) and vessels at rest is considered in Sections 5.1.1 and 5.3.1, respectively.
Temporal	1	Based on scientific studies and current Inuit Qaujimajatuqangit, bowheads occur in the Fisher and Evans Straits priority area from April to November but primarily occur there during summer (Idlout 2020; Loewen et al. 2020b). Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was recorded in the priority area approximately every other year from 2012-2019. The majority of overlap occurred during June (82% of total AIS data) with the remainder spread among July, August, and November (adapted from Maerospace 2020). Thus, there would be little temporal overlap, resulting in a score of 1.
Spatial	6	Spatial = Areal x Depth = 2 x 3 = 6
Areal	2	Bowhead whales can occur throughout the priority area. Nearshore areas around SE SI in Evans Strait are known calving and nursery grounds (DFO 2020; Idlout 2020; Loewen et al. 2020b). Overlap between icebreaker AIS data and sea ice cover, as an indication of active icebreaking taking place, was recorded in the priority area from 2012-2019. This accounted for 32% of AIS data throughout the entire AOI though is still a low absolute number (adapted from Maerospace 2020). Icebreaker tracks follow a consistent route through the priority area (Figure 5-12). Underwater sound would propagate beyond the vessel track. Koski and Johnson (1987) reported that bowheads 1-2 km from a (non-icebreaking) supply vessel swam rapidly away to distances of 4-6 km from the vessel track. If the vessel travels slowly, bowhead whales often are more tolerant, and may show little or no reaction, even when the vessel is within several hundred metres (e.g., Richardson and Finley 1989; Wartzok et al. 1989). This is especially so when the vessel is not directed toward the whale and when there are no sudden changes in direction or engine speed (Wartzok et al. 1989; Richardson et al. 1995a). Bowhead whales engaged in social interactions or mating may be less responsive than other bowheads (Wartzok et al. 1989). Considering the above, icebreaking activity could overlap with a small proportion of bowhead distribution within the priority area, resulting in a score of 2.
Depth	3	Bowheads in the eastern Canadian Arctic routinely conduct foraging dives >100 m with maximum depths exceeding 650 m (Fortune et al. 2020). Sounds produced by icebreakers are loud (Roth et al. 2013) and would be detectable and may elicit a response at all water depths where bowheads occur in the priority area. This results in a score of 3.
Sensitivity	3 (binned)	Sensitivity= (Acute change + Chronic Change) × Recovery Factors = (2+1) × 2.3 = 6.9
Acute Change	2	The Fisher and Evans Straits priority area is considered important summering habitat for bowheads where they forage; the nearshore waters of SE Southampton Island in Evans Strait are calving/nursing grounds (see Figure 26 in DFO 2020). Bowhead whales are expected to avoid vessels that are underway, including icebreakers. In 1991 and 1994 in the Alaskan Beaufort Sea, Richardson et al. (1995b) recorded reactions of bowhead whales to playbacks of underwater propeller cavitation noise from the icebreaker *Robert Lemeur* operating in heavy ice. Bowheads migrating in a nearshore lead appeared to tolerate exposure to projected icebreaker sounds at received levels up to 20 dB or more above ambient noise levels. However, some appeared to divert their paths to remain farther away from the projected sounds, particularly when

Risk Factor	Score	Rationale
		exposed to levels >20 dB above ambient or received levels of 100 dB re 1 µPa (Richardson et al. 1995b). Turning frequency, surface duration, number of blows per surfacing, and two multivariate indices of behaviour were significantly correlated with the signal-to-noise ratio; behaviours were significantly different when the ratio exceeded 20 dB or, for turning frequency, exceeded 10 dB. The authors suggested that bowheads may commonly react to icebreakers at distances up to 10-50 km but noted that reactions were also dependent on several variables not controlled in the study. During the fall of 1992, migrating bowhead whales apparently avoided (by at least 25 km) a drill site that was supported near-daily by intensive icebreaking activity in the Alaskan Beaufort Sea (Brewer et al. 1993). However, in the fall of another year they also avoided a nearby drill site that had little supporting icebreaking (LGL Ltd. And Greeneridge 1987). Thus, it is uncertain from these studies what the relative roles of icebreaking, ice concentration, and drilling noise were in determining bowhead whale responses. Considering the information above, acute change was scored as 2.
Chronic Change	1	Bowheads may respond to underwater icebreaker noise produced multiple kilometers away by altering swim speed, direction, and behaviour (see *Acute Change*, above). Research on chronic effects of vessel noise on marine mammals is very limited (Erbe et al. 2019; Halliday et al. 2022). Though it is plausible that given known bowhead disturbance response from icebreakers bowheads may experience chronic impacts in certain contexts, given the low level of active icebreaking in the priority area chronic change was scored as a 1.
Recovery Factors:	2.3	Recovery factors = mean of the factors listed below. Fecundity: 3 (Adult female bowheads have 1 calf every 3-4 years [Miller et al. 1992; Koski et al. 1993; Tarpley et al. 2016, 2021]). Early life stage mortality: Unknown; excluded from consideration (There are no data on mortality rates in juvenile bowheads). Recruitment pattern: 1 (Although annual recruitment is low by some standards, bowhead pregnancies seem to be determined by the health of the prospective mother to maximize survival of the calf [W. Koski, pers. comm., 2022]. Because bowheads live to be about 200 years old, a single female produces a lot of young over her lifetime [Tarpley et al. 2016, 2021]). Natural mortality rate: 3 (The mortality rate of adult bowheads is extremely low, possibly the lowest of any animal. Survival has been estimated as 0.984 [0.948-1.00; Zeh et al. 2002] to 0.996 [0.976-1.00, Givens et al. 2018]). Age at maturity: 3 (Average age at sexual maturity of female bowheads is about 25 years [Koski et al. 1993; George et al. 1999] and appears to have declined in recent years [Tarpley et al. 2021]). Life stages affected: 3 (All life stages likely to be affected). Population connectivity: 2 (The EC-WG population of bowhead whales occur in the AOI. Until recently, the geographic distributions of the EC-WG and BCB bowhead populations were significantly different so that there was little or no overlap between the populations [Zeh et al. 1995]. With the opening of the NW passage resulting from climate change, interchange between these two populations is possible, as suggested by a sighting of two satellite tagged bowheads from the two populations in the same general area in the High Arctic [Heide-Jørgensen et al. 2011]). Population status: 1 (IUCN classifies the EC-WG bowhead whale population as *least concern* [Cooke and Reeves 2018]. COSEWIC (2009) classifies them as *threatened*; however, that status report is out of date and is currently being reviewed. Recent surveys indicate that the population has increased since

Risk Factor	Score	Rationale
		commercial overharvesting ended in the early 1900s. They may have increased to the point where this population has reached the carrying capacity of their habitat, based on sightings of skinny whales and apparent natural mortality in Cumberland Sound [Young et al. 2019] and recent cases of apparent natural mortality in other areas [DFO unpublished data]).
Consequence	3 (binned)	Consequence = Exposure x Sensitivity = 2 × 3 = Moderate
Likelihood	4	An interaction has the potential to occur when an icebreaker is actively ice breaking in close enough proximity to a bowhead. Bowheads have demonstrated measurable responses to this stressor. Though dependent on the behavioural state of the animal and the distance to the vessel, an interaction is likely to occur.
Overall Risk	Moderately -High Risk	Additional management measures should be considered, such as limiting icebreaking activities during important times of the year for bowheads in the Fisher and Evans Straits priority area.
Uncertainty		
Exposure	4	General patterns of icebreaking are known in the AOI, though additional investigation is needed to determine the fine-scale patterns by vessel trip. Information exists on the occupancy of bowheads in this area. Uncertainty is high.
Sensitivity	4	Certain aspects of bowhead biology and their response to icebreakers have been reported in other areas of the arctic, which provides some information for assessing likely behavioural response. However, since assumptions were based primarily on literature from other areas and there is limited scientific information available on the topic, the uncertainty is high.
Likelihood	4	Bowhead responses to icebreakers have been reported in other areas of the arctic, which provides some information for assessing likely behavioural response. Additional investigation is needed for the AOI. Uncertainty is high.

Risk Statement: If an interaction occurs involving polar bears and noise disturbance due to icebreaking the consequences could result in a negative impact on the polar bear population in the Fisher and Evans Straits priority area.

Table 5-30. Polar Bear – Icebreaking (Fisher and Evans Straits) – Noise Disturbance.

Risk Factor	Score	Rationale
Exposure	1 (binned)	Exposure = Intensity x Temporal x Spatial (Depth × Areal) = 1 x 1 x 1 = 1 (raw score)
Intensity	1	Currently, active icebreaking is rare in the AOI and only occurs in the shoulder seasons (DFO 2024). Indeed, overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was recorded in the priority area approximately every other year from 2012-2019 (adapted from Maerospace 2020). Therefore, an intensity score of 1 was assigned. This assessment considers noise produced by active icebreaking, including noise produced by vessels during regular operation (i.e., from engines, propellers, and wave action) and the hull colliding with ice. Noise disturbance from vessels underway (including icebreakers that are not actively icebreaking) and vessels at rest is considered in Sections 5.1.1 and 5.3.1, respectively.
Temporal	1	Polar bears are expected to occur in the Fisher and Evans Strait priority area year-round, although the bears move onto land when the ice breaks up in the

Risk Factor	Score	Rationale
		summer. Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was recorded in the priority area approximately every two years from 2012-2019. The majority of overlap occurred during June (82% of total AIS data) with the remainder spread among July, August, and November (adapted from Maerospace 2020). Thus, there would be little temporal overlap, resulting in a score of 1.
Spatial	4	Spatial = Areal x Depth = 2 x 2 = 4
Areal	1	Polar bears are known to occur in the Fisher and Evans Straits priority area (Peacock et al. 2009; Sahanatien et al. 2015). They are frequently found in areas of landfast ice or consolidated pack ice (Stirling et al. 1993) where most icebreaking occurs; during the summer, they are often found on land (Durner et al. 2009). Polar bears are likely widely distributed and occur at low densities of 1-11 bears/1,000 km^2 throughout their range (Taylor and Lee 1995; Evans et al. 2003; Aars et al. 2009). Overlap between icebreaker AIS data and sea ice cover, as an indication of active icebreaking taking place, was recorded in the priority area from 2012-2019. This accounted for 32% of AIS data throughout the entire AOI though is still a low absolute number (adapted from Maerospace 2020). Icebreaker tracks follow a consistent route through the priority area (Figure 5-12). Considering the above, overlap is expected to occur at few restricted locations and a score of 1.
Depth	1	Icebreaking is a loud activity (Roth et al. 2013) and sounds produced by icebreaker cavitation would be elevated throughout the water column. However, polar bears spend most of their time on the ice surface and not in the water (or in the water but not with their head/ears submerged). Polar bears on the ice would be exposed to in-air sounds (and the visual cues of the icebreaker). Therefore, this stressor would occur over a small portion of the depth range and a score of 1 was assigned.
Sensitivity	1 (binned)	Sensitivity= (Acute change + Chronic Change) × Recovery Factors = (1+1) × 2.4 = 4.8
Acute Change	1	Non-denning polar bears typically do not exhibit negative responses to anthropogenic noise, although they will occasionally investigate sources of noise (Stirling 1988b; Shideler 1993). However, Smultea al. (2016) reported brief behavioral responses (increased vigilance) by polar bears to icebreaking activities; infrequent and brief responses are likely to have low energetic costs for individuals. Thus, there would be insignificant or undetectable changes to polar bear mortality rates against background variability and/or limited behavioural impacts, resulting in a score of 1.
Chronic Change	1	Polar bears are unlikely to change their geographic distribution due to icebreaking noise and there is not expected to be any long-term harm to them from this stressor. Insignificant or undetectable change to overall fitness compared with background variability is expected, with no impact on population dynamics. Thus, a score of 1 was assigned.
Recovery Factors:	2.4	Recovery factors = mean of the factors listed below. Fecundity: 3 (Adult female polar bears have an average of 2 [range 1-3] cubs every 3 years [Stirling 1988a]). Early life stage mortality: 2 (Polar bear cubs experience moderate mortality [43%; Taylor et al. 2005; Aars et al. 2006]). Recruitment pattern: 2 (Polar bears have a moderate level of recruitment due to long life span and have an average of two cubs at regular intervals). Natural mortality rate: 3 (Tagging studies from other areas suggest a high level of survival for adult bears [e.g., adult female survival ranges: 0.91-1.00; see

Risk Factor	Score	Rationale
		Regehr et al. 2015 for review]. Most populations are stable or increasing and have sustainable levels of harvest allowed under regulated quotas). Age at maturity: 3 (Earliest age at sexual maturity of females is 4 years with most females not reproducing until 5 or 6 years of age [Ramsay and Stirling 1988; Stirling 1988a]. Males reach sexual maturity as early as 2 years of age [Richardson et al. 2020]). Life stages affected: 3 (All life stages may be affected). Population connectivity: 2 (Studies suggest that there is little interchange between Canadian Arctic polar bear populations, but there is some exchange within the AOI, including the Fisher and Evans Straits priority area [Paetkau et al. 1999; Sahanatien et al. 2015]). Population status: 1 (IUCN classifies polar bears as *vulnerable* [Wiig et al. 2015], and COSEWIC [2018] classifies them as *special concern* due to threats by global warming. However, aerial surveys of the Foxe Basin area suggest that populations are stable [Stapleton et al. 2016] despite a well-documented decline in cub production and survival in western Hudson Bay [Stirling et al. 1999]).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 2 × 1 = Negligible
Likelihood	3	Smultea et al. (2016) have reported brief behavioural responses of polar bears to icebreaking activities. Thus, the interaction may occur in some but not all circumstances.
Overall Risk	Low Risk	No additional management measures need to be considered at this time.
Uncertainty		
Exposure	4	General patterns of icebreaking are known in the AOI, though additional investigation is needed to determine the fine-scale patterns by vessel trip. Information exists on the occupancy of polar bears in this area. Uncertainty is high.
Sensitivity	2	Although there is very little information from the Fisher and Evans Straits priority area, there is substantial information from anthropogenic activities in other parts of the Arctic. It is very unlikely that polar bears in the Fisher and Evans Straits would react differently. Uncertainty is low.
Likelihood	2	As noted above, polar bears are unlikely to behave differently in the Fisher and Evans Straits than in other parts of the Arctic where there is substantial information. Uncertainty is low.

5.2.2 Vessel Strikes

The evidence of existing and potential PoE related to vessel strikes from icebreaking activities are similar to those from vessel traffic in general, with the exception of ringed and bearded seals. These seals give birth and nurse their pups on the ice surface, which increases the risk of a ship strike, particularly during the period when pups have not adapted to spending time in the water (see Davis and Malme 1997; Yurkowski et al. 2019). Assessments for ringed and bearded seals in the Fisher and Evans Straits priority area were undertaken (Table 5-31). The risk of ship strikes for bowhead whales and common eider were assessed for Vessels Underway in Section 5.1.2.

Table 5-31. Icebreaking – Vessel Strikes: ESC Subcomponents and Priority Areas Assessed.

ESC Subcomponent	Priority Area	Assessed by Proxy
Ringed seal	Fisher and Evans Straits	
Bearded seal	Fisher and Evans Straits	

Risk Statement: If an interaction occurs involving ringed seals and icebreaking resulting in a collision the consequence could result in a negative impact on ringed seals in the Fisher and Evans Straits priority area.

Table 5-32. Ringed Seal – Icebreaking (Fisher and Evans Straits) – Vessel Strikes.

Risk Factor	Score	Rationale
Exposure	1 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 2 = 2 (raw score)
Intensity	1	Currently, active icebreaking is rare in the AOI and only occurs in the shoulder seasons (DFO 2024). Indeed, overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was recorded in the priority area approximately every other year from 2012-2019 (adapted from Maerospace 2020). Therefore, an intensity score of 1 was assigned.
Temporal	1	Ringed seals are expected to occur in the priority area year-round (Idlout 2020; Loewen et al. 2020b). Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was recorded in the priority area approximately every two years from 2012-2019. The majority of overlap occurred during June (82% of total AIS data) with the remainder spread among July, August, and November (adapted from Maerospace 2020). Therefore, there is very little overlap between when active icebreaking may occur and ringed seals may be present, resulting in a score of 1.
Spatial	2	Spatial = Areal x Depth = 1 x 2 = 2
Areal	1	Ringed seals are expected to be widely distributed throughout the priority area (but during the ice-covered season more prevalent in areas of fast-ice with water depths >3 m). Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was recorded in the priority area from 2012-2019. This accounted for 32% of AIS data throughout the entire AOI though is still a low absolute number (adapted from Maerospace 2020). Icebreaker tracks follow a consistent route through the priority area (Figure 5-12). Vessel strikes would only occur directly along the vessel's path. Therefore, icebreaking activity is expected to be limited to a few restricted locations of ringed seal distribution within the priority area, resulting in a score of 1.
Depth	2	Potential icebreaker strikes of ringed seals would be limited to the upper portion of the water depth range where this species occurs. Ringed seals could also be struck when hauled out on the ice. A score of 2 was assigned to account for the stressor occurring over a combination of primary and secondary habitats.
Sensitivity	1 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (1 + 1) x 2.1 = 4.2
Acute Change	1	Although there are no specific studies on seal mortality from icebreaker and/or vessel strikes in open water, it is possible that ringed seals could be struck by icebreakers. In a detailed analysis of the potential effects of icebreaking ore carriers on ringed seals off the Labrador coast, Davis and Malme (1997) concluded that adult ringed seals have more than enough mobility under the ice to avoid the close approach of an icebreaker, and that it is unlikely that icebreaking vessels will strike adult seals and cause mortality. Ringed seal pups are vulnerable to strikes, particularly if a vessel passes through a birth lair, as very young pups might be killed by crushing or exposure to cold water. Based on a study of the movement and growth of nursing pups (Lydersen and Hammill 1993), it is expected that newborns are vulnerable to direct mortality from icebreaker traffic for the first three weeks of life (Davis and Malme 1997). Considering the

Risk Factor	Score	Rationale
		rare occurrence of active icebreaking in the priority area, the lack of susceptibility of adult seals, and the short time span in which pups are vulnerable, the impacts of icebreaker strikes on ringed seal mortality at the population level is considered insignificant or undetectable. Thus, a score of 1 was assigned.
Chronic Change	1	Considering the lack of expected mortality (see *Acute Change*, above) the chronic change in overall fitness of ringed seals in the priority area is ranked as insignificant or undetectable, resulting in a score of 1.
Recovery Factors	2.1	Recovery factors = mean of the factors listed below. Fecundity: 3 (Females typically give birth to one pup a year). Early life stage mortality: 2 (Mortality could increase in the future as climate change affects the amount and suitability of ice required for important life functions [pupping, nursing; Reeves et al. 1992]). Recruitment pattern: 2 (Recruitment is variable depending on prevailing environmental conditions [Ferguson et al. 2005; Stirling 2005; Chambellant et al. 2010]). Natural mortality rate: 3 (Mortality rates have been reported low in adult ringed seals with survivorship of 0.89 for age 6+ seals. Survivorship of age 0+ seals is reported to be much lower [0.59] [Smith 1975; Reimer et al. 2019]). Age at maturity: 3 (Best estimate of the population-wide average age at maturity is 4-7 years old [in most areas; can range from 3-9; see COSEWIC 2019]). Life stages affected: 2 (See above, only seal pups are expected to be affected by this stressor). Population connectivity: 1 (Ringed seals in the Canadian Arctic are known to move extensively to different arctic regions, regularly making annual journeys that are 1,000s of kilometers). Population status: 1 (Ringed seals are considered *special concern* by COSEWIC [2019] and are not listed under SARA. The COSEWIC [2019] report does not offer insight into population trend. Ringed seals are listed as *threatened* in the USA [related to potential habitat loss], *least concern* in Greenland, no listing in Russia, and *least concern* by IUCN).
Consequence	1	Consequence = Exposure x Sensitivity = 1 × 1 = Negligible
Likelihood	2	An interaction has the potential to occur when ringed seals and an icebreaker are present at the same time/space within the priority area and when ringed seals are most vulnerable to a ship strike (i.e., spring pupping/nursing period). Seal pups are more vulnerable to icebreaker strikes (see *Acute Change,* above); however, even ringed seals pups demonstrate advanced swimming ability early in life and the possibility of individuals being struck is low. Therefore, a score of 2 was assigned.
Overall Risk	Low Risk	No additional management actions need to be considered.
Uncertainty		
Exposure	4	General patterns of icebreaking are known in the AOI, though additional investigation is needed to determine the fine-scale patterns by vessel trip. Some information exists on the general distribution of ringed seals, including in the priority area. Uncertainty is high.
Sensitivity	4	Certain aspects of ringed seal biology have been reported in other areas of the arctic, with little investigation on their susceptibility to this stressor. Uncertainty is high.
Likelihood	4	Little investigation has occurred on the probability of ringed seals being struck by an icebreaker, and this occurred in other areas. Additional investigation is needed for the AOI. Uncertainty is high.

Risk Statement: If an interaction occurs involving bearded seals and icebreaking resulting in a collision the consequence could result in a negative impact on bearded seals in the Fisher and Evans Straits priority area.

Table 5-33. Bearded Seal – Icebreaking (Fisher and Evans Straits) – Vessel Strikes.

Risk Factor	Score	Rationale
Exposure	1 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 2 = 2 (raw score)
Intensity	1	Currently, active icebreaking is rare in the AOI and only occurs in the shoulder seasons (DFO 2024). Indeed, overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was recorded in the priority area approximately every other year from 2012-2019 (adapted from Maerospace 2020). Therefore, an intensity score of 1 was assigned.
Temporal	1	Bearded seals are expected to occur in the priority area year-round (Idlout 2020; Loewen et al. 2020b). Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was recorded in the priority area approximately every two years from 2012-2019. The majority of overlap occurred during June (82% of total AIS data) with the remainder spread among July, August, and November (adapted from Maerospace 2020). Therefore, there is very little overlap between when active icebreaking may occur and bearded seals may be present, resulting in a score of 1.
Spatial	2	Spatial = Areal x Depth = 1 x 2 = 2
Areal	1	Bearded seals are expected to be widely distributed throughout the priority area in areas that have ready access to open-water (Loewen et al. 2020b). Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was recorded in the priority area from 2012-2019. This accounted for 32% of AIS data throughout the entire AOI though is still a low absolute number (adapted from Maerospace 2020). Icebreaker tracks follow a consistent route through the priority area (Figure 5-12). Vessel strikes would only occur directly along the vessel's path. Therefore, icebreaking activity is expected to be limited to a few restricted locations of ringed seal distribution within the priority area, resulting in a score of 1.
Depth	2	Potential icebreaker strikes of bearded seals would be limited to the upper portion of the water depth range where this species occurs. Bearded seals could also be struck when hauled out on the ice. A score of 2 was assigned to account for the stressor occurring over a combination of primary and secondary habitats.
Sensitivity	1 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (1 + 1) x 2.2 = 4.4
Acute Change	1	Although there are no specific studies on seal mortality from icebreaking and/or vessel strikes in open water, it is possible that bearded seals could be struck by icebreaking ships in particular. Although bearded seals are capable of maintaining breathing holes in landfast ice, their preferred habitat is drifting ice floes or the edge of landfast ice, leads, and polynyas (Lydersen et al. 1994). These habitat preferences allow them to readily move away from disturbances. There is some concern that bearded seal pups may be at risk of mortality from vessel collisions. Based on a study conducted in Svalbard, Norway bearded seals give birth primarily in free-floating pack ice very close to the water's edge (Kovacs et al. 1996). This affords them quick access to the water in the event they have to escape from polar bears; bearded seal pups are born on the open ice without a

Risk Factor	Score	Rationale
		sheltering lair. Unlike ringed seal pups, bearded seal pups enter the water within hours of birth (approximately two hours in one instance; Kovacs et al. 1996). Nursing pups less than one week old spend about ~50 % of their time in the water, where they can dive as deep as 84 m (Lydersen et al. 1994). Within two months, bearded seal pups dive to depths >400 m (Gjertz et al. 2000). Lydersen et al. (1994) noted that the "development of swimming and diving skills at this early age may enhance their ability to avoid predation and permit the use of many different nursing platforms in their very unstable drifting ice habitat." It stands to reason that the same skills would help bearded seals to avoid icebreaking vessels. Given the expected lack of susceptibility of adult seals to this stressor and that bearded seal pups are adapted to enter the water shortly after birth, the impacts of vessel strikes on bearded seal mortality at the population level is considered insignificant or undetectable. Thus, a score of 1 was assigned.
Chronic Change	1	Considering the lack of expected mortality (see *Acute Change*, above) the chronic change in overall fitness of bearded seals in the priority area is ranked as insignificant or undetectable, resulting in a score of 1.
Recovery Factors	2.2	Recovery factors = mean of the factors listed below. Fecundity: 3 (Females typically give birth to one pup a year). Early life stage mortality: 2 (Mortality could increase in the future as climate change affects the amount and suitability of ice required for important life functions [pupping, nursing; Reeves et al. 1992]). Recruitment pattern: Unknown; excluded from analysis. Natural mortality rate: Unknown; excluded from analysis. Age at maturity: 3 (In general, bearded seals attain sexual maturity at 5-6 years old for females and 6-7 for males [Cameron et al. 2010; Kovacs 2016]; however, some females in the Arctic have been found to attain sexual maturity between 3-7 years of age [Andersen et al. 1999]). Life stages affected: 2 (See above, only seal pups are expected to be affected). Population connectivity: Unknown; excluded from analysis (It is unknown if bearded seals in the AOI remain there year-round or undertake seasonal movements in and out of the region). Population status: 1 (Bearded seals are considered *data deficient* by COSEWIC [2021] and are not listed under SARA. Bearded seals are listed as *threatened* in the USA [related to potential habitat loss], *not threatened* in Greenland, and *least concern* by IUCN).
Consequence	1	Consequence = Exposure x Sensitivity = 1 × 1 = Negligible
Likelihood	2	An interaction has the potential to occur when bearded seals and an icebreaker are present at the same time/space within the priority area and when bearded seals are most vulnerable to a ship strike (i.e., spring pupping/nursing period). Seal pups are more vulnerable to icebreaker strikes (see *Acute Change*, above); however, even pups demonstrate advanced swimming ability early in life and the possibility of individuals being struck is low. Therefore, a score of 2 was assigned.
Overall Risk	Low Risk	No additional management actions need to be considered.
Uncertainty		
Exposure	4	General patterns of icebreaking are known in the AOI, though additional investigation is needed to determine the fine-scale patterns by vessel trip. Some information exists on the general distribution of bearded seals, including in the priority area. Uncertainty is high.

Risk Factor	Score	Rationale
Sensitivity	4	Certain aspects of bearded seal biology have been reported in other areas of the arctic, with little investigation on their susceptibility to this stressor. Uncertainty is high.
Likelihood	4	Little investigation has occurred on the probability of bearded seals being struck by an icebreaker, and this occurred in other areas. Additional investigation is needed for the AOI. Uncertainty is high.

5.2.3 Habitat Alteration/Removal

Icebreaking alters the sea ice habitat along its route, forming artificial channels of broken ice and open water which can result in the temporary alteration and fragmentation of habitat. There is some potential that marine mammals (notably cetaceans) may become trapped in these open-water areas created by icebreaking. Narwhals and beluga whales were assessed since they may be susceptible (to varying degrees) to ice entrapments (Laidre and Heide-Jørgensen 2005; Heide-Jørgensen et al. 2013b; Halliday et al. 2020) (Table 5-34) and this type of event will be the focus of the tables for these subcomponents. Although there is record of a single individual bowhead whale entrapped in ice from the eastern Canadian Arctic (Heide-Jørgensen et al. 2002) the recorded frequency for this species is lower than that of belugas and narwhals, bowheads are larger and able to break through thicker sea ice (George et al. 1989), no records exist in the literature linking ice entrapments to icebreaking tracks, and such an event is not known in the AOI. Therefore, bowhead whales were not assessed. Ice-dependent marine mammals, such as seals and walruses, may be affected by altered ice habitat during spring and early-summer when they use the ice for pupping, nursing, and moulting (Huntington et al. 2015; Wilson et al. 2017; Yurkowski et al. 2019; Stewart et al. 2020). Effects of icebreaking disturbance on seabirds have been less studied but may include disruption of feeding behaviour or enhanced foraging opportunities from the creation of new ice edge habitat, depending on the duration of the opening, as well as the potential of getting trapped in re-freezing vessel tracks if the seabirds no longer have the required space needed (up to several metres, depending on species) to take off from the water. Hudson Bay eiders in the Belcher Islands (a unique subspecies of common eider that overwinters in the bay) routinely suffer winter mortality when leads close in or freeze-up (Nakashima 1990). It is possible that ship tracks could be used by seabirds with subsequent mortality either via freezing of open water or by being crushed by moving ice. As a result, although it is recognized that different seabird species utilize differing foraging strategies (e.g., divers versus pelagic foragers) and that strategies vary with dive depth capabilities and the availability of prey, these differences are not substantial enough to warrant separate assessments for different seabird species and, therefore, common eider were selected for assessment and serve as a proxy for other seabirds. Polynyas are consistent areas of open water surrounded by sea ice and are important habitats that support increased primary and benthic productivity and higher trophic level feeding (Loewen et al. 2020b). Polynya habitat was assessed as it contains features that may be susceptible to habitat alteration from icebreaking (i.e., sea ice). Icebreaking can also occur through sea ice that is not associated with a polynya and this interaction was assessed.

Table 5-34. Icebreaking – Habitat Alteration/Removal: ESC Subcomponents and Priority Areas Assessed.

ESC Subcomponent	Priority Area	Assessed by Proxy
Common eider	East Bay	
Other seabirds		Via common eider
Ringed seal	Fisher and Evans Straits	
Bearded seal	Fisher and Evans Straits	
Walrus	Fisher and Evans Straits	
Beluga	East Bay	

ESC Subcomponent	Priority Area	Assessed by Proxy
Narwhal	Repulse Bay/Frozen Strait	
Polynya habitat	Chesterfield Inlet/Narrows	
Sea ice	Roes Welcome Sound	

Risk Statement: If an interaction occurs involving common eiders and habitat alteration due to icebreaking the consequence could result in a negative impact on the common eider population in the East Bay priority area.

Table 5-35. Common eider – Icebreaking (East Bay) – Habitat Alteration/Removal.

Risk Factor	Score	Rationale
Exposure	1 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 2 = 2 (raw score)
Intensity	1	Currently, active icebreaking is rare in the AOI and only occurs in the shoulder seasons (DFO 2024). Indeed, overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was not recorded in the priority area from 2012-2019 (adapted from Maerospace 2020). Therefore, an intensity score of 1 was assigned.
Temporal	1	Common eiders are present in the East Bay priority area from mid-June to September (Abraham and Finney 1986). Adult males depart on their moult migration in July. Eggs hatch in July and the flightless females rear their precocial broods in the marine and intertidal waters of East Bay. Groups of females and young are present until late-September (Abraham and Finney 1986), primarily foraging on benthic invertebrates in waters <20 m deep (Goudie et al. 2020). Ice break-up in the priority area begins in April or May, but pack ice is blown in and out of East Bay through July (Mallory et al. 2019). Freeze-up begins in mid-October with the formation of landfast ice. Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was not recorded in the priority area from 2012-2019 (adapted from Maerospace 2020). In addition, the eiders depart when ice begins to form in the fall. Consequently, there is very little overlap between when icebreaking occurs in the East Bay priority area and when common eiders are present in marine waters, resulting in a score of 1.
Spatial	2	Spatial = Areal x Depth = 1 x 2 = 2
Areal	1	Eider females and broods are expected to be distributed in intertidal and marine waters, primarily <20 m deep, within the East Bay priority area. Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was not recorded in the priority area from 2012-2019 (adapted from Maerospace 2020) and vessel tracks, regardless of vessel type, are generally towards the northern extent of the priority area (see Figure 5-1 and Figure 5-12). Consequently, the area of overlap between eider broods and icebreaking vessels is expected to be limited to a few restricted locations within the common eider distribution in the priority area; resulting in a score of 1.
Depth	2	Common eider habitat includes the water's surface to a depth of typically <20 m. Although icebreaking occurs at the surface, it may uncover waters with suitable benthic eider prey at accessible depths. It would not affect flying eiders. Therefore, habitat alteration due to icebreaking covers a combination of primary and secondary eider habitat, resulting in a score of 2.
Sensitivity	2 (binned)	Sensitivity = (Acute change + Chronic Change) x Recovery Factors = (1 + 1) x 2.6 = 5.2

Risk Factor	Score	Rationale
Acute Change	1	Multiple outcomes are possible due to habitat alteration from icebreaking. Icebreaking could uncover benthic invertebrate food resources if it takes place in depths accessible to eiders, mildly increasing foraging opportunities. Hudson Bay eiders in the Belcher Islands (a unique subspecies of common eider that overwinters in the bay) routinely suffer winter mortality when leads close in or freeze-up (Nakashima 1990). However, though possible, the common eiders in the AOI are migratory and the proportion of the population that may suffer mortality in this way is expected to be small. As a result, this stressor would result in an insignificant or undetectable change to the common eider mortality rates against background variability, and a score of 1.
Chronic Change	1	A small proportion of common eiders could be affected by habitat alteration from icebreaking in the East Bay priority area. However, the low frequency of icebreaking in the priority area and migratory behaviour of the area's eiders would be unlikely to cause repeated effects or, therefore, chronic change in the common eider population. As a result, there would be an insignificant or undetectable change to overall fitness and no impact on population dynamics, resulting in a score of 1.
Recovery Factors	2.6	Recovery factors = mean of the factors listed below. Fecundity: 2 (Three to five eggs laid per year; nesting success 0-40% [Goudie et al. 2020]). Early life stage mortality**:** 3 (90-95% in first year [Goudie et al. 2020]). Recruitment pattern**:** 3 (Probability: 0.17-0.47 [Nicol-Harper et al. 2021]). Natural mortality rate**:** 3 (13% [Goudie et al. 2020]). Age at maturity**:** 2 (≥4 years [Goudie et al. 2020]). Life stages affected**:** 3 (All life stages could potentially occur in the East Bay priority area [Goudie et al. 2020]). Population connectivity**:** 3 (High degree of fine-scale spatial population genetic structuring [Talbot et al. 2015]). Population status**:** 2 (Common eider is listed as *near threatened* by IUCN [BirdLife International 2018a] but is not listed under SARA or COSEWIC. However, the population may be declining due to increased polar bear predation in the East Bay priority area [Loewen et al. 2020b]). Also, avian cholera has the potential to cause mass mortality and significantly impact the East Bay population [Descamps et al. 2012]).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 1 x 2 = Negligible
Likelihood	2	Though mortality is known in the unique subspecies of common eiders that occur year-round in southern Hudson Bay, the behavioural and migratory patterns of common eiders in the AOI decreases the probability of such an event occurring. Therefore, likelihood was assigned a score of 2.
Overall Risk	Low Risk	No additional management measures need to be considered at this time. However, icebreaking vessels should observe minimum set-back distances from at-sea concentrations of common eiders as prescribed by ECCC-CWS. A 15 km buffer around breeding colonies was recommended by Mallory and Fontaine (2004).
Uncertainty		
Exposure	4	There is a moderate amount of scientific information available regarding the abundance and distribution of common eiders in the East Bay priority area. General patterns of icebreaking are known in the AOI, though additional investigation is needed to determine the fine-scale patterns by vessel trip. Uncertainty is high.

Risk Factor	Score	Rationale
Sensitivity	5	There is no scientific information on the sensitivity of common eiders to habitat alteration due to icebreaking in the East Bay priority area, and little information overall, so uncertainty is very high
Likelihood	5	There is no scientific information on the likelihood of common eiders interacting with habitat alteration due to icebreaking in the East Bay priority area, and little information overall. Consequently, uncertainty is very high.

Risk Statement: If an interaction occurs involving ringed seals and habitat alteration/removal due to icebreaking the consequence could result in a negative impact on the ringed seal population in the Fisher and Evans Straits priority area.

Table 5-36. Ringed Seal – Icebreaking (Fisher and Evans Straits) – Habitat Alteration/Removal.

Risk Factor	Score	Rationale
Exposure	1 (binned)	Exposure = Intensity x Temporal x Spatial (Depth × Areal) = 1 x 1 x 3 = 3 (raw score)
Intensity	1	Currently, active icebreaking is very rare in the AOI and only occurs in the shoulder seasons (DFO 2024). Indeed, overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was recorded in the priority area approximately every other year from 2012-2019, mainly in June (adapted from Maerospace 2020). Therefore, an intensity score of 1 was assigned.
Temporal	1	Ringed seals are expected to occur in the priority area year-round (Idlout 2020; Loewen et al. 2020b), with pupping and rearing occurring in the spring (Lowry et al. 2016b). Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was recorded in the priority area approximately every other year from 2012-2019, mainly in June (adapted from Maerospace 2020). Thus, there would be very little temporal overlap resulting in a score of 1.
Spatial	3	Spatial = Areal x Depth = 1 x 3 = 3
Areal	1	Ringed seals are expected to be widely distributed throughout the priority area (but during the ice-covered season more prevalent in areas of fast-ice with water depths >3 m). Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was recorded in the priority area from 2012-2019. This accounted for 32% of AIS data throughout the entire AOI though is still a low absolute number (adapted from Maerospace 2020). Icebreaker tracks follow a consistent route through the priority area (Figure 5-12). Habitat alteration would only occur directly along the vessel's path. Therefore, icebreaking activity is expected to be limited to a few restricted locations of ringed seal distribution within the priority area, resulting in a score of 1.
Depth	3	Alteration of ice habitat from icebreaking would be restricted to the water surface/ice, therefore the physical disruption of ringed seal habitat would be limited to the upper portion of the water depth range where this species occurs. Since this upper portion is critical to ringed seal life-history (i.e., for breathing holes, lairs, and birthing lairs), the stressor would cover a large portion of ringed seal primary habitat, resulting in a score of 3.
Sensitivity	1 (binned)	Sensitivity= (Acute change + Chronic Change) x Recovery Factors = (1+1) x 2.3 = 4.6

Risk Factor	Score	Rationale
Acute Change	1	Sea ice is critical habitat for ringed seals as they use the platform for important life history events including moulting, breeding, birthing, and resting (Reeves 1998; Lowry 2016b). Based on available scientific literature ringed seals on ice adjacent to an icebreaker, some ringed seals may avoid the icebreaker when it is breaking ice by ~1 km whereas seals may occur within a few tens of metres of an icebreaker when the vessels are not actively breaking ice (Brueggeman et al. 1992; Brewer et al. 1993). There is little to no risk that seals will be trapped in channels of broken ice created by the icebreaker, as ringed seals maintain a series of breathing holes and are well-adapted to changing ice conditions. Some evidence indicates that ringed seals preferentially establish breathing holes in the tracks of icebreakers (Alliston 1980, 1981); however, their ability to maintain lairs may be negatively affected depending on the timing and frequency of icebreaking. Although the ability to maintain a lair may be impacted for a small number of individuals, given that ringed seals are widely distributed in the priority area and displacement is considered temporary and in a small area, the impact of physical disruption of ice on ringed seal habitat use at the population level is considered insignificant or undetectable, resulting in a score of 1.
Chronic Change	1	Although sea ice is critical habitat for ringed seals, using the platform for important life history events including moulting, breeding, birthing, and resting (Reeves 1998; Lowry 2016b), active icebreaking density is low (or does not occur) during spring in the area when ringed seals give birth, nurse pups, and undergo mating and are presumed to be most sensitive (pups are weaned before ice break-up; Chambellant 2010). Given the limited expected acute impacts (see *Acute Change*, above) chronic change in overall fitness of ringed seals in the priority area from this stressor is expected to be insignificant or undetectable, resulting in a score of 1.
Recovery Factors:	2.3	Recovery factors = mean of the factors listed below. Fecundity: 3 (Females typically give birth to one pup a year). Early life stage mortality: 2 (Mortality could increase in the future as climate change affects the amount and suitability of ice required for important life functions [pupping, nursing; Reeves et al. 1992]). Recruitment pattern: 2 (Recruitment is variable depending on prevailing environmental conditions [Ferguson et al. 2005; Stirling 2005; Chambellant et al. 2010]). Natural mortality rate: 3 (Mortality rates have been reported low in adult ringed seals with survivorship of 0.89 for age 6+ seals. Survivorship of age 0+ seals is reported to be much lower [0.59] [Smith 1975; Reimer et al. 2019]). Age at maturity: 3 (Best estimate of the population-wide average age at maturity is 4-7 years old [in most areas; can range from 3-9; see COSEWIC 2019]). Life stages affected: 3 (All stages). Population connectivity: 1 (Ringed seals in the Canadian Arctic are known to move extensively to different arctic regions, regularly making annual journeys that are 1,000s of kilometers). Population status: 1 (Ringed seals are considered *special concern* by COSEWIC [2019] and are not listed under SARA. The COSEWIC [2019] report does not offer insight into population trend. Ringed seals are listed as *threatened* in the USA [related to potential habitat loss], *least concern* in Greenland, no listing in Russia, and *least concern* by IUCN).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 2 × 1

Risk Factor	Score	Rationale
		= Negligible
Likelihood	4	Sea ice is critical habitat for ringed seals as they use the platform for important life history events including moulting, breeding, birthing, and resting (Reeves 1998; Lowry 2016b). Icebreaking alters sea ice habitat along its route, temporarily forming artificial channels of broken ice and open water. Therefore, ringed seal habitat alteration/removal has the potential to occur when active ringed seal habitat and the track of an icebreaker overlap. However, some evidence indicates that ringed seals preferentially establish breathing holes in the tracks of icebreakers (Alliston 1980, 1981). Considering this information, likelihood was scored as 4.
Overall Risk	Low Risk	No additional management actions need to be considered at this time.
Uncertainty		
Exposure	4	General patterns of icebreaking are known in the AOI, though additional investigation is needed to determine the fine-scale patterns by vessel trip. Some information exists on the general distribution of ringed seals, including in the priority area. Uncertainty is high.
Sensitivity	4	Certain aspects of ringed seals biology and their response to the physical disruption of ice by icebreakers have been reported in other areas of the arctic, which provides some information for assessing likely effects from habitat alteration.
Likelihood	4	Available information, not specific to the priority area or AOI, indicates that some ringed seals will exhibit a temporary behavioural response to icebreaking but that there is little to no risk of seals becoming trapped in the track of an icebreaker.

Risk Statement: If an interaction occurs involving bearded seals and habitat alteration/removal due to icebreaking the consequence could result in a negative impact on the bearded seal population in the Fisher and Evans Straits priority area.

Table 5-37. Bearded Seal – Icebreaking (Fisher and Evans Straits) – Habitat Alteration/Removal.

Risk Factor	Score	Rationale
Exposure	1 (binned)	Exposure = Intensity x Temporal x Spatial (Depth × Areal) = 1 x 1 x 3 = 3 (raw score)
Intensity	1	Currently, active icebreaking is rare in the AOI and only occurs in the shoulder seasons (DFO 2024). Indeed, overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was recorded in the priority area approximately every other year from 2012-2019, mainly in June (adapted from Maerospace 2020). Therefore, an intensity score of 1 was assigned.
Temporal	1	Bearded seals are expected to occur in the priority area year-round (Idlout 2020; Loewen et al. 2020b), with pupping and rearing occurring in the spring (Lowry et al. 2016b). Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was recorded in the priority area approximately every other year from 2012-2019, mainly in June (adapted from Maerospace 2020). Thus, there would be very little temporal overlap resulting in a score of 1.
Spatial	3	Spatial = Areal x Depth = 1 x 3 = 3
Areal	1	Bearded seals are expected to be widely distributed throughout the priority area in areas that have ready-access to open-water. Overlap between

Risk Factor	Score	Rationale
		icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was recorded in the priority area from 2012-2019. This accounted for 32% of AIS data throughout the entire AOI though is still a low absolute number (adapted from Maerospace 2020). Icebreaker tracks follow a consistent route through the priority area (Figure 5-12). Habitat alteration would only occur directly along the vessel's path. Therefore, icebreaking activity is expected to be limited to a few restricted locations of bearded seal distribution within the priority area, resulting in a score of 1.
Depth	3	Bearded seals are typically found in areas of open water/moving ice. Since the alteration of ice habitat from icebreaking would be restricted to the water surface/ice, the physical disruption of bearded seal habitat would be limited to the upper portion of the water depth range where this species occurs. However, since this upper portion of their depth range (i.e., sea ice) is important habitat for bearded seals, using the platform to rest, moult, and birth young (Kovacs et al. 1996), the stressor would cover a large portion of bearded seal primary habitat, resulting in a score of 3.
Sensitivity	1 (binned)	Sensitivity= (Acute change + Chronic Change) x Recovery Factors = (1+1) x 2.4 = 4.8
Acute Change	1	Sea ice is important habitat for bearded seals as they use the platform to rest, moult, and birth young (Kovacs et al. 1996). Based on available scientific literature bearded seals on ice adjacent to an icebreaker, some bearded seals may avoid the icebreaker when it is breaking ice by <1 km (Brueggeman et al. 1992; Lomac-MacNair et al. 2019). Bearded seals are typically located on ice adjacent to areas of open water. These habitat preferences allow them to readily move away from disturbances. There is little to no risk that bearded seals will be trapped in channels of broken ice created by the icebreaker. Unlike ringed seal pups, bearded seal pups enter the water within hours of birth (approximately two hours in one instance; Kovacs et al. 1996). Nursing pups less than one week old spend about ~50 % of their time in the water, where they can dive as deep as 84 m (Lydersen et al. 1994). Within two months, bearded seal pups dive to depths >400 m (Gjertz et al. 2000). Lydersen et al. (1994) noted that the "development of swimming and diving skills at this early age may enhance their ability to avoid predation and permit the use of many different nursing platforms in their very unstable drifting ice habitat." It stands to reason that the same skills would help bearded seals to avoid icebreaking vessels and adapt to altered habitat along an icebreaker track. Given limited expected behavioural impacts, the ability of bearded seals to readily exploit habitat preferences near open water to avoid disturbance, and the swimming capabilities of young pups, the impact of physical disruption (habitat alteration/removal) of at the population level is considered insignificant or undetectable, resulting in a score of 1.
Chronic Change	1	Although sea ice is important habitat for bearded seals, using the platform for moulting, birthing, and resting (Kovacs et al. 1996), active icebreaking density is low (or does not occur) during spring when bearded seals give birth, nurse pups, and undergo mating and are presumed to be most sensitive. Given the limited expected acute impacts (see *Acute Change*, above) chronic change in overall fitness of bearded seals in the priority area from this stressor is expected to be insignificant or undetectable, resulting in a score of 1.
Recovery Factors:	2.4	Recovery factors = mean of the factors listed below. <u>Fecundity</u>: 3 (Females typically give birth to one pup a year).

Risk Factor	Score	Rationale
		Early life stage mortality: 2 (Mortality could increase in the future as climate change affects the amount and suitability of ice required for important life functions [pupping, nursing; Reeves et al. 1992]). Recruitment pattern: Unknown; excluded from analysis. Natural mortality rate: Unknown; excluded from analysis. Age at maturity: 3 (In general, bearded seals attain sexual maturity at 5-6 years old for females and 6-7 for males [Cameron et al. 2010; Kovacs 2016]; however, some females in the Arctic have been found to attain sexual maturity between 3-7 years of age [Andersen et al. 1999]). Life stages affected: 3 (All stages may be affected). Population connectivity: Unknown; excluded from analysis (It is unknown if bearded seals in the AOI remain there year-round or undertake seasonal movements in and out of the region). Population status: 1 (Bearded seals are considered *data deficient* by COSEWIC [2021] and are not listed under SARA. Bearded seals are listed as *threatened* in the USA [related to potential habitat loss], *not threatened* in Greenland, and *least concern* by IUCN).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 1 × 1 = Negligible
Likelihood	4	Sea ice is important habitat for bearded seals as they use the platform to rest, moult, and birth young (Kovacs et al. 1996). Icebreaking alters sea ice habitat along its route, temporarily forming artificial channels of broken ice and open water. Therefore, bearded seal habitat alteration/removal has the potential to occur when active bearded seal habitat and the track of an icebreaker overlap. Considering this information, likelihood was scored as 4.
Overall Risk	Low Risk	No additional management actions need to be considered at this time.
Uncertainty		
Exposure	4	General patterns of icebreaking are known in the AOI, though additional investigation is needed to determine the fine-scale patterns by vessel trip. Some information exists on the general distribution of bearded seals, including in the priority area. Uncertainty is high.
Sensitivity	4	Certain aspects of bearded seal biology and their response to the physical disruption of ice by icebreakers have been reported in other areas of the arctic, which provides some information for assessing likely effects from habitat alteration.
Likelihood	4	Available information, not specific to the priority area or AOI, indicates that some bearded seals will exhibit a temporary behavioural response to icebreaking but that there is little to no risk of seals becoming trapped in the track of an icebreaker.

Risk Statement: If an interaction occurs involving walruses and habitat alteration/removal due to ice breaking the consequence could result in a negative impact on the walrus population in the Fisher and Evans Straits priority area.

Table 5-38. Walrus – Icebreaking (Fisher and Evans Straits) – Habitat Alteration/Removal.

Risk Factor	Score	Rationale
Exposure	1 (binned)	Exposure = Intensity x Temporal x Spatial (Depth × Areal) = 1 x 1 x 3 = 3 (raw score)

Risk Factor	Score	Rationale
Intensity	1	Currently, active icebreaking is very rare in the AOI and only occurs in the shoulder seasons (DFO 2024). Indeed, overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was recorded in the priority area approximately every other year from 2012-2019, mainly in June (adapted from Maerospace 2020). Therefore, an intensity score of 1 was assigned.
Temporal	1	Based on scientific studies and current Inuit Qaujimajatuqangit walruses occur in the Fisher and Evans Straits priority area year-round (Idlout 2020; Loewen et al. 2020b). Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was recorded in the priority area approximately every other year from 2012-2019, mainly in June (adapted from Maerospace 2020). Thus, there would be little temporal overlap resulting in a score of 1.
Spatial	3	Spatial = Areal x Depth = 1 x 3 = 3
Areal	1	Walruses are relatively sedentary in summer (Stewart 2008), tending to remain in areas where their food is most abundant and in water less than 80 m deep (Fay 1982; Reeves et al. 2002; Dehn et al. 2007; Lowry 2016a; COSEWIC 2017). The priority area provides walrus foraging habitat, calving areas, and key terrestrial haul-out sites (on Walrus, Bencas, and Coats Islands). During winter, walruses occur off the floe edge along the south and east coasts of Southampton Island and in late spring and summer, walruses use the floating pack ice of Evans Strait (Loewen et al. 2020b). Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was recorded in the priority area from 2012-2019. This accounted for 32% of AIS data throughout the entire AOI though is still a low absolute number (adapted from Maerospace 2020). Icebreaker tracks follow a consistent route through the priority area (Figure 5-12). Habitat alteration would only occur directly along the vessel's path. Therefore, icebreaking activity is expected to be limited to a few restricted locations of walrus distribution within the priority area, resulting in a score of 1.
Depth	3	Walruses haul-out on ice pans to rest and feed in water depths typically less than 80 m (Fay 1982; COSEWIC 2017). Alteration of ice habitat from icebreaking would be restricted to the water surface/ice, however, since this upper portion of their depth range (i.e., sea ice) is important habitat for walruses depth was scored as 3.
Sensitivity	1 (binned)	Sensitivity= (Acute change + Chronic Change) x Recovery Factors = (1+1) x 2.1 = 4.2
Acute Change	1	Important walrus haul-out sites, calving, and foraging habitat occur in the Fisher and Evans Straits priority area. Habitat alteration as a result of ice breaking is not anticipated to detrimentally change the behaviour or impact the health of individual walruses. Though it has been recorded that a walrus might be frightened and enter the water from an ice pan if the vessel closely approaches a pan where a walrus was resting (Salter 1979; Brueggeman 1993), in most cases alteration of ice habitat would be beneficial to walrus because it would make more habitat available since walrus cannot access feeding habitat under landfast ice, consolidated pack ice, or extensive ice pans. In rare cases, ice breaking might degrade resting habitat used by walrus to remain near feeding areas in a mostly open water situation. Thus, a score of 1 was assigned.
Chronic Change	1	The physical disruption of ice by an icebreaker is not expected to affect the overall fitness of walruses, particularly due to the low density of this activity in the priority area. Chronic change in overall fitness of walrus in the priority area

Risk Factor	Score	Rationale
		is ranked as insignificant or undetectable relative to background variability, resulting in a score of 1.
Recovery Factors:	2.1	Recovery factors = mean of the factors listed below. Fecundity: 3 (Adult female walrus have 1 calf every 3 years [Garlich-Miller and Stewart 1999]). Early life stage mortality: 1 (The data are sparse but the population structure and relatively high proportion of juveniles in the population suggests low mortality in all juvenile stages [Fay et al. 1997]). Recruitment pattern: 1 (Although annual recruitment is low by some standards, recruitment seems to be consistent among years and because walrus are long lived [40 years; Kovacs and Lydersen 2006], a single female produces a lot of young over her lifetime]). Natural mortality rate: 3 (The data are sparse but the population structure and relatively high proportion of juveniles in the population suggests low mortality in all life stages [Fay et al. 1997]). Age at maturity: 3 (Average age at sexual maturity of females is 7 years [Garlich-Miller and Stewart 1999]). Life stages affected: 3 (All life stages may be affected) Population connectivity: 2 (Studies suggest that there is some interchange among Canadian Arctic walrus populations [Stewart 2008; Charette et al. 2020; Loewen et al. 2020b]). Population status: 1 (COSEWIC [2017] lists walruses as *special concern* due to threats associated with global warming. The Hudson Bay-Davis Strait stock has increased from a minimum of 3,900 in 1986 to approximately 7,000 and the authors suggest that walruses remain abundant in the Southampton Island area [Hammill et al. 2016a]).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 1 × 1 = Negligible
Likelihood	4	Icebreaking alters sea ice habitat along its route, temporarily forming artificial channels of broken ice and open water. Therefore, walrus habitat alteration/removal has the potential to occur when active walrus habitat and the track of an icebreaker overlap. Sea ice is important habitat for walruses as they use the platform to rest between foraging bouts (Fay 1982; COSEWIC 2017). Considering this information, likelihood was scored as 4.
Overall Risk	Low Risk	No additional management measures need to be considered at this time.
Uncertainty		
Exposure	4	General patterns of icebreaking are known in the AOI, though additional investigation is needed to determine the fine-scale patterns by vessel trip. Information exists on the known haul-out sites and distribution of walruses in the priority area. Uncertainty is high.
Sensitivity	5	Certain aspects of walrus biology have been reported in other areas of the Arctic, which provides some information for assessing likely behavioural response. Investigation of the impacts of icebreaking on walrus habitat are not known. Uncertainty is very high.
Likelihood	4	Walrus responses to icebreakers have been reported in other areas of the arctic, which provides some information for assessing likely behavioural response. Additional investigation is needed for the AOI. Uncertainty is high.

Risk Statement: If an interaction occurs involving belugas and habitat alteration/removal due to icebreaking the consequence could result in a negative impact on the beluga population in the East Bay priority area.

Table 5-39. Beluga – Icebreaking (East Bay) – Habitat Alteration/Removal.

Risk Factor	Score	Rationale
Exposure	1 (binned)	Exposure = Intensity x Temporal x Spatial (Depth × Areal) = 1 x 1 x 1 = 1 (raw score)
Intensity	1	Currently, active icebreaking is rare in the AOI and only occurs in the shoulder seasons (DFO 2024). Indeed, overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was not recorded in the priority area from 2012-2019 (adapted from Maerospace 2020). Therefore, an intensity score of 1 was assigned.
Temporal	1	Belugas are expected to migrate into the AOI and presumably the East Bay priority area in May and June and occur in the priority area during summer, with migration out of the priority area beginning in early to late September (Loewen et al. 2020b). There is limited potential for temporal overlap with icebreaking activity given that break-up of ice occurs in mid-July with ice re-forming in mid-November. Indeed, overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was not recorded in the priority area from 2012-2019 (adapted from Maerospace 2020). This results in little overlap between when the stressor occurs and when belugas may be present, for a score of 1.
Spatial	1	Spatial = Areal x Depth = 1 x 1 = 1
Areal	1	Belugas migrate into the priority area in spring/early summer, congregate in the shallow waters of East Bay during summer, and migrate out of East Bay by end of September. Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was not recorded in the priority area from 2012-2019 (adapted from Maerospace 2020) and vessel tracks, regardless of vessel type, are generally towards the northern extent of the priority area (see Figure 5-1 and Figure 5-12). Habitat alteration would be restricted to the direct vessel path. Therefore, a few restricted locations of beluga habitat in the East Bay priority area could overlap with this stressor, for a score of 1.
Depth	1	Alteration of ice habitat from icebreaking would be restricted to the water surface and belugas regularly forage at depths of 100s of metres (Martin et al. 1998; Watt et al. 2016). ; therefore, there would only be overlap with a small portion of beluga depth range in the East Bay priority area, resulting in a score of 1.
Sensitivity	3 (binned)	Sensitivity= (Acute change + Chronic Change) x Recovery Factors = (2+1) x 2.4 = 7.2
Acute Change	2	Belugas are expected to migrate into the AOI and presumably the East Bay priority area in May and June and occur in the priority area during summer, with migration out of the priority area beginning in early to late September (Loewen et al. 2020b). Icebreaking in the priority area may provide belugas with access to feeding opportunities which were not available previously. When leads open in landfast or pack ice, belugas move into them (Koski 1980; Finley et al. 1990) to take advantage of previously unavailable food beneath the ice. While this would be energetically beneficial, there is also the possibility that direct mortality could occur if icebreaking were conducted late in the season as

Risk Factor	Score	Rationale
		belugas that enter the icebreaker track may get trapped (Heide-Jørgensen et al. 2002). Though some information exists investigating the effects of this stressor on closely related narwhals, little information exists specific to belugas beyond recorded ice entrapment events. Ice entrapments of narwhals can cause mortality to hundreds of individuals though not all entrapments are lethal (Laidre et al. 2011: Heide-Jørgensen et al. 2013b; Watt et al. 2019). Two entrapments in 2008 and 2015 near the community of Pond Inlet, Nunavut resulted in mortality of 629 and 249 individuals respectively (Watt et al. 2019). Though the cause of these events is unknown, it has been suggested that delayed departure from summering habitat and greater unpredictability in freeze-up may have contributed (Watt et al. 2019). These events can also naturally re-occur in particular locations influenced by the area's ice and freeze-up regime along with narwhal migratory behaviour and timing (e.g., the region of Disko Bay, Greenland; Laidre et al. 2011). Beluga entrapments are known to occur in Disko Bay, Greenland due to similar reasons discussed above for narwhals (Laidre et al. 2011). An entrapment of at least 24 belugas was recorded near Sanikiluaq, Nunavut though no speculation on the cause was included (Hopper 2013). Heide-Jørgensen et al. (2002) describe in some detail two entrapment events in the eastern Canadian high Arctic involving belugas (40 and 170 individuals) and reference other beluga entrapments noted elsewhere; it was also hypothesized here that these cases were caused by rapidly changing ice conditions in the fall which trapped the whales. Beluga ice entrapment is not known to have occurred in the AOI. Entrapments attributed to icebreaking are not known in the literature. Were entrapment in an icebreaker track to occur it is reasonable to assume it would involve fewer individuals than those documented. Considering the above, there could be a measurable change to beluga mortality rates against background variability resulting in a score of 2.
Chronic Change	1	Though some information exists investigating the effects of this stressor on closely related narwhals at the population level, no similar investigations have been made in regard to belugas. Ice entrapments of narwhals can cause mortality to hundreds of individuals though not all entrapments are lethal, and mortalities attributed to icebreaking are not known in the literature (see *Acute Change*, above). Modelling of the Eclipse Sound narwhal stock indicates that entrapment-induced mortality of 1,000 individuals every 3, 5, or 10 years could contribute to population decline if this source of mortality is not accurately represented by estimated mortality rates. However, if entrapments are a major source of mortality rates already captured in estimates 1,000 individuals killed every 5 years would result in no growth to the population while 1,000 individuals killed every 10 years from such an event would not impact the population (Watt et al. 2019). Though uncertain, it has been suggested that females may be more susceptible to entrapment-induced mortality than males, which would result in greater population impacts due to lost reproductive potential (Watt et al. 2019). However, the low density of active icebreaking in the AOI along with the presumed lower number of individuals that would be entrapped in an icebreaker track compared with those documented above limits potential impacts from this stressor. Considering the information above it is not likely to affect overall beluga population fitness compared to background levels nor impact population dynamics, resulting in a score of 1.
Recovery	2.4	Recovery factors = mean of the factors listed below.

Risk Factor	Score	Rationale
Factors:		Fecundity: 3 (Adult female belugas have 1 calf every 3 years [Sergeant 1973; Matthews and Ferguson 2015]). Early life stage mortality: Unknown; excluded from analyses (There are no data on mortality rates in juvenile belugas). Recruitment pattern: 2 (Although annual recruitment is low by some standards, belugas live to be about 70 years old assuming a single growth layer is formed in their teeth in a year [Waugh et al. 2018: Vos et al. 2020]. The maximum longevity may be 100 years [Harwood 2002]. Because of their longevity, a single female could produce a lot of young over her lifetime even if they become reproductively senescent at 35-40 years old, as suggested by Hobbs et al. [2015] and Ellis et al. [2018]). Natural mortality rate: 3 (The natural mortality rate of belugas must be low if they live to ~70 years old. Ice entrapments of belugas are known to recur in the Canadian High Arctic and in northern Foxe Basin [Smith and Sjare 1990]. Polar bears and Inuit hunters take advantage of these incidents to harvest belugas. The proportion of mortality in these situations that is attributable to predation is not well documented and remains debatable [Kilabuk 1998]. Age at maturity: 3 (Average age at sexual maturity of female beluga is 6-14 years [COSEWIC 2020]). Life stages affected: 3 (It is likely that all life stages of belugas will be affected). Population connectivity: 2 (The Western Hudson Bay population that occurs in the AOI overlaps with the Eastern Hudson Bay and Ungava Bay beluga populations in Hudson Strait during winter.) Population status: 1 (IUCN classifies the beluga whale as *near threatened*. COSEWIC [2020] lists the Western Hudson Bay population that occurs in the AOI as *least concern*]).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 1 × 3 = Negligible
Likelihood	1	Though ice entrapments are known to occur to large numbers of belugas it is hypothesized that variable climatic conditions and rapidly changing weather are the main contributing factors. It has also been suggested that anthropogenic activity (i.e., seismic surveys for petroleum exploration) could contribute to narwhals (and possibly belugas) remaining in summering habitat longer than usual, increasing the potential for an ice entrapment (Heide-Jørgensen et al. 2013b). However, this same argument has not been made in relation to icebreaking activity and no records of ice entrapment of belugas in an icebreaker track are known in the literature and have not been noted in the AOI. Considering the above, likelihood was scored as 1.
Overall Risk	Low Risk	No additional management measures need to be considered at this time.
Uncertainty		
Exposure	4	General patterns of icebreaking are known in the AOI, though additional investigation is needed to determine the fine-scale patterns by vessel trip. Information exists on the occupancy of belugas in the priority area. Uncertainty is high.
Sensitivity	5	Investigation of potential impacts of icebreaking on beluga entrapments or increased foraging opportunities is limited, and little information exists on natural entrapments for belugas. Uncertainty is very high.
Likelihood	4	The likelihood of belugas entering an icebreaker track and becoming trapped has not been studied, and little information exists for belugas regarding natural entrapments (though some exists for the closely-related narwhal). Uncertainty is high.

Risk Statement: If an interaction occurs involving narwhals and habitat alteration/removal due to icebreaking the consequence could result in a negative impact on the narwhal population in the Repulse Bay and Frozen Strait priority area.

Table 5-40. Narwhal – Icebreaking (Repulse Bay and Frozen Strait) – Habitat Alteration/Removal.

Risk Factor	Score	Rationale
Exposure	1 (binned)	Exposure = Intensity x Temporal x Spatial (Depth × Areal) = 1 x 1 x 1 = 1 (raw score)
Intensity	1	Currently, active icebreaking is very rare in the AOI and only occurs in the shoulder seasons (DFO 2024). Indeed, overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was only recorded for one trip—in September 2015—in the priority area from 2012-2019 (adapted from Maerospace 2020). Therefore, an intensity score of 1 was assigned.
Temporal	1	Narwhals migrate into Repulse Bay in June and July and out in August and September through Frozen Strait (Westdal et al. 2010). Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was only recorded for one trip—in September 2015—in the priority area from 2012-2019 (adapted from Maerospace 2020). Thus, there would be little overlap between when the stressor occurs and when narwhals are present, for a score of 1.
Spatial	2	Spatial = Areal x Depth = 2 x 1 = 2
Areal	1	Narwhal preferred habitats are leads in landfast or pack ice and are seldom found in areas of fast-ice (Koski and Davis 1994; Kovacs et al. 2011). Narwhals migrate through Frozen Strait en route to Repulse Bay during spring/early summer break-up and en route to Hudson Strait prior to freeze-up in the fall. Sea ice in Frozen Strait is some of the first to be reduced in the area with much melt occurring by late June/early July. Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was only recorded for one trip—in September 2015—in the priority area from 2012-2019 (adapted from Maerospace 2020). It is assumed that icebreaker navigation would follow a consistent route through the priority area. Habitat alteration would be restricted to the direct path of the vessel. Considering the above, the area of overlap would be in restricted locations of narwhal range in the priority area, resulting in a score of 1.
Depth	1	Alteration of ice habitat from icebreaking would be restricted to the water surface and narwhals typically forage in waters up to 500 m deep (Heide-Jørgensen and Dietz 1995; Laidre et al. 2003); therefore, there would only be overlap with a small portion of narwhal depth range in the Repulse Bay/Frozen Strait priority area, resulting in a score of 1.
Sensitivity	3 (binned)	Sensitivity= (Acute change + Chronic Change) x Recovery Factors = (2+1) x 2.5 = 7.5
Acute Change	2	Icebreaking in the priority area may provide narwhals with access to feeding opportunities which were not available previously. When leads open in landfast or pack ice, narwhals move into them (Koski 1980; Finley et al. 1990) to take advantage of previously unavailable food beneath the ice. While this would be energetically beneficial, there is also the possibility that direct mortality could occur due to entrapment (Heide-Jørgensen et al. 2002; Laidre et al. 2012).

		Ice entrapments of narwhals can cause mortality to hundreds of individuals though not all entrapments are lethal (Laidre et al. 2011: Heide-Jørgensen et al. 2013b; Watt et al. 2019). Two entrapments in 2008 and 2015 near the community of Pond Inlet, Nunavut resulted in mortality of 629 and 249 individuals respectively (Watt et al. 2019). Though the cause of these events is unknown, it has been suggested that delayed departure from summering habitat and greater unpredictability in freeze-up may have contributed (Watt et al. 2019). These events can also naturally re-occur in particular locations influenced by the area's ice and freeze-up regime along with narwhal migratory behaviour and timing (e.g., the region of Disko Bay, Greenland; Laidre et al. 2011). However, major entrapments attributed to icebreaking are not known in the literature. Were entrapment in an icebreaker track to occur it is reasonable to assume it would involve fewer individuals than those documented. Considering the above, there could be a measurable change to narwhal mortality rates against background variability resulting in a score of 2.
Chronic Change	1	Ice entrapments of narwhals can cause mortality to hundreds of individuals though not all entrapments are lethal, and mortalities attributed to icebreaking are not known in the literature (see *Acute Change*, above). Modelling of the Eclipse Sound narwhal stock indicates that entrapment-induced mortality of 1,000 individuals every 3, 5, or 10 years could contribute to population decline if this source of mortality is not accurately represented by estimated mortality rates. However, if entrapments are a major source of mortality rates already captured in estimates 1,000 individuals killed every 5 years would result in no growth to the population while 1,000 individuals killed every 10 years from such an event would not impact the population (Watt et al. 2019). Though uncertain, it has been suggested that females may be more susceptible to entrapment-induced mortality than males, which would result in greater population impacts due to lost reproductive potential (Watt et al. 2019). However, the low density of active icebreaking in the AOI along with the presumed lower number of individuals that would be entrapped in an icebreaker track compared with those documented above, limits potential impacts from this stressor. Considering the information above it is not likely to affect overall narwhal population fitness compared to background levels nor impact population dynamics, resulting in a score of 1.
Recovery Factors:	2.5	Recovery factors = mean of the factors listed below. Fecundity: 3 (Adult female narwhals have a calf about every 3 years [Garde et al. 2015]). Early life stage mortality: 2 (Few data on first year mortality of narwhal calves are available. Koski and Davis [1994] estimated that 17% of calves died when between 1 and 13 months of age; this is lower than for many other marine mammal species]). Recruitment pattern: 2 (Although annual recruitment is low by some standards, recruitment seems to be consistent among years and because narwhals are long lived [80 years; Garde et al. 2015], a single female can produce a lot of young over her lifetime]). Natural mortality rate: 3 (The data are sparse but the stable population size with the removals by subsistence hunters suggests low mortality in all life stages). Age at maturity: 3 (Age at sexual maturity of females is 6-9 years and older for males [Garde et al. 2015]). Life stages affected: 3 (All life stages except for newborn calves are likely to be affected. An adult female accompanied by a yearling was seen in the AOI [Carlyle et al. 2021]).

		Population connectivity: 3 (Studies suggest that there is limited interchange among Canadian Arctic narwhal populations [Westdal et al. 2010; Heide-Jørgensen et al. 2013a; Doniol-Valcroze et al. 2020]). Population status: 1 (IUCN classifies narwhals as *least concern* [Lowry et al. 2017]. The last COSEWIC assessment is outdated [from 2004]. Narwhal populations are considered stable [Furgal and Laing 2012; Lowry et al. 2017]).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 1 × 3 = Negligible
Likelihood	1	Though ice entrapments are known to occur to large numbers of narwhals it is hypothesized that variable climatic conditions and rapidly changing weather are the main contributing factors. It has also been suggested that anthropogenic activity (i.e., seismic surveys for petroleum exploration) could contribute to narwhals remaining in summering habitat longer than usual, increasing the potential for an ice entrapment (Heide-Jørgensen et al. 2013b). However, this same argument has not been made in relation to icebreaking activity and no records of ice entrapment of narwhals in an icebreaker track are known in the literature and have not been noted in the AOI. Additionally, narwhals are good at navigating high concentrations of sea ice (Laidre and Jørgensen 2011). Considering the above, likelihood was scored as 1.
Overall Risk	Low Risk	No additional management measures need to be considered at this time.
Uncertainty		
Exposure	4	General patterns of icebreaking are known in the AOI, though additional investigation is needed to determine the fine-scale patterns by vessel trip. Information exists on the occupancy of narwhals in the priority area. Uncertainty is high.
Sensitivity	5	Investigation of potential impacts of icebreaking on narwhal entrapments or increased foraging opportunities is limited, though some information exists on natural entrapments. Uncertainty is very high.
Likelihood	4	The likelihood of narwhals entering an icebreaker track and becoming trapped has not been studied, though some information exists for narwhals regarding natural entrapments. Uncertainty is high.

Risk Statement: If an interaction occurs involving polynya habitat and habitat alteration/removal due to icebreaking the consequence could result in a negative impact on the ecosystem function of polynya habitat in the Chesterfield Inlet/Narrows priority area.

Table 5-41. Polynya Habitat – Icebreaking (Chesterfield Inlet/Narrows) – Habitat Alteration/Removal.

Risk Factor	Score	Rationale
Exposure	1 (binned)	Exposure = Intensity x Temporal x Spatial (Depth x Areal) = 1 x 1 x 3 = 3 (raw score)
Intensity	1	Currently, active icebreaking is very rare in the AOI and only occurs in the shoulder seasons (DFO 2024). Indeed, overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was not recorded in the priority area from 2012-2019 (adapted from Maerospace 2020). Therefore, an intensity score of 1 was assigned.
Temporal	1	The Western Hudson Bay polynya in the Chesterfield Inlet/Narrows priority area opens up in December and merges with adjacent open water during summer (Gunn 2014). Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was not recorded in the priority area from 2012-2019 (adapted from Maerospace 2020). Therefore, a temporal score of 1 was assigned.

Risk Factor	Score	Rationale
Spatial	3	Spatial = Areal x Depth = 1 x 3 = 3
Areal	1	The Western Hudson Bay polynya is a recurring coastal polynya that reforms annually along the coast within Chesterfield Inlet/Narrows priority area and is characterized by the recurrence of lower sea ice concentration and extent, and surface wind forcing (DFO 2020a; Bruneau et al. 2020). Although polynyas have areas of open water throughout the year, icebreaking may occur through the ice that surrounds the polynya. Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was not recorded in the priority area from 2012-2019 (adapted from Maerospace 2020). Therefore, an areal score of 1 was assigned.
Depth	3	As icebreaking is intended to create a navigable path through sea ice, the depth overlap for icebreaking covers the entire depth range where ice is present within polynya habitat resulting in a score of 3.
Sensitivity	2 (binned)	Sensitivity = (Acute change + Chronic Change) x Recovery Factors = (2 + 1) x 2.0 = 6.0
Acute Change	2	Polynyas are areas of open water that are bordered by mobile sea ice, landfast ice, or the coastline. The presence of a polynya can increase productivity and influence food web structures, supporting increased numbers of upper trophic level species such as marine mammals and birds (Arrigo and van Dijken 2004). Sea ice provides habitat to a unique community of ice-associated biota (e.g., Mundy et al. 2014; Lange et al. 2017; Kohlbach et al. 2019). This habitat can be disturbed by icebreaking activities, creating channels of open water, partially frozen water, and broken ice and causing fragmentation of habitat, especially in regard to pupping for seals (e.g., Wilson et al. 2017; Yurkowski et al. 2019). The sea ice would likely reform after disturbance as the coastal polynya is generally maintained via wind-forcing (DFO 2020a; Bruneau et al. 2021). Besides habitat alternation, icebreaking can also cause injuries or mortality in ice-associated biota. Although the density of active icebreaking in the priority area is currently low (or non-existent), the activity does cause fragmentation of polynya habitat and due to its importance to myriad species and processes, may cause measurable change in ecosystem function. Thus, a score of 2 was assigned.
Chronic Change	1	Changes to community assemblages can occur if ice is broken up (e.g., Kohlbach et al. 2020) and other ecosystem impacts, such as changes in abundance of amphipods, are also possible (e.g., Melnikov et al. 2002). Although icebreaking will alter sea ice, since it grows and melts over an annual cycle, localized and temporally-confined activities impacting the ice should not have a long-lasting impact, particularly given that this polynya is thought to be maintained by wind-forcing (DFO 2020a; Bruneau et al. 2021). Though icebreaking will create an open water path that can absorb more heat and lead to increased ice melting, the contribution compared to overall ice-cover is expected to be negligible. Habitat alteration due to the current level of icebreaking activities is not expected to have a measurable change to long-term viability of the habitat across its range as it relates to its function in the ecosystem, resulting in a score of 1.
Recovery Factors	2.0	Recovery factors = mean of the factors listed below for sea ice adjacent and within the polynya Growth rate (biogenic)/rate of structural rebuilding (abiotic): 2 (sea ice re-freezes during fall).

Risk Factor	Score	Rationale
		Resistance: 2 (sea ice is relatively hard and durable). Regenerative potential: 1 (sea ice grows each year and any removal of it will be met by its replacement if temperatures are below freezing. The Western Hudson Bay polynya is predominantly maintained by wind-forcing, which likely allows the boundaries to reform relatively quickly). External stress: 3 (Climate change adds to stress).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 1 x 2 = Negligible
Likelihood	4	Habitat alteration is likely to occur if icebreaking does take place in the vicinity of the polynya as it is designed to create channels of open water through sea ice. Therefore, a score of 4 was assigned.
Overall Risk	Low Risk	No additional management actions need to be considered at this time.
Uncertainty		
Exposure	4	General patterns of icebreaking are known in the AOI, though additional investigation is needed to determine the fine-scale patterns by vessel trip. The general characteristics of the Western Hudson Bay polynya have been studied. Uncertainty is high.
Sensitivity	4	The sensitivity of polynya habitat to icebreaking is uncertain. Little to no scientific information is available for life history information for ice-associated species in polynya habitat or for the polynya's ability to function as habitat after interaction with this stressor.
Likelihood	4	Icebreaking will cause habitat alteration as it is designed to create a path of open water through ice; however, the resulting effects of this alteration on a polynya's ability to function as habitat are uncertain given the dynamic nature of the habitat. Therefore, uncertainty is high.

Risk Statement: If an interaction occurs involving sea ice and habitat alteration/removal due to icebreaking the consequence could result in a negative impact on the ecosystem function of sea ice habitat in Roes Welcome Sound priority area.

Table 5-42. Sea Ice – Icebreaking (Roes Welcome Sound) – Habitat Alteration/Removal.

Risk Factor	Score	Rationale
Exposure	1 (binned)	Exposure = Intensity x Temporal x Spatial (Depth x Areal) = 1 x 1 x 3 = 3 (raw score)
Intensity	1	Currently, active icebreaking is rare in the AOI and only occurs in the shoulder seasons (DFO 2024). Indeed, overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was only recorded for one trip—in June 2018—in the priority area from 2012-2019 (adapted from Maerospace 2020). Therefore, an intensity score of 1 was assigned.
Temporal	1	Sea ice occurs in the Roes Welcome sound priority area from late fall through late spring (~8 months of the year); it melts during the summer. Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was only recorded for one trip—in June 2018—in the priority area from 2012-2019 (adapted from Maerospace 2020). Thus, there is little temporal overlap with sea ice resulting in a score of 1.
Spatial	3	Spatial = Areal x Depth = 1 x 3 = 3

Risk Factor	Score	Rationale
Areal	1	Sea ice occurs throughout the Roes Welcome Sound priority area for ~8 months of the year consisting of landfast ice and mobile pack ice. Additionally, an ice arch also forms across Roes Welcome Sound south of Wager Bay every ~4 years. Overlap between icebreaker AIS data and sea ice cover, as a proxy for active icebreaking taking place, was only recorded for one trip—in June 2018—in the priority area from 2012-2019 (adapted from Maerospace 2020). Thus, icebreaking would occur in a few restricted locations in the priority area, resulting in a score of 1.
Depth	3	As icebreaking is intended to create a navigable path through sea ice, the depth overlap for icebreaking covers the entire depth range where ice is present, resulting in a score of 3.
Sensitivity	2 (binned)	Sensitivity = (Acute change + Chronic Change) x Recovery Factors = (2 + 1) x 2.0 = 6.0
Acute Change	2	Sea ice provides habitat to a unique community of ice-associated biota (e.g., Mundy et al. 2014; Lange et al. 2017; Kohlbach et al. 2019). This habitat can be disturbed by icebreaking activities, creating channels of open water, partially frozen water, and broken ice, and causing fragmentation of habitat, especially in regard to pupping for seals (e.g., Wilson et al. 2017; Yurkowski et al. 2019). Icebreaking can also cause changes to the community assemblages and species abundance (e.g., Melnikov et al. 2002; Kohlbach et al. 2020) and injuries or mortality in ice-associated biota. Measurable change to habitat function in the ecosystem at the localized scale over an acute timeframe is expected. Particularly to Arctic cod, as an important component of the ice-associated biotic community, this species has adapted to the presence of ice during its early life stages, including spawning under the ice and feeding on zooplankton during seasonal ice-melt water blooms (Huserbråten et al. 2019) and some individuals may be disturbed by icebreaking activities. Although the density of active icebreaking in the priority area is currently low, the activity does cause fragmentation of sea ice habitat and due to its importance to myriad species and processes, may cause measurable change in ecosystem function. Thus, a score of 2 was assigned.
Chronic Change	1	Although icebreaking will alter sea ice, since it grows and melts over an annual cycle, localized and temporally-confined activities impacting the ice should not have a long-lasting impact. Though icebreaking will create an open water path that can absorb more heat and lead to increased ice melting, the contribution compared to overall ice-cover is expected to be negligible. Habitat alteration due to the current level of icebreaking activities is not expected to have a measurable change to long-term viability of the habitat across its range as it relates to its function in the ecosystem, resulting in a score of 1.
Recovery Factors	2.0	Recovery factors for sea ice = mean of the factors listed below. Growth rate (biogenic)/rate of structural rebuilding (abiotic): 2 (sea ice refreezes during fall). Resistance: 2 (sea ice is relatively hard and durable). Regenerative potential: 1 (sea ice grows each year and any removal of it will be met by its replacement if temperatures are below freezing). External stress: 3 (Climate change adds to stress).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 1 x 2 = Negligible
Likelihood	4	Habitat alteration is likely to occur if icebreaking does take place in sea ice as it is designed to create channels of open water through sea ice. Therefore, a score of 4 was assigned.

Risk Factor	Score	Rationale
Overall Risk	Low Risk	No additional management actions need to be considered at this time.
Uncertainty		
Exposure	4	General patterns of icebreaking are known in the AOI, though additional investigation is needed to determine the fine-scale patterns by vessel trip. Little study has focused on sea ice habitat in the priority area. Uncertainty is high.
Sensitivity	4	The sensitivity of sea ice to function as habitat after icebreaking is uncertain. Little to no scientific information is available for life history information for ice-associated species in the AOI or for sea ice's ability to function as habitat after interaction with this stressor.
Likelihood	4	Icebreaking will cause habitat alteration as it is designed to create a path of open water through ice; however, the resulting effects of this alteration on sea ice's ability to function as habitat are uncertain given the dynamic nature of the habitat. Therefore, uncertainty is high.

5.3 Vessel at Rest

This sub-activity addresses stressors from stationary vessels that are at rest, either at anchor, attached to a mooring system, or adrift. Vessels at rest have the potential to affect the marine ecosystem through several stressors, including noise disturbance, disturbance from artificial light, and the introduction of pathogens or non-indigenous species (NIS). The focus of this section is on the vessel itself. Though there is currently a limited amount of vessel traffic within the SI AOI, there has been concern expressed that vessels anchored or moored near communities, especially Chesterfield Inlet, for an extended period of time may cause negative impacts (DFO 2023a). Based on input received from residents of Chesterfield Inlet, we have assumed that a vessel could be at rest for up to two weeks. The PoE of a vessel at rest are similar to those for a vessel underway; however, the effects of artificial light and noise may differ and were assessed here.

5.3.1 Noise Disturbance

There is limited information on the effects of the noise produced by a vessel at rest on marine fauna. Vessels at rest typically generate noise from the continuous running of the engines (though only periodically when the vessel is anchored), pumps and auxiliary engines, generators, compressors, other machinery, and daily deck activities (Hannah et al. 2020); some vessels may also use Dynamic Positioning thrusters to maintain position. It is possible, albeit considered limited relative to a vessel underway, that vessel noise may elicit behavioural responses (including masking effects) in marine mammals and possibly affect fish feeding or communication behaviour, which may lead to reduced fitness of fish species (Hannah et al. 2020). The risks of noise effects from a vessel at rest on all marine mammal ESC subcomponents (with the exception of polar bears) and on Arctic cod (acting as proxy for assessments on Arctic char and other forage fish based on the rationale provided in Section 5.1.1) have been assessed (Table 5-43).

Table 5-43. Vessels at Rest − Noise Disturbance: ESC Subcomponents and Priority Areas Assessed.

ESC Subcomponent	Priority Area	Assessed by Proxy
Arctic cod	Chesterfield Inlet/Narrows	
Arctic char	Chesterfield Inlet/Narrows	Via Arctic cod
Other forage fish		Via Arctic cod
Ringed seal	Chesterfield Inlet/Narrows	
Bearded seal	Chesterfield Inlet/Narrows	Via ringed seal
Walrus	Chesterfield Inlet/Narrows	
Beluga	Chesterfield Inlet/Narrows	
Narwhal	Chesterfield Inlet/Narrows	

ESC Subcomponent	Priority Area	Assessed by Proxy
Bowhead whale	Fisher and Evans Straits	

Risk Statement: If an interaction occurs involving Arctic cod and noise disturbance due to a vessel at rest the consequence could result in a negative impact on Arctic cod populations in the Chesterfield Inlet/Narrows priority area.

Table 5-44. Arctic cod – Vessel at Rest (Chesterfield Inlet/Narrows) – Noise Disturbance.

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial (Depth x Areal) = 1 x 2 x 3 = 6 (raw score)
Intensity	1	Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that to 5-9), a trend corroborated by others (Dawson et al. 2018). The Chesterfield Inlet/Narrows priority area experiences a high density of vessel traffic relative to other portions of the AOI (see Figure 2 in Maerospace 2020) representing 61% of total AIS data within the AOI from 2012-2019. Even so, it should be noted that relative to other areas that experience shipping and vessel traffic and for which biological effects literature is largely based, in absolute terms the AOI receives a low density of vessel traffic. Vessels at rest continually produce low-intensity sounds from the use of pumps, auxiliary engines, generators, and other machinery (Hannah et al. 2020). Though noise itself is not persistent in the environment once the source has been removed, AIS data indicate that vessels may remain at rest in this priority area for up to two weeks (Maerospace 2020) with common anchorages near the community of Chesterfield Inlet and at Helicopter Island near Chesterfield Narrows (Idlout 2020; Agnico Eagle 2022). The density of vessels at any one time is generally either zero or one. Considering this information, intensity was scored as 1.
Temporal	2	Arctic cod are expected to occur in the area year-round. Vessels (with available AIS) are typically present in the priority area during July to September, and occasionally during June (Maerospace 2020), though they may not be present throughout that entire period. A vessel may remain at rest in the priority area for several days up to two weeks and numerous vessels will occur in the priority area throughout the summer (Maerospace 2020). This results in some overlap (25-50%) between when a vessel at rest and Arctic cod are present and a score of 1.
Spatial	3	Spatial = Areal x Depth = 1 x 3 = 3
Areal	1	A ubiquitous species, Arctic cod occupy coastal and offshore waters in areas with and without sea ice and are expected to be widespread throughout the Arctic Ocean (Coad and Reist 2018). Arctic cod distribution in the Chesterfield Inlet/Narrows priority area is not currently known; however, nearshore areas have been identified as potentially important habitats for this species (Loewen et al. 2020b) and Arctic cod were among the most common marine fish families observed from sample stations ranging between Coral Harbor and Chesterfield Inlet during a 2019 GenICE research cruise (DFO 2020). Sounds may travel in water beyond the source. Vessels at rest would only occur in a few specific locations. Thus, the area of overlap is a few restricted locations within the Arctic cod range in the priority area, resulting in a score of 1.

Risk Factor	Score	Rationale
Depth	3	Arctic cod are widespread across the circumpolar Arctic, but they occur at different depths throughout the water column based on factors such as life history stage (e.g., Geoffroy et al. 2016), seasonal diet (e.g., Majewski et al. 2016), and light regime (e.g., Benoit et al. 2010). Noise from a vessel at rest is expected to overlap the entire depth range of Arctic cod in the Chesterfield Inlet/Narrows priority area resulting in a score of 3.
Sensitivity	1 (binned)	Sensitivity = (Acute change + Chronic Change) x Recovery Factors = (1 + 1) x 1.9 = 3.8
Acute Change	1	As with all members of the Gadidae family, Arctic cod have swim bladders positioned close to their ears, their hearing is more sensitive to a wider range of frequencies compared to other fish species that do not have a swim bladder; however, they are less sensitive than fish that have swim bladders linked to their ears (Popper and Hawkins 2019). Gadids are sensitive to sound pressure as well as particle motion, giving them the ability to locate sound sources and discriminate sounds against background noise (Popper and Hawkins 2019). Passive acoustic monitoring indicated that sound pressure levels (SPL: 20−24,000 Hz) were elevated 2-8 dB re: 1μPa throughout Cowichan Bay, British Columbia when a carrier vessel anchored there; the increase in sound pressure occurred for the entire time a carrier vessel was anchored, which ranged from 2-22 days (Murchy et al. 2022). Murchy et al. (2022) determined that the noise field being emitted by an anchored bulk carrier is highly directional, with the highest noise levels detected when the bow of a vessel was pointed towards a hydrophone and lowest when the stern faced the same hydrophone. Gadids can hear frequencies up to 500 Hz (Popper and Hawkins 2019), which overlap with the low frequencies typically emitted by large vessels; Gadids also produce sounds (Riera et al. 2018). Fish use sound to communicate, avoid predators, select habitat, and for mating behaviour (see Popper and Hawkins 2019). Noise can impact fish behaviour, physiology, and hearing (Popper and Hawkins 2019), it can mask natural sounds and decrease communication space (e.g., Stanley et al. 2017; Pine et al. 2018), and impact spawning success (e.g., de Jong et al. 2018, 2020). Several studies have shown changes in behaviour and physiology of gadids exposed to noise, including reduced spawning success (e.g., Nedelec et al. 2015; Sierra-Flores et al. 2015; Ivanova et al. 2020), but most studies have been conducted on fish in laboratories, not free-ranging animals in natural conditions. Although there could be limited behavioural impacts (e.g., avoidance) by Arctic cod, due to the overall low level of vessel traffic in the Chesterfield Inlet/Narrows priority area and the fact that sounds emitted by vessels at rest are restricted to specific locations and are generally less loud than vessels underway, it is expected that there would be an insignificant or undetectable change to Arctic cod mortality rates against background variability and limited behavioural impacts. Thus, a score of 1 was assigned.
Chronic Change	1	Noise can impact fish behaviour, physiology, and hearing (Popper and Hawkins 2019), and can mask natural sounds and decrease communication space (e.g., Stanley et al. 2017; Pine et al. 2018). If critical life functions, such as spawning success (e.g., de Jong et al. 2018, 2020) are compromised by sound or avoidance responses result from sound, fitness consequences could result (Slabbekoorn et al. 2010). There is a risk that vessel noise could mask Gadid sounds and interfere with the production and detection of important acoustic signals or cause behavioural changes (e.g., avoidance), possibly leading to further impacts (e.g., interruptions to spawning behaviour). Although long-term effects associated with reduced spawning success and prolonged avoidance are possible, this has not been shown to occur in naturally occurring environments where fish are able to swim away from loud source sources. Based on the low density of vessel traffic and the few restricted locations where vessels would be

Risk Factor	Score	Rationale
		at rest, no detectable changes to overall fitness or population dynamics are expected. This results in a score of 1.
Recovery Factors	1.9	Recovery factors = mean of the factors listed below. Fecundity: 2 (Spawn only once in their lifetime with a relatively low number of eggs; between 9,000 to 21,000 eggs are produced, with an average of 11,900 per female [Cohen et al. 1990]). Early life stage mortality: 3 (R-selected species with high mortality [Coad and Reist 2018]). Recruitment pattern: 2 (Increased recruitment expected with climate change [LeBlanc et al. 2019]). Natural mortality rate: 1 (Mortality is high [Coad and Reist 2018]). Age at maturity: 2 (2-3 years for males and 3-4 years for females [Coad and Reist 2018]). Life stages affected: 3 (All life stages could potentially occur in the area). Population connectivity: 1 (Arctic cod range widely throughout the Arctic). Population status: 1 (IUCN classification is *least concern* [Fernandes et al. 2015], but population trend is unknown. Abundant in Arctic marine waters [Coad and Reist 2018]).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 2 x 1 = Negligible
Likelihood	3	An interaction has the potential to occur when Arctic cod and a vessel are present at the same time within the Chesterfield Inlet/Narrows priority area and within close enough proximity for the vessel noise to cause a disturbance to the animal. Gadids are relatively sensitive to sound and depending on the behavioural state of the animal and the distance to the vessel, an interaction may occur in some but not all circumstances.
Overall Risk	Low Risk	No additional management actions need to be considered at this time.
Uncertainty		
Exposure	4	How noise may affect individuals and populations over different spatial and temporal scales is uncertain, as details regarding the distribution of Arctic cod in the Chesterfield Inlet/Narrows priority area are scarce. The general distribution of Arctic cod is known. However, since little scientific information is available on the topic and assumptions were made from other areas, the uncertainty is high.
Sensitivity	4	The impacts of anthropogenic noise on fish, including Arctic cod, are not well understood, in particular how particle motion rather than sound pressure, may affect their behaviour and physiology (Popper and Hawkins 2018). In addition, most studies on fish hearing and sound production have focused on laboratory experiments, and results may differ if experiments were conducted in natural settings (Popper and Hawkins 2019). Some research has been done on the sensitivity of this taxonomic group to this stressor. Thus, uncertainty is considered high.
Likelihood	4	Research is needed on the response of Arctic cod to vessel noise. However, responses of other gadids are variable and depend on the cod's behavioural state, distance from the vessel, and received sound levels. Since little scientific information is available on the topic and assumptions were made from other areas, the uncertainty is high.

Risk Statement: If an interaction occurs involving ringed seals and noise disturbance due to a vessel at rest the consequence could result in a negative impact on the ringed seal population that occurs in the Chesterfield Inlet/Narrows priority area.

Table 5-45. Ringed Seal – Vessel at Rest (Chesterfield Inlet/Narrows) – Noise Disturbance.

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 2 x 3 = 6 (raw score)
Intensity	1	Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Chesterfield Inlet/Narrows priority area experiences a high density of vessel traffic relative to other portions of the AOI (see Figure 2 in Maerospace 2020) representing 61% of total AIS data within the AOI from 2012-2019. Even so, it should be noted that relative to other areas that experience shipping and vessel traffic and for which biological effects literature is largely based, in absolute terms the AOI receives a low density of vessel traffic. Vessels at rest continually produce low-intensity sounds from the use of pumps, auxiliary engines, generators, and other machinery (Hannah et al. 2020). Though noise itself is not persistent in the environment once the source has been removed, AIS data indicate that vessels may remain at rest in this priority area for up to two weeks (Maerospace 2020) with common anchorages near the community of Chesterfield Inlet and at Helicopter Island near Chesterfield Narrows (Idlout 2020; Agnico Eagle 2022). The density of vessels at any one time is generally either zero or one. Considering this information, intensity was scored as 1.
Temporal	2	Based on available scientific information and Inuit Qaujimajatuqangit, ringed seals in the Chesterfield Inlet/Narrows priority area are likely year-round residents (Idlout 2020; Loewen et al. 2020b). Vessels (with available AIS) are typically present in the priority area during July to September, and occasionally during June (Maerospace 2020), though they may not be present throughout that entire period. A vessel may remain at rest in the priority area for several days up to two weeks (Maerospace 2020) and numerous vessels will occur in the priority area throughout the summer. This results in some overlap (25-50%) and a score of 2.
Spatial	3	Spatial = Areal x Depth = 1 x 3 = 3
Areal	1	Ringed seals are expected to be widely distributed throughout the priority area (but during the ice-covered season more prevalent in areas of fast-ice with water depths >3 m). Sounds may travel in water beyond the source. Vessels at rest would occur only in a few specific locations in the Chesterfield Inlet/Narrows priority area. Thus, the area of overlap is a few restricted locations within the range of ringed seals in the priority area, resulting in a score of 1.
Depth	3	Ringed seals may be found throughout the water column (maximum dive depth for ringed seals is >500 m; Ogloff et al. 2021). Sound from a vessel at rest may occur at levels that influence ringed seal behaviour throughout the water column where ringed seals occur resulting in a score of 3.
Sensitivity	1 (binned)	Sensitivity= (Acute change + Chronic Change) × Recovery Factors = (1+1) × 2.3 = 4.46

Risk Factor	Score	Rationale
Acute Change	1	The Chesterfield Inlet/Narrows priority area presumably provides year-round habitat for ringed seals; however, ringed seals are thought to occur in low abundances in the Chesterfield Inlet/Narrows priority area (DFO 2020). Ringed seals can hear vessel noise. Sounds produced from vessels are not predicted to cause hearing damage or mortality. Given that sounds important to ringed seals are predominantly at much higher frequencies than shipping noise and given the reduced sound levels when a vessel is at rest, it is unlikely that masking would affect ringed seals. Few authors have described the responses of phocids to vessels, and most of the available information concerns pinnipeds hauled out on land or ice and their response to moving vessels. Ringed seals hauled out on ice pans often showed short-term escape reactions when a ship came within 250-500 m (Brueggeman et al. 1992). However, during the open-water season in the Beaufort Sea, ringed seals are commonly observed close to vessels (e.g., Harris et al. 1997, 1998, 2001, 2007, 2009). Several Hunter and Trapper Committee members in the Inuvialuit Settlement Region in the Beaufort Sea indicated that during seal hunting, they often create underwater noise to attract ringed seals to their boat, noting that seals are “curious”. When in the water (vs. hauled out), seals appear less responsive to approaching vessels. Some seals will approach a vessel out of apparent curiosity, including noisy vessels such as those operating airgun arrays (Moulton and Lawson 2002). Suryan and Harvey (1999) reported that Pacific harbour seals commonly left the shore when powerboat operators approached to observe them. These seals apparently detected a powerboat at a mean distance of 264 m, and seals left their haul-out sites when boats approached to within 144 m. Harbour seals hauled out on floating ice in fjords in Disenchantment Bay, Alaska, were more likely to enter the water when a cruise ship approached within 500 m (Jansen et al. 2010). Seals that were approached as close as 100 m were 25 times more likely to enter the water than those approached at 500 m. Cruise ships that approached directly vs. abeam resulted in more seals entering the water. Based on available information, some seals may avoid a vessel at rest by a few hundreds of metres, and some curious seals approach a vessel at rest. Given that behavioural impacts on ringed seals are variable and that displacement is considered temporary and in a small area, the impact of noise from a vessel at rest on ringed seal behaviour at the population level is considered insignificant or undetectable. Thus, a score of 1 was assigned.
Chronic Change	1	Though behavioural impacts have been recorded in response to noise disturbance (e.g., Brueggeman et al. 1992; see *Acute Change*, above), they are variable. Furthermore, vessels at rest are not anticipated to occur during spring (Maerospace 2020) when ringed seals are more susceptible to disturbance (i.e., during birthing, nursing of pups, and mating). Given the reduced sound levels when a vessel is at rest and the limited amount of vessels in the priority area, it is unlikely that vessels at rest would have long-term effects on ringed seals. Thus, a score of 1 was assigned.
Recovery Factors	2.3	Recovery factors = mean of the factors listed below. Fecundity: 3 (Females typically give birth to one pup a year). Early life stage mortality: 2 (Mortality could increase in the future as climate change affects the amount and suitability of ice required for important life functions [pupping, nursing; Reeves et al. 1992]). Recruitment pattern: 2 (Recruitment is variable depending on prevailing environmental conditions [Ferguson et al. 2005; Stirling 2005; Chambellant et al. 2010]).

Risk Factor	Score	Rationale
		Natural mortality rate: 3 (Mortality rates have been reported low in adult ringed seals with survivorship of 0.89 for age 6+ seals. Survivorship of age 0+ seals is reported to be much lower [0.59] [Smith 1975; Reimer et al. 2019]). Age at maturity: 3 (Best estimate of the population-wide average age at maturity is 4-7 years old [in most areas; can range from 3-9; see COSEWIC 2019]). Life stages affected: 3 (All stages). Population connectivity: 1 (Ringed seals in the Canadian Arctic are known to move extensively to different arctic regions, regularly making annual journeys that are 1,000s of kilometers). Population status: 1 (Ringed seals are considered *special concern* by COSEWIC [2019] and are not listed under SARA. The COSEWIC [2019] report does not offer insight into population trend. Ringed seals are listed as *threatened* in the USA [related to potential habitat loss], *least concern* in Greenland, no listing in Russia, and *least concern* by IUCN).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 2 × 1 = Negligible
Likelihood	2	An interaction has the potential to occur when ringed seals and a vessel at rest are present at the same time within the study area and within close enough proximity for the vessel noise to cause a disturbance to the animal. Ringed seal responses to vessel noise are variable (see *Acute Change*, above); therefore, considering the lower-intensity, less variable, and point-source sounds produced by a vessel at rest, an interaction may occur in some but not all circumstances.
Overall Risk	Low Risk	No additional management actions need to be considered at this time.
Uncertainty		
Exposure	4	It is known that vessels spend some time at rest in the Chesterfield Inlet/Narrows priority area (Maerospace 2020). Distribution and abundance information for ringed seals in the priority area is lacking. It is uncertain how many vessels will occur in the priority area in future and whether (and for how long) they will anchor near areas used by ringed seals.
Sensitivity	4	Certain aspects of ringed seals biology and their response to vessels (transiting) have been reported in other areas of the arctic, which provides some information for assessing likely behavioural response to a vessel at rest.
Likelihood	4	Studies reporting on ringed seal response to vessels at rest are lacking, though some knowledge exists from moving vessels in other areas.

Risk Statement: If an interaction occurs involving walruses and noise disturbance due to a vessel at rest the consequence could result in a negative impact on the walrus population that occurs in the Chesterfield Inlet/Narrows priority area.

Table 5-46. Walrus – Vessel at Rest (Chesterfield Inlet/Narrows) – Noise Disturbance.

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 2 x 3 = 6 (raw score)
Intensity	1	Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years

Risk Factor	Score	Rationale
		(Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Chesterfield Inlet/Narrows priority area experiences a high density of vessel traffic relative to other portions of the AOI (see Figure 2 in Maerospace 2020) representing 61% of total AIS data within the AOI from 2012-2019. Even so, it should be noted that relative to other areas that experience shipping and vessel traffic and for which biological effects literature is largely based, in absolute terms the AOI receives a low density of vessel traffic. Vessels at rest continually produce low-intensity sounds from the use of pumps, auxiliary engines, generators, and other machinery (Hannah et al. 2020). Though noise itself is not persistent in the environment once the source has been removed, AIS data indicate that vessels may remain at rest in this priority area for up to two weeks (Maerospace 2020) with common anchorages near the community of Chesterfield Inlet and at Helicopter Island near Chesterfield Narrows (Idlout 2020; Agnico Eagle 2022). The density of vessels at any one time is generally either zero or one. Considering this information, intensity was scored as 1.
Temporal	2	Based on available scientific information and Inuit Qaujimajatuqangit, walruses in the Chesterfield Inlet/Narrows priority area are likely year-round residents (Idlout 2020; Loewen et al. 2020b). Vessels (with available AIS) are typically present in the priority area during July to September, and occasionally during June (Maerospace 2020), though they may not be present throughout that entire period. A vessel may remain at rest in the priority area for several days up to two weeks (Maerospace 2020) and numerous vessels will occur in the priority area throughout the summer. This results in some overlap (25-50%) and a score of 2.
Spatial	3	Spatial = Areal x Depth = 1 x 3 = 3
Areal	1	Walrus are relatively sedentary in summer (Stewart 2008), tending to remain in areas where their food is most abundant and in water less than 80 m deep (Fay 1982; Reeves et al. 2002; Dehn et al. 2007; Lowry 2016a; COSEWIC 2017). Walrus hauled out on ice or land could also hear vessel sounds but they would not be audible as far in air as they are in water. Vessels at rest would occur only in a few specific locations in the Chesterfield Inlet/Narrows priority area. Thus, the area of overlap is a few restricted locations within the range of walrus in the priority area, resulting in a score of 1.
Depth	3	Walrus typically feed in waters <80 m deep but sometimes feed in waters up to 200 m (Fay 1982, Outridge et al. 2003; COSEWIC 2017). Sounds produced by stationary vessels would be detectable at all depths where walrus might occur, including if hauled out. Therefore, depth was scored as a 3.
Sensitivity	1 (binned)	Sensitivity= (Acute change + Chronic Change) × Recovery Factors = (1+1) × 2.1 = 4.2
Acute Change	1	Depot Island (approximately 64 km from the regular anchorage area near the community of Chesterfield Inlet) has been identified as an important haul-out site and feeding area (Idlout 2020; Loewen et al. 2020b). Though not specific to vessels at rest, walruses are known to be disturbed by anthropogenic noise; walruses at haul-out sites or on sea ice often react to loud sounds produced by moving vessels by entering the water (Salter 1979; Brueggeman 1993; Funk et al. 2013). Young animals can be injured or killed during these evacuations (Fischbach et al. 2009). However, the impacts of stationary vessels on walruses are relatively well known based on observations in the northern Chukchi Sea associated with oil and gas operations (Brueggeman 1993; Funk

Risk Factor	Score	Rationale
		et al. 2013). Walruses will approach drifting or anchored vessels and stationary drilling platforms. Being stationary, vessels would not approach walruses hauled out on land/ice so any walrus-vessel interactions would be initiated by walruses themselves. It is presumed that if walruses approached a stationary vessel, they would not be disturbed by the vessel sounds and so undetectable changes in mortality rates and limited behavioural responses relative to background variability would be expected. This results in a score of 1.
Chronic Change	1	Noise disturbance may cause indirect impacts, including interruption of foraging and social interactions (e.g., interference of mother-offspring communication or insufficient nursing of calves) and increased stress and energy expenditure (Born et al. 1995). Additionally, walruses may abandon haul-out sites after repeated exposure that may cause a shift in distribution away from preferred feeding areas (Johnson et al. 1989; Born et al. 1995), which would result in a loss of important habitat and a change in geographic range. A vessel at rest produces lower sound levels than a vessel underway (Hannah et al. 2020) and walruses are known to approach stationary vessels (Brueggeman 1993; Funk et al. 2013). Given the low density of vessel traffic, limited known haul-out sites in the Chesterfield Inlet/Narrows priority area, the distance of approximately 64 km between the community of Chesterfield Inlet (where vessels at rest are known to occur for up to two weeks) and the known haul-out site at Depot Island, and the variable behaviour of walruses in response to a stationary vessel, an insignificant or undetectable change to overall fitness compared with background variability and no impact on population dynamics would be expected, resulting in a score of 1. To note regarding habituation: Stewart et al. (2012) generally found that evidence of walrus habituation to noise disturbance from vessels and aircraft has not been sufficiently supported. Additionally, observations for walrus haul-out disturbance behaviour from one area may not be transferable to another. For example, since walruses in Canada are hunted, they tend to be more sensitive to human presence compared to other areas where they are not (Higdon et al. 2022). Øren et al. (2018) looked at the effects of tourist visitations on haul-out dynamics and site use by walruses in Svalbard, Norway and found that tourists on land and boats near the haul-out sites did not disturb walrus haul-out behaviour significantly at any of the sites, with a single exception. This perhaps suggests that habituation occurred; however, it has been suggested that this is due to the fact that walruses are not hunted in this area (Higdon et al. 2022). At Round Island, Alaska long-term datasets have suggested that Pacific walruses have not habituated to disturbance from both boats and aircraft as reactions have remained similar over a 20+ year monitoring period (DFO 2019a; Higdon et al. 2022). Habituation may therefore not occur consistently among Pacific and Atlantic walruses, populations, or individuals. Since there is potential for walruses to experience chronic stress whether they were to habituate or not in response to ship noise (Stewart et al. 2012) and since walruses in the Southampton Island AOI may respond differently to sound given that they are hunted for subsistence, the possibility of habituation was not incorporated into the risk score calculations.
Recovery Factors	2.1	Recovery factors = mean of the factors listed below. Fecundity: 3 (Adult female walrus have 1 calf every 3 years [Garlich-Miller and Stewart 1999]). Early life stage mortality: 1 (The data are sparse but the population structure and relatively high proportion of juveniles in the population suggests low mortality in all juvenile stages [Fay et al. 1997]).

Risk Factor	Score	Rationale
		Recruitment pattern: 1 (Although annual recruitment is low by some standards, recruitment seems to be consistent among years and because walrus are long lived [40 years; Kovacs and Lydersen 2006], a single female produces a lot of young over her lifetime]). Natural mortality rate: 3 (The data are sparse but the population structure and relatively high proportion of juveniles in the population suggests low mortality in all life stages [Fay et al. 1997]). Age at maturity: 3 (Average age at sexual maturity of females is 7 years [Garlich-Miller and Stewart 1999]). Life stages affected: 3 (All life stages may be affected) Population connectivity: 2 (Studies suggest that there is some interchange among Canadian Arctic walrus populations [Stewart 2008; Charette et al. 2020; Loewen et al. 2020b]). Population status: 1 (COSEWIC [2017] lists walruses as *special concern* due to threats associated with global warming. The Hudson Bay-Davis Strait stock has increased from a minimum of 3,900 in 1986 to approximately 7,000 and the authors suggest that walruses remain abundant in the Southampton Island area [Hammill et al. 2016a]).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 2 × 1 = Negligible
Likelihood	3	Walruses have a known sensitivity to disturbance from noise (Brueggeman 1993; Funk et al. 2013). However, the lower-intensity, less variable, and point-source sounds produced by a vessel at rest as well as the known behaviour of walruses in approaching a vessel at rest indicates that an interaction may occur in some but not all circumstances, resulting in a likelihood of 3.
Overall Risk	Low Risk	No additional management actions need to be considered at this time.
Uncertainty		
Exposure	4	It is known that vessels spend some time at rest in the Chesterfield Inlet/Narrows priority area (Maerospace 2020). However, important foraging and haul-out sites for walruses, which are likely year-round residents in the priority area, have only been identified at Depot Island (approximately 65 km from the known anchorage area near the community of Chesterfield Inlet). It is uncertain how many vessels will occur in the priority area in future and whether (and for how long) they will anchor near walrus haul-out sites or important feeding areas.
Sensitivity	3	The impacts of stationary vessels on walruses are relatively well known based on observations in the northern Chukchi Sea associated with oil and gas operations (Brueggeman 1993; Funk et al. 2013). Walruses will approach drifting or anchored vessels and stationary drilling platforms. There is a moderate amount of scientific information available not specific to the area.
Likelihood	3	Available shipping data (Maerospace 2020), known distribution and abundance of walruses in the Chesterfield Inlet/Narrows priority area (Idlout 2020; Loewen et al. 2020b), and studies reporting on walrus response to vessels at rest result in ranking of 3. There is a moderate amount of scientific information available, mainly from non-peer reviewed sources and first-hand observations.

Risk Statement: If an interaction occurs involving belugas and noise disturbance due to a vessel at rest the consequence could result in a negative impact on the beluga population that occurs in the Chesterfield Inlet/Narrows priority area.

Table 5-47. Beluga – Vessel at Rest (Chesterfield Inlet/Narrows) – Noise Disturbance.

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 3 x 3 = 9 (raw score)
Intensity	1	Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Chesterfield Inlet/Narrows priority area experiences a high density of vessel traffic relative to other portions of the AOI (see Figure 2 in Maerospace 2020) representing 61% of total AIS data within the AOI from 2012-2019. Even so, it should be noted that relative to other areas that experience shipping and vessel traffic and for which biological effects literature is largely based, in absolute terms the AOI receives a low density of vessel traffic. Vessels at rest continually produce low-intensity sounds from the use of pumps, auxiliary engines, generators, and other machinery (Hannah et al. 2020). Though noise itself is not persistent in the environment once the source has been removed, AIS data indicate that vessels may remain at rest in this priority area for up to two weeks (Maerospace 2020) with common anchorages near the community of Chesterfield Inlet and at Helicopter Island near Chesterfield Narrows (Idlout 2020; Agnico Eagle 2022). The density of vessels at any one time is generally either zero or one. Considering this information, intensity was scored as 1.
Temporal	3	Belugas are known to occur in the priority area in May and forage in the Narrows during summer before migrating eastward in the fall (Idlout 2020). Vessels (with available AIS) are typically present in the priority area during July to September, and occasionally during June (Maerospace 2020), though they may not be present throughout that entire period. A vessel may remain at rest in the priority area for several days up to two weeks (Maerospace 2020) and numerous vessels will occur in the priority area throughout the summer. Thus, there is a large amount of temporal overlap (50-75%) between when vessels at rest and belugas may be present, resulting in a score of 3.
Spatial	3	Spatial = Areal x Depth = 1 x 3 = 3
Areal	1	Chesterfield Inlet/Narrows priority area provides foraging habitat for belugas (Idlout 2020). Sounds may travel in water beyond the source. Vessels at rest would occur only in a few specific locations in the Chesterfield Inlet/Narrows priority area. Thus, the area of overlap is a few restricted locations within the range of belugas in the priority area, resulting in a score of 1.
Depth	3	Belugas regularly forage at depths of 100s of metres (Martin et al. 1998; Watt et al. 2016), with some dives to depths greater than 800 m (Heide-Jørgensen et al. 1998; Richard et al. 2001). Sounds produced by stationary vessels would be detectable and may elicit a response at all water depths where belugas may feed in the priority area, resulting in a score of 3.
Sensitivity	1 (binned)	Sensitivity= (Acute change + Chronic Change) × Recovery Factors = (1+1) × 2.4 = 4.8
Acute Change	1	Direct mortality to belugas would not be expected to occur because of exposure to sounds produced by a resting vessel. Belugas can react to low sound levels from a vessel at long distances (Finley et al. 1990; Richardson et

Risk Factor	Score	Rationale
		al. 1995a), suggesting that at times they may be extremely sensitive to sounds that they are not familiar with, and may exhibit a startle response. They are known to react to underwater vessel noise produced multiple kilometers away by altering swim speed, direction, and behaviour (Finley et al. 1990; Heide-Jørgensen et al. 2021). However, a vessel at rest produces lower-intensity and less variable sounds than a vessel underway (Hannah et al. 2020). Additionally, it has been reported that although beluga responses to a vessel at rest are variable, they sometimes approach vessels (DFO 2023a). No expected mortality and limited behavioural responses result in a score of 1.
Chronic Change	1	Belugas exhibit variable responses to vessel noise (see *Acute Change*, above). Though research on chronic effects of vessel noise, particularly vessels at rest, on belugas is very limited (Erbe et al. 2019), it is plausible that beluga may experience chronic impacts in certain contexts. However, given the low density of vessels in the priority area, considering that a vessel at rest produces lower-intensity sounds than a vessel underway (Hannah et al. 2020), and that belugas may sometimes approach vessel at rest, chronic change was scored as a 1.
Recovery Factors	2.4	Recovery factors = mean of the factors listed below. Fecundity: 3 (Adult female belugas have 1 calf every 3 years [Sergeant 1973; Matthews and Ferguson 2015]). Early life stage mortality: Unknown; excluded from analyses (There are no data on mortality rates in juvenile belugas). Recruitment pattern: 2 (Although annual recruitment is low by some standards, belugas live to be about 70 years old assuming a single growth layer is formed in their teeth in a year [Waugh et al. 2018: Vos et al. 2020]. The maximum longevity may be 100 years [Harwood 2002]. Because of their longevity, a single female could produce a lot of young over her lifetime even if they become reproductively senescent at 35-40 years old, as suggested by Hobbs et al. [2015] and Ellis et al. [2018]). Natural mortality rate: 3 (The natural mortality rate of belugas must be low if they live to ~70 years old. Ice entrapments of belugas are known to recur in the Canadian High Arctic and in northern Foxe Basin [Smith and Sjare 1990]. Polar bears and Inuit hunters take advantage of these incidents to harvest belugas. The proportion of mortality in these situations that is attributable to predation is not well documented and remains debatable [Kilabuk 1998]. Age at maturity: 3 (Average age at sexual maturity of female belugas is 6-14 years [COSEWIC 2020]). Life stages affected: 3 (It is likely that all life stages of belugas will be affected). Population connectivity: 2 (The Western Hudson Bay population that occurs in the AOI overlaps with the Eastern Hudson Bay and Ungava Bay beluga populations in Hudson Strait during winter.) Population status: 1 (IUCN classifies the beluga whale as *near threatened*. COSEWIC [2020] lists the Western Hudson Bay population that occurs in the AOI as *least concern*]).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 2 × 1 = Negligible
Likelihood	3	Belugas are know to react to vessel noise in some situations but not in others (see *Acute Change*, above). The lower-intensity, less variable, and point source sounds produced by a vessel at rest compared with a vessel underway suggests that an interaction could occur in some but not all circumstance and a score of 3.
Overall Risk	Low Risk	No additional management actions need to be considered at this time.

Risk Factor	Score	Rationale
Uncertainty		
Exposure	4	It is known that vessels transit and spend some time at rest in the priority area (Maerospace 2020). The propagation of noise in water from vessels at rest is poorly studied as is the distance and depth at which belugas might exhibit a response.
Sensitivity	4	There is uncertainty about how exposure to sounds from resting vessels affects beluga behaviour and health. Although a resting vessel is much quieter than one underway, sensitivity to occasional loud sounds from a resting vessel could be more disturbing to belugas than a steady louder sound because of a startle response.
Likelihood	4	Uncertainty exists in evaluating the likelihood of belugas being exposed to loud sounds by a stationary vessel in the priority area because there is limited information on what types and characteristics of sounds elicit behavioural responses in belugas. However, disturbances are known from noise generated by moving vessels in other areas.

Risk Statement: If an interaction occurs involving narwhals and noise disturbance due to a vessel at rest the consequence could result in a negative impact on the narwhal population that occurs in the Chesterfield Inlet and Narrows priority area.

Table 5-48. Narwhal – Vessel at Rest (Chesterfield Inlet/Narrows) – Noise Disturbance.

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 3 x 3 = 9 (raw score)
Intensity	1	Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Chesterfield Inlet/Narrows priority area experiences a high density of vessel traffic relative to other portions of the AOI (see Figure 2 in Maerospace 2020) representing 61% of total AIS data within the AOI from 2012-2019. Even so, it should be noted that relative to other areas that experience shipping and vessel traffic and for which biological effects literature is largely based, in absolute terms the AOI receives a low density of vessel traffic. Vessels at rest continually produce low-intensity sounds from the use of pumps, auxiliary engines, generators, and other machinery (Hannah et al. 2020). Though noise itself is not persistent in the environment once the source has been removed, AIS data indicate that vessels may remain at rest in this priority area for up to two weeks (Maerospace 2020) with common anchorages near the community of Chesterfield Inlet and at Helicopter Island near Chesterfield Narrows (Idlout 2020; Agnico Eagle 2022). The density of vessels at any one time is generally either zero or one. Considering this information, intensity was scored as 1.
Temporal	3	Narwhals migrate into Repulse Bay in June and July, with some continuing down the west coast of Hudson Bay, and leave the area in August and September through Frozen Strait (Westdal et al. 2010); some narwhal are expected to occur in the Chesterfield Inlet/Narrows priority area during summer (DFO 2020a). Vessels (with available AIS) are typically present in the priority

Risk Factor	Score	Rationale
		area during July to September, and occasionally during June (Maerospace 2020), though they may not be present throughout that entire period. A vessel may remain at rest in the priority area for several days up to two weeks (Maerospace 2020) and numerous vessels will occur in the priority area throughout the summer. Thus, there is a large amount of temporal overlap (50-75%) between when vessels at rest and narwhals may be present, resulting in a score of 3.
Spatial	3	Spatial = Areal x Depth = 1 x 3 = 3
Areal	1	Narwhals are expected to forage in summer throughout the priority area with the exception of most of the Narrows (DFO 2020a). Sounds may travel in water beyond the source. Vessels at rest would occur only in a few specific locations in the Chesterfield Inlet/Narrows priority area, generally near the community. Thus, the area of overlap is a few restricted locations within the range of narwhals in the priority area, resulting in a score of 1.
Depth	3	Sounds produced by stationary vessels would be detectable and may elicit a response at all water depths where narwhals might be feeding, which typically is <500 m (Heide-Jørgensen and Dietz 1995; Laidre et al. 2003). Thus, a score of 3 was assigned.
Sensitivity	2 (binned)	Sensitivity= (Acute change + Chronic Change) × Recovery Factors = (1+1) × 2.5 = 5.0
Acute Change	1	Direct mortality to narwhals would not be expected to occur because of exposure to sounds produced by a resting vessel. Narwhals rely on acoustic communication for critical life functions (Shapiro 2006) and are known to react to underwater vessel noise produced multiple kilometers away by altering swim speed, direction, and behaviour (Finley et al. 1990; Heide-Jørgensen et al. 2021). Narwhals reacted to low sound levels from a vessel at long distances (Finley et al. 1990; Richardson et al. 1995a), suggesting that at times they may be extremely sensitive to sounds that they are not familiar with, and may exhibit a startle response. However, a vessel at rest produces lower-intensity and less variable sounds than a vessel underway (Hannah et al. 2020). No expected mortality and limited behavioural response result in a score of 1.
Chronic Change	1	Noise disturbance is known to affect narwhals (see *Acute Change*, above). Though research on chronic effects of vessel noise, particularly vessels at rest, on narwhals is very limited (Erbe et al. 2019; Halliday et al. 2022), it is plausible that narwhals may experience chronic impacts in certain contexts. However, given the low density of vessels in the priority area and considering that a vessel at rest produces lower-intensity sounds than a vessel underway (Hannah et al. 2020), chronic change was scored as a 1.
Recovery Factors	2.5	Recovery factors = mean of the factors listed below. Fecundity: 3 (Adult female narwhals have a calf about every 3 years [Garde et al. 2015]). Early life stage mortality: 2 (Few data on first year mortality of narwhal calves are available. Koski and Davis [1994] estimated that 17% of calves died when between 1 and 13 months of age; this is lower than for many other marine mammal species]). Recruitment pattern: 2 (Although annual recruitment is low by some standards, recruitment seems to be consistent among years and because narwhals are long lived [80 years; Garde et al. 2015], a single female can produce a lot of young over her lifetime]).

Risk Factor	Score	Rationale
		Natural mortality rate: 3 (The data are sparse but the stable population size with the removals by subsistence hunters suggests low mortality in all life stages). Age at maturity: 3 (Age at sexual maturity of females is 6-9 years and older for males [Garde et al. 2015]). Life stages affected: 3 (All life stages are likely to be affected. An adult female accompanied by a yearling was seen in the AOI [Carlyle et al. 2021]). Population connectivity: 3 (Studies suggest that there is limited interchange among Canadian Arctic narwhal populations [Westdal et al. 2010; Heide-Jørgensen et al. 2013a; Doniol-Valcroze et al. 2020]). Population status: 1 (IUCN classifies narwhals as *least concern* [Lowry et al. 2017]. The last COSEWIC assessment is outdated [from 2004]. Narwhal populations are considered stable [Furgal and Laing 2012; Lowry et al. 2017]).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 2 × 2 = Low
Likelihood	3	Narwhals have a known sensitivity to disturbance from vessel noise (Finley et al. 1990; Heide-Jørgensen et al. 2021). However, the lower-intensity, less variable, and point source sounds produced by a vessel at rest compared with a vessel underway suggests that an interaction could occur in some but not all circumstance and a score of 3.
Overall Risk	Moderate Risk	Additional management measures should be considered, such as limiting noise generation while vessels are at rest or working to find more sheltered anchoring locations.
Uncertainty		
Exposure	4	It is known that vessels transit and spend some time at rest in the priority area (Maerospace 2020). It is uncertain how many vessels will occur in the priority area in future and whether (and for how long) they will anchor near important narwhal areas.
Sensitivity	4	The reactions of narwhals to a resting vessel have not been studied so there is a great deal of uncertainty about how exposure to sounds from resting vessels affects their behaviour and health. Although a resting vessel is much quieter than one underway, sensitivity to occasional loud sounds from a resting vessel could be more disturbing to narwhals than a steady louder sound because of a startle response.
Likelihood	4	Uncertainty exists in evaluating the likelihood of narwhals being exposed to loud sounds by a stationary vessel in the priority area because there is limited information on what types and characteristics of sounds elicit behavioural responses in narwhals. However, disturbances are known from noise generated by moving vessels in other areas.

Risk Statement: If an interaction occurs involving bowhead whales and noise disturbance due to a vessel at rest the consequence could result in a negative impact on the bowhead whale population that occurs in the Fisher and Evans Straits priority area.

Table 5-49. Bowhead Whale – Vessel at Rest (Fisher and Evans Straits) – Noise Disturbance.

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 2 x 3 = 6 (raw score)

Risk Factor	Score	Rationale
Intensity	1	Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Fisher and Evans Straits priority area experiences a higher density of vessel traffic relative to other priority areas except Chesterfield Inlet/Narrows (see Figures 5-1 and 5-10), representing 9.5% of total AIS data within the AOI from 2012-2019. Even so, it should be noted that relative to other areas that experience shipping and vessel traffic and for which biological effects literature is largely based, in absolute terms the AOI receives a low density of vessel traffic. Vessels at rest continually produce low-intensity sounds from the use of pumps, auxiliary engines, generators, and other machinery (Hannah et al. 2020). Though noise itself is not persistent in the environment once the source has been removed, AIS data indicate that vessels may remain at rest in this priority area for up to one week and more commonly a few days (Maerospace 2020) with common anchorages near the community of Coral Harbour. Multiple vessels are not commonly at rest in the area at one time. Considering this information, intensity was scored as 1.
Temporal	2	Based on scientific studies and current Inuit Qaujimajatuqangit, bowheads occur in the Fisher and Evans Straits priority area from April to November but primarily occur there during summer to feed and calve (Idlout 2020; Loewen et al. 2020b). Vessels are typically present in the priority area during July to October, and very occasionally during June and November (Maerospace 2020), though they may not be present throughout that entire period. AIS data indicate that vessels may remain at rest in this priority area for up to one week and more commonly a few days, which will occur a few times per summer (Maerospace 2020). Therefore, there is some temporal overlap (25-50%) between when vessels at rest and bowheads may be present, resulting in a score of 2.
Spatial	3	Spatial = Areal x Depth = 1 x 3 = 3
Areal	1	Bowhead whales are expected to primarily occur in the Fisher and Evans Straits priority area during the summer and can occur throughout the priority area. Nearshore areas around SE SI in Evans Strait are known calving and nursery grounds (DFO 2020; Idlout 2020; Loewen et al. 2020b). Sounds may travel in water beyond the source. Vessels at rest would occur only in a few specific locations in the priority area, likely near the community of Coral Harbour. Thus, the area of overlap is a few restricted locations within the range of bowheads in the priority area, resulting in a score of 1.
Depth	3	Bowheads in the eastern Canadian Arctic routinely conduct foraging dives >100 m with maximum depths exceeding 650 m (Fortune et al. 2020). Sounds produced by stationary vessels would be detectable and may elicit a response at all water depths where bowheads may occur, resulting in a score of 3.
Sensitivity	1 (binned)	Sensitivity= (Acute change + Chronic Change) × Recovery Factors = (1+1) × 2.3 = 4.6
Acute Change	1	The Fisher and Evans Straits priority area is considered important summering habitat for bowheads where they forage; the nearshore waters of SE SI in Evans Strait are calving/nursing grounds (see Figure 26 in DFO 2020).

Risk Factor	Score	Rationale
		Direct mortality to bowheads would not be expected to occur because of exposure to sounds produced by a vessel at rest. Bowhead whale responses to industrial activity, including shipping, are variable; as with other cetaceans, they appear to depend on the whale's activity, its habitat, and the type of industrial activity. There have been no specific systematic studies of bowhead response to vessels at rest, but bowheads have exhibited more obvious behavioural responses to approaching vessels versus vessels which are not approaching, and which are travelling at slower speeds. For example, Wartzok et al. (1989) noted that bowheads often approached small ships within 100-500 m when the vessel was not moving toward them. Bowheads begin to avoid approaching vessels at distances of 4 km or greater, where received levels are as low as 84 dB re 1 µPa (Richardson et al. 1995a). If a vessel approaches within several hundred metres, the avoidance response usually is conspicuous: the whale may increase its swimming speed, attempt to out-swim the vessel or change direction to swim perpendicularly away from the vessel's path, or decrease its time at the surface (Richardson et al. 1985a, b, 1995a; Richardson and Malme 1993). Koski and Johnson (1987) reported that bowheads 1-2 km from a supply vessel swam rapidly away to distances of 4-6 km from the vessel track; displaced individuals returned to feeding locations within one day. If the vessel travels slowly, bowhead whales often are more tolerant, and may show little or no reaction, even when the vessel is within several hundred metres (e.g., Richardson and Finley 1989; Wartzok et al. 1989). This is especially so when the vessel is not directed toward the whale and when there are no sudden changes in direction or engine speed (Wartzok et al. 1989; Richardson et al. 1995a). Bowhead whales engaged in social interactions or mating may be less responsive than other bowheads (Wartzok et al. 1989). Also, bowheads engaged in foraging seem less responsive to anthropogenic noise. Given the low density of vessels in the priority area and the lower-intensity and less variable sounds produced by a vessel at rest (Hannah et al. 2020), no expected mortality and limited behavioural response by bowheads result in a score of 1.
Chronic Change	1	Research on chronic effects of vessel noise on marine mammals is very limited (Erbe et al. 2019; Halliday et al. 2022). However, bowheads are not expected to exhibit a strong behavioural response to a vessel at rest (see *Acute Change*, above). Given this and the low density of vessels in the priority area, and considering that a vessel at rest produces lower-intensity sounds than a vessel underway (Hannah et al. 2020), chronic change was scored as a 1.
Recovery Factors	2.3	Recovery factors = mean of the factors listed below. Fecundity: 3 (Adult female bowheads have 1 calf every 3-4 years [Miller et al. 1992; Koski et al. 1993; Tarpley et al. 2016, 2021]). Early life stage mortality: Unknown; excluded from consideration (There are no data on mortality rates in juvenile bowheads). Recruitment pattern: 1 (Although annual recruitment is low by some standards, bowhead pregnancies seem to be determined by the health of the prospective mother to maximize survival of the calf [W. Koski, pers. comm., 2022]. Because bowheads live to be about 200 years old, a single female produces a lot of young over her lifetime [Tarpley et al. 2016, 2021]). Natural mortality rate: 3 (The mortality rate of adult bowheads is extremely low, possibly the lowest of any animal. Survival has been estimated as 0.984 [0.948-1.00; Zeh et al. 2002] to 0.996 [0.976-1.00, Givens et al. 2018]). Age at maturity: 3 (Average age at sexual maturity of female bowheads is about 25 years [Koski et al. 1993; George et al. 1999] and appears to have declined in recent years [Tarpley et al. 2021]).

Risk Factor	Score	Rationale
		Life stages affected: 3 (All life stages are expected to be affected by this stressor). Population connectivity: 2 (The EC-WG population of bowhead whales occur in the AOI. Until recently, the geographic distributions of the EC-WG and BCB bowhead populations were significantly different so that there was little or no overlap between the populations [Zeh et al. 1995]. With the opening of the NW passage resulting from climate change, interchange between these two populations is possible, as suggested by a sighting of two satellite tagged bowheads from the two populations in the same general area in the High Arctic [Heide-Jørgensen et al. 2011]). Population status: 1 (IUCN classifies the EC-WG bowhead whale population as *least concern* [Cooke and Reeves 2018]. COSEWIC (2009) classifies them as *threatened*; however, that status report is out of date and is currently being reviewed. Recent surveys indicate that the population has increased since commercial overharvesting ended in the early 1900s. They may have increased to the point where this population has reached the carrying capacity of their habitat, based on sightings of skinny whales and apparent natural mortality in Cumberland Sound [Young et al. 2019] and recent cases of apparent natural mortality in other areas [DFO unpublished data]).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 2 × 1 = Negligible
Likelihood	2	Bowhead responses generally to vessel noise are variable (see *Acute Change*, above) with available information indicating that bowhead responses to vessels at rest are also variable. Considering the lower-intensity, less variable, and point source sounds produced by a vessel at rest compared with a vessel underway an interaction is unlikely to occur resulting in a score of 2.
Overall Risk	Low Risk	No additional management actions need to be considered at this time.
Uncertainty		
Exposure	4	It is known that vessels transit and spend some time at rest in the priority area (Maerospace 2020). It is uncertain how many vessels will occur in the priority area in future and whether (and for how long) they will anchor near important bowhead areas. Information exists on the occupancy of bowheads in the priority area.
Sensitivity	4	The reactions of bowheads to a resting vessel have not been studied so there is a great deal of uncertainty about how exposure to sounds from resting vessels affects their behaviour and possible health. Although a resting vessel is much quieter than one underway, sensitivity to occasional loud sounds from a resting vessel could be more disturbing to bowheads than a steady louder sound because of a startle response.
Likelihood	4	Uncertainty exists in evaluating the likelihood of bowheads being exposed to loud sounds by a stationary vessel in the priority area because there is limited information on what types and characteristics of sounds elicit behavioural responses in bowheads. However, some studies have occurred on bowhead responses to noise generated by moving vessels in other areas.

5.3.2 Disturbance from Artificial Light

The introduction of artificial light is known to affect marine biota, especially in environments that receive limited natural light. In contrast to a similar pathway from vessels underway, exposure to artificial light from vessels at rest occurs within a restricted space over a potentially prolonged period which may result in differing effects. Arctic zooplankton have demonstrated a strong light-escape response when exposed to artificial light (Ludvigsen et al. 2018) and zooplankton were assessed

(Table 5-50). The effects of artificial light from vessels at rest are unlikely to have a measurable impact on marine mammals (Greer et al. 2010). In the Arctic, many marine fishes have adapted to living in darkness and the effect of artificial light on their behaviour is not well understood (Hammerschlag et al. 2017); for this reason, the ecological risk of light attraction for Arctic cod and Arctic char have been undertaken, with the understanding that there would be prolonged daylight during the period that vessel traffic is present in the area (i.e., mainly July to September and potentially June or November). The Arctic cod assessment will act as a proxy for other forage fish. Some seabirds, particularly petrels, have a known attraction to light (Montevecchi 2006; Rodriguez et al. 2015) and disorientation/contact is expected to negatively impact survival (assuming no mitigation measures are in place), even if a collision is not immediately lethal (Ryan 1991; Black 2005; Kingsley 2006; Bocetti 2011). Resident and especially migrating seabirds may also become disoriented and undergo a holding effect, whereby they encircle a lighted structure for an unnatural period of time, depleting their energy reserves (Montevecchi 2006; Ronconi et al. 2015); this has mainly been documented with oil and gas platforms. However, petrels do not occur in the AOI and negative effects from attraction to artificial light is not known for the species that do occur in the AOI. Therefore, seabirds were not assessed for this stressor.

Table 5-50. Vessels at Rest – Disturbance from Artificial Light: ESC Subcomponents and Priority Areas Assessed.

ESC Subcomponent	Priority Area	Assessed by Proxy
Zooplankton	Chesterfield Inlet/Narrows	
Arctic cod	Chesterfield Inlet/Narrows	
Arctic char	Chesterfield Inlet/Narrows	
Other forage fish		Via Arctic cod

Risk Statement: If an interaction occurs involving zooplankton and disturbance from artificial light due to a vessel at rest the consequence could result in a negative impact on zooplankton populations in the Chesterfield Inlet/Narrows priority area.

Table 5-51. Zooplankton – Vessel at Rest (Chesterfield Inlet/Narrows) – Disturbance from Artificial Light.

Risk Factor	Score	Rationale
Exposure	1 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 2 = 2 (raw score)
Intensity	1	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low absolute density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Chesterfield Inlet/Narrows priority area experiences a high density of vessel traffic relative to other portions of the AOI (see Figure 2 in Maerospace 2020) representing 61% of total AIS data within the AOI from 2012-2019, though those at rest make up a smaller proportion of that total. Vessels at rest maintain the use of navigational safety lights at all times but the extended period of daylight that occurs during June and July means that more powerful lights associated with nighttime deck lighting would either not be in use or would have limited use and there would generally be a minimal difference

Risk Factor	Score	Rationale
		between ambient light levels and those introduced by the vessel. During the latter half of the shipping season in August and September there would be periods of darkness and the more powerful deck lighting would be in use for a portion of the day. AIS data indicate that vessels may remain at rest in this priority area for up to two weeks (Maerospace 2020) with common anchorages near the community of Chesterfield Inlet and at Helicopter Island near Chesterfield Narrows (Idlout 2020; Agnico Eagle 2022). Considering this information, intensity was scored as 1.
Temporal	1	Zooplankton may occur in the Chesterfield Inlet/Narrows priority area year-round. Vessels (with available AIS) are typically present in the priority area during July to September, and occasionally during June (Maerospace 2020), though they are not present throughout that entire period. A vessel may remain at rest in the priority area for several days up to two weeks and numerous vessels will occur in the priority area throughout the summer (Maerospace 2020). Additionally, June and July have extended periods of daylight which would further limit the use of powerful deck lighting. This results in very little overlap (<25%) between when a vessel at rest and zooplankton are present and a score of 1.
Spatial	2	Spatial = Areal x Depth = 1 x 2 = 2
Areal	1	Zooplankton are expected to be distributed throughout the Chesterfield Inlet/Narrows priority area. Artificial light would occur within a restricted area within zooplankton range in the priority area, at the location of a vessel at rest. This results in a score of 1.
Depth	2	Depending on the species and life stage, zooplankton may inhabit the entire water column depth of the Chesterfield Inlet/Narrows priority area (e.g., sub-adult stages of the copepod *Calanus finmarchicus* have been recorded to descend to depths >2,000 m in a dormant state of diapause during the winter [Jónasdóttir et al. 2022; Kville et al. 2022]). Artificial light from routine vessel operations may extend to at least 200 m depth in open water (Berge et al. 2020). Water depths in the priority area are generally <200 m (see Figure 16 in DFO 2020). However, as light penetration into the water column would attenuate with depth and because the extended period of daylight that occurs during a portion of the time when vessels would be present would generally result in minimal difference between ambient light levels and those produced artificially, depth was scored as 2.
Sensitivity	1 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (1 + 1) x 1.3 = 2.6
Acute Change	1	Artificial light can affect marine biota in environments that typically receive limited natural light (Berge et al. 2020). In ice-free areas, artificial vessel lighting may impact zooplankton behaviour to depths of at least 200 m and within 0.125 km^2 of the vessel (Berge et al. 2020). During nighttime periods, krill have demonstrated avoidance of artificial vessel light on the Scotian Shelf (Berge et al. 2020). Berge et al. (2020) reported that zooplankton changed orientation when exposed to artificial light and descended up to 18 m (zooplankton communities dominated by krill) and 27 m (predominantly northern shrimp) in the water column. Arctic zooplankton, especially krill, have been found to undergo diel vertical migrations during polar night and civil twilight, and there is some evidence that suggests these migrations also occur during nautical polar night and in response to lunar light (Ludvigsen et al. 2018). Observations of Arctic zooplankton during January in Kongsfjorden, Svalbard indicated that in the absence of artificial light, zooplankton performed synchronous diel vertical migrations within the upper 30 m of the water column in response to ambient light, and the presence of artificial vessel light caused a strong light-escape response down to 100 m depth by most of the zooplankton community (Ludvigsen et al. 2018; Marangoni et al. 2022). However, the affected zooplankton rapidly resumed their normal distribution upon cessation

Risk Factor	Score	Rationale
		of artificial vessel light (Ludvigsen et al. 2018). Geoffroy et al. (2021) similarly observed strong avoidance behaviour by pelagic Arctic and temperate zooplankton to artificial white, blue, and red lights from scientific instruments lowered into the water column. Given the relatively low vessel traffic in the priority area and that artificial light would be emanating from a single point source (and therefore, very localized), there could be limited short-term physiological and/or behavioural impacts from artificial light on zooplankton in the Chesterfield Inlet/Narrows priority area, but such effects would be expected to ultimately be insignificant or undetectable relative to background variability, resulting in a score of 1.
Chronic Change	1	Exposure to artificial light from a vessel at rest would occur within a limited area and may occur for a period of up to two weeks. Although long-term effects are possible, zooplankton have demonstrated the ability to recover quickly from this stressor once eliminated (Ludvigsen et al. 2018). No detectable changes to overall fitness are expected based on the low density of vessel traffic in the priority area, resulting in a score of 1.
Recovery Factors	1.3	At least 65 species/taxonomic groups of zooplankton have been documented to occur within or near the AOI (Loewen et al. 2020a). There were more copepod and amphipod species/taxonomic groups than any other zooplankton taxa (Loewen et al. 2020a), suggesting that these species may serve an important function in the AOI's marine food web. Of these species, the copepod *Calanus finmarchicus* is the most well studied and is a key species in the broader region's pelagic ecosystem (Rubao et al. 2012; Jónasdóttir et al. 2022); therefore, it was used for the determination of Recovery Factors. There have been no dedicated baseline studies for the Chesterfield Inlet/Narrows priority area; therefore, information is provided here for the AOI to represent the priority area. Recovery factors = mean of the factors listed below. Fecundity: 1 (Females of the copepod *C. finmarchicus* may produce 250 eggs [Sameoto and Herman 1990]). Early life stage mortality: 1 (During the winter, sub-adult *C. finmarchicus* descend into the mesopelagic zone in a dormant state of diapause [Jónasdóttir et al. 2022]. Most predation on *C. finmarchicus* occurs on adults upon the arrival of migratory fish in synchronicity with the spring bloom [Kaartvedt 2000]). Recruitment pattern: 1 (The copepod *C. finmarchicus* may produce two to four generations in a single year [Sameoto and Herman 1990]). Natural mortality rate: 1 (Zooplankton are primary prey sources for organisms higher in the Arctic marine food web. Various Arctic fish species attune their migratory activities to copepod productivity, particularly towards the abundance of the lipid-rich *C. finmarchicus* [Jónasdóttir et al. 2022]). Age at maturity: 1 (The copepod *C. finmarchicus* matures in <1 year [Sameoto and Herman 1990]). Life stages affected: 3 (All life stages could potentially occur in the AOI). Population connectivity: Unknown; excluded from consideration. Population status: 1 (Not listed under SARA, COSEWIC, or IUCN. Population presumed stable due to importance of AOI as a feeding area for organisms higher in the marine food web [DFO 2020]).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 1 x 1 = Negligible
Likelihood	3	An interaction has the potential to occur during summer/fall when zooplankton and a vessel at rest emitting artificial light are present at the same time in the Chesterfield Inlet/Narrows priority area and within close enough proximity for the

Risk Factor	Score	Rationale
		light to cause a disturbance to the zooplankton. Depending on ambient light levels and the species, life stage/behavioural state, and distance of the zooplankton to the vessel, an interaction may occur in some but not all circumstances.
Overall Risk	Low Risk	No additional management actions need to be considered at this time. However, as a precautionary measure, lighting for a vessel at rest could be minimized to the extent allowable within safety parameters.
Uncertainty		
Exposure	5	The spatial extent of artificial light in open and ice-covered waters from vessels at rest is poorly understood for the Chesterfield Inlet/Narrows priority area. General vessel traffic patterns are known. Some information exists to identify important areas and times for zooplankton, based on phytoplankton blooms.
Sensitivity	5	Studies on zooplankton communities in the AOI are limited and there are no reports for zooplankton abundance or species diversity for Chesterfield Inlet, or for ice floe edge zooplankton and sympagic amphipods in the AOI (DFO 2020; Loewen et al. 2020b), though some information exists for the AOI as a whole.
Likelihood	5	Additional research is needed on the response of zooplankton to artificial light, though some exists from other areas.

Risk Statement: If an interaction occurs involving Arctic cod and disturbance from artificial light due to a vessel at rest the consequence could result in a negative impact on Arctic cod populations in the Chesterfield Inlet/Narrows priority area.

Table 5-52. Arctic cod – Vessel at Rest (Chesterfield Inlet/Narrows) – Disturbance from Artificial Light.

Risk Factor	Score	Rationale
Exposure	1 (binned)	Exposure = Intensity x Temporal x Spatial (Depth x Areal) = 1 x 1 x 2 = 2 (raw score)
Intensity	1	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low absolute density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Chesterfield Inlet/Narrows priority area experiences a high density of vessel traffic relative to other portions of the AOI (see Figure 2 in Maerospace 2020) representing 61% of total AIS data within the AOI from 2012-2019, though those at rest make up a smaller proportion of that total. Vessels at rest maintain the use of navigational safety lights at all times but the extended period of daylight that occurs during June and July means that more powerful lights associated with nighttime deck lighting would either not be in use or would have limited use and there would generally be a minimal difference between ambient light levels and those introduced by the vessel. During the latter half of the shipping season in August and September there would be periods of darkness and the more powerful deck lighting would be in use for a portion of the day. AIS data indicate that vessels may remain at rest in this priority area for up to two weeks (Maerospace 2020) with common anchorages near the community of Chesterfield Inlet and at Helicopter Island near Chesterfield Narrows (Idlout 2020; Agnico Eagle 2022). Considering this information, intensity was scored as 1.

Risk Factor	Score	Rationale
Temporal	1	Arctic cod are expected to occur in the area year-round. Vessels (with available AIS) are typically present in the priority area during July to September, and occasionally during June (Maerospace 2020), though they are not present throughout that entire period. A vessel may remain at rest in the priority area for several days up to two weeks and numerous vessels will occur in the priority area throughout the summer (Maerospace 2020). Additionally, June and July have extended periods of daylight which would further limit the use of powerful deck lighting. This results in very little overlap (<25%) between when a vessel at rest and Arctic cod are present and a score of 1.
Spatial	2	Spatial = Areal x Depth = 1 x 2 = 2
Areal	1	A ubiquitous species, Arctic cod occupy coastal and offshore waters in areas with and without sea ice and are expected to be widespread throughout the Arctic Ocean (Coad and Reist 2018). Arctic cod distribution in the Chesterfield Inlet/Narrows priority area is not currently known; however, nearshore areas have been identified as potentially important habitats for this species (Loewen et al. 2020b), and Arctic cod were among the most common marine fish families observed from sample stations ranging between Coral Harbor and Chesterfield Inlet during a 2019 GenICE research cruise (DFO 2020). Artificial light would occur within a restricted area within the total Arctic cod range in the priority area, at the location of a vessel at rest. This results in a score of 1.
Depth	2	Arctic cod are widespread across the circumpolar Arctic, but they occur at different depths throughout the water column based on factors such as life history stage (e.g., Geoffroy et al. 2016), seasonal diet (e.g., Majewski et al. 2016), and light regime (e.g., Benoit et al. 2010). Eggs and larvae concentrate under the sea ice. During the Arctic polar night, artificial light from routine vessel operations may extend to at least a depth of 200 m in open water (Berge et al. 2020). However, as light penetration into the water column would attenuate with depth and because the extended period of daylight that occurs during a portion of the time when vessels would be present would generally result in minimal difference between ambient light levels and those produced artificially, depth was scored as a 2.
Sensitivity	1 (binned)	Sensitivity = (Acute change + Chronic Change) x Recovery Factors = (1 + 1) x 1.9 = 3.8
Acute Change	1	Artificial light can affect marine biota in environments that typically receive limited natural light (Berge et al. 2020). Depending on the species, artificial light may attract or repel pelagic organisms (Berge et al. 2020; Geoffroy et al. 2021). Zooplankton and perhaps fish can also detect changes in light intensity under the ice (Cohen et al. 2015; Tarling 2015). In arctic environments, many fishes have adapted to living in darkness under the cover of ice, but the effect of artificial light on their behaviour is not well understood (Hammerschlag et al. 2017). However, artificial light can affect the physiology and behaviour of fish (Nightingale et al. 2006; Berge et al. 2020; Geoffrey et al. 2021). Berge et al. (2020) reported that fish changed orientation when exposed to artificial light, descending up to 18-27 m in the water column. Physiological and genomic changes associated with circadian rhythms have been reported for fish exposed to artificial light during darkness cycles (López-Olmeda et al. 2013; Lazado et al. 2014; Kopperud and Grace 2017). Newman et al. (2015) did not detect any stress responses when they exposed Atlantic salmon to artificial light, while Szekeres et al. (2017) did report physiological effects when juvenile bonefish were exposed to artificial light, although no changes in behaviour were observed. Arctic cod show diel vertical migrations synchronized with light/dark cycles (Benoit et al. 2010; Geoffroy et al. 2011), which could be impacted by artificial light. They have also been shown to

Risk Factor	Score	Rationale
		aggregate at greater depth when light intensity increases with the seasons, likely to avoid predators (Geoffroy et al. 2011). Although there could be physiological and/or behavioural impacts (e.g., avoidance) for Arctic cod, due to the overall low level of vessel traffic, limited duration of a vessel at rest, and minimal difference between ambient and artificial light while vessels would be present in the Chesterfield Inlet/Narrows priority area, such impacts would be expected to be insignificant or undetectable against background variability, resulting in a score of 1.
Chronic Change	1	Physiological and genomic changes associated with circadian rhythms have been reported for fish exposed to artificial light during darkness cycles (López-Olmeda et al. 2013; Lazado et al. 2014; Kopperud and Grace 2017). Exposure to artificial light from vessels at rest occurs within a limited area and would be unlikely to occur for an extended period of time (typically only a few days). Based on the low number of vessels that would be at rest and emitting artificial light in the Chesterfield Inlet/Narrows priority area, no detectable changes to overall fitness are expected, resulting in a score of 1.
Recovery Factors	1.9	Recovery factors = mean of the factors listed below. Fecundity: 2 (Spawn only once in their lifetime with a relatively low number of eggs; between 9,000 to 21,000 eggs are produced, with an average of 11,900 per female [Cohen et al. 1990]). Early life stage mortality: 3 (R-selected species with high mortality [Coad and Reist 2018]). Recruitment pattern: 2 (Increased recruitment expected with climate change [LeBlanc et al. 2019]). Natural mortality rate: 1 (Mortality is high [Coad and Reist 2018]). Age at maturity: 2 (2-3 years for males and 3-4 years for females [Coad and Reist 2018]). Life stages affected: 3 (All life stages could potentially occur in the area). Population connectivity: 1 (Arctic cod range widely throughout the Arctic). Population status: 1 (IUCN classification is *least concern* [Fernandes et al. 2015], but population trend is unknown. Abundant in Arctic marine waters [Coad and Reist 2018]).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 1 x 1 = Negligible
Likelihood	3	An interaction has the potential to occur when Arctic cod and a vessel are present at the same time within the Chesterfield Inlet/Narrows priority area and within close enough proximity for the vessel lights to cause a disturbance to the animal. Arctic cod demonstrate diel vertical migrations synchronized with light/dark cycles (Benoit et al. 2010; Geoffroy et al. 2011) indicating that they do perceive and alter their behaviour with light stimulus. Though the extended period of daylight that occurs when vessels would be present in the priority area would result in minimal difference between ambient light levels and those produced artificially in June and July, there are still periods of darkness throughout the summer. Though dependent on an animal's behavioural state, distance from the vessel, and ambient light levels, an interaction may occur in some but not all circumstances.
Overall Risk	Low Risk	No additional management measures need to be considered at this time. However, as a precautionary measure, lighting for a vessel at rest could be minimized to the extent allowable within safety parameters.
Uncertainty		
Exposure	5	How artificial light may impact individuals and populations over different spatial and temporal scales is uncertain. General vessel traffic patterns are known.

Risk Factor	Score	Rationale
		Limited information exists regarding the distribution of Arctic cod in the priority area, though general information is known from other areas. Thus, the uncertainty is very high.
Sensitivity	4	The impacts of artificial light on fish, including Arctic cod, are not well understood, though some research has occurred in other areas and laboratories. Thus, the uncertainty is considered high.
Likelihood	4	Research is needed on the response of Arctic cod to artificial light. Some scientific information is available on the topic from other areas; thus, uncertainty is high.

Risk Statement: If an interaction occurs involving Arctic char and disturbance from artificial light due to a vessel at rest the consequence could result in a negative impact on Arctic char populations in the Chesterfield Inlet/Narrows priority area.

Table 5-53. Arctic Char – Vessel at Rest (Chesterfield Inlet/Narrows) – Disturbance from Artificial Light.

Risk Factor	Score	Rationale
Exposure	1 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 2 x 2 = 4 (raw score)
Intensity	1	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low absolute density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Chesterfield Inlet/Narrows priority area experiences a high density of vessel traffic relative to other portions of the AOI (see Figure 2 in Maerospace 2020) representing 61% of total AIS data within the AOI from 2012-2019, though those at rest make up a smaller proportion of that total. Vessels at rest maintain the use of navigational safety lights at all times but the extended period of daylight that occurs during June and July means that more powerful lights associated with nighttime deck lighting would either not be in use or would have limited use and there would generally be a minimal difference between ambient light levels and those introduced by the vessel. During the latter half of the shipping season in August and September there would be periods of darkness and the more powerful deck lighting would be in use for a portion of the day. AIS data indicate that vessels may remain at rest in this priority area for up to two weeks (Maerospace 2020) with common anchorages near the community of Chesterfield Inlet and at Helicopter Island near Chesterfield Narrows (Idlout 2020; Agnico Eagle 2022). Considering this information, intensity was scored as 1.
Temporal	2	Arctic char primarily occur in coastal waters during summer (June-August). Vessels (with available AIS) are typically present in the priority area during July to September, and occasionally during June (Maerospace 2020), though they are not present throughout that entire period. A vessel may remain at rest in the priority area for several days up to two weeks and numerous vessels will occur in the priority area throughout the summer (Maerospace 2020). Additionally, June and July have extended periods of daylight which would further limit the use of

Risk Factor	Score	Rationale
		powerful deck lighting. Thus, there is some temporal overlap (25-50%) between when vessels at rest and Arctic char may be present, resulting in a score of 2.
Spatial	2	Spatial = Areal x Depth = 1 x 2 = 2
Areal	1	Arctic char are expected to occur in the coastal waters of the Chesterfield Inlet/Narrows priority area (GN 2012; Idlout 2020; Loewen et al. 2020a, b) generally within 1,500 m from shore (Moore et al. 2016). Artificial light would occur within a restricted area within the total Arctic char range in the priority area, at the location of a vessel at rest. This results in a score of 1.
Depth	2	Arctic char are distributed in shallow coastal waters. During the Arctic polar night, artificial light from routine vessel operations may extend to at least 200 m depth in open water (Berge et al. 2020). However, as light penetration into the water column would attenuate with depth, because the extended period of daylight that occurs during a portion of the time when vessels would be present would generally result in minimal difference between ambient light levels and those produced artificially, and to account for the shallower depth range of Arctic char, depth was scored as a 2.
Sensitivity	2 (binned)	Sensitivity = (Acute change + Chronic Change) x Recovery Factors = (1 + 1) x 2.5 = 5.0
Acute Change	1	Artificial light can affect marine biota in environments that typically receive limited natural light (Berge et al. 2020). Depending on the species, fish may be attracted or repelled by artificial light (Berge et al. 2020; Geoffroy et al. 2021). Fish may also detect changes in light intensity under the ice (Cohen et al. 2015; Tarling 2015). In Arctic environments, many fishes have adapted to living in darkness under the cover of ice, and while the impacts of artificial light are not well understood (Hammerschlag et al. 2017), artificial light can affect fish physiology and behaviour (Nightingale et al. 2006; Berge et al. 2020; Geoffrey et al. 2021). Berge et al. (2020) reported that fish changed orientation when exposed to artificial light, descending up to 18-27 m in the water column. Physiological and genomic changes associated with circadian rhythms have been reported for fish exposed to artificial light during darkness cycles (López-Olmeda et al. 2013; Lazado et al. 2014; Kopperud and Grace 2017). Newman et al. (2015) did not detect any stress responses when they exposed Atlantic salmon to artificial light, while Szekeres et al. (2017) did report physiological effects when juvenile bonefish were exposed to artificial light, although no changes in behaviour were observed. Arctic char show diel melatonin rhythms depending on the amount of light (Strand et al. 2008); this rhythm could be impacted by artificial light. Although there could be physiological and/or behavioural impacts (e.g., avoidance) for Arctic char, due to the overall low level of vessel traffic, limited stay of a vessel at rest, and minimal difference between ambient and artificial light during June and July while vessels would be present in the Chesterfield Inlet/Narrows priority area, such impacts would be expected to be insignificant or undetectable against background variability. This results in a score of 1.
Chronic Change	1	Physiological and genomic changes associated with circadian rhythms have been reported for fish exposed to artificial light during darkness cycles (López-Olmeda et al. 2013; Lazado et al. 2014; Kopperud and Grace 2017). Exposure to artificial light from vessels at rest occurs within a limited area and would be unlikely to occur for an extended period of time (typically only a few days to several weeks); in addition, Arctic char only occur in coastal waters during the summer. Based on the low number of vessels that would be at rest and emitting artificial light in the Chesterfield Inlet/Narrows priority area, no detectable changes to overall fitness are expected, resulting in a score of 1.

Risk Factor	Score	Rationale
Recovery Factors	2.5	Recovery factors = mean of the factors listed below. Fecundity: 2 (Fecundity declines with latitude, but Arctic char spawn several times throughout their life [Coad and Reist 2018]). Early life stage mortality: 3 (High mortality likely associated with environmental factors, as well as density-dependent factors [Coad and Reist 2018]). Recruitment pattern: 2 (Anadromous Arctic char are not as long lived as lake-dwelling populations but may live 20+ years and spawn multiple times throughout their lives [Coad and Reist 2018]). Natural mortality rate: 2 (Mean annual mortality for Canadian anadromous populations is 30-45%, for age classes 6-15 years [Coad and Reist 2018]). Age at maturity: 3 (Age at maturity is 3-10 years [Coad and Reist 2018]). Life stages affected: 3 (All stages). Population connectivity: 3 (Discrete stocks/populations occur in rivers and lakes [Coad and Reist 2018]). Population status: 2 (IUCN classification is *least concern* [Freyhof and Kottelat 2008], but many discrete stocks exist, and the population trends are unknown).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 1 x 2 = Negligible
Likelihood	2	An interaction has the potential to occur when Arctic char and a vessel are present at the same time within the Chesterfield Inlet/Narrows priority area and within close enough proximity for the vessel lights to cause a disturbance to the animal. Some processes in Arctic char are known to be impacted by light (Strand et al. 2008) yet behavioural impacts are not known. Though the extended period of daylight that occurs when vessels would be present in the priority area would result in minimal difference between ambient light levels and those produced artificially in June and July, there are still periods of darkness throughout the summer. Though dependent on an animal's behavioural state and distance from the vessel, an interaction is unlikely to occur.
Overall Risk	Low Risk	No additional management measures need to be considered at this time. However, as a precautionary measure, lighting for a vessel at rest could be minimized to the extent allowable within safety parameters.
Uncertainty		
Exposure	5	How artificial light may impact individuals and populations over different spatial and temporal scales is uncertain. General vessel traffic patterns are known. Thus, the uncertainty is very high.
Sensitivity	4	The impacts of artificial light on fish, including Arctic char, are not well understood. Thus, the uncertainty is considered high.
Likelihood	4	Research is needed on the response of Arctic char to artificial light. Some scientific information is available on the topic from other areas; thus, the uncertainty is high.

5.3.3 Pathogens/NIS Introductions

Though the total impact from the introduction and establishment of NIS is difficult to predict, effects are known to occur through competition for resources (e.g., space, prey) and through direct impacts on native species' health (e.g., epiphytic bryozoans on kelp; Levin et al. 2002; Lutz-Collins et al. 2009). The current low level of vessel traffic in the AOI reduces propagule pressure (i.e., the number of viable organisms introduced to an area) and thereby minimizes introduction risk compared with regions hosting higher levels of vessel traffic, and the differences in environmental conditions from source waters reduces establishment risk compared with temperate regions (Goldsmit et al. 2020).

Although establishment risk is low for many species, it is predicted that northern Hudson Bay, including the AOI, contains suitable habitat for a portion of 23 high-risk aquatic NIS currently and in two future scenarios (i.e., year 2050 and 2100; Goldsmit et al. 2020). Past examples demonstrate the myriad impacts that may result from NIS introductions in various ecosystems (Walker et al. 2019) and this stressor has the potential to impact many organisms.

NIS may foul multiple parts of a vessel, including the hull, anchoring gear, and other submerged locations (Lacoursière-Roussel et al. 2012; Chan et al. 2015, 2022) and are therefore transported along the route travelled by a vessel, with the potential for introduction to new locations. Most of the vessels entering the Hudson Bay Complex historically arrived at the Port of Churchill (Dawson et al. 2018). However, since 2006 there has been increased traffic through Hudson Strait to communities on the northwest coast of Hudson Bay, including Chesterfield Inlet (Dawson et al. 2018). The main route for this increased traffic passes between Coats and Southampton Islands towards Chesterfield Inlet and includes portions of the Evans and Fisher Straits and Chesterfield Inlet/Narrows priority areas (Maerospace 2020).

Anti-fouling measures in Canada include adoption of IMO's 2011 Guidelines for the Control and Management of Ships' Biofouling to Minimize the Transfer of Aquatic Invasive Species, adoption of the *International Convention on the Control of Harmful Anti-fouling Systems on Ships* (2008), voluntary guidance for in-water cleaning of vessels, as well as other regulations in the *Canada Shipping Act 2001* (TC 2022). Though followed by some vessel operators as there are benefits for fuel efficiency, anti fouling measures are voluntary in Canada and niche areas are often heavily fouled (Chan et al. 2015; Brinklow et al. 2022). Additionally, although some early studies suggested that biofouling organisms are likely to have poor survivorship during Arctic voyages due to the inclement conditions (e.g., water velocity and ice), a study of biofouling organisms present on ship hulls in Churchill, Manitoba identified 15 non-Arctic species, seven of which were well-known hull fouling NIS (Chan et al. 2015). Fouling organisms on vessels at rest may detach or expel gametes, and these vessels at rest are expected to be in place for an extended period. As the effects from all fouling organisms are expected to manifest similarly, other pathways were assessed by proxy through the vessel at rest pathway. Separate assessments were not conducted for this stressor under the anchoring/mooring, grounding/foundering, or vessel underway pathways (see Appendix B).

If fouling NIS can successfully establish, they are likely to compete directly with native organisms that associate with a restricted space on a solid substrate, such as the seafloor. There are known examples in the Northwest Atlantic of these interactions, such as ascidian tunicates affecting abundance of native tunicates and polychaetes, and epiphytic bryozoans contributing to gap formation in kelp beds (Levin et al. 2002; Lutz-Collins et al. 2009; Sephton et al. 2017). Additionally, suitable habitat is expected for multiple high-risk zoobenthic organisms within the AOI (Goldsmit et al. 2020). Therefore, assessments for kelp beds/other macroalgae and benthic invertebrates were conducted (Table 5-54).

Table 5-54. Vessels at Rest – Pathogens/NIS: ESC Subcomponents and Priority Areas Assessed.

ESC Subcomponent	Priority Area	Assessed by Proxy
Kelp beds and other macroalgae	Chesterfield Inlet/Narrows	
Benthic Invertebrates	Chesterfield Inlet/Narrows	

Risk Statement: If an interaction occurs involving kelps beds/other macroalgae and the introduction of pathogens/NIS (fouling organisms) from a vessel at rest the consequence could result in a negative impact on the ecosystem function of kelp bed/other macroalgae habitat in the Chesterfield Inlet/Narrows priority area.

Table 5-55. Kelp beds and other macroalgae – Vessels at rest (Chesterfield Inlet/Narrows) – Pathogens/Non-Indigenous Species (NIS) Introductions (fouling organisms).

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 2 x 3 = 6 (raw score)
Intensity	1	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low absolute density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Chesterfield Inlet/Narrows priority area experiences a high density of vessel traffic relative to other portions of the AOI (see Figures 5-1 and 5-10) representing approximately 61% of total AIS data within the AOI from 2012-2019, though those at rest make up a smaller proportion of that total. AIS data indicate that vessels may remain at rest in this priority area for up to two weeks (Maerospace 2020) with common anchorages near the community of Chesterfield Inlet and at Helicopter Island near Chesterfield Narrows (Idlout 2020; Agnico Eagle 2022). Chan and authors (2015) estimated that a mean of 4.3% of hull surface of international bulk carriers was fouled by a mean of 29 different species for vessels arriving to the port of Churchill in Hudson Bay, with seven of those species being well-recognized fouling NIS. However, fouling organisms must be dislodged or expel gametes in order to be introduced to the system, meaning that, though present, only a subset of these organisms may be introduced (Chan et al. 2015). Once surviving NIS are transported to a port by large, commercial vessels, smaller vessels (e.g., recreational, fishing) can be vectors for the potentially rapid spread of invasive organisms throughout a local region (Davenport and Davenport 2006; Riley et al. 2022). Though this priority area receives a high density of vessel traffic compared with the rest of the AOI and fouling organisms are known to survive the transit to the Arctic, the density of vessels at any one time is generally either zero or one and only a subset of the fouling organisms would dislodge/reproduce in order to be introduced to the system. Considering this information, intensity was scored as 1.
Temporal	2	Kelp beds and other macroalgae are present in the Chesterfield Inlet/Narrows priority area year-round, though photosynthetic activity, important in advance of the growth phase which largely occurs under ice (Chapman and Lindley 1980), is restricted to the ice-free season. Vessels (with available AIS data) occur in the priority area mainly during July to September, and occasionally during June (Maerospace 2020) though they may not be present throughout that entire period. Some fouling NIS are known to survive the transit to Arctic ports (Chan et al. 2015, 2022) and, especially in summer, some are expected to survive in the environmental conditions present in Hudson Bay (Goldsmit et al. 2019, 2020); therefore, they are expected to persist for a portion of the time a vessel at rest is present in the AOI. A vessel may remain at rest in the priority area for several days to up to two weeks, with longer stationary times increasing the probability of

Risk Factor	Score	Rationale
		release/introduction of NIS, and numerous vessels will occur in the priority area throughout the summer (Maerospace 2020). This results in some overlap between when a (fouled) vessel is at rest and the time kelp beds/other macroalgae are present, and a score of 2.
Spatial	3	Spatial = Areal x Depth = 1 x 3 = 3
Areal	1	Macroalgae typically occurs in water depths between 5-50 m in the AOI, with higher densities at 10 and 15 m compared with 5 m (Krause-Jensen et al 2012; Filbee-Dexter et al. 2022). Pathogens/NIS may be transported beyond a vessel's immediate location via water currents, including a species' pelagic larvae or propagules (i.e., fragments or gametophytes), however the greatest concentration would be localized. This results in an areal score of 1.
Depth	3	Macroalgae inhabit surficial seabed substrate. Pathogens/NIS that transfer from a vessel (either from the hull or another portion of a vessel's structure) into the water are likely to sink to the seabed given that the majority of reported marine NIS are benthic (Streftaris et al. 2005), thus covering the entire depth range of kelp/other macroalgae. This results in a score of 3.
Sensitivity	4 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (2 + 3) x 2.0 = 10.0
Acute Change	2	Though introduction and establishment risk varies by species, with biofouling communities on vessel hulls generally thought to have poor survivorship during Arctic voyages due to inclement conditions (e.g., water temperature/velocity and ice) and the number of introductions into the Arctic being relatively low compared to other regions of the world (e.g., Chan et al. 2015, 2016), a vessel at rest could still be a vector for the introduction of hull fouling pathogens/NIS to the Arctic environment (Chan et al. 2015; Hannah et al. 2020; see Likelihood, below). Although the specific effects of the introduction of NIS into the Arctic marine environment can be difficult to predict, it is reasonable to presume they can have direct, likely negative, effects on the viability and function of kelp/other macroalgae habitats. Though many negative effects stemming from NIS are due to establishment and manifest over a longer timeframe (e.g., competition for resources) and are covered under Chronic Change (below), the introduction of novel pathogens can have widespread effects for species that lack pathogen-specific immunity, potentially including the outbreak of epidemic disease and high mortality (Burek et al. 2008). Therefore, measurable changes in viability of kelp bed/other macroalgae habitat and its function in the ecosystem could occur, resulting in a score of 2.
Chronic Change	3	Though the number of introductions into the Arctic is expected to be relatively low compared to other regions of the world (e.g., Chan et al. 2015, 2016), higher temperatures, reduced sea ice cover, and intensified vessel traffic in the Canadian Arctic due to climate change are increasing the risk of the introduction and spread of NIS in the region (Goldsmit et al. 2021a). The establishment of NIS can significantly affect marine ecosystem function and community composition and the human economies/lifestyles that depend on them (Drake and Lodge 2007; Bellard et al. 2016; Blackburn et al. 2019; Riley et al. 2022). The Hudson Bay Complex was identified as high-risk for the establishment of NIS, particularly by crabs, mollusks, macrozooplankton, and macroalgae (Goldsmit et al. 2020, 2021a). Macroalgae comprise ~20% of the world's marine NIS and their establishment affects native macroalgal ecosystems by monopolizing available habitat, acting as ecosystem engineers, and altering community composition (Andreakis and Schaffelke 2012). For example, tunicate,

Risk Factor	Score	Rationale
		sea squirt, Japanese skeleton shrimp, and lacy-crust bryozoan NIS are currently threatening coastal marine ecosystems (including kelp beds) by outcompeting native species in Eastern Canada's Maritimes region (Sephton et al. 2017). Another example can be found in the Northwest Atlantic: the colonial bryozoan *Membranipora membranacea* has been linked to defoliation of kelp beds in Nova Scotia (Scheibling and Gagnon 2009) by making the kelp fronds more brittle (Krumhansl et al. 2011) and prone to erosion, breakage and dislodgement via wave action (Lambert et al. 1992; Krumhansl and Scheibling 2011). Subsequent studies have suggested that kelp defoliation caused by this bryozoan facilitates establishment of another NIS, the green alga oyster thief (*Codium fragile*), enabling replacement of large portions of kelp beds (Scheibling and Gagnon 2006). Oyster thief are unable to displace established kelp beds, but given the opportunity provided by the bryozoan, oyster thief can begin to dominate (Levin et al. 2002; Schiebling and Gagnon 2006). Though over a longer timeframe it has been suggested that kelp may begin to outcompete oyster thief, as *C. fragile* was dominant at 54% of Nova Scotian sites sampled in 2000 but this decreased to only 15% by 2007 (Watanabe et al. 2010), impacts from *M. membranacea* and subsequent oyster thief establishment to native kelp beds can be widespread, severe, and persistent (Filbee-Dexter et al. 2016; O'Brien and Scheibling 2018). Where it has become established in Nova Scotia, the effects of *M. membrancea* are projected to be exacerbated by climate change and alter the structure and function of kelp beds (e.g., energy and resource subsidies to adjacent ecosystems; Krumhansl et al. 2014). If pathogens/NIS were to establish in the Chesterfield Inlet/Narrows priority area, they could result in significant changes to long-term viability of the habitat and its function in the ecosystem resulting in a score of 3.
Recovery Factors	2.0	At least 19 species/taxonomic groups of macroalgae have been documented to occur within or near the AOI (DFO 2020; Loewen et al. 2020a, b; Filbee-Dexter et al. 2022). At least 8 species/taxonomic groups have been reported for the Chesterfield Inlet/Narrows priority area. Of these macroalgae, three kelp species, *Laminaria solidungula*, edible kelp, and sugar kelp are among the most abundant in the AOI, creating extensive kelp forests reaching up to 3-4 m in height and spreading several kilometers from shore (DFO 2020; Loewen et al. 2020b; Filbee-Dexter et al. 2022). *L. solidungula* is an Arctic endemic species (Roleda 2016). Biomasses of up to 34 kg/m^2 were observed for these kelp forests in the AOI, the highest ever reported for the eastern Canadian Arctic (Filbee-Dexter et al. 2022). Other types of macroalgae also occur amongst these kelp species, including coralline encrusting algae, and are important to create the structural complexity beneficial to its inhabitants (Wharton and Mann 1981; Christie et al. 1998; Steen et al. 2016; Misiuk and Aitken 2020). Habitat recovery factors were used. Recovery factors = mean of the factors listed below. Growth rate (biogenic)/rate of structural rebuilding (abiotic): 1 (Kelp sporophyte growth rates are high compared to other organisms [Mann 1973]). Resistance: 3 (Kelp can easily be disturbed physically, known to break apart during physical duress such as sample collection [Mundy 2020]. A change in ecosystem structure, such as an increase in urchin populations [e.g., Filbee-Dexter and Scheibling 2014] can lead to rapid and extensive defoliation of kelp). Regenerative potential: 2 (The regeneration of kelp forests after destructive events highly depends on the strength and duration of the event(s). Different clearing experiments in the northern Atlantic have shown that a full kelp regrowth can be observed after 1-3 years when environmental pressures are removed (Scheibling 1986; Christie et al. 1998; Steen et al. 2016). However, fully grown kelp forests also host a great variety of understorey algae along with many fish and invertebrates, that can take over 5 years to recolonize the habitat (Wharton and

Risk Factor	Score	Rationale
		Mann 1981; Christie et al. 1998; Steen et al. 2016). In the Arctic, many authors have concurred that coastal recovery processes should be much slower than in temperate waters (Dunton et al. 1982; Conlan 2005; Keck et al. 2020). Several experiments and measurements done in the Beaufort Sea's Boulder Patch have shown that following a major disturbance on the site, it could take more than a decade for the sessile community, including kelp, to fully recover (Konar 2013; Bonsell and Dunton 2021). External stress: 2 (Climate change and warming waters add to stress [e.g., Filbee-Dexter et al. 2020]).
Consequence	3 (binned)	Consequence = Exposure x Sensitivity = 2 x 4 = Moderate
Likelihood	2	Survival and establishment of NIS has the potential to occur during summer/fall when fouled vessels may be present in the Chesterfield Inlet/Narrows priority area. A vessel at rest could be a vector for the introduction of fouling pathogens/NIS to the Arctic environment, as it is estimated that 39% of Arctic NIS introductions occurred via vessels and that fouling is the more prominent vector for Arctic marine ecosystems (Chan et al. 2015, 2019). Chan et al. (2015) examined vessel hulls of mainly international bulk carriers in Churchill, Manitoba and found biofouling covering up to 38% of hull surfaces (mean of 4.3%), with a maximum of 79 fouling species per vessel (mean of 29 species per vessel). A total of 86 invertebrate taxa were identified from hull samples, 15 of which were non-Arctic species and seven of which were well-known fouling NIS; the fouling taxa were mainly comprised of barnacles and, to a lesser extent, nematodes and copepods (Chan et al. 2015). At least six non-Arctic fouling taxa were observed on the hulls of military vessels transiting from temperate to Arctic ports in Canadian waters (Chan et al. 2016). Overall, fouling algae seem more tolerant of Arctic conditions during vessel transit than mobile, sessile, and sedentary invertebrate taxa (Chan et al. 2016). However, blue mussels and zebra mussels, for example, are quite tolerant of contrasting environmental conditions, including temperature variations and salinity levels ranging from marine to freshwater (Riley et al. 2022). Bivalves, gastropods, barnacles, and some bryozoans may survive for weeks to over a month via physical isolation from unfavourable environmental conditions, while soft-bodied taxa (e.g., tunicates, sponges, cnidarians) or those unable to osmoregulate (e.g., echinoderms) may experience rapid mortality (Riley et al. 2022). Only a subset of introduced species will establish. In order to be introduced to the surrounding environment, fouling organisms would need to be dislodged from the vessel or release gametes, two events that will only occur in a subset of organisms present (Chan et al. 2015). Introduced organisms must then survive and reproduce to establish populations. However, Hudson Bay has been identified as a location with environmental conditions suitable to certain high risk and indicator NIS, increasing the probability of survival and establishment over other areas in the Arctic (Goldsmit et al. 2019, 2020). Additionally, any interactions that were to occur would happen in the summer months, which increases the chance of survival and establishment compared with other times of the year (Goldsmit et al. 2019). Long-term establishment requires overwintering populations. Fouling NIS can establish on a vessel's structure from multiple previous ports of call since its last cleaning (Chan et al. 2011, 2022) which for some vessels can be multiple years (Chan et al. 2022). Some vessels that visit the AOI are exclusively domestic and others may conduct international voyages when they are not travelling to the AOI. Brinklow et al. (2022) has estimated <1 NIS establishment is likely to occur per year, with higher potential for introductions from niche areas

Risk Factor	Score	Rationale
		rather than main hulls. The vessels that have travelled internationally that visit the AOI are also likely to be coming from Canadian waters before travelling north, and therefore may be transporting both internationally- and domestically-established fouling NIS. Regarding domestic vessels, they generally operate in areas in southern Canada that are more at-risk to the establishment of NIS before coming to the AOI, such as the Gulf of St. Lawrence. The waters of the Great Lakes-St. Lawrence River west of Quebec City are estimated to accrue ~1.5 NIS establishments/year from hulls and ~4.5 NIS establishments/year from niche areas solely due to international vessels, while Atlantic waters (including Newfoundland and in the Gulf of St. Lawrence east of Quebec City) are expected to have ~2 NIS establishments/year from international vessel hulls and ~7.5 species/year from niche areas (Brinklow et al. 2022). Chan (2011) identifies that domestic vessels generally do not transport NIS to the Arctic that are new to Canada but that they are likely to be involved in the spread of already-established NIS, and that NIS are more likely to survive domestic journeys as they are shorter and coming from locations with more similar environmental conditions. Additionally, though anti-fouling measures exist and certain vessel operators are diligent due to the benefits for fuel efficiency, in Canada these measures are voluntary, some vessels may not employ an anti-fouling system at all (Chan et al. 2022), and heavily fouled niche areas are often not a focus for these measures; therefore, the measures may not be adequate for mitigation of fouling NIS (Chan et al. 2015; Brinklow et al. 2022). Combined with the expected habitat suitability for NIS in the area (Chan et al. 2011; Goldsmit et al. 2020), this information supports the potential of NIS survival and establishment from this vector in this priority area. Thus, though annual NIS establishment estimates have not been generated for the Arctic from domestic vessels, considering that domestic vessels are expected to transport more viable NIS (Chan et al. 2011), it is expected that the estimates for NIS establishments from international vessels are conservative, and a combination of domestic and internationally-travelled vessels may result in establishment of a NIS in the AOI every couple years, for a score of 2.
Overall Risk	Moderately-High Risk	Additional management measures should be considered, including working with vessel operators to implement measures in the 2023 Biofouling Guidelines, including ship-specific biofouling management plans and monitoring of vessels and the area for fouling NIS, particularly in habitats identified as important kelp areas (see areas identified during an Inuit Qaujimajatuqangit workshop in February 2020 [Idlout 2020]).
Uncertainty		
Exposure	3	There is some scientific literature and information available regarding prevalence of fouling NIS on vessels entering the Arctic, and general vessel traffic patterns and routine operations are known. Environmental DNA and metabarcoding should be used to detect newly arriving NIS into the Chesterfield Inlet/Narrows priority area, as these methods are currently being successfully used to monitor other remote regions (Goldsmit et al. 2020).
Sensitivity	3	Macroalgal documentation in the priority area is limited (e.g., DFO 2020; Loewen et al. 2020a, b), although macroalgae and coastal kelp beds have been identified near the mouth of Chesterfield Inlet and it is known that the Western Hudson Bay Coastline EBSA features dense coastal kelp beds and macroalgae (DFO 2020). Life history information is generally limited for macroalgae species that occur in/near the priority area. However, there is some scientific literature for other areas that studies the response of macroalgae to pathogens/NIS. Impacts to macroalgae from NIS have been documented in other areas of Canada.
Likelihood	4	Goldsmit et al. (2020, 2021a) did consider the Hudson Bay Complex as an invasion hotspot for marine NIS. The resistance and survival time of

Risk Factor	Score	Rationale
		pathogens/NIS transported into Arctic conditions is largely unknown and likely variable between species (Riley et al. 2022).

Risk Statement: If an interaction occurs involving benthic invertebrates and pathogens/NIS (fouling organisms) from a vessel at rest the consequence could result in a negative impact on benthic invertebrate populations in the Chesterfield Inlet/Narrows priority area.

Table 5-56. Benthic Invertebrates – Vessel at Rest (Chesterfield Inlet/Narrows) – Pathogens/Non-Indigenous Species (NIS) Introductions (fouling organisms).

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 2 x 3 = 6 (raw score)
Intensity	1	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low absolute density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Chesterfield Inlet/Narrows priority area experiences a high density of vessel traffic relative to other portions of the AOI (see Figures 5-1 and 5-10) representing approximately 61% of total AIS data within the AOI from 2012-2019, though those at rest make up a smaller proportion of that total. AIS data indicate that vessels may remain at rest in this priority area for up to two weeks (Maerospace 2020) with common anchorages near the community of Chesterfield Inlet and at Helicopter Island near Chesterfield Narrows (Idlout 2020; Agnico Eagle 2022). Chan and authors (2015) estimated that a mean of 4.3% of hull surface of international bulk carriers was fouled by a mean of 29 different species for vessels arriving to the port of Churchill in Hudson Bay, with seven of those species being well-recognized fouling NIS. However, fouling organisms must be dislodged or expel gametes in order to be introduced to the system, meaning that, though present, only a subset of these organisms may be introduced (Chan et al. 2015). Once surviving NIS are transported to a port by large, commercial vessels, smaller vessels (e.g., recreational, fishing) can be vectors for the potentially rapid spread of invasive organisms throughout a local region (Davenport and Davenport 2006; Riley et al. 2022). Though this priority area receives a high density of vessel traffic compared with the rest of the AOI and fouling organisms are known to survive the transit to the Arctic, the density of vessels at any one time is generally either zero or one and only a subset of the fouling organisms would dislodge/reproduce in order to be introduced to the system. Considering this information, intensity was scored as 1.
Temporal	2	Benthic invertebrates are present in the Chesterfield Inlet/Narrows priority area year-round. Vessels (with available AIS data) occur in the priority area mainly during July to September, and occasionally during June (Maerospace 2020) though they may not be present throughout that entire period. Some fouling NIS are known to survive the transit to Arctic ports (Chan et al. 2015, 2022) and, especially in summer, some are expected to survive in the environmental conditions present in Hudson Bay (Goldsmit et al. 2019, 2020); therefore, they are expected to persist for a portion of the time a vessel at rest is present in the AOI.

Risk Factor	Score	Rationale
		A vessel may remain at rest in the priority area for several days to up to two weeks, with longer stationary times increasing the probability of release/introduction of NIS, and numerous vessels will occur in the priority area throughout the summer (Maerospace 2020). This results in some overlap between when a (fouled) vessel is at rest and the time benthic invertebrates are present, and a score of 2.
Spatial	3	Spatial = Areal x Depth = 1 x 3 = 3
Areal	1	Benthic invertebrates are anticipated to occur throughout the Chesterfield Inlet/Narrows priority area. Pathogens/NIS may be transported beyond a vessel's immediate location via water currents, including a species' pelagic larvae or propagules (i.e., fragments or gametophytes), however the greatest concentration would be localized. This results in an areal score of 1.
Depth	3	Benthic invertebrates inhabit the seabed. Pathogens/NIS that transfer from a vessel (either from the hull or another portion of a vessel's structure) into the water are likely to sink to the seabed given that the majority of reported marine NIS are benthic (Streftaris et al. 2005), thus covering the entire depth range of benthic invertebrates. This results in a score of 3.
Sensitivity	4 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (2 + 3) x 2.3 = 11.5
Acute Change	2	Though introduction and establishment risk varies by species, with biofouling communities on vessel hulls generally thought to have poor survivorship during Arctic voyages due to inclement conditions (e.g., water temperature/velocity and ice) and the number of introductions into the Arctic being relatively low compared to other regions of the world (e.g., Chan et al. 2015, 2016), a vessel at rest could still be a vector for the introduction of hull fouling pathogens/NIS to the Arctic environment (Chan et al. 2015; Hannah et al. 2020; see Likelihood, below). Although the specific effects of the introduction of NIS into the Arctic marine environment can be difficult to predict, it is reasonable to presume they can have direct, likely negative, effects on the health of native benthic invertebrate species. Though many negative effects stemming from NIS are due to establishment and manifest over a longer timeframe (e.g., competition for resources) and are covered under Chronic Change (below), the introduction of novel pathogens can have widespread effects for species that lack pathogen-specific immunity, potentially including the outbreak of epidemic disease and high mortality (Burek et al. 2008). Accounting for pathogen outbreaks, measurable changes in mortality rates of benthic invertebrates relative to background variability could occur resulting in a score of 2.
Chronic Change	3	Though the number of introductions into the Arctic is expected to be relatively low compared to other regions of the world (e.g., Chan et al. 2015, 2016), higher temperatures, reduced sea ice cover, and intensified vessel traffic in the Canadian Arctic due to climate change are increasing the risk of the introduction and spread of NIS in the region (Goldsmit et al. 2021a). The establishment of NIS can significantly affect marine ecosystem function and community composition and the human economies/lifestyles that depend on them (Drake and Lodge 2007; Bellard et al. 2016; Blackburn et al. 2019; Riley et al. 2022). During the 1960s, the Kamchatka red king crab (*P. camtschaticus*) was deliberately introduced to the Northeast Atlantic, as it was a valuable species in the commercial fisheries of the Bering Sea and North Pacific (Christiansen et al. 2015). Since then, this invasive, benthic top predator has established in the Barents Sea and spread westward to Norway and northeastward to offshore

Risk Factor	Score	Rationale
		Russian waters, disrupting native biodiversity and biomass throughout its spread (Christiansen et al. 2015; Kourantidou et al. 2015). During 2011, an increase in benthic megafauna biomass was observed in the northeastern Barents Sea due in part to increased abundance of the invasive snow crab (*Chionoecetes opilio*), which is one of the greatest threats to biological diversity in the area (Jørgensen et al. 2017). The Hudson Bay Complex was identified as high-risk for the establishment of NIS, particularly by crabs, mollusks, macrozooplankton, and macroalgae (Goldsmit et al. 2020, 2021a). If macroalgae propagules become established they can alter the benthic ecosystem by acting as ecosystem engineers (Andreakis and Schaffelke 2012). Further, the introduction of novel pathogens can have widespread effects for species that lack pathogen-specific immunity, potentially including the outbreak of epidemic disease and high mortality (Burek et al. 2008) that may continue over time if the pathogen becomes established. If pathogens/NIS were to establish in the Chesterfield Inlet/Narrows priority area and outcompete or otherwise cause high mortality to native benthic invertebrates, they could result in a significant change to overall fitness and/or survival compared to background variability. This results in a score of 3.
Recovery Factors	2.3	At least 430 benthic invertebrate species have been identified within or near the AOI, including corals (e.g., the soft coral *Gersemia rubiformis*), sponges, sea stars, brittle stars, sea urchins, bivalves, cephalopods, crinoids, gastropods, holothuroids (sea cucumbers), hydrozoans, amphipods, cumaceans, decapods, euphausiids, isopods, Leptostracans, ostracods, sea spiders, polychaetes, barnacles, and chitons (DFO 2020; Loewen et al. 2020a, b). Corals and sponges are known sensitive benthic invertebrate groups that have been identified in the priority area and were used for the determination of Recovery Factors. There have been limited benthic invertebrate studies for the Chesterfield Inlet/Narrows priority area (e.g., GN 2010; Misiuk and Aitken 2020; Pierrejean et al. 2020). Recovery factors = mean of the factors listed below. Fecundity: 1 (*Geodia phlegraei* sponges from the North Atlantic were observed to produce ~16 million oocytes/sponge and ~30 billion spermatozoa/sponge [Koutsouveli et al. 2020]. It is currently unknown whether *Geodia* sponges occur in the AOI, but the information presented here may be generally used for the Porifera Phylum reported for the AOI). Early life stage mortality: 3 (During four years of observations in water depths >650 m in the Gulf of Maine, the deep-water gorgonian coral *Primnoa resedaeformis* experienced high mortality during its early benthic stage, possibly due to biological disturbance, such as by suspension-feeding brittle stars, and limited food supply [Lacharité and Metaxas 2013]. Larvae of the cold-water coral *Lophelia pertusa* had an average survival rate of 60% during three months of laboratory observations and a maximum longevity of one year [Strömberg and Larsson 2017]. Although neither of these species have been reported for the AOI (Loewen et al. 2020a), their habitat conditions may be considered analogous to those of the AOI and the information presented here is applied in a precautionary manner for species within the AOI, for which no specific early life stage mortality information could be found). Recruitment pattern: 2 (Of two deep-water gorgonian corals observed in the Gulf of Maine, the broadcast spawner *P. resedaeformis* had high recruit abundance while the brooder spawner *Paragorgia arborea* had few recruits [Lacharité and Metaxas 2013]. The life span and rates of asexual and sexual reproduction in the soft coral *G. rubiformis* are unknown; however, asexual reproduction can be stimulated by physical disturbance [Henry et al. 2003; Iken et al. 2012]. The lifespan of *Geodia* spp. Sponges is unknown, but they are likely to be slow growing [Last et al. 2019]. Although the corals *P. resedaeformis* and *P. arborea* and *Geodia* sponges have not been reported for the AOI, the information provided

Risk Factor	Score	Rationale
		here has been applied for the AOI, for which no specific information could be found). Natural mortality rate: Unknown; excluded from consideration. Age at maturity: Unknown (DFO 2015b); excluded from consideration. Life stages affected: 3 (All life stages are expected to be affected). Population connectivity: Unknown; excluded from consideration. Population status: Unknown (The population size of the soft coral *G. rubiformis* is unknown [Boutillier et al. 2019] and corals/sponges are not considered under Sara or COSEWIC); excluded from consideration.
Consequence	3 (binned)	Consequence = Exposure x Sensitivity = 2 x 4 = Moderate
Likelihood	2	Survival and establishment of NIS has the potential to occur during summer/fall when fouled vessels may be present in the Chesterfield Inlet/Narrows priority area. A vessel at rest could be a vector for the introduction of fouling pathogens/NIS to the Arctic environment, as it is estimated that 39% of Arctic NIS introductions occurred via vessels and that fouling is the more prominent vector for Arctic marine ecosystems (Chan et al. 2015, 2019). Chan et al. (2015) examined vessel hulls of mainly international bulk carriers in Churchill, Manitoba and found biofouling covering up to 38% of hull surfaces (mean of 4.3%), with a maximum of 79 fouling species per vessel (mean of 29 species per vessel). A total of 86 invertebrate taxa were identified from hull samples, 15 of which were non-Arctic species and seven of which were well-known fouling NIS; the fouling taxa were mainly comprised of barnacles and, to a lesser extent, nematodes and copepods (Chan et al. 2015). At least six non-Arctic biofouling taxa were observed on the hulls of military vessels transiting from temperate to Arctic ports in Canadian waters (Chan et al. 2016). Overall, biofouling algae seem more tolerant of Arctic conditions during vessel transit than mobile, sessile, and sedentary invertebrate taxa (Chan et al. 2016). However, blue mussels and zebra mussels, for example, are quite tolerant of contrasting environmental conditions, including temperature variations and salinity levels ranging from marine to freshwater (Riley et al. 2022). Bivalves, gastropods, barnacles, and some bryozoans may survive for weeks to over a month via physical isolation from unfavourable environmental conditions, while soft-bodied taxa (e.g., tunicates, sponges, cnidarians) or those unable to osmoregulate (e.g., echinoderms) may experience rapid mortality (Riley et al. 2022). Only a subset of introduced species will establish. In order to be introduced to the surrounding environment, fouling organisms would need to be dislodged from the vessel or release gametes, two events that will only occur in a subset of organisms present (Chan et al. 2015). Introduced organisms must then survive and reproduce to establish populations. However, Hudson Bay has been identified as a location with environmental conditions suitable to certain high risk and indicator NIS, increasing the probability of survival and establishment over other areas in the Arctic (Goldsmit et al. 2019, 2020). Additionally, any interactions that were to occur would happen in the summer months, which increases the chance of survival and establishment compared with other times of the year (Goldsmit et al. 2019). Long-term establishment requires overwintering populations. Fouling NIS can establish on a vessel's structure from multiple previous ports of call since its last cleaning (Chan et al. 2011, 2022) which for some vessels can be multiple years (Chan et al. 2022). Some vessels that visit the AOI are exclusively domestic and others may conduct international voyages when they are not travelling to the AOI. Brinklow et al. (2022) has estimated <1 NIS establishment is

Risk Factor	Score	Rationale
		likely to occur per year, with higher potential for introductions from niche areas rather than main hulls. The vessels that have travelled internationally that visit the AOI are also likely to be coming from Canadian waters before travelling north, and therefore may be transporting both internationally- and domestically-established fouling NIS. Regarding domestic vessels, they generally operate in areas in southern Canada that are more at-risk to the establishment of NIS before coming to the AOI, such as the Gulf of St. Lawrence. The waters of the Great lakes-St. Lawrence River west of Quebec City are estimated to accrue ~1.5 NIS establishments/year from hulls and ~4.5 NIS establishments/year from niche areas solely due to international vessels, while Atlantic waters (including Newfoundland and in the Gulf east of Quebec City) are expected to have ~2 NIS establishments/year from international vessel hulls and ~7.5 species/year from niche areas (Brinklow et al. 2022). Chan (2011) identifies that domestic vessels generally do not transport NIS to the Arctic that are new to Canada but that they are likely to be involved in the spread of already-established NIS, and that NIS are more likely to survive domestic journeys as they are shorter and coming from locations with more similar environmental conditions. Additionally, though anti-fouling measures exist and certain vessel operators are diligent due to the benefits for fuel efficiency, in Canada these measures are voluntary, some vessels may not employ an anti-fouling system at all (Chan et al. 2022), and heavily fouled niche areas are often not a focus for these measures; therefore, the measures may not be adequate for mitigation of fouling NIS (Chan et al. 2015; Brinklow et al. 2022). Combined with the expected habitat suitability for NIS in the area (Chan et al. 2011; Goldsmit et al. 2020), this information supports the potential of NIS survival and establishment from this vector in this priority area. Thus, though annual NIS establishment estimates have not been generated for the Arctic from domestic vessels, considering that domestic vessels are expected to transport more viable NIS (Chan et al. 2011), it is expected that the estimates for NIS establishments from international vessels are conservative, and a combination of domestic and internationally-travelled vessels may result in establishment of a NIS in the AOI every couple years, for a score of 2.
Overall Risk	Moderately-High Risk	Additional management measures should be considered, including working with vessel operators to implement measures in the 2023 Biofouling Guidelines, including ship-specific biofouling management plans and monitoring of vessels and the area for fouling NIS
Uncertainty		
Exposure	3	There is some scientific literature and information available regarding prevalence of fouling NIS on vessels entering the Arctic, and general vessel traffic patterns and routine operations are known. Environmental DNA and metabarcoding should be used to detect newly arriving NIS into the Chesterfield Inlet/Narrows priority area, as these methods are currently being successfully used to monitor other remote regions (Goldsmit et al. 2020).
Sensitivity	4	Limited information is available for benthic community diversity and abundance for the Chesterfield Inlet/Narrows priority area (DFO 2020). Life history information is generally limited for sensitive benthic invertebrate species that may occur within the priority area. Although scientific literature exists regarding the response of benthic fauna to NIS in other regions, the relative scarcity of information for the priority area's benthic community results in a score of 4.
Likelihood	3	Goldsmit et al. (2020, 2021a) did consider the Hudson Bay complex as an invasion hotspot for marine NIS. The resistance and survival time of pathogens/NIS transported into Arctic conditions is largely unknown and likely variable between species (Riley et al. 2022), although scientific literature exists for other areas.

5.4 Anchoring and Mooring

Anchoring and mooring refer to the act of deploying and retrieving anchors, or attaching to a mooring system during vessel operations, both with and without the engine running, including the subsequent movement of the anchoring or mooring buoy system while deployed. Commercial vessel mooring buoys are not commonly used by vessels engaged in Canadian commercial shipping, as moorings are expensive to install and maintain, are more complex to tie to, and bulk carriers generally require a tug to enable their attachment (Hannah et al. 2020).

There is a paucity of published data on the effects of anchoring by large commercial vessels in the vicinity of deep-water habitats and on other physical effects resulting from recreational boating and commercial shipping (Abdulla and Linden 2008; Davis et al. 2016). The scope of the damage to an ecosystem from anchoring and mooring will depend largely on substrate type and benthic community composition, with soft substrate or species like coralline algae likely to be more adversely affected. The extent of damage done by an anchor will also depend on the size and type of anchor, which is contingent on the size of the vessel. The duration of anchoring can range from a few hours to several days or weeks depending on the purpose of the vessel needing to be anchored (Transport Canada 2018).

5.4.1 Habitat Alteration/Removal

For the purposes of this risk assessment, habitat alteration/removal refers to resuspension and subsequent resettling of sediments and direct disturbance or crushing of the seabed (regardless of the composition of the substrate) resulting from anchor deployment and retrieval or movement of the anchoring and mooring chains while a vessel is anchored or moored. The most substantial impacts of an anchor results from the dragging of chains across the seabed as the anchored vessel moves in response to currents and wind. Kelp beds/other macroalgae and benthic invertebrates have been assessed since they are susceptible to the effects of physical disturbance and sedimentation caused by anchoring activity (Leatherbarrow 2003; Collins et al. 2010) (Table 5-57). Studies have shown that boat anchors lowered onto seagrass beds can damage the habitat by uprooting plants and anchoring on both rocky bottoms and/or in deeper waters may have impacts on algae and sensitive benthic species associated with such habitat types (Abdulla and Linden 2008; Panigada et al. 2008). Any direct effects on fish, diving birds, and marine mammals are likely to be negligible, and as such, they have not been assessed.

Table 5-57. Anchoring and Mooring – Habitat Alteration/Removal: ESC Subcomponents and Priority Areas Assessed.

ESC Subcomponent	Priority Area	Assessed by Proxy
Kelp beds and other macroalgae	Chesterfield Inlet/Narrows	
Benthic invertebrates	Chesterfield Inlet/Narrows	

Risk Statement: If an interaction occurs involving kelp beds/other macroalgae and habitat alteration/removal due to anchoring and mooring the consequence could result in a negative impact on the ecosystem function of kelp bed/other macroalgae habitat in the Chesterfield Inlet/Narrows priority area

Table 5-58. Kelp beds and other macroalgae – Anchoring and Mooring (Chesterfield Inlet/Narrows) – Habitat Alteration/Removal.

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 2 x 3 = 6 (raw score)
Intensity	1	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low absolute density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Chesterfield Inlet/Narrows priority area experiences a high density of vessel traffic relative to other portions of the AOI (see Figures 5-1 and 5-10) representing approximately 61% of total AIS data within the AOI from 2012-2019, though those at rest make up a smaller proportion of that total. The intensity of vessel traffic and the resulting stressor is not uniform, and the density would be higher in areas of higher vessel traffic (e.g., near regular anchorage areas). The activity of anchoring/mooring implies persistence in the priority area; however, AIS data indicate that vessels may remain at rest in this priority area for up to two weeks (Maerospace 2020) with common anchorages near the community of Chesterfield Inlet and at Helicopter Island near Chesterfield Narrows (Idlout 2020; Agnico Eagle 2022). There would also be a low density of vessels anchoring at any one time. Therefore, intensity was scored as 1.
Temporal	2	Macroalgae are present in the Chesterfield Inlet/Narrows priority area year-round, though photosynthetic activity, important in advance of the growth phase which largely occurs under ice (Chapman and Lindley 1980), is restricted to the ice-free season. Vessels are typically present in the priority area during July to September, and occasionally during June (Maerospace 2020), though they are not present throughout that entire period. AIS data indicate that vessels may remain at rest in this priority area for up to two weeks (Maerospace 2020) with common anchorages near the community of Chesterfield Inlet and at Helicopter Island near Chesterfield Narrows (Idlout 2020; Agnico Eagle 2022). Numerous vessels will occur in the priority area throughout the summer. Considering the above, there is an approximate temporal overlap of 33-50% between when vessels and macroalgae are present, resulting in a score of 2.
Spatial	3	Spatial = Areal x Depth = 1 x 3 = 3
Areal	1	Macroalgae typically occurs in water depths between 5-50 m in the AOI, with higher densities at 10 and 15 m compared with 5 m (Krause-Jensen et al 2012; Filbee-Dexter et al. 2022). An anchor and anchoring/mooring chains would be restricted to a single point source location relative to a vessel anchored/moored in the priority area, resulting in a score of 1.
Depth	3	Macroalgae inhabit surficial seabed substrate. An anchor and anchoring/mooring chains would be in direct contact with the seabed and thus cover the entire depth range of macroalgae in the Chesterfield Inlet/Narrows priority area.
Sensitivity	1 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (1 + 1) x 2.0 = 4.0
Acute Change	1	The deployment and retrieval of a vessel anchor and movement of anchoring/ mooring chains (“anchor scour”) can cause disturbance to the seabed and

Risk Factor	Score	Rationale
		associated biota (Broad et al. 2020), including suspension and resettling of sediments and crushing. Vessel movement at the surface, such as due to the tide or wind, results in the chains dragging across the seabed (Broad et al. 2020). Chain scope is generally 5-10x greater than water depth, with more chain payout required during poor weather conditions (Broad et al. 2020). Greater chain scope has been associated with higher seabed disturbance (Broad et al. 2020), as evidenced by larger mooring scars observed in seagrass beds from moorings installed in deeper waters (Montefalcone et al. 2008; Glasby and West 2018). Fauna inhabiting the seabed in nearshore locations that experience regular, natural disturbance (e.g., wind, wave, and tidal action) are likely adapted to physical disruptions and would be expected to experience minimal effects from anchoring/mooring (Broad et al. 2020). More pronounced effects would be expected in seabed habitats that normally experience little in the way of natural disturbance, particularly in areas with predominantly mud/clay substrates (Broad et al. 2020). Macroalgae may be smothered by the resettling of suspended sediments from anchoring/mooring (WWF 2020). Suspension of sediment may decrease light availability for regions where light penetrates to the seabed and the resuspension of sediments can rerelease nutrients from the substrate, altering the surrounding nutrient concentrations, all of which may ultimately affect productivity (WWF 2020). Regardless of size, anchors and chains can damage, dislodge, and crush macroalgae, which can reduce percent cover and diversity (e.g., Broad et al. 2020). Localized physical impacts from anchoring/mooring can be intense; anchors from large vessels may penetrate over 1 m into the seafloor and each link in their chain may weigh more than 200 kg (Broad et al. 2020). Boat anchorages in Brazil's Arraial do Cabo Marine Extractive Reserve were observed to cause the greatest physical damage to the epilithic algal matrix relative to other benthic organisms, with anchor chains/cables causing more damage than anchors; however, recovery is expected to occur quickly due to high succession and replacement rates (Giglio et al. 2017). Creed and Filho (1999) estimated that 0.5% of algal-seagrass beds were damaged annually from anchoring related to tourism activities within the Abrolhos Marine National Park in Brazil, where the authors estimated a mean anchor scar size of 0.16 m^2. Creed and Filho (1999) also observed the impacts and recovery of algal-seagrass beds subjected to four days of simulated anchor damage in the Park; short-term effects included reduced seagrass density, total seagrass and macroalgae standing stock, and abundance of the red algae *Laurencia corpi* that grew epiphytically on the macroalgae *Udotea flabellum*. At the current relatively low level of vessel traffic, changes in the habitat function of kelp beds/other macroalgae would be expected to be insignificant or undetectable. Thus, a score of 1 was assigned.
Chronic Change	1	Persistent or frequent anchoring/mooring activities may cause chronic disturbance that results in local changes in community composition towards disturbance-tolerant species and requires lengthy periods for ecosystem recovery (Broad et al. 2020; WWF 2020). In benthic regions with limited natural disturbance to the substrate, such as in predominantly mud/clay habitats, evidence of physical disturbance from anchoring/mooring can persist for months (Jennings et al. 2001a). Anchor scars in the seabed from large vessels can be similar to tracks made by fishing trawlers and chronic disturbance by anchoring/mooring has been likened to the effects of bottom-contact fishing on benthic biota (Broad et al. 2020), which can result in an altered trophic community structure and function (Jennings et al. 2001b). Areas of seagrass beds scoured by anchors and chains may experience increased susceptibility to disease, reduced chlorophyll production, and an initiation of sulphide intrusion into the pore water, which would

Risk Factor	Score	Rationale
		cause further limitations to plant growth and present ideal conditions for colonization by non-indigenous species (Broad et al. 2020). The fast-growing seagrass *Halodule wrightii* reoccupied 0.25 m^2 areas within nine months of being experimentally cleared to simulate anchor damage in the Abrolhos Marine National Park, Brazil (Creed and Filho 1999). The recovering seagrass produced a greater number of short shoots than plants in uncleared areas (Creed and Filho 1999). Conversely, slower-growing seagrass species, such as *Posidonia* spp., only partially recovered within 12 months following simulated anchor damage and may require decades to fully recover from such a disturbance (Broad et al. 2020). However, even fast-growing/resilient seagrass species may experience difficulty recolonizing if anchoring occurs year-round or at high intensity (Broad et al. 2020). Some macroalgae species, such as *U. flabellum*, recovered quickly following the disturbance, while other common macroalgae species in the area (e.g., *Dictyota mertensii*, *D. cervicornis*, and *L. corpi*) recovered more slowly (Creed and Filho 1999). Rhodolith beds are fragile, habitat-forming coralline algae that are associated with high biodiversity (Broad et al. 2020); their brittle nature renders them particularly sensitive to physical disturbance. Anchoring may crush and shatter rhodolith beds and cause long-lasting effects due to their slow growth rates (<1 mm/year). Repeated crushing disturbance will likely result in a transition from rhodolith beds to sands, which have been associated with lower biodiversity and decreased environmental stability. Long-term, repeated crushing or fragmentation could eliminate this habitat-providing species if their growth rate is unable to compensate for the disturbance (Broad et al. 2020). Experimental anchoring in a temperate coastal barrier lagoon in southeastern New South Whales resulted in the removal of fragments of the invasive green seaweed *Caulerpa taxifolia* during 82% of anchor deployments (West et al. 2007). Similarly-sized seaweed clumps were removed regardless of anchor composition (rock vs. sand) and anchors with chain attachments removed significantly larger clumps than anchors tied with ropes (West et al. 2007). A measurable change to long-term viability of kelp bed/other macroalgae habitat could occur in portions of the Chesterfield Inlet/Narrows priority area impacted by chronic anchoring/mooring; however, the current low level of vessel traffic would be anticipated to result in such changes being insignificant or undetectable. Thus, a score of 1 was assigned.
Recovery Factors	2.0	At least 19 species/taxonomic groups of macroalgae have been documented to occur within or near the AOI (DFO 2020; Loewen et al. 2020a, b; Filbee-Dexter et al. 2022). At least 8 species/taxonomic groups have been reported for the Chesterfield Inlet/Narrows priority area. Of these macroalgae, three kelp species, *Laminaria solidungula*, edible kelp and sugar kelp are among the most abundant in the AOI, creating extensive kelp forests reaching up to 3-4 m in height and spreading several kilometers from shore (DFO 2020; Loewen et al. 2020b; Filbee-Dexter et al. 2022). *L. solidungula* is an Arctic endemic species (Roleda 2016). Biomasses of up to 34 kg/m^2 were observed for these kelp forests in the AOI, the highest ever reported for the eastern Canadian Arctic (Filbee-Dexter et al. 2022). Other types of macroalgae also occur amongst these kelp species, including coralline encrusting algae, and are important to create the structural complexity beneficial to its inhabitants (Wharton and Mann 1981; Christie et al. 1998; Steen et al. 2016; Misiuk and Aitken 2020). Habitat recovery factors were used. Recovery factors = mean of the factors listed below. Growth rate (biogenic)/rate of structural rebuilding (abiotic): 1 (Kelp sporophyte growth rates are high compared to other organisms [Mann 1973]). Resistance: 3 (Kelp can easily be disturbed physically, known to break apart during physical duress such as sample collection [Mundy 2020]. A change in

Risk Factor	Score	Rationale
		ecosystem structure, such as an increase in urchin populations [e.g., Filbee-Dexter and Scheibling 2014] can lead to rapid and extensive defoliation of kelp). Regenerative potential: 2 (The regeneration of kelp forests after destructive events highly depends on the strength and duration of the event(s). Different clearing experiments in the northern Atlantic have shown that a full kelp regrowth can be observed after 1-3 years when environmental pressures are removed (Scheibling 1986; Christie et al. 1998; Steen et al. 2016). However, fully grown kelp forests also host a great variety of understorey algae along with many fish and invertebrates, that can take over 5 years to recolonize the habitat (Wharton and Mann 1981; Christie et al. 1998; Steen et al. 2016). In the Arctic, many authors have concurred that coastal recovery processes should be much slower than in temperate waters (Dunton et al. 1982; Conlan 2005; Keck et al. 2020). Several experiments and measurements done in the Beaufort Sea's Boulder Patch have shown that following a major disturbance on the site, it could take more than a decade for the sessile community, including kelp, to fully recover (Konar 2013; Bonsell and Dunton 2021). External stress: 2 (Climate change and warming waters add to stress [e.g., Filbee-Dexter et al. 2020]).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 2 x 1 = Negligible
Likelihood	5	As kelp and other macroalgae are benthic organisms and anchoring/mooring devices are designed to interact with the seabed, an interaction is certain to occur for macroalgae present directly where the device rests. Therefore, likelihood was scored as 5.
Overall Risk	Low Risk	No additional management measures need to be considered at this time. However, limiting anchoring/mooring activities in the Chesterfield Inlet/Narrows priority area and reducing chain scope to the extent possible within vessel safety limits, particularly in habitats identified as important kelp areas (see areas identified during an Inuit Qaujimajatuqangit workshop in February 2020 [Idlout 2020]) could be employed as precautionary measures.
Uncertainty		
Exposure	5	Research is needed on the extent of the effects of anchoring/mooring in Arctic environments. Most available literature focuses on the effects of anchor scour from recreational vessels; relatively few studies assess the effects from large vessels, and most studies are for tropical or temperate ecosystems (Broad et al. 2020). There is also limited research for the impacts of anchor scour in water depths >10 m (Broad et al. 2020). General vessel traffic patterns and routine operations are known.
Sensitivity	4	Macroalgal documentation in the Chesterfield Inlet/Narrows priority area is limited (e.g., DFO 2020; Loewen et al. 2020a, b), although macroalgae and coastal kelp beds have been identified near the mouth of Chesterfield Inlet and it is known that the Western Hudson Bay Coastline EBSA features dense coastal kelp beds and macroalgae (DFO 2020). Life history information is generally limited for macroalgae species that occur in/near the priority area. No studies have focused on the effects of anchoring/mooring on Arctic benthic biota (Broad et al. 2020). More research is needed to understand the recovery speed of damaged macroalgae in the Arctic.
Likelihood	2	Kelp and other macroalgae are benthic organisms and anchoring/mooring devices are designed to interact with the seabed. Therefore, an interaction is certain to occur where they overlap and the uncertainty is low.

Risk Statement: If an interaction occurs involving benthic invertebrates and habitat alteration/removal due to anchoring and mooring the consequence could result in a negative impact on benthic invertebrate populations in the Chesterfield Inlet/Narrows priority area.

Table 5-59. Benthic Invertebrates – Anchoring and Mooring (Chesterfield Inlet/Narrows) – Habitat Alteration/Removal.

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 2 x 3 = 6 (raw score)
Intensity	1	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low absolute density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Chesterfield Inlet/Narrows priority area experiences a high density of vessel traffic relative to other portions of the AOI (see Figures 5-1 and 5-10) representing approximately 61% of total AIS data within the AOI from 2012-2019, though those at rest make up a smaller proportion of that total. The intensity of vessel traffic and the resulting stressor is not uniform, and the density would be higher in areas of higher vessel traffic (e.g., near regular anchorage areas). The activity of anchoring/mooring implies persistence in the priority area; however, AIS data indicate that vessels may remain at rest in this priority area for up to two weeks (Maerospace 2020) with common anchorages near the community of Chesterfield Inlet and at Helicopter Island near Chesterfield Narrows (Idlout 2020; Agnico Eagle 2022). There would also be a low density of vessels anchoring at any one time. Therefore, intensity was scored as 1.
Temporal	2	Benthic invertebrates are present in the Chesterfield Inlet/Narrows priority area year-round. Vessels are typically present in the priority area during July to September, and occasionally during June (Maerospace 2020), though they are not present throughout that entire period. AIS data indicate that vessels may remain at rest in this priority area for up to two weeks (Maerospace 2020) with common anchorages near the community of Chesterfield Inlet and at Helicopter Island near Chesterfield Narrows (Idlout 2020; Agnico Eagle 2022). Numerous vessels would occur in the priority area throughout the summer. Considering the above, there is an approximate temporal overlap of 33-50% between when vessels and benthic invertebrates are present, resulting in a score of 2.
Spatial	3	Spatial = Areal x Depth = 1 x 3 = 3
Areal	1	Benthic invertebrates are anticipated to occur throughout the Chesterfield Inlet/Narrows priority area. An anchor and anchoring/mooring chains would be restricted to a single point source location relative to a vessel anchored/moored in the priority area. Thus, a score of 1 was assigned.
Depth	3	Benthic invertebrates inhabit the seabed. An anchor and anchoring/mooring chains would be in direct contact with the seabed and thus cover the entire depth range of benthic invertebrates in the Chesterfield Inlet/Narrows priority area.
Sensitivity	1 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (1 + 1) x 2.3 = 4.6

Risk Factor	Score	Rationale
Acute Change	1	The deployment and retrieval of a vessel anchor and movement of anchoring/ mooring chains ("anchor scour") can cause disturbance to the seabed and associated biota (Broad et al. 2020), including suspension and resettling of sediments and crushing. Vessel movement at the surface, such as due to the tide or wind, results in the chains dragging across the seabed (Broad et al. 2020). Chain scope is generally 5-10x greater than water depth, with more chain payout required during poor weather conditions (Broad et al. 2020). Greater chain scope has been associated with higher seabed disturbance (Broad et al. 2020), as evidenced by larger mooring scars observed in seagrass beds from moorings installed in deeper waters (Montefalcone et al. 2008; Glasby and West 2018). Fauna inhabiting the seabed in nearshore locations that experience regular, natural disturbance (e.g., wind, wave, and tidal action) are likely adapted to physical disruptions and would be expected to experience minimal effects from anchoring/mooring (Broad et al. 2020). More pronounced effects would be expected in seabed habitats that normally experience little in the way of natural disturbance, particularly in areas with predominantly mud/clay substrates (Broad et al. 2020). Benthic biota may be smothered by the resettling of suspended sediments from anchoring/mooring (WWF 2020). Suspension of sediment may decrease light availability for regions where light penetrates to the seabed, and the resuspension of sediments can rerelease nutrients from the substrate, altering the surrounding nutrient concentrations; both of which may ultimately affect productivity (WWF 2020). The distribution of benthic invertebrates may also be impacted if sediment resuspension alters oxygen concentrations or the exchange of organic carbon (WWF 2020). Increases in suspended sediment from anchoring/mooring can cause a decrease or complete stop in filter feeding pumping rates of some sponge species (Grant et al. 2019). Regardless of size, anchors and chains damage, dislodge, and crush benthic fauna, which can reduce colony size, percent cover, architectural complexity, and diversity of sensitive benthic invertebrate species, such as corals (Broad et al. 2020). Localized crushing impacts from anchoring/mooring can be intense; anchors from large vessels may penetrate over 1 m into the seafloor and each link in their chain may weigh more than 200 kg (Broad et al. 2020). Some colonial cnidarians, such as the soft coral *Gersemia rubiformis*, can survive some degree of crushing or abrasion; these organisms inflate or retract their polyps and may react to disturbance by enacting reproduction; however, these potential survival responses occur at the cost of lost time spent feeding, performing waste exchange, or propagating clonally (Henry et al. 2003). Corals and sponges can be easily detached from their substrate by chain movement/impact (Henry et al. 2003). Once dislodged, corals and large sponges generally do not reattach to the substrate and ultimately die (McMurray and Pawlik 2009). At the current relatively low rate of vessel traffic, changes in benthic invertebrate mortality rates against background variability would be expected to be insignificant or undetectable, resulting in a score of 1.
Chronic Change	1	Persistent anchoring/mooring or frequent anchoring/mooring activities may cause chronic disturbance that results in local changes in community composition towards disturbance-tolerant species and requires lengthy periods for ecosystem recovery (Broad et al. 2020; WWF 2020). In benthic regions with limited natural disturbance to the substrate, such as in predominantly mud/clay habitats, evidence of physical disturbance from anchoring/mooring can persist for months (Jennings et al. 2001a). Anchor scars in the seabed from large vessels can be similar to tracks made by fishing trawlers and chronic disturbance by anchoring/mooring has been likened to the effects of bottom-contact fishing on

Risk Factor	Score	Rationale
		benthic invertebrates (Broad et al. 2020), which can result in an altered trophic community structure and function (Jennings et al. 2001b). If colonial cnidarians are subject to chronic exposure of anchor scour, it is expected that colony expansion would be impaired for those organisms that survive crushing disturbance, due to the interruption of normal daily activities and physical damage (Henry et al. 2003). Coral cover was found to have only half recovered a decade after an accidental anchoring event by a cruise ship in the U.S. Virgin Islands (Rogers and Garrison 2001). Benthic invertebrates in areas of the Gulf Islands National Park Reserve of Canada subject to high recreational boating anchoring/mooring activity exhibited poorer overall health compared to those in low-intensity anchoring/mooring areas of the Reserve (Leatherbarrow 2009). A measurable change to overall fitness and population dynamics could occur in portions of the Chesterfield Inlet/Narrows priority area impacted by chronic anchoring/mooring; however, the current low rate of vessel traffic and of associated anchoring/mooring events would be anticipated to result in such changes being insignificant or undetectable. Thus, a score of 1 was assigned.
Recovery Factors	2.3	At least 430 benthic invertebrate species have been identified within or near the AOI, including corals (e.g., the soft coral *Gersemia rubiformis*), sponges, sea stars, brittle stars, sea urchins, bivalves, cephalopods, crinoids, gastropods, holothuroids (sea cucumbers), hydrozoans, amphipods, cumaceans, decapods, euphausiids, isopods, Leptostracans, ostracods, sea spiders, polychaetes, barnacles, and chitons (DFO 2020; Loewen et al. 2020a, b). Corals and sponges are the most sensitive benthic invertebrate groups identified for the priority area and were used for the determination of Recovery Factors. There have been limited benthic invertebrate studies for the Chesterfield Inlet/Narrows priority area (e.g., GN 2010; Misiuk and Aitken 2020; Pierrejean et al. 2020). Recovery factors = mean of the factors listed below. Fecundity: 1 (*Geodia phlegraei* sponges from the North Atlantic were observed to produce ~16 million oocytes/sponge and ~30 billion spermatozoa/sponge [Koutsouveli et al. 2020]. It is currently unknown whether *Geodia* sponges occur in the AOI, but the information presented here may be generally used for the Porifera Phylum reported for the AOI). Early life stage mortality: 3 (During four years of observations in water depths >650 m in the Gulf of Maine, the deep-water gorgonian coral *Primnoa resedaeformis* experienced high mortality during its early benthic stage, possibly due to biological disturbance, such as by suspension-feeding brittle stars, and limited food supply [Lacharité and Metaxas 2013]. Larvae of the cold-water coral *Lophelia pertusa* had an average survival rate of 60% during three months of laboratory observations and a maximum longevity of one year [Strömberg and Larsson 2017]. Although neither of these species have been reported for the AOI (Loewen et al. 2020a), their habitat conditions may be considered analogous to those of the AOI and the information presented here is applied in a precautionary manner for species within the AOI, for which no specific early life stage mortality information could be found). Recruitment pattern: 2 (Of two deep-water gorgonian corals observed in the Gulf of Maine, the broadcast spawner *P. resedaeformis* had high recruit abundance while the brooder spawner *Paragorgia arborea* had few recruits [Lacharité and Metaxas 2013]. The life span and rates of asexual and sexual reproduction in the soft coral *G. rubiformis* are unknown; however, asexual reproduction can be stimulated by physical disturbance [Henry et al. 2003; Iken et al. 2012]. The lifespan of *Geodia* spp. Sponges is unknown, but they are likely to be slow growing [Last et al. 2019]. Although the corals *P. resedaeformis* and *P. arborea* and *Geodia* sponges have not been reported for the AOI, the information provided

Risk Factor	Score	Rationale
		here has been applied for the AOI, for which no specific information could be found). Natural mortality rate: Unknown; excluded from consideration. Age at maturity: Unknown (DFO 2015b); excluded from consideration. Life stages affected: 3 (All life stages are expected to be affected). Population connectivity: Unknown; excluded from consideration. Population status: Unknown (The population size of the soft coral *G. rubiformis* is unknown [Boutillier et al. 2019] and corals/sponges are not considered under Sara or COSEWIC); excluded from consideration.
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 2 x 1 = Negligible
Likelihood	4	As benthic invertebrates occupy the seabed and anchoring/mooring devices are designed to interact with the seabed, it is reasonably likely that the devices and chains would contact benthic invertebrates (e.g., epifauna on the seabed surface or infauna within soft benthic sediments). Therefore, an interaction would occur in most circumstances and likelihood was scored as 4.
Overall Risk	Low Risk	No additional management actions need to be considered at this time. However, limiting anchoring/mooring activities in the Chesterfield Inlet/Narrows priority area and reducing chain scope to the extent possible within vessel safety limits, particularly in habitats hosting sensitive benthic invertebrate species, could be employed as precautionary measures.
Uncertainty		
Exposure	5	Research is needed on the extent of the effects of anchoring/mooring in Arctic environments. Most available literature focuses on the effects of anchor scour from recreational vessels; relatively few studies assess the effects from large vessels, and most studies are for tropical or temperate ecosystems (Broad et al. 2020). There is also limited research for the impacts of anchor scour in water depths >10 m (Broad et al. 2020). General vessel traffic patterns and routine operations are known.
Sensitivity	5	Limited information is available for benthic community diversity and abundance for the Chesterfield Inlet/Narrows priority area (DFO 2020). Life history information is generally limited for sensitive benthic invertebrate species that may occur within the priority area.
Likelihood	4	Benthic invertebrates occupy the seabed and anchoring/mooring devices are designed to interact with the seabed. Therefore, the likelihood of an interaction is fairly certain, though more research is needed to cover the suite of benthic invertebrates present.

5.5 Vessel Discharge

Discharge from a vessel includes any ballast water, wastewater, sewage, petroleum products, and other contaminants that are intentionally or unintentionally discharged from marine vessels (Davenport and Davenport 2006; Hannah et al. 2020). Discharge can affect the marine environment through a number of stressors, including introduction of biological material (i.e., wastewater and sewage), introduction of pathogens/NIS, petroleum products, black carbon, and other contaminants.

5.5.1 Biological Material

Raw sewage and greywater (i.e., water from galleys, showers, sinks, etc.) discharge from vessels may pose risks to ESC subcomponents, including the potential for smothering, excess nutrient load, and exposure to toxins (Science Advisory Panel 2002; Holeton et al. 2011). The main stressor associated with raw sewage and greywater discharge is the release of nutrients into the marine environment, as well as the potential for the introduction of pathogens/NIS. Pathogens, including toxin producing algae, from ballast water discharges are addressed as a separate pathogen/NIS pathway in Section 5.5.2. Suspended solids are an additional potential stressor from sewage and grey water discharge, but they were not explicitly considered in the Southampton Island AOI PoE report (Johnson et al. unpublished[16]) and are not expected to result in measurable impact to any ESC subcomponents; as such, this section addresses the specific stressor of nutrient enrichment from sewage and grey water discharge.

Section 4(1) of the *Arctic Waters Pollution Prevention Act* (1985) prohibits the discharge of any waste in Arctic waters, with waste defined as:

(a) "any substance that, if added to any water, would degrade or alter or form part of a process of degradation or alteration of the quality of that water to an extent that is detrimental to their use by man or by any animal, fish or plant that is useful to man"; and,
(b) "any water that contains a substance in such a quantity or concentration, or that has been so treated, processed or changed, by heat or other means, from a natural state that it would, if added to any other water, degrade or alter or form part of a process of degradation or alteration of the quality of that water to the extent described in paragraph (a)

Although the discharge of wastewater from vessels is prohibited under the *Arctic Waters Pollution Prevention Act* (1985), the *Arctic Shipping Safety and Pollution Prevention Regulations* (2017) include some exemptions for the discharge of untreated and treated sewage (GoC 2015; Dawson et al. 2018). Wastewater may be discharged if required during an emergency (i.e., to save a life, for vessel safety, or to prevent immediate vessel loss) (*Arctic Shipping Safety and Pollution Prevention Regulations* 2017). During non-emergency, regular operations, for vessels constructed prior to 2017, ice class vessels of ≥400 gross tonnage or that are certified to carry >15 persons may discharge sewage that is comminuted and disinfected when the vessel is ≥3 nm from an ice-shelf or fast-ice and "as far as practicable from areas of ice concentration exceeding 1/10"; if the sewage is not comminuted/disinfected, the distance increases to ≥12 nm. Ice class vessels or passenger vessels built on or after 1 January 2017 are required to have an approved, on-board sewage treatment system and discharges of treated sewage are permitted in accordance with International Convention

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[16] Johnson et al. 2019. Pathways of effects modelling for the ecological and biological components of the Southampton Island Area of Interest. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/nnn. vi + xx p.

for the Prevention of Pollution by Ships (MARPOL) regulations when the vessel is “as far as practicable from the nearest land, ice-shelf, fast-ice, or areas of ice concentration exceeding 1/10”. Otherwise, if an ice class vessel is required to operate for a prolonged period in an area where ice conditions exceed 1/10, sewage may be discharged providing it has been treated using an approved, on-board sewage treatment plant. Vessels of 16-399 gross tonnage that are certified to carry ≤15 persons may discharge sewage provided the sewage is comminuted and disinfected using a regulatory-compliant marine sanitation device and the vessel is ≥1 nm from shore, an ice-shelf, or fast-ice or while the vessel is en route at its “fastest feasible speed” ≥3 nm from shore, an ice-shelf, or fast-ice; if it is not possible for a vessel en route to meet these speed or distance conditions, discharges may only occur in the deepest available waters farthest from shore, ideally during an ebb tide and in fast moving waters. Otherwise, either discharge scenario (treatment or en route) may occur providing the vessel is “as far as practicable from areas of ice concentrations exceeding 1/10”. Vessels of ≤15 gross tonnage carrying ≤15 persons are permitted to discharge sewage generated on board the vessel. It is not expected that vessels will be discharging wastewater constantly.

The *Arctic Shipping Safety and Pollution Prevention Regulations* (2017) address the permissible discharge of sewage (black water) in restricted situations, as described above. By contrast, greywater is not mentioned in the Regulations and ambiguity exists whether greywater is classified as waste. If greywater is classified as waste, vessel operators would have to process and discharge greywater before entering zero-discharge regions and would require large holding tank systems to not discharge during their voyage, or for the operator to ignore regulations and continue to discharge greywater in spite of the prohibition (Vard Marine Inc. 2018). It is suggested that many vessels visiting the Arctic do not have holding tank systems large enough to contain all the greywater generated during their Arctic voyages (Vard Marine Inc. 2018). While greywater discharge may be prohibited, the lack of practical alternatives has resulted in a lack of monitoring and enforcement (Vard Marine Inc. 2018). Therefore, untreated greywater discharge is expected to occur.

All vessel types may discharge wastewater into the environment, though the scale with which it occurs will depend on vessel type. The main source of wastewater discharge in the marine environment from vessels is generally expected to be from cruise ships, as they can carry thousands of people and expel correspondingly large amounts of wastewater each day (Holeton et al. 2011). However, cruise ships that have operated in the AOI are smaller, expedition-type cruise ships that may only carry several hundred people rather than thousands. For example, the only cruise ship identified in the AOI from 2012 to 2019 (Maerospace 2020) was the *Silver Explorer*, with a guest capacity of 144 and crew capacity of 118 (Silversea Cruises Ltd. 2022). Though an increase in the number and/or size of cruise ships operating in the AOI in the future may require additional investigation at that time, with the possibility of adaptive management measures being implemented based on discussions with the MPA co-management partners and as described in an MPA management plan, this assessment is based on the current extent of activities. Therefore, this assessment will investigate wastewater discharge from all vessel types combined.

Studies examining nutrient enrichment (from vessel sewage, among other sources) are lacking in Arctic marine environments. Based on studies of non-arctic ecosystems, depending on the intensity (temporal and spatial) of enrichment, effects could range from moderate increases in primary productivity (e.g., Back et al. 2021) to more definitive eutrophication. It is not clear whether any Arctic marine species or habitats have been negatively impacted by eutrophication from vessel discharges, but nutrient inputs from sewage have increased phytoplankton productivity over short time frames in Arctic coastal environments receiving municipal sewage (Back et al. 2021). Elevated nutrient concentrations may also persist in Arctic coastal waters near municipal sewage discharge locations, but available research is limited (Chaves-Barquero et al. 2016; Krumhansl et al. 2016). Research examining municipal wastewater nutrient enrichment in the Arctic should be applicable to vessel sewage discharge as treatment in Nunavut communities is generally more limited than in southern jurisdictions, similar to vessel sewage treatment (e.g., Back et al. 2021). Based on the large body of research generally addressing eutrophication in aquatic systems, the added nutrients from raw sewage and grey water are likely to have more direct impacts at the base of Arctic marine food webs, with secondary effects to higher trophic levels. Therefore, kelp beds/ other macroalgae, benthic invertebrates, phytoplankton, Arctic cod, and other forage fish (e.g., sculpin) have been assessed (Table 5-60). Zooplankton will be assessed by proxy through the assessment on phytoplankton as discussed in Section 3.0.

Table 5-60. Vessel Discharge – Biological Material: ESC Subcomponents and Priority Areas Assessed.

ESC Subcomponent	Priority Area	Assessed by Proxy
Kelp beds and other macroalgae	Chesterfield Inlet/Narrows	
Benthic invertebrates	Chesterfield Inlet/Narrows	
Phytoplankton	Chesterfield Inlet/Narrows	
Zooplankton		Via phytoplankton
Arctic cod	Fisher and Evans Straits	
Other forage fish	Chesterfield Inlet/Narrows	

Risk Statement: If an interaction occurs involving kelp beds/other macroalgae and biological material (from grey/other wastewater and/or sewage) discharged from a vessel the consequence could result in a negative impact on the ecosystem function of kelp bed/other macroalgae habitat in the Chesterfield Inlet/Narrows priority area

Table 5-61. Kelp beds and other macroalgae – Vessel Discharge (Wastewater; Chesterfield Inlet/Narrows) – Biological Material.

Risk Factor	Score	Rationale
Exposure	3 (binned)	Exposure = Intensity x Temporal x Spatial = 2 x 2 x 4 = 16 (raw score)
Intensity	2	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low absolute density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Chesterfield Inlet/Narrows priority area experiences a high density of vessel traffic relative to other portions of the AOI (see Figures 5-1 and 5-10) representing approximately 61% of total AIS data within the AOI from 2012-2019. The intensity of vessel traffic and the resulting stressor is not uniform, and the density would be higher in areas of higher vessel traffic (e.g., near regular anchorage areas at Helicopter Island or near Chesterfield Inlet). Although the current management system limits the discharge of sewage to specific situations, such as emergencies (GoC 2015) and it is recognized that the discharge of greywater does occur (Vard Marine Inc. 2018), the discharge of wastewater from vessels is prohibited in Arctic waters under the *Arctic Waters Pollution Prevention Act*; therefore, wastewater discharge from vessels is not expected to be occurring constantly.

Risk Factor	Score	Rationale
		Biological material from vessel discharge consists of nutrients and other organic matter associated with human waste from sewage/greywater, and this assessment considers the potential effects of nutrient enrichment due to the discharge of such material from vessels. Little is known regarding the persistence of biological material from vessel discharge into Arctic ecosystems. If biological material uptake into ice were to occur (e.g., via brine channels), its presence could persist until the summer ice melt (Castellani et al. 2017) and be released into the water column, as was found to be the case for microplastics and other anthropogenic litter microparticles in Svalbard, Norway (von Friesen et al. 2020). To account for the higher density of vessel traffic in this priority area and the possible persistence of biological material due to uptake in sea ice, intensity was scored as a 2. Though there is minimal passenger vessel traffic in the AOI, passenger vessels produce higher volumes of greywater and sewage than other types of vessels (US EPA 2011). If cruise ship traffic were to increase, the frequency and amount of discharge of biological material could increase, as cruise ships are major contributors of wastewater release into Canadian marine waters (WWF 2019).
Temporal	2	Macroalgae are present in the Chesterfield Inlet/Narrows priority area year-round, though photosynthetic activity, important in advance of the growth phase which largely occurs under ice (Chapman and Lindley 1980), is restricted to the ice-free season. Vessels are typically present in the priority area during July to September, and occasionally during June (Maerospace 2020), though they may not be present throughout that entire period. Although the discharge of wastewater from vessels is prohibited in Arctic waters under the *Arctic Waters Pollution Prevention Act*, sewage discharge is permitted in some situations such as emergencies (GoC 2015) and it is recognized that the discharge of greywater does occur (Vard Marine Inc. 2018). Wastewater discharge is presumed possible any time vessels are present in the priority area though it is expected that vessels will not be discharging wastewater constantly. Considering the above, there is an approximate temporal overlap of 25-50%, resulting in a score of 2.
Spatial	4	Spatial = Areal x Depth = 2 x 2 = 4
Areal	2	Macroalgae typically occurs in water depths between 5-50 m in the AOI, with higher densities at 10 and 15 m compared with 5 m (Krause-Jensen et al 2012; Filbee-Dexter et al. 2022). Biological material from vessel discharge could be transported beyond the vessel's immediate location via water currents, winds, or river flow, but the greatest concentration of biological material would be localized, thereby overlapping a small portion of the total macroalgae range in the priority area and a score of 2.
Depth	2	Macroalgae inhabit surficial seabed substrate. Although vessel discharge of biological material would occur at the water/ice surface, biological material could sink in the water column. If biological material sank in the water column, it could occur within the entire depth range of macroalgae. However, biological material would be expected to attenuate with depth, especially in deeper water; therefore, depth was scored as 2.
Sensitivity	1 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (1 + 1) x 2.0 = 4.0
Acute Change	1	Although the discharge of wastewater from vessels is prohibited in Arctic waters under the *Arctic Waters Pollution Prevention Act*, sewage discharge is permitted in some situations such as emergencies (GoC 2015) and it is recognized that the discharge of greywater does occur (Vard Marine Inc. 2018). There are no records indicating whether Arctic macroalgae have ever been negatively affected by

Risk Factor	Score	Rationale
		eutrophication due to the release of biological material from vessel discharge. The input of biological material from a vessel discharge may result in a temporary increase in nitrogen compounds, nutrient availability, and macroalgal productivity (Steneck et al. 2002). Phytoplankton primary production rapidly increased in response to a month-long discharge of effluent from a wastewater lagoon-wetland system near Cambridge Bay, Nunavut though macroalgal productivity was not measured (Back et al. 2021). Back et al (2021) suggest that the input of biological material from municipal discharge may increase the probability of harmful algal blooms. Tegner et al. (1995) demonstrated that the density of giant kelp sporophytes *(Macrocystis pyrifera*) was significantly reduced during a large, two-month-long sewage spill in California, though effects were not seen on older individuals; this example led to significantly larger biological material input than would discharge from vessels. Considering the above, it is not expected that this stressor would result in detectable change to the habitat function of kelp beds/other macroalgae, resulting in a score of 1.
Chronic Change	1	Biodegradation and non-biotic elimination of wastewater/sewage can be temperature-dependent and occur slowly in cold, icy water environments (Gunnarsdóttir et al. 2013; Gomes et al. 2022). Marine ecosystems can be subject to eutrophication in response to increased input of biological material from wastewater, which can result in the creation of hypoxic areas within the water column and increase the probability of harmful algal blooms (Back et al. 2021). The authors suggested that build-up over time could possibly result in a release of legacy nutrients in a rapid turnover event. However, there is no evidence that Arctic marine species have ever been negatively affected by eutrophication from vessel discharge. A kelp forest experienced no chronic effects from a large sewage spill (7.1×10^8 litres/day for two months) when a sewage outfall in San Diego, USA broke during winter 1992 (Tegner et al. 1995). During the spill, surface ammonium levels were elevated to potentially toxic levels and light levels were reduced within 1 km of the outfall site, while the kelp canopy benefitted from increased ammonium concentrations beyond 1 km. The density and growth of microscopic sporophytes of giant kelp were significantly reduced during the spill, but the effects disappeared within 11 days following outfall repair; no significant effects were observed for outplants of juvenile giant kelp. Soon after the outfall was repaired, upwelling resulted in optimal conditions for kelp germination and growth, and the area that was most strongly impacted during the spill developed into a dense kelp forest (Tegner et al. 1995). Primary productivity may be enhanced by the input of biological material into the priority area, but productivity would decrease as nutrients are depleted upon cessation of wastewater input into the ecosystem (Back et al. 2021). If macroalgae experience a temporary change in reproductive capacity due to an influx of nutrients from biological material released into their habitat from an occasional vessel discharge, it would be expected to be insignificant relative to natural annual variation in population dynamics (e.g., due to natural factors such as upwelling, ice scour, or stormy conditions). Thus, impacts to long-term viability of kelp bed/other macroalgae habitat is not expected and a score of 1 was assigned.
Recovery Factors	2.0	At least 19 species/taxonomic groups of macroalgae have been documented to occur within or near the AOI (DFO 2020; Loewen et al. 2020a, b; Filbee-Dexter et al. 2022). At least 8 species/taxonomic groups have been reported for the Chesterfield Inlet/Narrows priority area. Of these macroalgae, three kelp species, *Laminaria solidungula*, edible kelp, and sugar kelp are among the most abundant in the AOI, creating extensive kelp forests reaching up to 3-4 m in height and spreading several kilometers from shore (DFO 2020; Loewen et al. 2020b; Filbee-Dexter et al. 2022). *L. solidungula* is an Arctic endemic species (Roleda 2016). Biomasses of up to 34 kg/m^2 were observed for these kelp forests in the AOI, the highest ever reported for the eastern Canadian Arctic (Filbee-Dexter et al. 2022).

Risk Factor	Score	Rationale
		Other types of macroalgae also occur amongst these kelp species, including coralline encrusting algae, and are important to create the structural complexity beneficial to its inhabitants (Wharton and Mann 1981; Christie et al. 1998; Steen et al. 2016; Misiuk and Aitken 2020). Habitat recovery factors were used. Recovery factors = mean of the factors listed below. Growth rate (biogenic)/rate of structural rebuilding (abiotic): 1 (Kelp sporophyte growth rates are high compared to other organisms [Mann 1973]). Resistance: 3 (Kelp can easily be disturbed physically, known to break apart during physical duress such as sample collection [Mundy 2020]. A change in ecosystem structure, such as an increase in urchin populations [e.g., Filbee-Dexter and Scheibling 2014] can lead to rapid and extensive defoliation of kelp). Regenerative potential: 2 (The regeneration of kelp forests after destructive events highly depends on the strength and duration of the event(s). Different clearing experiments in the northern Atlantic have shown that a full kelp regrowth can be observed after 1-3 years when environmental pressures are removed (Scheibling 1986; Christie et al. 1998; Steen et al. 2016). However, fully grown kelp forests also host a great variety of understorey algae along with many fish and invertebrates, that can take over 5 years to recolonize the habitat (Wharton and Mann 1981; Christie et al. 1998; Steen et al. 2016). In the Arctic, many authors have concurred that coastal recovery processes should be much slower than in temperate waters (Dunton et al. 1982; Conlan 2005; Keck et al. 2020). Several experiments and measurements done in the Beaufort Sea's Boulder Patch have shown that following a major disturbance on the site, it could take more than a decade for the sessile community, including kelp, to fully recover (Konar 2013; Bonsell and Dunton 2021). External stress: 2 (Climate change and warming waters add to stress [e.g., Filbee-Dexter et al. 2020]).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 3 x 1 = Negligible
Likelihood	3	An interaction may occur if wastewater discharge took place in shallow waters of the priority area, or a sufficient quantity of biological material was discharged in deeper waters such that it was transported to macroalgae habitat. An interaction would not likely occur for smaller discharge events in deeper waters. An interaction between macroalgae and biological material from vessel discharge has the potential to occur in some but not all circumstances.
Overall Risk	Low Risk	No additional management actions need to be considered at this time.
Uncertainty		
Exposure	5	Macroalgal documentation has occurred in the priority area (e.g., DFO 2020; Loewen et al. 2020a, b); macroalgae and coastal kelp beds have been identified near the mouth of Chesterfield Inlet and it is known that the Western Hudson Bay Coastline EBSA features dense coastal kelp beds and macroalgae (DFO 2020). No scientific information could be found regarding the persistence of biological material from vessel discharge in the Arctic. General vessel traffic patterns are known and were used to inform vessel discharge exposure parameters. Modelling could be conducted for the Chesterfield Inlet/Narrows priority area to better understand the fate of biological material release via vessel discharge during different times of year.
Sensitivity	4	Life history information is generally limited for macroalgae species that occur in/near the priority area. Some scientific information exists for the response of macroalgae to wastewater discharges, though little is focused on the vessel discharge pathway.

Risk Factor	Score	Rationale
Likelihood	5	Research is needed on the response of Arctic macroalgae to biological material released via vessel discharge, both in open water and ice-covered habitats. Responses would likely vary with species, location (under the ice or in open water), depth, and water circulation.

Risk Statement: If an interaction occurs involving benthic invertebrates and biological material (from grey/other wastewater and/or sewage) discharged from a vessel the consequence could result in a negative impact on benthic invertebrate populations in the Chesterfield Inlet/Narrows priority area.

Table 5-62. Benthic Invertebrates – Vessel Discharge (Wastewater; Chesterfield Inlet/Narrows) – Biological Material.

Risk Factor	Score	Rationale
Exposure	3 (binned)	Exposure = Intensity x Temporal x Spatial = 2 x 2 x 4 = 16 (raw score)
Intensity	2	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low absolute density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Chesterfield Inlet/Narrows priority area experiences a high density of vessel traffic relative to other portions of the AOI (see Figures 5-1 and 5-10) representing approximately 61% of total AIS data within the AOI from 2012-2019. The intensity of vessel traffic and the resulting stressor is not uniform, and the density would be higher in areas of higher vessel traffic (e.g., near regular anchorage areas at Helicopter Island or near Chesterfield Inlet). Although the current management system limits the discharge of sewage to specific situations, such as emergencies (GoC 2015) and it is recognized that the discharge of greywater does occur (Vard Marine Inc. 2018), the discharge of wastewater from vessels is prohibited in Arctic waters under the *Arctic Waters Pollution Prevention Act*; therefore, wastewater discharge from vessels is not expected to be occurring constantly. Biological material from vessel discharge consists of nutrients and other organic matter associated with human waste from sewage/greywater, and this assessment considers the potential effects of nutrient enrichment due to the discharge of such material from vessels. Little is known regarding the persistence of biological material from vessel discharge into Arctic ecosystems. If biological material uptake into ice were to occur (e.g., via brine channels), its presence could persist until the summer ice melt (Castellani et al. 2017) and be released into the water column, as was found to be the case for microplastics and other anthropogenic litter microparticles in Svalbard, Norway (von Friesen et al. 2020). To account for the higher density of vessel traffic in this priority area and the possible persistence of biological material due to uptake in sea ice, intensity was scored as a 2. Though there is minimal passenger vessel traffic in the AOI, passenger vessels produce higher volumes of greywater and sewage than other types of vessels (US EPA 2011). If cruise ship traffic were to increase, the frequency and amount of

Risk Factor	Score	Rationale
		discharge of biological material could increase, as cruise ships are major contributors of grey water release into Canadian marine waters (WWF 2019).
Temporal	2	Benthic invertebrates are present in the Chesterfield Inlet/Narrows priority area year-round. Vessels are typically present in the priority area during July to September, and occasionally during June (Maerospace 2020), though they may not be present throughout that entire period. Although the discharge of wastewater from vessels is prohibited in Arctic waters under the *Arctic Waters Pollution Prevention Act*, sewage discharge is permitted in some situations such as emergencies (GoC 2015) and it is recognized that the discharge of greywater does occur (Vard Marine Inc. 2018). Wastewater discharge is presumed possible any time vessels are present in the priority area though it is expected that vessels will not be discharging wastewater constantly. Considering the above, there is an approximate temporal overlap of 25-50%, resulting in a score of 2.
Spatial	4	Spatial = Areal x Depth = 2 x 2 = 4
Areal	2	Benthic invertebrates are anticipated to occur throughout the Chesterfield Inlet/Narrows priority area. Biological material from vessel discharge could be transported beyond the vessel's immediate location via water currents, winds, and river flow, but the greatest concentration of biological material would be localized, thereby overlapping a small portion of the total benthic invertebrate range in the priority area and a score of 2.
Depth	2	Benthic invertebrates inhabit the seabed. Although vessel discharge of biological material would occur at the water/ice surface, biological material could sink in the water column. If biological material sank in the water column, it could occur within the entire depth range of benthic invertebrates. However, biological material would be expected to attenuate with depth; therefore, depth was scored as 2.
Sensitivity	1 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (1 + 1) x 2.3 = 4.6
Acute Change	1	Although the discharge of wastewater from vessels is prohibited in Arctic waters under the *Arctic Waters Pollution Prevention Act*, sewage discharge is permitted in some situations such as emergencies (GoC 2015) and it is recognized that the discharge of greywater does occur (Vard Marine Inc. 2018). Marine ecosystems can be subject to eutrophication in response to increased input of biological material from wastewater, which can result in the creation of hypoxic areas within the water column and increase the probability of harmful algal blooms (Back et al. 2021). However, there are no records indicating whether Arctic benthos have ever been negatively affected by eutrophication due to the release of biological material from vessel discharge. The input of biological material from a vessel discharge may result in a temporary increase in nitrogen compounds, nutrient availability, and primary productivity (Steneck et al. 2002). Benthic macroinvertebrates are generally long-lived, and their predominantly sessile lifestyle renders them largely unable to avoid changing environmental conditions (Reiss and Krönke 2005). The low absolute volume of vessel traffic within the Chesterfield Inlet/Narrows priority area and the relatively small amount of biological material that could be expected to reach the benthic substrate from an occasional vessel discharge at surface would not be expected to result in sufficient organic enrichment (e.g., Krumhansl et al. 2015) to cause sediment anoxia or mortality. There would be no expected detectable change to benthic invertebrate mortality rates or behaviour against background variability resulting in a score of 1.
Chronic Change	1	Biodegradation and non-biotic elimination of wastewater/sewage can be temperature-dependent and occur slowly in cold, icy water environments (Gunnarsdóttir et al. 2013; Gomes et al. 2022). Marine ecosystems can be subject to enrichment in response to increased input of biological material from

Risk Factor	Score	Rationale
		wastewater/sewage, which can result in the creation of anoxic or hypoxic areas or hydrogen sulphite toxicity within benthic substrate, potentially causing full loss of benthic fauna, altered biological functioning, reduced biodiversity, or changes in abundance (Krumhansl et al. 2015; Culhane et al. 2019). Available research examining the impacts of nutrient enrichment from sewage in polar marine environments has mostly focused on permanent point sources adjacent to human settlements. Krumhansl et al. (2015) monitored benthic biota exposed to effluent from five communities within Nunavut; minimal effects were observed for four of the communities, including changes in benthic invertebrate species richness, diversity, evenness, density, and species composition, while sediment anoxia (due to organic enrichment) and a complete lack of benthic macrofauna were found within 580 m of the effluent source in the fifth community. A higher volume of effluent, and therefore higher volume of organic input, was the likely reason for the observed differences, as the fifth community was noted to have a population over 4,000 persons greater than either of the other four communities (Krumhansl et al. 2015). The discharge of untreated sewage from the McMurdo Sound Research Station in Antarctica caused contamination of benthic sediment and invertebrates by fecal products, including *Clostridium perfringens* (bacteria found in human intestines which causes food poisoning in high quantities; BC CDC 2022) and coprostanol (Edwards et al. 1998); however, possible effects of contamination were not provided. Sewage discharge from an outfall pipe in western Scotland caused increased benthic invertebrate species richness with each passing year post-construction and altered community composition to favour species tolerant of organic enrichment (Culhane et al. 2019). Unlike these studies looking at permanent point sources of nutrients from shore-based sewage discharge locations, the relatively small amount of biological material that could be expected to reach the benthic substrate from a vessel discharge at surface would not likely result in significant organic enrichment or benthic invertebrate community/physiological changes. If benthic invertebrates did experience changes due to an influx of nutrients from biological material released into their habitat from an occasional vessel discharge, they are expected to be insignificant to overall fitness compared to background variability (e.g., natural seasonal variations in food web dynamics during Arctic spring algae blooms; Leu et al. 2015; Castellani et al. 2017). Thus, a score of 1 was assigned.
Recovery Factors	2.3	At least 430 benthic invertebrate species have been identified within or near the AOI, including corals (e.g., the soft coral *Gersemia rubiformis*), sponges, sea stars, brittle stars, sea urchins, bivalves, cephalopods, crinoids, gastropods, holothuroids (sea cucumbers), hydrozoans, amphipods, cumaceans, decapods, euphausiids, isopods, Leptostracans, ostracods, sea spiders, polychaetes, barnacles, and chitons (DFO 2020; Loewen et al. 2020a, b). Corals and sponges are the most sensitive benthic invertebrate groups identified for the priority area and were used for the determination of Recovery Factors. There have been limited benthic invertebrate studies for the Chesterfield Inlet/Narrows priority area (e.g., GN 2010; Misiuk and Aitken 2020; Pierrejean et al. 2020). Recovery factors = mean of the factors listed below. Fecundity: 1 (*Geodia phlegraei* sponges from the North Atlantic were observed to produce ~16 million oocytes/sponge and ~30 billion spermatozoa/sponge [Koutsouveli et al. 2020]. It is currently unknown whether *Geodia* sponges occur in the AOI, but the information presented here may be generally used for the Porifera Phylum reported for the AOI). Early life stage mortality: 3 (During four years of observations in water depths >650 m in the Gulf of Maine, the deep-water gorgonian coral *Primnoa resedaeformis* experienced high mortality during its early benthic stage, possibly

Risk Factor	Score	Rationale
		due to biological disturbance, such as by suspension-feeding brittle stars, and limited food supply [Lacharité and Metaxas 2013]. Larvae of the cold-water coral *Lophelia pertusa* had an average survival rate of 60% during three months of laboratory observations and a maximum longevity of one year [Strömberg and Larsson 2017]. Although neither of these species have been reported for the AOI (Loewen et al. 2020a), their habitat conditions may be considered analogous to those of the AOI and the information presented here is applied in a precautionary manner for species within the AOI, for which no specific early life stage mortality information could be found). Recruitment pattern: 2 (Of two deep-water gorgonian corals observed in the Gulf of Maine, the broadcast spawner *P. resedaeformis* had high recruit abundance while the brooder spawner *Paragorgia arborea* had few recruits [Lacharité and Metaxas 2013]. The life span and rates of asexual and sexual reproduction in the soft coral *G. rubiformis* are unknown; however, asexual reproduction can be stimulated by physical disturbance [Henry et al. 2003; Iken et al. 2012]. The lifespan of *Geodia* spp. Sponges is unknown, but they are likely to be slow growing [Last et al. 2019]. Although the corals *P. resedaeformis* and *P. arborea* and *Geodia* sponges have not been reported for the AOI, the information provided here has been applied for the AOI, for which no specific information could be found). Natural mortality rate: Unknown; excluded from consideration. Age at maturity: Unknown (DFO 2015b); excluded from consideration. Life stages affected: 3 (All life stages are expected to be affected). Population connectivity: Unknown; excluded from consideration. Population status: Unknown (The population size of the soft coral *G. rubiformis* is unknown [Boutillier et al. 2019] and corals/sponges are not considered under Sara or COSEWIC); excluded from consideration.
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 3 x 1 = Negligible
Likelihood	3	An interaction may occur if wastewater discharge took place in shallow waters of the priority area, or a sufficient quantity of biological material was discharged in deeper waters such that it was transported to benthic habitat. The abundance of benthic invertebrates is largely dependent upon primary productivity and the resulting availability and quality of prey items for organisms higher in the food web. If the discharge did not result in measurably increased primary productivity (e.g., small-volume discharge and/or discharge low in nutrients) or anoxia/hypoxia, an interaction is not expected. Therefore, an interaction may occur in some but not all circumstances.
Overall Risk	Low Risk	No additional management actions need to be considered at this time.
Uncertainty		
Exposure	5	The distribution of benthic invertebrates in the priority area is not well understood. General vessel traffic patterns are known and were used to inform vessel discharge exposure parameters. Modelling should be conducted for the Chesterfield Inlet/Narrows priority area to better understand the fate of biological material release via vessel discharge during different times of year.
Sensitivity	5	Little to no scientific information exists for the response of Arctic benthic invertebrates to biological material from a vessel discharge. Limited information is available for benthic community diversity and abundance for the Chesterfield Inlet/Narrows priority area (DFO 2020). Life history information is generally limited for sensitive benthic invertebrate species that may occur within the priority area.

Risk Factor	Score	Rationale
Likelihood	5	Research is needed on the response of Arctic benthic invertebrates to biological material released via vessel discharge. Responses would likely vary with species, depth, and substrate type (e.g., Molis et al. 2019).

Risk Statement: If an interaction occurs involving phytoplankton and biological material (from grey/other wastewater and/or sewage) discharged from a vessel the consequence could result in a negative impact on phytoplankton populations in the Chesterfield Inlet/Narrows priority area.

Table 5-63. Phytoplankton – Vessel Discharge (Wastewater; Chesterfield Inlet/Narrows) – Biological Material.

Risk Factor	Score	Rationale
Exposure	3 (binned)	Exposure = Intensity x Temporal x Spatial = 2 x 3 x 4 = 24 (raw score)
Intensity	2	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low absolute density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Chesterfield Inlet/Narrows priority area experiences a high density of vessel traffic relative to other portions of the AOI (see Figures 5-1 and 5-10) representing approximately 61% of total AIS data within the AOI from 2012-2019. The intensity of vessel traffic and the resulting stressor is not uniform, and the density would be higher in areas of higher vessel traffic (e.g., near regular anchorage areas at Helicopter Island or near Chesterfield Inlet). Although the current management system limits the discharge of sewage to specific situations, such as emergencies (GoC 2015) and it is recognized that the discharge of greywater does occur (Vard Marine Inc. 2018), the discharge of wastewater from vessels is prohibited in Arctic waters under the *Arctic Waters Pollution Prevention Act*; therefore, wastewater discharge from vessels is not expected to be occurring constantly. Biological material from vessel discharge consists of nutrients and other organic matter associated with human waste from sewage/greywater, and this assessment considers the potential effects of nutrient enrichment due to the discharge of such material from vessels. Little is known regarding the persistence of biological material from vessel discharge into Arctic ecosystems. If biological material uptake into ice were to occur (e.g., via brine channels), its presence could persist until the summer ice melt (Castellani et al. 2017) and be released into the water column, as was found to be the case for microplastics and other anthropogenic litter microparticles in Svalbard, Norway (von Friesen et al. 2020). To account for the higher density of vessel traffic in this priority area and the possible persistence of biological material due to uptake in sea ice, intensity was scored as a 2. Though there is minimal passenger vessel traffic in the AOI, passenger vessels produce higher volumes of greywater and sewage than other types of vessels (US EPA 2011). If cruise ship traffic were to increase, the frequency and amount of discharge of biological material could increase, as cruise ships are major contributors of grey water release into Canadian marine waters (WWF 2019).

Risk Factor	Score	Rationale
Temporal	3	Phytoplankton may occur in the Chesterfield Inlet/Narrows priority area year-round; however, phytoplankton abundance/density is significantly greater during open-water periods and the spring bloom relative to other times of the year (Matthes et al. 2021). Matthes et al. (2021) found that the highly abundant sub ice diatom, *Melosira artica*, plays an important role in local production. The area that encompasses the mouth of the Chesterfield Inlet/Narrows priority area is part of the northwestern polynya of the Hudson Bay that has been known to be the largest contributor to annual production in Hudson Bay (Matthes et al. 2021). Vessels are typically present in the priority area during July to September, and occasionally during June (Maerospace 2020), though they may not be present throughout that entire period. Although the discharge of wastewater from vessels is prohibited in Arctic waters under the *Arctic Waters Pollution Prevention Act*, sewage discharge is permitted in some situations such as emergencies (GoC 2015) and it is recognized that the discharge of greywater does occur (Vard Marine Inc. 2018). Wastewater discharge is presumed possible any time vessels are present in the priority area though it is expected that vessels will not be discharging wastewater constantly. To account for overlap during the time of the year with highest phytoplankton densities (i.e., summer open water period), a score of 3 was assigned.
Spatial	4	Spatial = Areal x Depth = 2 x 2 = 4
Areal	2	Phytoplankton are expected to be distributed throughout the Chesterfield Inlet/Narrows priority area, though localized areas of higher density are likely. Biological material from vessel discharge could be transported beyond the vessel's immediate location via water currents, winds, and river flow, but the greatest concentration of biological material would be localized, thereby overlapping a small portion of the total phytoplankton range in the priority area and a score of 2.
Depth	2	Phytoplankton are limited to the euphotic zone, which is generally limited to the upper ~200 m of open marine water in sub-tropical regions (WHOI 2022) but is restricted to the upper ~50 m in Hudson Bay (Matthes et al. 2021). Although vessel discharge of biological material would occur at the water/ice surface, biological material could sink in the water column. Thus, the biological material could occur within the entire depth range for phytoplankton in the Chesterfield Inlet/Narrows priority area. However, biological material would be expected to attenuate with depth; therefore, depth was scored as 2.
Sensitivity	1 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (1 + 2) x 1.5 = 4.5
Acute Change	1	Although the discharge of wastewater from vessels is prohibited in Arctic waters under the *Arctic Waters Pollution Prevention Act*, sewage discharge is permitted in some situations such as emergencies (GoC 2015) and it is recognized that the discharge of greywater does occur (Vard Marine Inc. 2018). Marine ecosystems can be subject to eutrophication in response to increased input of biological material from wastewater, which can result in the creation of hypoxic areas within the water column and increase the probability of harmful algal blooms (Back et al. 2021). Primary production rapidly increased in response to a month-long discharge of effluent from a wastewater lagoon-wetland system near Cambridge Bay, Nunavut (Back et al. 2021). A relatively high proportion of heterotrophic dinoflagellate cysts were observed in sediment samples near wastewater outfalls off southern Vancouver Island, which is indicative of areas with high primary productivity (Krepakevich and Pospelova 2010). Furthermore, ***Psuedo-nitzschia,*** a likely harmful algal taxa, can be found in the arctic (Poulin et al. 2011; Percopo et al. 2016; AMAP 2017). The input of biological material from a vessel discharge

Risk Factor	Score	Rationale
		may result in a temporary increase in ice algae abundance; however, it is not expected to cause mortality. Possible behavioural impacts, such as increased cyst production, would be anticipated to be limited in scope and duration as elevated nutrient levels from a discharge event become depleted. No change to phytoplankton mortality rates against background variability and limited behavioural impacts would be expected resulting in a score of 1.
Chronic Change	2	Biodegradation and non-biotic elimination of wastewater/sewage can be temperature-dependent and occur slowly in cold/icy water environments (Gunnarsdóttir et al. 2013; Gomes et al. 2022). Elevated nutrient concentrations may persist in Arctic waters near sources of chronic biological material release, such as coastal municipal sewage discharge locations (Chaves-Barquero et al. 2016; Krumhansl et al. 2016); however, no change in nutrient levels are anticipated beyond the relatively immediate vicinity of a discharge site (e.g., Krepakevich and Pospelova 2010; Chaves-Barquero et al. 2016). Enhanced primary productivity following the introduction of biological material from wastewater decreases as nutrients are depleted upon cessation of wastewater input into the ecosystem (Back et al. 2021). If phytoplankton experience a temporary change in overall fitness (i.e., growth rate) due to an influx of nutrients from biological material released into their habitat from vessel discharge, it would be expected to be insignificant to overall fitness relative to natural variation in population dynamics, particularly during the highly productive spring bloom that occurs in the priority area (Matthes et al. 2021). However, measurable changes in ice algal community composition could occur to favour taxa more tolerant of prolonged increased nutrient concentrations and/or those that thrive on the nutrient types that may be released from chronic vessel discharges of grey/wastewater or untreated sewage (e.g., nitrogen, phosphorous), resulting in a score of 2.
Recovery Factors	1.5	Recovery Factors = mean of the factors listed below. Growth rate (biogenic)/rate of structural rebuilding (abiotic): 1 (A phytoplankton bloom can develop rapidly when irradiance conditions are favourable and last until growth becomes limited by factors such as nutrient supply. Increased irradiance due to snow melt during June 2014 allowed phytoplankton under ice cover in Arctic waters of the Beaufort Sea/Barrow Canyon/Hanna Shoal to experience a bloom within approximately one week, with increased growth rates continuing for nearly two weeks before being halted by nutrient limitation [Hill et al. 2018]). Resistance: 1 (As the base of the marine food chain, phytoplankton are subject to regular biological disturbance in the form of predation by herbivorous grazers. During a spring bloom in 2011, phytoplankton communities in Disko Bay, West Greenland were observed to experience high mortality [up to 0.58 d^{-1}] from herbivorous predators [Menden-Deuer et al. 2018]. In polar waters, phytoplankton biomass appears to experience more intense fluctuations due to natural factors, such as temperature changes, than to continual grazing losses [Menden-Deuer et al. 2018]). Regenerative potential: 2 (Phytoplankton communities go through seasonal succession in terms of species composition/biomass and they also adapt to seasonally changing environmental conditions, particularly temperature, light, and/or nutrients [e.g., Lewis et al. 2019]. Arctic phytoplankton from West Greenland experienced significantly greater growth rates at higher temperatures during short-term temperature change incubation experiments and did not exhibit any growth rate limitations at low temperatures [Menden-Deuer et al. 2018]. Arctic phytoplankton are adapted to function in even extreme low-light conditions; during 2017-2019, net phytoplankton growth occurred under complete ice cover as early as February in Baffin Bay, which is ice-covered during seven months of the year

Risk Factor	Score	Rationale
		[Randelhoff et al. 2020]. Such adaptations would compensate for biota loss from disturbance at discrete locations). External Stress: 2 (Climate change is a major stressor for primary producers in the Arctic, as loss of snow cover and/or ice results in drastic increases in the transmission of surface irradiance to the water column which can quickly trigger phytoplankton growth [Hill et al. 2018] and may shift community composition towards taxa more tolerant of increased light levels. Thinning Arctic ice has increased the occurrence of favourable conditions for the formation of under-ice phytoplankton blooms [Hill et al. 2018]. Recent studies indicate that Arctic phytoplankton growth can now sustainably begin underneath seasonal ice cover, in some instances as deep as 100 km from the ice edge [Hill et al. 2018]).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 3 x 1 = Negligible
Likelihood	3	Phytoplankton abundance and community composition are largely dependent upon irradiance and nutrient availability. An interaction may occur if a sufficient quantity of biological material was discharged such that it affected nutrient concentrations and/or types in the water column. An interaction would not likely occur for smaller discharge events, as these would not likely result in a measurable change in nutrients available for phytoplankton. Therefore, an interaction between phytoplankton and biological material from vessel discharge has the potential to occur in some but not all circumstances.
Overall Risk	Low Risk	No additional management actions need to be considered at this time.
Uncertainty		
Exposure	5	Information on primary productivity and the phytoplankton community has recently been studied and has found that there are pockets of high primary productivity in Repulse Bay and Frozen Strait, Roes Welcome Sound, and Chesterfield Inlet (Matthes et al. 2021; Kitching 2022). No scientific information could be found regarding the persistence of biological material from vessel discharge in the Arctic, though some exists for wastewater from other pathways. General vessel traffic patterns are known and were used to inform vessel discharge exposure parameters. Modelling could be conducted for the Chesterfield Inlet/Narrows priority area to better understand the fate of biological material release via vessel discharge during different times of year.
Sensitivity	5	Literature examining nutrient enrichment from the discharge of biological material is generally lacking in Arctic marine environments, along with how this might affect Arctic organisms.
Likelihood	5	Research is needed on the response of Arctic phytoplankton to biological material released via vessel discharge (e.g., Back et al. 2021). Responses would likely vary with species, depth, and water circulation.

Risk Statement: If an interaction occurs involving Arctic cod and biological material (from grey/wastewater and/or sewage) discharged from a vessel the consequence could result in a negative impact on Arctic cod populations in the Fisher and Evans Straits priority area.

Table 5-64. Arctic cod – Vessel Discharge (Wastewater; Fisher and Evans Straits) – Biological Material.

Risk Factor	Score	Rationale
Exposure	3 (binned)	Exposure = Intensity x Temporal x Spatial = 2 x 2 x 4 = 16 (raw score)
Intensity	2	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely

Risk Factor	Score	Rationale
		based, the AOI receives a low density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Fisher and Evans Straits priority area experiences a higher density of vessel traffic relative to other priority areas except Chesterfield Inlet/Narrows (see Figures 5-1 and 5-10), representing 9.5% of total AIS data within the AOI from 2012-2019. The intensity of vessel traffic and the resulting stressor is not uniform, and the density would be higher in areas of higher vessel traffic (e.g., near regular transit corridors). Although the current management system limits the discharge of sewage to specific situations, such as emergencies (GoC 2015) and it is recognized that the discharge of greywater does occur (Vard Marine Inc. 2018), the discharge of wastewater from vessels is prohibited in Arctic waters under the *Arctic Waters Pollution Prevention Act*; therefore, wastewater discharge from vessels is not expected to be occurring constantly. Biological material from vessel discharge consists of nutrients and other organic matter associated with human waste from sewage/greywater, and this assessment considers the potential effects of nutrient enrichment due to the discharge of such material from vessels. Little is known regarding the persistence of biological material from vessel discharge into Arctic ecosystems. If biological material uptake into ice were to occur (e.g., via brine channels), its presence could persist until the summer ice melt (Castellani et al. 2017) and be released into the water column, as was found to be the case for microplastics and other anthropogenic litter microparticles in Svalbard, Norway (von Friesen et al. 2020). To account for the higher density of vessel traffic in this priority area and the possible persistence of biological material due to uptake in sea ice, intensity was scored as a 2. Though there is minimal passenger vessel traffic in the AOI, passenger vessels produce higher volumes of greywater and sewage than other types of vessels (US EPA 2011). If cruise ship traffic were to increase, the frequency and amount of discharge of biological material could increase, as cruise ships are major contributors of grey water release into Canadian marine waters (WWF 2019).
Temporal	2	Arctic cod are expected to occur in the Fisher and Evans Straits priority area year-round. Vessels are typically present in the priority area during July to October, and very occasionally during June and November (Maerospace 2020), though they may not be present throughout that entire period. Although the discharge of wastewater from vessels is prohibited in Arctic waters under the *Arctic Waters Pollution Prevention Act*, sewage discharge is permitted in some situations such as emergencies (GoC 2015) and it is recognized that the discharge of greywater does occur (Vard Marine Inc. 2018). Wastewater discharge is presumed possible any time vessels are present in the priority area though it is expected that vessels will not be discharging wastewater constantly. Considering the above, there is an approximate temporal overlap of 25-50%, resulting in a score of 2.
Spatial	4	Spatial = Areal x Depth = 2 x 2 = 4
Areal	2	A ubiquitous species, Arctic cod occupy coastal and offshore waters in areas with and without sea ice and are expected to be widespread throughout the Arctic Ocean (Coad and Reist 2018). Based on Loewen et al. (2020a), most records for Arctic cod within the AOI are for Evans Strait though Loewen et al. (2020b) also

Risk Factor	Score	Rationale
		noted the occurrence of Arctic cod around small islands in Fisher Strait. Based on available AIS data, vessel activity (see Figures 5-1 and 5-10) is typically focused along two primary paths that occur north and south of Coats Island. Biological material from vessel discharge could be transported beyond the vessel's immediate location via water currents, winds, and river flow, but the greatest concentration of biological material would be localized, thereby overlapping a small portion of the total Arctic cod range in the priority area and a score of 2.
Depth	2	Arctic cod are widespread across the circumpolar Arctic, but they occur at different depths throughout the water column based on factors such as life history stage (e.g., Geoffroy et al. 2016), seasonal diet (e.g., Majewski et al. 2016), and light regime (e.g., Benoit et al. 2010). Eggs and larvae concentrate under the sea ice. Although vessel discharge of biological material would occur at the water/ice surface, biological material could sink in the water column. If biological material sank in the water column, it could occur within the entire depth range for Arctic cod. However, biological material would be expected to attenuate with depth; therefore, depth was scored as 2.
Sensitivity	1 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (1 + 1) x 1.9 = 3.8
Acute Change	1	Although the discharge of wastewater from vessels is prohibited in Arctic waters under the *Arctic Waters Pollution Prevention Act*, sewage discharge is permitted in some situations such as emergencies (GoC 2015) and it is recognized that the discharge of greywater does occur (Vard Marine Inc. 2018). Marine ecosystems can be subject to eutrophication in response to increased input of biological material from wastewater, which can result in the creation of hypoxic areas within the water column and increase the probability of harmful algal blooms (Back et al. 2021). However, there are no records indicating whether Arctic forage fish have ever been negatively affected by eutrophication due to the release of biological material from wastewater (sourced from vessel traffic or other pathways). The input of biological material from a vessel discharge may result in a temporary increase in primary and secondary production (possibly including larval Arctic cod life stages), which may have short-term effects on juvenile and/or adult Arctic cod; in the absence of hypoxia or toxic algal blooms from eutrophication, it is not expected to cause mortality or behavioural impacts. Thus, a score of 1 was assigned.
Chronic Change	1	Biodegradation and non-biotic elimination of wastewater/sewage can be temperature-dependent and occur slowly in cold, icy water environments (Gunnarsdóttir et al. 2013; Gomes et al. 2022). Marine ecosystems can be subject to eutrophication in response to increased input of biological material from wastewater, which can result in the creation of hypoxic areas within the water column and increase the probability of harmful algal blooms (Back et al. 2021). However, there is no evidence that Arctic marine species have ever been negatively affected by eutrophication from vessel discharges. Landry et al. (2019) monitored the movements of shorthorn sculpin (*Myoxocephalus scorpius*) during open water periods in Resolute Bay, Nunavut; sculpin were found to aggregate (likely to feed) in Resolute Bay, which receives raw sewage input from a pipeline, resulting in increased local nutrient input and productivity. Primary productivity may be enhanced by the input of biological material into the Fisher and Evans Straits priority area, but productivity would decrease as nutrients are depleted upon cessation of wastewater input into the ecosystem (Back et al. 2021). During periods of increased primary productivity, prey availability is increased for planktivorous biota, which, depending on the life cycle of the planktivores, could lead to increased prey abundance for forage fish predators higher in the food web. If Arctic cod experienced a temporary change in reproductive capacity due to an influx of nutrients from biological material from a vessel discharge, it is expected to

Risk Factor	Score	Rationale
		be insignificant to overall fitness relative to natural seasonal variations in food web dynamics (e.g., Arctic spring algae blooms; Leu et al. 2015; Castellani et al. 2017). Thus, a score of 1 was assigned.
Recovery Factors	1.9	Recovery factors = mean of the factors listed below. Fecundity: 2 (Spawn only once in their lifetime with a relatively low number of eggs; between 9,000 to 21,000 eggs are produced, with an average of 11,900 per female [Cohen et al. 1990]). Early life stage mortality: 3 (R-selected species with high mortality [Coad and Reist 2018]). Recruitment pattern: 2 (Increased recruitment expected with climate change [LeBlanc et al. 2019]). Natural mortality rate: 1 (Mortality is high [Coad and Reist 2018]). Age at maturity: 2 (2-3 years for males and 3-4 years for females [Coad and Reist 2018]). Life stages affected: 3 (All life stages could potentially occur in the area and could thus be affected). Population connectivity: 1 (Arctic cod range widely throughout the Arctic). Population status: 1 (IUCN classification is *least concern* [Fernandes et al. 2015], but population trend is unknown. Abundant in Arctic marine waters [Coad and Reist 2018]).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 3 x 1 = Negligible
Likelihood	3	The abundance of Arctic cod is largely dependent upon primary productivity and the resulting availability and quality of prey items for organisms higher in the food web. An interaction may occur if a sufficient quantity of biological material was discharged such that it affected nutrient concentrations and prey availability in the water column. If the discharge did not result in measurably increased primary productivity (e.g., small-volume discharge and/or discharge low in nutrients) or eutrophication, an interaction is not expected. Therefore, an interaction may occur in some but not all circumstances.
Overall Risk	Low Risk	No additional management measures need to be considered at this time.
Uncertainty		
Exposure	5	General information exists regarding the distribution of Arctic cod, as well as some information specific to the priority area, though it is limited. General vessel traffic patterns are known and were used to inform vessel discharge exposure parameters. Modelling could be conducted for the priority area to better understand the fate of biological material release via vessel discharge during different times of year.
Sensitivity	5	The impacts of biological material input from vessel discharge on forage fish are not well understood and it is unknown whether Arctic forage fish have ever experienced negative affects from eutrophication.
Likelihood	5	Research is needed on the response of Arctic forage fish to biological material released via vessel discharge, both in open water and ice-covered habitats. Responses would likely vary with species, life stage, behavioural state, and location (under the ice or in open water).

Risk Statement: If an interaction occurs involving forage fish (e.g., sculpin) and biological material (from grey/wastewater and/or sewage) discharged from a vessel the consequence could result in a negative impact on other forage fish populations in the Chesterfield Inlet/Narrows priority area.

Table 5-65. Other forage fish – Vessel Discharge (Wastewater; Chesterfield Inlet/Narrows) – Biological Material.

Risk Factor	Score	Rationale
Exposure	3 (binned)	Exposure = Intensity x Temporal x Spatial = 2 x 2 x 4 = 16 (raw score)
Intensity	2	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low absolute density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Chesterfield Inlet/Narrows priority area experiences a high density of vessel traffic relative to other portions of the AOI (see Figures 5-1 and 5-10) representing approximately 61% of total AIS data within the AOI from 2012-2019. The intensity of vessel traffic and the resulting stressor is not uniform, and the density would be higher in areas of higher vessel traffic (e.g., near regular anchorage areas at Helicopter Island or near Chesterfield Inlet). Although the current management system limits the discharge of sewage to specific situations, such as emergencies (GoC 2015) and it is recognized that the discharge of greywater does occur (Vard Marine Inc. 2018), the discharge of wastewater from vessels is prohibited in Arctic waters under the *Arctic Waters Pollution Prevention Act*; therefore, wastewater discharge from vessels is not expected to be occurring constantly. Biological material from vessel discharge consists of nutrients and other organic matter associated with human waste from sewage/greywater, and this assessment considers the potential effects of nutrient enrichment due to the discharge of such material from vessels. Little is known regarding the persistence of biological material from vessel discharge into Arctic ecosystems. If biological material uptake into ice were to occur (e.g., via brine channels), its presence could persist until the summer ice melt (Castellani et al. 2017) and be released into the water column, as was found to be the case for microplastics and other anthropogenic litter microparticles in Svalbard, Norway (von Friesen et al. 2020). To account for the higher density of vessel traffic in this priority area and the possible persistence of biological material due to uptake in sea ice, intensity was scored as a 2. Though there is minimal passenger vessel traffic in the AOI, passenger vessels produce higher volumes of greywater and sewage than other types of vessels (US EPA 2011). If cruise ship traffic were to increase, the frequency and amount of discharge of biological material could increase, as cruise ships are major contributors of grey water release into Canadian marine waters (WWF 2019).
Temporal	2	Other forage fish may be present in the Chesterfield Inlet/Narrows priority area year-round. Vessels are typically present in the priority area during July to September, and occasionally during June (Maerospace 2020), though they are not present throughout that entire period. Although the discharge of wastewater from vessels is prohibited in Arctic waters under the *Arctic Waters Pollution Prevention Act*, sewage discharge is permitted in some situations such as emergencies (GoC 2015) and it is recognized that the discharge of greywater does occur (Vard Marine Inc. 2018). Wastewater discharge is presumed possible any time vessels are present in the priority area though it is expected that vessels will not be discharging wastewater constantly. Considering the above, there is an approximate temporal overlap of 25-50%, resulting in a score of 2.

Risk Factor	Score	Rationale
Spatial	4	Spatial = Areal x Depth = 2 x 2 = 4
Areal	2	Other forage fish are expected to occur throughout the Chesterfield Inlet/Narrows priority area. Sculpins, including twohorn sculpin (*Icelus bicornis*), fourhorn sculpin (*Myoxocephalus quadricornis*), and ribbed sculpin (*Triglops pingelii*) have been recorded in nearshore areas of Chesterfield Inlet and the outer portion of Chesterfield Inlet (see Figure 2 in Loewen et al. 2020a). Biological material from vessel discharge could be transported beyond the vessel's immediate location via water currents, winds, and river flow, but the greatest concentration of biological material would be localized, thereby overlapping a small portion of the total forage fish range in the priority area and resulting in a score of 2.
Depth	2	Benthic forage fish, such as sculpins, inhabit waters near the seabed. Although vessel discharge of biological material would occur at the water/ice surface, biological material could sink in the water column. If biological material sank in the water column, it could occur within the entire depth range for some other forage fish in the Chesterfield Inlet/Narrows priority area. However, biological material would be expected to attenuate with depth; therefore, depth was scored as 2.
Sensitivity	1 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (1 + 1) x 1.9 = 3.8
Acute Change	1	Although the discharge of wastewater from vessels is prohibited in Arctic waters under the *Arctic Waters Pollution Prevention Act*, sewage discharge is permitted in some situations such as emergencies (GoC 2015) and it is recognized that the discharge of greywater does occur (Vard Marine Inc. 2018). There are no records indicating whether Arctic forage fish have ever been negatively affected by eutrophication due to the release of biological material from wastewater (sourced from vessel traffic or other pathways). The input of biological material from a vessel discharge may result in a temporary increase in primary and secondary production (possibly including larval forage fish life stages), which may have short-term effects on juvenile and/or adult forage fish; in the absence of hypoxia or toxic algal blooms from eutrophication, it is not expected to cause mortality or behavioural impacts. Thus, a score of 1 was assigned.
Chronic Change	1	Biodegradation and non-biotic elimination of wastewater/sewage can be temperature-dependent and occur slowly in cold, icy water environments (Gunnarsdóttir et al. 2013; Gomes et al. 2022). Marine ecosystems can be subject to eutrophication in response to increased input of biological material from wastewater, which can result in the creation of hypoxic areas within the water column and increase the probability of harmful algal blooms (Back et al. 2021). However, there is no evidence that Arctic marine species have ever been negatively affected by eutrophication from vessel discharges. Landry et al. (2019) monitored the movements of shorthorn sculpin during open water periods in Resolute Bay, Nunavut; sculpin were found to aggregate (likely to feed) in Resolute Bay, which receives raw sewage input from a pipeline, resulting in increased local nutrient input and productivity. Primary productivity may be enhanced by the input of biological material into the Chesterfield Inlet/Narrows priority area, but productivity would decrease as nutrients are depleted upon cessation of wastewater input into the ecosystem (Back et al. 2021). During periods of increased primary productivity, prey availability is increased for planktivorous biota, which, depending on the life cycle of the planktivores, could lead to increased prey abundance for forage fish predators higher in the food web. If forage fish experienced a temporary change in reproductive capacity due to an influx of nutrients from biological material released into their habitat from an occasional vessel discharge, it would be insignificant to overall fitness relative to

Risk Factor	Score	Rationale
		natural seasonal variations in food web dynamics (e.g., Arctic spring algae blooms; Leu et al. 2015; Castellani et al. 2017). Thus, a score of 1 was assigned.
Recovery Factors	1.9	Knowledge of other forage fish communities is limited for the AOI; however, species observed in the Hudson Bay, Hudson Strait, and/or Foxe Basin regions may occur in the AOI, including Atlantic poacher (*Leptagonus decagonus*), fish doctor (*Garra rufa*), Arctic alligatorfish (*Aspidophoroides olrikii*), Atlantic herring, capelin, sculpins *(Cottidae* spp.), lumpfish (*Cyclopterus lumpus)* and lumpsuckers (*Cyclopteridae* spp.), cods *(Gadidae* spp.), sticklebacks *(Gasterosteidae* spp.), snailfishes (*Liparidae* spp.), burbot (*Lota lota*), eelblennies *(Stichaeidae* spp.), Arctic shanny (*Stichaeus punctatus)*, eelpout (*Lycodes* sp.), *r*ainbow smelt *(Osmerus mordax)*, American plaice *(Hippoglossoides platessoides*), halibut, skates, cisco (*Coregonus artedi)*, whitefishes *(Salmonidae* spp*.),* and redfishes (*Sebastes* spp.) (Loewen et al. 2020a). Owing to their sensitivity to pollution and usefulness as bioindicator species for benthic habitat degradation (e.g., Khan 2010), sculpins were identified as the representative benthic species. These species were used for the determination of Recovery Factors. There have been no dedicated baseline studies for the Chesterfield Inlet/Narrows priority area; therefore, information is provided here for the AOI to represent the priority area. Recovery Factors = mean of the factors listed below. Fecundity: 2 (Depending on body size, female twohorn sculpin lay between 150 and 1000 eggs [FishBase 2022], ribbed sculpin may carry up to at least 400 eggs [Scott and Scott 1988], and twohorn sculpin may carry ~150-350 eggs [Scott and Scott 1988]). Early life stage mortality: 3 (The eggs of fourhorn sculpin are laid in nests on the seabed and guarded by the male during incubation [Scott and Scott 1998]; therefore, they likely experience low mortality. However, larvae are pelagic [NatureServe 2018] and may be subject to predation). Recruitment pattern: 1 (Ribbed sculpin have short lifespans of five to six years [Scott and Scott 1988; FishBase 2022] and fourhorn sculpin may live up to 14-15 years [FishBase 2022]. These species have relatively high recruitment). Natural mortality rate: 1 (Predation rates are unknown for sculpin, but there are reports of ribbed sculpin being preyed upon by thick-billed murre in Hudson Bay and they are likely also consumed by cod in Atlantic waters [Scott and Scott 1988]). Age at maturity: 2 (Age at maturity is unknown for twohorn, fourhorn, or ribbed sculpin [e.g., Scott and Scott 1988; FishBase 2022]; however, given their respective lifespans, maturity likely occurs within the first few years of life). Life stages affected: 3 (All life stages could potentially occur in the AOI and could thus be affected). Population connectivity: Unknown; excluded from consideration. Population status: 1 (Fourhorn sculpin are listed as *least concern* on the IUCN Red List [NatureServe 2018].
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 3 x 1 = Negligible
Likelihood	3	An interaction may occur if wastewater discharge took place in shallow waters of the Chesterfield Inlet/Narrows priority area, or a sufficient quantity of biological material was discharged in deeper waters such that it was transported to benthic habitat. The abundance of forage fish is largely dependent upon primary productivity and the resulting availability and quality of prey items for organisms higher in the food web. If the discharge did not result in measurably increased primary productivity (e.g., small-volume discharge and/or discharge low in

Risk Factor	Score	Rationale
		nutrients) or eutrophication, an interaction would not be expected. Therefore, an interaction may occur in some but not all circumstances.
Overall Risk	Low Risk	No additional management measures need to be considered at this time.
Uncertainty		
Exposure	5	Little is known of other forage fish species composition, abundance, or distribution for the Chesterfield Inlet/Narrows priority area. Most species have been documented from nearby areas and are presumed to possibly inhabit the AOI/priority area (Loewen et al. 2020a, b). General vessel traffic patterns are known and were used to inform vessel discharge exposure parameters. Modelling could be conducted for the Chesterfield Inlet/Narrows priority area to better understand the fate of biological material release via vessel discharge during different times of year.
Sensitivity	5	The impacts of biological material input from vessel discharge on other forage fish are not well understood as little research has focused on Arctic forage fish. Further study is needed to bridge this data gap. This assessment was conducted on representative forage fish species and examples were drawn as such; however, the assemblage includes numerous species and the assessment may not be accurate for all.
Likelihood	5	Research is needed on the response of other Arctic forage fish to biological material released via vessel discharge, both in open water and ice-covered habitats. Responses would likely vary with species, life stage, behavioural state, and location (under the ice or in open water).

5.5.2 Pathogens/NIS Introductions

Although the total impact from the introduction and establishment of NIS is difficult to predict, effects are known to occur through competition for resources (e.g., space, prey) and through direct impacts on native species' health (e.g., epiphytic bryozoans on kelp; Levin et al. 2002; Lutz-Collins et al. 2009). The current low level and routine operations of vessel traffic in the AOI generate a low propagule pressure (i.e., the number of viable organisms introduced to an area) thereby minimizing introduction risk compared with regions hosting higher levels of vessel traffic, and the differences in AOI environmental conditions from source waters reduce establishment risk (Goldsmit et al. 2020). Although for many NIS the risk of establishment is low, it is predicted that northern Hudson Bay, including the AOI, contains suitable habitat for a portion of 23 high-risk aquatic NIS currently and under two future scenarios (i.e., year 2050 and 2100; Goldsmit et al. 2020). Past examples demonstrate the myriad impacts that may result from NIS introductions in various ecosystems (Walker et al. 2019) and this stressor has the potential to impact many organisms.

Ballast water is necessary for vessels to operate safely by adjusting weight so the vessel floats at the correct depth and maintains stability. Ballast water is loaded/discharged by ships when transferring cargo to balance their weight and keep them stable. Though critical for safe operations, the global movement of ballast water by vessels creates a long-distance dispersal mechanism for microorganisms and waterborne diseases, acting as a vector for NIS introductions in many locations around the globe and causing significant impacts to a multitude of species and habitats (Ruiz et al. 2000; Groner et al. 2016; Kim et al. 2016). The management of ballast water aboard a vessel primarily involves two different processes: ballast water exchange and ballast water treatment. Ballast water exchange is a process that involves the substitution of coastal water in a ship's ballast tanks with offshore water, thereby removing coastal organisms from ballast tanks and introducing less suitable environmental conditions for the coastal organisms that may be present and reducing their ability to survive. Ballast water treatment involves the use of technology, such as filtration and ultraviolet irradiation (UV light), to remove or render organisms nonviable.

Canada's *Ballast Water Regulations* (2021) apply to all Canadian vessels and vessels operating in Canadian waters. Though past rules relied solely on ballast water exchange to manage the risk, the new regulations include discharge standards regarding the number and size of organisms that can be discharged in ballast water, resulting in the need for treatment systems. These new rules are being implemented using a phased approach and there are different exemptions to the rules based mainly on where the vessel operates and its date of construction. All international vessels and vessels operating exclusively in Canadian waters constructed in or after 2009 will have until September 8, 2024 to come into compliance with the performance standard, while those vessels constructed before 2009, operating exclusively in Canadian waters, will need to meet the discharge standards by September 2030. Vessels built after June 2021 had to meet the performance standards immediately. Vessels that take on board ballast water in the Great Lakes Basin or in the in the eastern waters of the St. Lawrence River, from Montreal to the Gaspé Peninsula, are deemed compliant with the new regulations if their treatment system was installed following these timelines, their management plan is up to date, the vessels hold a valid IBMW certificate, the BWM system is in good working order and operated appropriately, and the ballast water is managed in accordance with the manufacturer's instruction and the Type Approval Certificate issued to the BWMS.

The *Ballast Water Regulations* (2021) also outline standards for international vessels that conduct ballast water exchange, which include minimum distances from shore and minimum water depths. For vessels entering the Hudson Bay Complex, ballast water exchange from vessels travelling internationally is required to occur outside of Canadian coastal waters or at a designated alternate ballast water exchange area, none of which occur in Hudson Bay (TC 2021) and the closest of which is >1,000 km away from the AOI. Exclusively domestic vessels are not required to exchange ballast water before entering the Hudson Bay Complex. Ballast water discharge from any vessel may occur in the AOI if necessary for a vessel's safe operation.

The majority of vessels entering the AOI are domestic vessels and, though it has happened in the past, none are currently expected to travel directly from international ports to locations within the AOI. Vessels that visited the AOI from 2012-2019 (Maerospace 2020) and vessels that compose the current Canadian fleets of operators that service the AOI include those that were built before and after 2009 (CSL n.d.; Desgagnés n.d.), resulting in vessels required to abide by all three discharge standard timelines outlined above. Of the vessel types that occur in the AOI, only a subset (i.e., oil/chemical, cargo/supply, tug, icebreaker, and bulk carrier vessels) would routinely load/discharge ballast water during normal operations, however, given that most commercial vessels are transporting cargo to the AOI, they will load ballast water in the AOI as they unload cargo and ballast discharge would not be a regular occurrence. Though expected to be rare under the current management regime, unmanaged ballast water discharge may occur in the AOI under some circumstances, such as from an exclusively domestic vessel if it were to load cargo or an emergency situation to ensure a vessel's safe operation. Additionally, in cases where treatment systems are in use, the effectiveness of treatment for the reduction of living organisms can be low (Sayinli et al. 2022; Outinen et al. 2024).

Marine fishes have been directly impacted by NIS via harmful diatoms (e.g., the *Chaetoceros* diatom that can cause injury or mortality to fish through gill irritation; Klein et al. 2009); as such, Arctic cod and Arctic char have been assessed, with the assessment for Arctic cod serving as a proxy for other forage fish (Table 5-66). Other marine mammals, such as walrus and bearded seal, are considered most at risk to NIS via secondary effects on their prey. Stewart and Howland (2009) investigated the risk of NIS introductions in the Hudson Strait region and suggested that walruses may be susceptible to NIS introductions because they occur in vulnerable coastal areas, consume benthic invertebrates, and are reliant on the foraging habitat accessible from consistent haul-out sites. Likewise, bearded seals consume benthic prey and may be at increased risk to NIS via a secondary pathway of effect on their prey, whereas the varied diet of ringed seals minimizes their risk from NIS (Stewart and Howland 2009). For these reasons, bearded seals will be used as a proxy for ringed and harp seals. Narwhals and belugas are closely related benthic feeding odontocetes, with northern Hudson Bay narwhals foraging on benthic prey to a greater extent than Baffin Bay or East Greenland narwhal stocks (Watt et al. 2013). Inuit Qaujimajatuqangit indicates that beluga in the AOI spend time at river mouths to feed on Char (GN 2012), and other fish, including capelin, are also important in their diet (Loewen et al. 2020b). Directed research on the possible effects of NIS to prey is not known for either species; therefore, the assessment on narwhal will cover beluga by proxy. Effects of NIS on seabirds are expected to be linked to their prey. Common eider feed mainly on benthic invertebrates and were assessed, serving as a proxy for thick-billed murre and Thayer's gull. Macroalgae have been impacted by NIS in other regions of Canada (e.g., *Codium fragile*; Scheibling and Anthony 2001) and were assessed. Notable benthic invertebrate invasions, such as European green crab (*Carcinus maenus*) and zebra mussels, have been linked to ballast water exchange (Walker et al. 2019); therefore, benthic invertebrates were assessed.

Table 5-66. Vessel Discharge − Pathogens/NIS: ESC Subcomponents and Priority Areas Assessed.

ESC Subcomponent	**Priority Area**	**Assessed by Proxy**
Kelp beds and other macroalgae	Chesterfield Inlet/Narrows	
Benthic invertebrates	Chesterfield Inlet/Narrows	
Arctic cod	Fisher and Evans Straits	
Arctic char	Chesterfield Inlet/Narrows	
Other forage fish		Via Arctic cod
Common eider	East Bay	
Thick-billed murre		Via common eider
Thayer's gull		Via common eider
Ringed seal		Via bearded seal
Bearded seal	Fisher and Evans Straits	
Walrus	Fisher and Evans Straits	
Beluga		Via narwhal
Narwhal	Repulse Bay/Frozen Strait	
Bowhead whale	Fisher and Evans Straits	

Risk Statement: If an interaction occurs involving kelp beds/other macroalgae and pathogens/non-indigenous species (NIS) in ballast water discharged from a vessel the consequence could result in a negative impact on the ecosystem function of kelp bed/other macroalgae habitat in the Chesterfield Inlet/Narrows priority area.

Table 5-67. Kelp beds and other macroalgae – Vessel Discharge (Ballast Water; Chesterfield Inlet/Narrows) – Pathogens/Non-Indigenous Species (NIS).

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 6 = 6 (raw score)
Intensity	1	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely

Risk Factor	Score	Rationale
		based, the AOI receives a low absolute density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Chesterfield Inlet/Narrows priority area experiences a high density of vessel traffic relative to other portions of the AOI (see Figures 5-1 and 5-10) representing approximately 61% of total AIS data within the AOI from 2012-2019. The intensity of vessel traffic and the resulting stressor is not uniform, and the density would be higher in areas of higher vessel traffic (e.g., near regular anchorage areas at Helicopter Island or near Chesterfield Inlet). Canada's *Ballast Water Regulations* (2021) apply to all vessels operating in Canadian waters and although past rules relied solely on ballast water exchange to manage the risk, the new regulations include standards regarding the number and size of organisms that can be discharged in ballast water. These new rules are being implemented using a phased approach; all international vessels and vessels operating exclusively in Canadian waters constructed in or after 2009 will have until September 8, 2024 to come into compliance with the performance standard, while those vessels constructed before 2009, operating exclusively in Canadian waters, will need to meet the discharge standards by September 2030. Vessels built after June 2021 had to meet the performance standards immediately. Vessels that take on board ballast water in the Great Lakes Basin or the Gulf of St. Lawrence, from Montreal to the Gaspe peninsula, are deemed compliant with the new standards if their treatment system was installed following these timelines, the system is operated appropriately, and other requirements (see introductory text for this section). The *Ballast Water Regulations* also outline standards for international vessels that conduct ballast water exchange. For vessels entering the Hudson Bay Complex, ballast water exchange from vessels travelling internationally is required to occur outside of Canadian coastal waters or at a designated alternate ballast water exchange area, the closest of which is >1,000 km away from the AOI (TC 2021). Exclusively domestic vessels are not required to exchange ballast water before entering the Hudson Bay Complex. Untreated ballast water discharge from any vessel may occur in the AOI if necessary for a vessel's safe operation. The majority of vessels entering the AOI are domestic vessels and, though it has happened in the past, none are currently expected to travel directly from international ports to locations within the AOI. Vessels that visited the AOI from 2012-2019 (Maerospace 2020) and vessels that compose the current Canadian fleets of operators that service the AOI include those that were built before and after 2009 (CSL n.d.; Desgagnés n.d.), resulting in vessels required to abide by all three discharge standard timelines outlined above. Of the vessel types that occur in the AOI, only a subset (i.e., oil/chemical, cargo/supply, tug, icebreaker, and bulk carrier vessels) would routinely load/discharge ballast water during normal operations, and given that most commercial vessels are transporting cargo to the AOI they will load ballast water as they unload cargo and ballast discharge would not be a regular occurrence. Though expected to be rare under the current management regime, untreated ballast water discharge may occur in the AOI under some circumstances from an exclusively domestic vessel if they were to load cargo or in an emergency situation to ensure safe operation of the vessel. Additionally, in cases where treatment systems are in use, the effectiveness of treatment for the reduction of living organisms can be low (Sayinli et a. 2022; Outinen et al. 2024). Therefore, though untreated ballast water discharge could occur, such occurrences are rare under the current management system, and intensity was scored as 1.
Temporal	1	Kelp beds are present in the Chesterfield Inlet/Narrows priority area year-round, though photosynthetic activity, important in advance of the growth phase which

Risk Factor	Score	Rationale
		largely occurs under ice (Chapman and Lindley 1980), is restricted to the ice-free season. Vessels are typically present in the AOI from July to September, and occasionally during June (Maerospace 2020), though they are not present throughout that entire period. Although the exchange of untreated ballast water from vessels is prohibited in Canadian waters outside of designated alternate ballast water exchange areas (TC 2021), it is recognized that the discharge of untreated ballast water could occur if required for vessel safety or in the case of certain exclusively domestic vessels that might load cargo (noting that in the majority of cases vessels would be transporting cargo to nearby communities and would thus be unlikely to discharge ballast water). Vessel discharge of ballast water containing pathogens/NIS is presumed possible any time vessels are present in the priority area; however, it is expected to occur in only a small proportion of instances when vessels are present, and not during each trip by a vessel that uses ballast. Considering the above, there is an approximate temporal overlap of <25% between when vessels discharging ballast water and kelp beds are present, resulting in a score of 1.
Spatial	6	Spatial = Areal x Depth = 2 x 3 = 6
Areal	2	Kelp beds typically occur in water depths between 5-50 m in the AOI, with higher densities at 10 and 15 m compared with 5 m (Krause-Jensen et al 2012; Filbee-Dexter et al. 2022). Pathogens/NIS from vessel discharge of ballast water could be transported beyond the vessel's immediate location via water currents in open, ice-free areas or under the ice. The greatest concentration of ballast water would be localized, though dispersion could still overlap a small portion of the total kelp bed range in the priority area. This results in a score of 2.
Depth	3	Macroalgae inhabit surficial seabed substrate. If pathogens/NIS from vessel discharge of ballast water sank in the water column, as could be expected given that the majority of reported marine NIS are benthic (Streftaris et al. 2005), they could reach the seabed and occur within the entire depth range of macroalgae in the priority area.
Sensitivity	3 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (2 + 3) x 2.0 = 10.0
Acute Change	2	Though introduction risk and establishment risk vary by species, a vessel discharging ballast water could be a vector for the introduction of pathogens/NIS to the Arctic environment (Chan et al. 2015; Hannah et al. 2020; see likelihood, below). Although the specific effects of the introduction of NIS into the Arctic marine environment can be difficult to predict, it is reasonable to presume they can have direct, likely negative, effects on the viability and function of kelp/other macroalgae habitats. Though many negative effects stemming from NIS are due to establishment and manifest over a longer timeframe (e.g., competition for resources) and are covered under chronic change (below), the introduction of novel pathogens can have widespread effects for species that lack pathogen-specific immunity, potentially including the outbreak of epidemic disease and high mortality (Burek et al. 2008). Therefore, measurable changes in the habitat function of kelp beds/other macroalgae could occur, resulting in a score of 2.
Chronic Change	3	Though the number of introductions into the Arctic is expected to be relatively low compared to other regions of the world (e.g., Chan et al. 2015, 2016), higher temperatures, reduced sea ice cover, and intensified vessel traffic in the Canadian Arctic due to climate change are increasing the risk of the introduction and spread of NIS in the region (Goldsmit et al. 2021a). Climate change is also anticipated to alter pathogen transmission or distribution in the Arctic due to increased risk of

Risk Factor	Score	Rationale
		ballast pollution and other discharges from increased ship traffic (Burek et al. 2008). The establishment of NIS can significantly affect marine ecosystem function and community composition and the economies/lifestyles that depend on them (Drake and Lodge 2007; Bellard et al. 2016; Blackburn et al. 2019; Riley et al. 2022). The Hudson Bay Complex was identified as high-risk for the founding of NIS, particularly by crabs, mollusks, macrozooplankton, and macroalgae (Goldsmit et al. 2020, 2021a). Ballast water is a major vector for the transport of macroalgae propagules (Andreakis and Schaffelke 2012). Owing to their ability to survive long-range marine transport, macroalgae comprise ~20% of the world's marine NIS, and their establishment affects native macroalgal ecosystems by monopolizing available habitat, acting as ecosystem engineers, and altering community composition (Andreakis and Schaffelke 2012). For example, tunicate, sea squirt, Japanese skeleton shrimp, and lacy-crust bryozoan NIS are currently threatening coastal marine ecosystems (including kelp beds) by outcompeting native species in Canada's maritime region (Sephton et al. 2017). Another example can be found in the NW Atlantic: the colonial bryozoan *Membranipora membranacea* has been linked to defoliation of kelp beds in Nova Scotia (Scheibling and Gagnon 2009) by making the kelp fronds more brittle (Krumhansl et al. 2011) and prone to erosion, breakage, and dislodgement via wave action (Lambert et al. 1992; Krumhansl and Scheibling 2011). Subsequent studies have suggested that kelp defoliation caused by this bryozoan facilitates establishment of another NIS, the green alga oyster thief (*Codium fragile*) enabling replacement of large portions of kelp beds (Scheibling and Gagnon 2006). Oyster thief are unable to displace established kelp beds, but given the opportunity provided by the bryozoan, oyster thief can begin to dominate (Levin et al. 2002; Schiebling and Gagnon 2006). Though over a longer timeframe it has been suggested that kelp may begin to outcompete oyster thief, as *C. fragile* was dominant at 54% of Nova Scotian sites sampled in 2000 but this decreased to only 15% by 2007 (Watanabe et al. 2010), impacts from *M. membranacea* and subsequent oyster thief establishment to native kelp beds can be widespread, severe, and persistent (Filbee-Dexter et al. 2016; O'Brien and Scheibling 2018). Where it has become established in Nova Scotia, the effects of *M. membrancea* are projected to be exacerbated by climate change and alter the structure and function of kelp beds (e.g., energy and resource subsidies to adjacent ecosystems; Krumhansl et al. 2014). If pathogens/NIS were to establish in the Chesterfield Inlet/Narrows priority area, they could result in significant changes to long-term viability of the habitat and its function in the ecosystem resulting in a score of 3.
Recovery Factors	2.0	At least 19 species/taxonomic groups of macroalgae have been documented to occur within or near the AOI (DFO 2020; Loewen et al. 2020a, b; Filbee-Dexter et al. 2022). At least 8 species/taxonomic groups have been reported for the Chesterfield Inlet/Narrows priority area. Of these macroalgae, three kelp species, *Laminaria solidungula*, edible kelp and sugar kelp are among the most abundant in the AOI, creating extensive kelp forests reaching up to 3-4 m in height and spreading several kilometers from shore (DFO 2020; Loewen et al. 2020b; Filbee-Dexter et al. 2022). *L. solidungula* is an Arctic endemic species (Roleda 2016).Biomasses of up to 34 kg/m^2 were observed for these kelp forests in the AOI, the highest ever reported for the eastern Canadian Arctic (Filbee-Dexter et al. 2022). Other types of macroalgae also occur amongst these kelp species, including coralline encrusting algae, and are important to create the structural complexity beneficial to its inhabitants (Wharton and Mann 1981; Christie et al. 1998; Steen et al. 2016; Misiuk and Aitken 2020). Habitat recovery factors were used. Recovery factors = mean of the factors listed below.

Risk Factor	Score	Rationale
		Growth rate (biogenic)/rate of structural rebuilding (abiotic): 1 (Kelp sporophyte growth rates are high compared to other organisms [Mann 1973]). Resistance: 3 (Kelp can easily be disturbed physically, known to break apart during physical duress such as sample collection [Mundy 2020]. A change in ecosystem structure, such as an increase in urchin populations [e.g., Filbee-Dexter and Scheibling 2014] can lead to rapid and extensive defoliation of kelp). Regenerative potential: 2 (The regeneration of kelp forests after destructive events highly depends on the strength and duration of the event(s). Different clearing experiments in the northern Atlantic have shown that a full kelp regrowth can be observed after 1-3 years when environmental pressures are removed (Scheibling 1986; Christie et al. 1998; Steen et al. 2016). However, fully grown kelp forests also host a great variety of understorey algae, along with many fish and invertebrates, that can take over 5 years to recolonize the habitat (Wharton and Mann 1981; Christie et al. 1998; Steen et al. 2016). In the Arctic, many authors have concurred that coastal recovery processes should be much slower than in temperate waters (Dunton et al. 1982; Conlan 2005; Keck et al. 2020). Several experiments and measurements done in the Beaufort Sea's Boulder Patch have shown that following a major disturbance on the site, it could take more than a decade for the sessile community, including kelp, to fully recover (Konar 2013; Bonsell and Dunton 2021). External stress: 2 (Climate change and warming waters add to stress [e.g., Filbee-Dexter et al. 2020]).
Consequence	3 (binned)	Consequence = Exposure x Sensitivity = 2 x 3 = Moderate
Likelihood	1	An interaction (i.e., via survival and establishment of NIS) has the potential to occur during summer/fall when untreated ballast water is discharged from vessels in the priority area. Ballast water of commercial vessels is recognized as an important potential transfer mechanism for aquatic NIS in the Arctic (Chan et al. 2015, 2019). The greatest risk for the introduction of NIS into the Canadian Arctic via ballast water likely arises from domestic vessels, which may discharge untreated ballast water in some circumstances and undergo shorter voyages relative to international vessels, thereby increasing the potential survivability of transported NIS (Goldsmit et al. 2021a). Bivalves, gastropods, barnacles, and some bryozoans may survive for weeks to over a month via physical isolation from unfavourable environmental conditions, while soft-bodied taxa (e.g., tunicates, sponges, cnidarians) or those unable to osmoregulate (e.g., echinoderms) may experience rapid mortality (Riley et al. 2022). Planktonic life stages may also survive the journey, particularly where the organism has only one planktonic life stage, such as gastropods and some bivalves (Wonham et al. 2001). Only a subset of introduced species will survive and potentially establish. However, Hudson Bay has been identified as a location with environmental conditions suitable to certain high risk and indicator NIS, increasing the probability of survival and establishment over other areas in the Arctic (Goldsmit et al. 2019, 2020). Additionally, any discharges that may occur would happen in the summer months, which increases the chance of survival and establishment compared with other times of the year (Goldsmit et al. 2019). Overall, though some taxa can withstand the harsh environmental changes and establishment risks are increasing due to climate change, NIS in ballast water are generally thought to have poor survivorship after Arctic voyages due to inclement conditions (Goldsmit et al. 2020), and only a small proportion of introduced

Risk Factor	Score	Rationale
		species can be expected to establish. Therefore, pathogen/NIS survival and establishment is considered rare.
Overall Risk	Moderate Risk	Additional management measures may be considered, including restriction of untreated ballast water discharge in the AOI where possible, engagement with vessel operators to identify and address any barriers to compliance with the latest rules regarding ballast discharge, mandatory reporting of ballast water operations for vessels visiting the AOI, ~~and~~ monitoring for pathogens/NIS in ballast water, and monitoring for pathogens/NIS in the environment, particularly in habitats identified as important kelp areas (see areas identified during an Inuit Qaujimajatuqangit workshop in February 2020 [Idlout 2020]).
Uncertainty		
Exposure	3	No studies have quantitatively investigated the number of ballast water discharges in the area, though operational information from vessels can describe the general pattern. The fate of pathogens/NIS released from a vessel discharge of ballast water is unknown for the priority area. Environmental DNA and metabarcoding should be used to detect newly arriving NIS into the Chesterfield Inlet/Narrows priority area, as these methods are currently being successfully used to monitor other remote regions (Goldsmit et al. 2020).
Sensitivity	3	Macroalgal documentation in the priority area is limited (e.g., DFO 2020; Loewen et al. 2020a, b), although macroalgae and coastal kelp beds have been identified near the mouth of Chesterfield Inlet and it is known that the Western Hudson Bay Coastline EBSA features dense coastal kelp beds and macroalgae (DFO 2020). Life history information is generally limited for macroalgae species that occur in/near the priority area. However, there is some scientific literature available for other areas that studies the response of relevant benthic fauna to pathogens/NIS.
Likelihood	4	Little is known of the risk of pathogen/NIS survival and establishment via vessel discharge of ballast water for the Chesterfield Inlet/Narrows priority area, although there is some scientific literature available for other areas. Goldsmit et al. (2020, 2021a) did consider the Hudson Bay complex as an invasion hotspot for marine NIS; however, research is needed on the impacts of pathogens/NIS on Arctic macroalgae. The resistance and survival time of pathogens/NIS transported into Arctic conditions is largely unknown and likely variable between species (Riley et al. 2022).

Risk Statement: If an interaction occurs involving benthic invertebrates and pathogens/non-indigenous species (NIS) in ballast water discharged from a vessel the consequence could result in a negative impact on benthic invertebrate populations in the Chesterfield Inlet/Narrows priority area.

Table 5-68. Benthic Invertebrates – Vessel Discharge (Ballast Water; Chesterfield Inlet/Narrows) – Pathogens/Non-Indigenous Species (NIS).

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 6 = 6 (raw score)
Intensity	1	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low absolute density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Chesterfield

Risk Factor	Score	Rationale
		Inlet/Narrows priority area experiences a high density of vessel traffic relative to other portions of the AOI (see Figures 5-1 and 5-10) representing approximately 61% of total AIS data within the AOI from 2012-2019. The intensity of vessel traffic and the resulting stressor is not uniform, and the density would be higher in areas of higher vessel traffic (e.g., near regular anchorage areas at Helicopter Island or near Chesterfield Inlet). Canada's *Ballast Water Regulations* (2021) apply to all vessels operating in Canadian waters and although past rules relied solely on ballast water exchange to manage the risk, the new regulations include standards regarding the number and size of organisms that can be discharged in ballast water. These new rules are being implemented using a phased approach; all international vessels and vessels operating exclusively in Canadian waters constructed in or after 2009 will have until September 8, 2024 to come into compliance with the performance standard, while those vessels constructed before 2009, operating exclusively in Canadian waters, will need to meet the discharge standards by September 2030. Vessels built after June 2021 had to meet the performance standards immediately. Vessels that take on board ballast water in the Great Lakes Basin or the Gulf of St. Lawrence, from Montreal to the Gaspe peninsula, are deemed compliant with the new standards if their treatment system was installed following these timelines, the system is operated appropriately, and other requirements (see introductory text for this section). The *Ballast Water Regulations* also outline standards for international vessels that conduct ballast water exchange. For vessels entering the Hudson Bay Complex, ballast water exchange from vessels travelling internationally is required to occur outside of Canadian coastal waters or at a designated alternate ballast water exchange area, the closest of which is >1,000 km away from the AOI (TC 2021). Exclusively domestic vessels are not required to exchange ballast water before entering the Hudson Bay Complex. Untreated ballast water discharge from any vessel may occur in the AOI if necessary for a vessel's safe operation. The majority of vessels entering the AOI are domestic vessels and, though it has happened in the past, none are currently expected to travel directly from international ports to locations within the AOI. Vessels that visited the AOI from 2012-2019 (Maerospace 2020) and vessels that compose the current Canadian fleets of operators that service the AOI include those that were built before and after 2009 (CSL n.d.; Desgagnés n.d.), resulting in vessels required to abide by all three discharge standard timelines outlined above. Of the vessel types that occur in the AOI, only a subset (i.e., oil/chemical, cargo/supply, tug, icebreaker, and bulk carrier vessels) would routinely load/discharge ballast water during normal operations, and given that most commercial vessels are transporting cargo to the AOI they will load ballast water as they unload cargo and ballast discharge would not be a regular occurrence. Though expected to be rare under the current management regime, untreated ballast water discharge may occur in the AOI under some circumstances from an exclusively domestic vessel if they were to load cargo or in an emergency situation to ensure safe operation of the vessel. Additionally, in cases where treatment systems are in use, the effectiveness of treatment for the reduction of living organisms can be low (Sayinli et a. 2022; Outinen et al. 2024). Therefore, though untreated ballast water discharge could occur, such occurrences are rare under the current management system, and intensity was scored as 1.
Temporal	1	Benthic invertebrates are present in the Chesterfield Inlet/Narrows priority area year-round. Vessels are typically present in the AOI from July to September, and occasionally during June (Maerospace 2020), though they are not present throughout that entire period. Although the exchange of untreated ballast water from vessels is prohibited in Canadian waters outside of designated alternate ballast water exchange areas (TC 2021), it is recognized that the discharge of untreated ballast water could occur if required for vessel safety or in the case of

Risk Factor	Score	Rationale
		certain exclusively domestic vessels that might load cargo (noting that in the majority of cases vessels would be transporting cargo to nearby communities and would thus be unlikely to discharge ballast water). Vessel discharge of ballast water containing pathogens/NIS is presumed possible any time vessels are present in the priority area; however, it is expected to occur in only a small proportion of instances when vessels are present, and not during each trip by a vessel that uses ballast. Considering the above, there is an approximate temporal overlap of <25% between when vessels discharging ballast water and benthic invertebrates are present, resulting in a score of 1.
Spatial	6	Spatial = Areal x Depth = 2 x 3 = 6
Areal	2	Benthic invertebrates are anticipated to occur throughout the Chesterfield Inlet/Narrows priority area. Pathogens/NIS from vessel discharge of ballast water could be transported beyond the vessel's immediate location via water currents in open, ice-free areas or under the ice. The greatest concentration of ballast water would be localized, though dispersion could still overlap a small portion of the total benthic invertebrate range in the priority area. This results in a score of 2.
Depth	3	Benthic invertebrates inhabit the seabed. If pathogens/NIS from vessel discharge of ballast water sank in the water column, as could be expected given that the majority of reported marine NIS are benthic (Streftaris et al. 2005), they could reach the seabed and occur within the entire depth range of benthic invertebrates in the priority area.
Sensitivity	4 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (2 + 3) x 2.3 = 11.5
Acute Change	2	Though introduction risk and establishment risk vary by species, a vessel discharging ballast water could be a vector for the introduction of pathogens/NIS to the Arctic environment (Chan et al. 2015; Hannah et al. 2020; see likelihood, below). Although the specific effects of the introduction of NIS into the Arctic marine environment can be difficult to predict, it is reasonable to presume they can have direct, likely negative, effects on the health of native benthic invertebrate species. Though many negative effects stemming from NIS are due to establishment and manifest over a longer timeframe (e.g., competition for resources) and are covered under chronic change (below), the introduction of novel pathogens can have widespread effects for species that lack pathogen-specific immunity, potentially including the outbreak of epidemic disease and high mortality (Burek et al. 2008). Accounting for pathogen outbreaks, measurable changes in mortality rates of benthic invertebrates relative to background variability could occur resulting in a score of 2.
Chronic Change	3	Though the number of introductions into the Arctic is expected to be relatively low compared to other regions of the world (e.g., Chan et al. 2015, 2016), higher temperatures, reduced sea ice cover, and intensified vessel traffic in the Canadian Arctic due to climate change are increasing the risk of the introduction and spread of NIS in the region (Goldsmit et al. 2021a). Climate change is also anticipated to alter pathogen transmission or distribution in the Arctic due to increased risk of ballast pollution and other discharges from increased ship traffic (Burek et al. 2008). The establishment of NIS can significantly affect marine ecosystem function and community composition and the economies/lifestyles that depend on them (Drake and Lodge 2007; Bellard et al. 2016; Blackburn et al. 2019; Riley et al. 2022). During the 1960s, the Kamchatka red king crab was deliberately introduced to the

Risk Factor	Score	Rationale
		Northeast Atlantic, as it was a valuable species in the commercial fisheries of the Bering Sea and North Pacific (Christiansen et al. 2015). Since then, this invasive, benthic top predator has established in the Barents Sea and spread westward to Norway and northeastward to offshore Russian waters, disrupting native biodiversity and biomass throughout its spread (Christiansen et al. 2015; Kourantidou et al. 2015). During 2011, an increase in benthic megafauna biomass was observed in the northeastern Barents Sea due in part to increased abundance of the invasive snow crab, which is one of the greatest threats to biological diversity in the area (Jørgensen et al. 2017). The Hudson Bay Complex was identified as high-risk for the establishment of NIS, particularly by crabs, mollusks, macrozooplankton, and macroalgae (Goldsmit et al. 2020, 2021a). Ballast water is a major vector for the transport of macroalgae propagules and if they become established, can alter the benthic ecosystem by acting as ecosystem engineers (Andreakis and Schaffelke 2012). Further, the introduction of novel pathogens can have widespread effects for species that lack pathogen-specific immunity, potentially including the outbreak of epidemic disease and high mortality (Burek et al. 2008) that may continue over time if the pathogen becomes established. If pathogens/NIS were to establish in the Chesterfield Inlet/Narrows priority area and outcompete or otherwise cause high mortality to native benthic invertebrates, they could result in a significant change to overall fitness and/or survival compared to background variability, resulting in a score of 3.
Recovery Factors	2.3	At least 430 benthic invertebrate species have been identified within or near the AOI, including corals (e.g., the soft coral *Gersemia rubiformis*), sponges, sea stars, brittle stars, sea urchins, bivalves, cephalopods, crinoids, gastropods, holothuroids (sea cucumbers), hydrozoans, amphipods, cumaceans, decapods, euphausiids, isopods, Leptostracans, ostracods, sea spiders, polychaetes, barnacles, and chitons (DFO 2020; Loewen et al. 2020a, b). Corals and sponges are the most sensitive benthic invertebrate groups identified for the priority area and were used for the determination of Recovery Factors. There have been limited benthic invertebrate studies for the Chesterfield Inlet/Narrows priority area (e.g., GN 2010; Misiuk and Aitken 2020; Pierrejean et al. 2020). Recovery factors = mean of the factors listed below. Fecundity: 1 (*Geodia phlegraei* sponges from the North Atlantic were observed to produce ~16 million oocytes/sponge and ~30 billion spermatozoa/sponge [Koutsouveli et al. 2020]. It is currently unknown whether *Geodia* sponges occur in the AOI, but the information presented here may be generally used for the Porifera Phylum reported for the AOI). Early life stage mortality: 3 (During four years of observations in water depths >650 m in the Gulf of Maine, the deep-water gorgonian coral *Primnoa resedaeformis* experienced high mortality during its early benthic stage, possibly due to biological disturbance, such as by suspension-feeding brittle stars, and limited food supply [Lacharité and Metaxas 2013]. Larvae of the cold-water coral *Lophelia pertusa* had an average survival rate of 60% during three months of laboratory observations and a maximum longevity of one year [Strömberg and Larsson 2017]. Although neither of these species have been reported for the AOI (Loewen et al. 2020a), their habitat conditions may be considered analogous to those of the AOI and the information presented here is applied in a precautionary manner for species within the AOI, for which no specific early life stage mortality information could be found). Recruitment pattern: 2 (Of two deep-water gorgonian corals observed in the Gulf of Maine, the broadcast spawner *P. resedaeformis* had high recruit abundance while the brooder spawner *Paragorgia arborea* had few recruits [Lacharité and Metaxas 2013]. The life span and rates of asexual and sexual reproduction in the soft coral *G. rubiformis* are unknown; however, asexual reproduction can be

Risk Factor	Score	Rationale
		stimulated by physical disturbance [Henry et al. 2003; Iken et al. 2012]. The lifespan of *Geodia* spp. sponges is unknown, but they are likely to be slow growing [Last et al. 2019]. Although the corals *P. resedaeformis* and *P. arborea* and *Geodia* sponges have not been reported for the AOI, the information provided here has been applied for the AOI, for which no specific information could be found). Natural mortality rate: Unknown; excluded from consideration. Age at maturity: Unknown (DFO 2015b); excluded from consideration. Life stages affected: 3 (All life stages are expected to be affected). Population connectivity: Unknown; excluded from consideration. Population status: Unknown (the population size of the soft coral *G. rubiformis* is unknown [Boutillier et al. 2019] and corals/sponges are not considered under Sara or COSEWIC); excluded from consideration.
Consequence	3 (binned)	Consequence = Exposure x Sensitivity = 2 x 4 = Moderate
Likelihood	1	An interaction (i.e., via survival and establishment of NIS) has the potential to occur during summer/fall when untreated ballast water is discharged from vessels in the priority area. Ballast water of commercial vessels is recognized as an important potential transfer mechanism for aquatic NIS in the Arctic (Chan et al. 2015, 2019). The greatest risk for the introduction of NIS into the Canadian Arctic via ballast water likely arises from domestic vessels, which may discharge untreated ballast water in some circumstances and undergo shorter voyages relative to international vessels, thereby increasing the potential survivability of transported NIS (Goldsmit et al. 2021a). Bivalves, gastropods, barnacles, and some bryozoans may survive for weeks to over a month via physical isolation from unfavourable environmental conditions, while soft-bodied taxa (e.g., tunicates, sponges, cnidarians) or those unable to osmoregulate (e.g., echinoderms) may experience rapid mortality (Riley et al. 2022). Planktonic life stages may also survive the journey, particularly where the organism has only one planktonic life stage, such as gastropods and some bivalves (Wonham et al. 2001). Only a subset of introduced species will survive and potentially establish. However, Hudson Bay has been identified as a location with environmental conditions suitable to certain high risk and indicator NIS, increasing the probability of survival and establishment over other areas in the Arctic (Goldsmit et al. 2019, 2020). Additionally, any discharges that may occur would happen in the summer months, which increases the chance of survival and establishment compared with other times of the year (Goldsmit et al. 2019). Overall, though some taxa can withstand the harsh environmental changes and establishment risks are increasing due to climate change, NIS in ballast water are generally thought to have poor survivorship after Arctic voyages due to inclement conditions (Goldsmit et al. 2020), and only a small proportion of introduced species can be expected to establish. Therefore, pathogen/NIS survival and establishment is considered rare.
Overall Risk	Moderate Risk	Additional management measures should be considered, including restriction of ballast water discharge in the AOI where possible, engagement with vessel operators to identify and address any barriers to compliance with the latest rules regarding discharge, and monitoring for pathogens/NIS, particularly in habitats identified as important.
Uncertainty		

Risk Factor	Score	Rationale
Exposure	5	No studies have quantitatively investigated the number of ballast water discharges in the area, though operational information from vessels can describe the general pattern. The fate of pathogens/NIS released from a vessel discharge of ballast water is unknown for the priority area. Environmental DNA and metabarcoding should be used to detect newly arriving NIS into the Chesterfield Inlet/Narrows priority area, as these methods are currently being successfully used to monitor other remote regions (Goldsmit et al. 2020).
Sensitivity	5	Limited information is available for benthic community diversity and abundance for the Chesterfield Inlet/Narrows priority area (DFO 2020b). Life history information is generally limited for sensitive benthic invertebrate species that may occur within the priority area.
Likelihood	5	Little is known of the risk of pathogen/NIS introduction via vessel discharge of ballast water for the priority area. Goldsmit et al. (2020, 2021a) did consider the Hudson Bay complex as an invasion hotspot for marine NIS. The resistance and survival time of pathogens/NIS transported into Arctic conditions is largely unknown and likely variable between species (Riley et al. 2022).

Risk Statement: If an interaction occurs involving Arctic cod and pathogens/non-indigenous species (NIS) in ballast water discharged from a vessel the consequence could result in a negative impact on Arctic cod populations in the Fisher and Evans Straits priority area.

Table 5-69. Arctic cod – Vessel Discharge (Ballast Water; Fisher and Evans Straits) – Pathogens/Non-Indigenous Species (NIS).

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial (Depth x Areal) = 1 x 1 x 6 = 6 (raw score)
Intensity	1	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low absolute density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Fisher and Evans Straits priority area experiences a higher density of vessel traffic relative to other priority areas except Chesterfield Inlet/Narrows (see Figures 5-1 and 5-10), representing approximately 9.5% of total AIS data within the AOI from 2012-2019. The intensity of vessel traffic and the resulting stressor is not uniform, and the density would be higher in areas of higher vessel traffic (e.g., near regular anchorage areas). Canada's *Ballast Water Regulations* (2021) apply to all vessels operating in Canadian waters and although past rules relied solely on ballast water exchange to manage the risk, the new regulations include standards regarding the number and size of organisms that can be discharged in ballast water. These new rules are being implemented using a phased approach; all international vessels and vessels operating exclusively in Canadian waters constructed in or after 2009 will have until September 8, 2024 to come into compliance with the performance standard, while those vessels constructed before 2009, operating exclusively in Canadian waters, will need to meet the discharge standards by September 2030. Vessels built after June 2021 had to meet the performance standards immediately. Vessels that take on board ballast water in the Great Lakes Basin or

Risk Factor	Score	Rationale
		the Gulf of St. Lawrence, from Montreal to the Gaspe peninsula, are deemed compliant with the new standards if their treatment system was installed following these timelines, the system is operated appropriately, and other requirements (see introductory text for this section). The *Ballast Water Regulations* also outline standards for international vessels that conduct ballast water exchange. For vessels entering the Hudson Bay Complex, ballast water exchange from vessels travelling internationally is required to occur outside of Canadian coastal waters or at a designated alternate ballast water exchange, the closest of which is >1,000 km away from the AOI (TC 2021). Exclusively domestic vessels are not required to exchange ballast water before entering the Hudson Bay Complex. Untreated ballast water discharge from any vessel may occur in the AOI if necessary for a vessel's safe operation. The majority of vessels entering the AOI are domestic vessels and, though it has happened in the past, none are currently expected to travel directly from international ports to locations within the AOI. Vessels that visited the AOI from 2012-2019 (Maerospace 2020) and vessels that compose the current Canadian fleets of operators that service the AOI include those that were built before and after 2009 (CSL n.d.; Desgagnés n.d.), resulting in vessels required to abide by all three discharge standard timelines outlined above. Of the vessel types that occur in the AOI, only a subset (i.e., oil/chemical, cargo/supply, tug, icebreaker, and bulk carrier vessels) would routinely load/discharge ballast water during normal operations, and given that most commercial vessels are transporting cargo to the AOI they will load ballast water as they unload cargo and ballast discharge would not be a regular occurrence. Though expected to be rare under the current management regime, untreated ballast water discharge may occur in the AOI under some circumstances from an exclusively domestic vessel if they were to load cargo or in an emergency situation to ensure safe operation of the vessel. Additionally, in cases where treatment systems are in use, the effectiveness of treatment for the reduction of living organisms can be low (Sayinli et a. 2022; Outinen et al. 2024). Therefore, though untreated ballast water discharge could occur, such occurrences are rare under the current management system, and intensity was scored as 1.
Temporal	1	Arctic cod are expected to occur in the Fisher and Evans Straits priority area year-round. Vessels are typically present in the priority area during July to October, and very occasionally during June and November (Maerospace 2020), though they are not present throughout that entire period. Although the exchange of untreated ballast water from vessels is prohibited in Canadian waters outside of designated alternate ballast water exchange areas (TC 2021), it is recognized that the discharge of untreated ballast water could occur if required for vessel safety or in the case of certain exclusively domestic vessels that might load cargo (noting that in the majority of cases vessels would be transporting cargo to nearby communities and would thus be unlikely to discharge ballast water). Vessel discharge of ballast water containing pathogens/NIS is presumed possible any time vessels are present in the priority area; however, it is expected to occur in only a small proportion of instances when vessels are present, and not during each trip by a vessel that uses ballast. Considering the above, there is an approximate temporal overlap of <25% between when vessels discharging ballast water and Arctic cod are present, resulting in a score of 1.
Spatial	6	Spatial = Areal x Depth = 2 x 3 = 6
Areal	2	A ubiquitous species, Arctic cod occupy coastal and offshore waters in areas with and without sea ice and are expected to be widespread throughout the Arctic Ocean (Coad and Reist 2018). Based on Loewen et al. (2020a), most records for Arctic cod within the AOI are for Evans Strait though Loewen et al. (2020b) also

Risk Factor	Score	Rationale
		noted the occurrence of Arctic cod around small islands in Fisher Strait. Pathogens/NIS from vessel discharge of ballast water could be transported beyond the vessel's immediate location via water currents in open, ice-free areas or under the ice. The greatest concentration of ballast water would be localized, though dispersion could still overlap a small portion of the total Arctic cod range in the priority area. This results in a score of 2.
Depth	3	Arctic cod are widespread across the circumpolar Arctic, but they occur at different depths throughout the water column based on factors such as life history stage (e.g., Geoffroy et al. 2016), seasonal diet (e.g., Majewski et al. 2016), and light regime (e.g., Benoit et al. 2010). Eggs and larvae concentrate under the sea ice. If pathogens/NIS from vessel discharge of ballast water sank in the water column, as could be expected given that the majority of reported marine NIS are benthic (Streftaris et al. 2005), they could reach the seabed and occur within the entire depth range of Arctic cod in the priority area.
Sensitivity	4 (binned)	Sensitivity = (Acute change + Chronic Change) x Recovery Factors = (2 + 3) x 1.9 = 9.5
Acute Change	2	Though introduction risk and establishment risk vary by species, a vessel discharging ballast water could be a vector for the introduction of pathogens/NIS to the Arctic environment (Chan et al. 2015; Hannah et al. 2020; see likelihood, below). Although the specific effects of the introduction of NIS into the Arctic marine environment can be difficult to predict, it is reasonable to presume they can have direct, likely negative, effects on the health of native species. Though many negative effects stemming from NIS are due to establishment and manifest over a longer timeframe (e.g., competition for resources) and are covered under chronic change (below), the introduction of novel pathogens can have widespread effects for species that lack pathogen-specific immunity, potentially including the outbreak of epidemic disease and high mortality (Burek et al. 2008). In other areas where pathogens/NIS have been introduced, the harmful Chaetoceros diatom was shown to cause injury or mortality to fish through gill irritation (Klein et al. 2009), and algal blooms caused mass mortalities (Katsanevakis et al. 2014). Accounting for pathogen outbreaks, measurable changes in mortality rates of Arctic cod relative to background variability could occur, resulting in a score of 2.
Chronic Change	3	Though the number of introductions into the Arctic is expected to be relatively low compared to other regions of the world (e.g., Chan et al. 2015, 2016), higher temperatures, reduced sea ice cover, and intensified vessel traffic in the Canadian Arctic due to climate change are increasing the risk of the introduction and spread of NIS in the region (Goldsmit et al. 2021a). Climate change is also anticipated to alter pathogen transmission or distribution in the Arctic due to increased risk of ballast pollution and other discharges from increased ship traffic (Burek et al. 2008). The establishment of NIS can significantly affect marine ecosystem function and community composition and the economies/lifestyles that depend on them (Drake and Lodge 2007; Bellard et al. 2016; Blackburn et al. 2019; Riley et al. 2022). During the 1960s, the Kamchatka red king crab was deliberately introduced to the Northeast Atlantic, as it was a valuable species in the commercial fisheries of the Bering Sea and North Pacific (Christiansen et al. 2015). Since then, this invasive, benthic top predator has established in the Barents Sea and spread westward to Norway and northeastward to offshore Russian waters, disrupting native biodiversity and biomass throughout its spread (Christiansen et al. 2015; Kourantidou et al. 2015). During 2011, an increase in benthic megafauna

Risk Factor	Score	Rationale
		biomass was observed in the northeastern Barents Sea due in part to increased abundance of the invasive snow crab, which is one of the greatest threats to biological diversity in the area (Jørgensen et al. 2017). The Hudson Bay Complex was identified as high-risk for the establishment of NIS, particularly by crabs, mollusks, macrozooplankton, and macroalgae (Goldsmit et al. 2020, 2021a). Ballast water is a major vector for the transport of macroalgae propagules and if they become established, can alter the benthic ecosystem by acting as ecosystem engineers (Andreakis and Schaffelke 2012). Fish (adults as well as larvae) can also be transported in ballast water (Ricciardi and MacIsaac 2000). Further, the introduction of novel pathogens can have widespread effects for species that lack pathogen-specific immunity, potentially including the outbreak of epidemic disease and high mortality (Burek et al. 2008) that may continue over time if the pathogen becomes established. If pathogens/NIS were to establish in the Fisher and Evans Straits priority area and cause high mortality to Arctic cod or otherwise interrupt ecosystem function, it could result in a significant change to overall fitness and/or survival compared to background variability, resulting in a score of 3.
Recovery Factors	1.9	Recovery factors = mean of the factors listed below. Fecundity: 2 (Spawn only once in their lifetime with a relatively low number of eggs; between 9,000 to 21,000 eggs are produced, with an average of 11,900 per female [Cohen et al. 1990]). Early life stage mortality: 3 (R-selected species with high mortality [Coad and Reist 2018]). Recruitment pattern: 2 (Increased recruitment expected with climate change [LeBlanc et al. 2019]). Natural mortality rate: 1 (Mortality is high [Coad and Reist 2018]). Age at maturity: 2 (2-3 years for males and 3-4 years for females [Coad and Reist 2018]). Life stages affected: 3 (All life stages could potentially occur in the area). Population connectivity: 1 (Arctic cod range widely throughout the Arctic). Population status: 1 (IUCN classification is *least concern* [Fernandes et al. 2015], but population trend is unknown. Abundant in Arctic marine waters [Coad and Reist 2018]).
Consequence	3 (binned)	Consequence = Exposure x Sensitivity = 2 x 4 = Moderate
Likelihood	1	An interaction (i.e., via survival and establishment of NIS) has the potential to occur during summer/fall when untreated ballast water is discharged from vessels in the priority area. Ballast water of commercial vessels is recognized as an important potential transfer mechanism for aquatic NIS in the Arctic (Chan et al. 2015, 2019). The greatest risk for the introduction of NIS into the Canadian Arctic via ballast water likely arises from domestic vessels, which may discharge untreated ballast water in some circumstances and undergo shorter voyages relative to international vessels, thereby increasing the potential survivability of transported NIS (Goldsmit et al. 2021a). Bivalves, gastropods, barnacles, and some bryozoans may survive for weeks to over a month via physical isolation from unfavourable environmental conditions, while soft-bodied taxa (e.g., tunicates, sponges, cnidarians) or those unable to osmoregulate (e.g., echinoderms) may experience rapid mortality (Riley et al. 2022). Planktonic life stages may also survive the journey, particularly where the organism has only one planktonic life stage, such as gastropods and some bivalves (Wonham et al. 2001).

Risk Factor	Score	Rationale
		Only a subset of introduced species will survive and potentially establish. However, Hudson Bay has been identified as a location with environmental conditions suitable to certain high risk and indicator NIS, increasing the probability of survival and establishment over other areas in the Arctic (Goldsmit et al. 2019, 2020). Additionally, any discharges that may occur would happen in the summer months, which increases the chance of survival and establishment compared with other times of the year (Goldsmit et al. 2019). Overall, though some taxa can withstand the harsh environmental changes and establishment risks are increasing due to climate change, NIS in ballast water are generally thought to have poor survivorship after Arctic voyages due to inclement conditions (Goldsmit et al. 2020), and only a small proportion of introduced species can be expected to establish. Therefore, pathogen/NIS survival and establishment is considered rare.
Overall Risk	Moderate Risk	Additional management measures should be considered, including restriction of ballast water discharge in the AOI where possible, engagement with vessel operators to identify and address any barriers to compliance with the latest rules regarding discharge, and monitoring for pathogens/NIS, particularly in habitats identified as important.
Uncertainty		
Exposure	5	No studies have quantitatively investigated the number of ballast water discharges in the area, though operational information from vessels can describe the general pattern. The fate of pathogens/NIS released from a vessel discharge of ballast water is unknown for the priority area. General information exists regarding the distribution of Arctic cod, as well as some information specific to the priority area, though it is limited. Environmental DNA and metabarcoding should be used to detect newly arriving NIS into the priority area, as these methods are currently being successfully used to monitor other remote regions (Goldsmit et al. 2020).
Sensitivity	5	The impacts of pathogens/NIS on fish, including Arctic cod, are not well understood. How pathogens/NIS may affect individuals and populations is highly uncertain.
Likelihood	5	Little is known of the risk of pathogen/NIS survival and establishment via vessel discharge of ballast water for the Fisher and Evans Straits priority area. Goldsmit et al. (2020, 2021a) did consider the Hudson Bay complex as an invasion hotspot for marine NIS. The resistance and survival time of pathogens/NIS transported into Arctic conditions is largely unknown and likely variable between species (Riley et al. 2022).

Risk Statement: If an interaction occurs involving Arctic char and pathogens/non-indigenous species (NIS) in ballast water discharged from a vessel the consequence could result in a negative impact on Arctic char populations in the Chesterfield Inlet/Narrows priority area.

Table 5-70. Arctic Char – Vessel Discharge (Ballast Water; Chesterfield Inlet/Narrows) – Pathogens/Non-Indigenous Species (NIS).

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 2 x 6 = 12 (raw score)
Intensity	1	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low absolute density of vessel traffic. Vessel

Risk Factor	Score	Rationale
		traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Chesterfield Inlet/Narrows priority area experiences a high density of vessel traffic relative to other portions of the AOI (see Figures 5-1 and 5-10) representing approximately 61% of total AIS data within the AOI from 2012-2019. The intensity of vessel traffic and the resulting stressor is not uniform, and the density would be higher in areas of higher vessel traffic (e.g., near regular anchorage areas at Helicopter Island or near Chesterfield Inlet). Canada's *Ballast Water Regulations* (2021) apply to all vessels operating in Canadian waters and although past rules relied solely on ballast water exchange to manage the risk, the new regulations include standards regarding the number and size of organisms that can be discharged in ballast water. These new rules are being implemented using a phased approach; all international vessels and vessels operating exclusively in Canadian waters constructed in or after 2009 will have until September 8, 2024 to come into compliance with the performance standard, while those vessels constructed before 2009, operating exclusively in Canadian waters, will need to meet the discharge standards by September 2030. Vessels built after June 2021 had to meet the performance standards immediately. Vessels that take on board ballast water in the Great Lakes Basin or the Gulf of St. Lawrence, from Montreal to the Gaspe peninsula, are deemed compliant with the new standards if their treatment system was installed following these timelines, the system is operated appropriately, and other requirements (see introductory text for this section). The *Ballast Water Regulations* also outline standards for international vessels that conduct ballast water exchange. For vessels entering the Hudson Bay Complex, ballast water exchange from vessels travelling internationally is required to occur outside of Canadian coastal waters or at a designated alternate ballast water exchange area, the closest of which is >1,000 km away from the AOI (TC 2021). Exclusively domestic vessels are not required to exchange ballast water before entering the Hudson Bay Complex. Untreated ballast water discharge from any vessel may occur in the AOI if necessary for a vessel's safe operation. The majority of vessels entering the AOI are domestic vessels and, though it has happened in the past, none are currently expected to travel directly from international ports to locations within the AOI. Vessels that visited the AOI from 2012-2019 (Maerospace 2020) and vessels that compose the current Canadian fleets of operators that service the AOI include those that were built before and after 2009 (CSL n.d.; Desgagnés n.d.), resulting in vessels required to abide by all three discharge standard timelines outlined above. Of the vessel types that occur in the AOI, only a subset (i.e., oil/chemical, cargo/supply, tug, icebreaker, and bulk carrier vessels) would routinely load/discharge ballast water during normal operations, and given that most commercial vessels are transporting cargo to the AOI they will load ballast water as they unload cargo and ballast discharge would not be a regular occurrence. Though expected to be rare under the current management regime, untreated ballast water discharge may occur in the AOI under some circumstances from an exclusively domestic vessel if they were to load cargo or in an emergency situation to ensure safe operation of the vessel. Additionally, in cases where treatment systems are in use, the effectiveness of treatment for the reduction of living organisms can be low (Sayinli et a. 2022; Outinen et al. 2024). Therefore, though untreated ballast water discharge could occur, such occurrences are rare under the current management system, and intensity was scored as 1.

Risk Factor	Score	Rationale
Temporal	2	Arctic char primarily occur in coastal waters during summer (June-August). Vessels are typically present in the priority area during July to September, and occasionally during June (Maerospace 2020), though they are not present throughout that entire period. Although the exchange of untreated ballast water from vessels is prohibited in Canadian waters outside of designated alternate ballast water exchange areas (TC 2021), it is recognized that the discharge of untreated ballast water could occur if required for vessel safety or in the case of certain exclusively domestic vessels that might load cargo (noting that in the majority of cases vessels would be transporting cargo to nearby communities and would thus be unlikely to discharge ballast water). Vessel discharge of ballast water containing pathogens/NIS is presumed possible any time vessels are present in the priority area; however, it is expected to occur in only a small proportion of instances when vessels are present, and not during each trip by a vessel that uses ballast. Considering the above, there is an approximate temporal overlap of 25-50% between when vessels and Arctic char are present, resulting in a score of 2.
Spatial	6	Spatial = Areal x Depth = 2 x 3 = 6
Areal	2	Arctic char are expected to occur in the coastal waters of the Chesterfield Inlet/Narrows priority area (GN 2012; Idlout 2020; Loewen et al. 2020a, b), generally within 1,500 m from shore (Moore et al. 2016). Pathogens/NIS from vessel discharge of ballast water could be transported beyond the vessel's immediate location via water currents in open, ice-free areas or under the ice. The greatest concentration of ballast water would be localized, though dispersion could still overlap a small portion of the total Arctic char range in the priority area. This results in a score of 2.
Depth	3	Arctic char are distributed in shallow coastal waters. If pathogens/NIS from vessel discharge of ballast water sank in the water column, as could be expected given that the majority of reported marine NIS are benthic (Streftaris et al. 2005), they could reach the seabed and occur within the entire depth range of Arctic char in the priority area.
Sensitivity	5 (binned)	Sensitivity = (Acute change + Chronic Change) x Recovery Factors = (2 + 3) x 2.5 = 12.5
Acute Change	2	Though introduction risk and establishment risk vary by species, a vessel discharging ballast water could be a vector for the introduction of pathogens/NIS to the Arctic environment (Chan et al. 2015; Hannah et al. 2020; see likelihood, below). Although the specific effects of the introduction of NIS into the Arctic marine environment can be difficult to predict, it is reasonable to presume they can have direct, likely negative, effects on the health of native species. Though many negative effects stemming from NIS are due to establishment and manifest over a longer timeframe (e.g., competition for resources) and are covered under chronic change (below), the introduction of novel pathogens can have widespread effects for species that lack pathogen-specific immunity, potentially including the outbreak of epidemic disease and high mortality (Burek et al. 2008). In other areas where pathogens/NIS have been introduced, the harmful Chaetoceros diatom was shown to cause injury or mortality to fish through gill irritation (Klein et al. 2009), and algal blooms caused mass mortalities (Katsanevakis et al. 2014). Accounting for pathogen outbreaks, measurable changes in mortality rates of Arctic char relative to background variability could occur resulting in a score of 2.

Risk Factor	Score	Rationale
Chronic Change	3	Though the number of introductions into the Arctic is expected to be relatively low compared to other regions of the world (e.g., Chan et al. 2015, 2016), higher temperatures, reduced sea ice cover, and intensified vessel traffic in the Canadian Arctic due to climate change are increasing the risk of the introduction and spread of NIS in the region (Goldsmit et al. 2021a). Climate change is also anticipated to alter pathogen transmission or distribution in the Arctic due to increased risk of ballast pollution and other discharges from increased ship traffic (Burek et al. 2008). The establishment of NIS can significantly affect marine ecosystem function and community composition and the economies/lifestyles that depend on them (Drake and Lodge 2007; Bellard et al. 2016; Blackburn et al. 2019; Riley et al. 2022). During the 1960s, the Kamchatka red king crab was deliberately introduced to the Northeast Atlantic, as it was a valuable species in the commercial fisheries of the Bering Sea and North Pacific (Christiansen et al. 2015). Since then, this invasive, benthic top predator has established in the Barents Sea and spread westward to Norway and northeastward to offshore Russian waters, disrupting native biodiversity and biomass throughout its spread (Christiansen et al. 2015; Kourantidou et al. 2015). During 2011, an increase in benthic megafauna biomass was observed in the northeastern Barents Sea due in part to increased abundance of the invasive snow crab, which is one of the greatest threats to biological diversity in the area (Jørgensen et al. 2017). The Hudson Bay Complex was identified as high-risk for the establishment of NIS, particularly by crabs, mollusks, macrozooplankton, and macroalgae (Goldsmit et al. 2020, 2021a). Ballast water is a major vector for the transport of macroalgae propagules and if they become established, can alter the benthic ecosystem by acting as ecosystem engineers (Andreakis and Schaffelke 2012). Fish (adults as well as larvae) can also be transported in ballast water (Ricciardi and MacIsaac 2000). Further, the introduction of novel pathogens can have widespread effects for species that lack pathogen-specific immunity, potentially including the outbreak of epidemic disease and high mortality (Burek et al. 2008) that may continue over time if the pathogen becomes established. If pathogens/NIS were to establish in the Chesterfield Inlet/Narrows priority area and cause high mortality to Arctic char or otherwise interrupt ecosystem function, it could result in a significant change to overall fitness and/or survival compared to background variability, resulting in a score of 3.
Recovery Factors	2.5	Recovery factors = mean of the factors listed below. Fecundity: 2 (Fecundity declines with latitude, but Arctic char spawn several times throughout their life [Coad and Reist 2018]). Early life stage mortality: 3 (High mortality likely associated with environmental factors, as well as density-dependent factors [Coad and Reist 2018]). Recruitment pattern: 2 (Anadromous Arctic char are not as long lived as lake-dwelling populations but may live 20+ years and spawn multiple times throughout their lives [Coad and Reist 2018]). Natural mortality rate: 2 (Mean annual mortality for Canadian anadromous populations is 30-45%, for age classes 6-15 years [Coad and Reist 2018]). Age at maturity: 3 (Age at maturity is 3-10 years [Coad and Reist 2018]). Life stages affected: 3 (All stages). Population connectivity: 3 (Discrete stocks/populations occur in rivers and lakes [Coad and Reist 2018]). Population status: 2 (IUCN classification is *least concern* [Freyhof and Kottelat 2008], but many discrete stocks exist, and the population trends are unknown).
Consequence	4	Consequence = Exposure x Sensitivity

Risk Factor	Score	Rationale
	(binned)	= 2 x 5 = High
Likelihood	1	An interaction (i.e., via survival and establishment of NIS) has the potential to occur during summer/fall when untreated ballast water is discharged from vessels in the priority area. Ballast water of commercial vessels is recognized as an important potential transfer mechanism for aquatic NIS in the Arctic (Chan et al. 2015, 2019). The greatest risk for the introduction of NIS into the Canadian Arctic via ballast water likely arises from domestic vessels, which may discharge untreated ballast water in some circumstances and undergo shorter voyages relative to international vessels, thereby increasing the potential survivability of transported NIS (Goldsmit et al. 2021a). Bivalves, gastropods, barnacles, and some bryozoans may survive for weeks to over a month via physical isolation from unfavourable environmental conditions, while soft-bodied taxa (e.g., tunicates, sponges, cnidarians) or those unable to osmoregulate (e.g., echinoderms) may experience rapid mortality (Riley et al. 2022). Planktonic life stages may also survive the journey, particularly where the organism has only one planktonic life stage, such as gastropods and some bivalves (Wonham et al. 2001). Only a subset of introduced species will survive and potentially establish. However, Hudson Bay has been identified as a location with environmental conditions suitable to certain high risk and indicator NIS, increasing the probability of survival and establishment over other areas in the Arctic (Goldsmit et al. 2019, 2020). Additionally, any discharges that may occur would happen in the summer months, which increases the chance of survival and establishment compared with other times of the year (Goldsmit et al. 2019). Overall, though some taxa can withstand the harsh environmental changes and establishment risks are increasing due to climate change, NIS in ballast water are generally thought to have poor survivorship after Arctic voyages due to inclement conditions (Goldsmit et al. 2020), and only a small proportion of introduced species can be expected to establish. Therefore, pathogen/NIS survival and establishment is considered rare.
Overall Risk	Moderately-High Risk	Additional management measures should be implemented, including restriction of ballast water discharge in the AOI where possible, engagement with vessel operators to identify and address any barriers to compliance with the latest rules regarding discharge, and monitoring for pathogens/NIS, particularly in habitats identified as important (e.g., areas identified during an Inuit Qaujimajatuqangit workshop in February 2020 [Idlout 2020]).
Uncertainty		
Exposure	5	No studies have quantitatively investigated the number of ballast water discharges in the area, though operational information from vessels can describe the general pattern. The fate of pathogens/NIS released from a vessel discharge of ballast water is unknown for the priority area. Details regarding the coastal distribution of Arctic char in the priority area are not available. Environmental DNA and metabarcoding should be used to detect newly arriving NIS into the priority area, as these methods are currently being successfully used to monitor other remote regions (Goldsmit et al. 2020).
Sensitivity	5	The impacts of pathogens/NIS on fish, including Arctic char, are not well understood. How pathogens/NIS may affect individuals and populations is highly uncertain.
Likelihood	5	Little is known of the risk of pathogen/NIS survival and establishment via vessel discharge of ballast water for the Chesterfield Inlet/Narrows priority area. Goldsmit et al. (2020, 2021a) did consider the Hudson Bay complex as an invasion hotspot for marine NIS. The resistance and survival time of

Risk Factor	Score	Rationale
		pathogens/NIS transported into Arctic conditions is largely unknown and likely variable between species (Riley et al. 2022).

Risk Statement: If an interaction occurs involving common eiders and pathogens/non-indigenous species (NIS) in ballast water discharged from a vessel the consequence could result in a negative impact on the common eider population in the East Bay priority area.

Table 5-71. Common eider – Vessel Discharge (Ballast Water; East Bay) – Pathogens/Non-Indigenous Species (NIS).

Risk Factor	Score	Rationale
Exposure	1 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 3 = 3 (raw score)
Intensity	1	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low absolute density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The East Bay priority area experiences a low density of vessel traffic relative to other priority areas (see Figures 5-1 and 5-10) representing <1% of total AIS data within the AOI from 2012-2019. Canada's *Ballast Water Regulations* (2021) apply to all vessels operating in Canadian waters and although past rules relied solely on ballast water exchange to manage the risk, the new regulations include standards regarding the number and size of organisms that can be discharged in ballast water. These new rules are being implemented using a phased approach; all international vessels and vessels operating exclusively in Canadian waters constructed in or after 2009 will have until September 8, 2024 to come into compliance with the performance standard, while those vessels constructed before 2009, operating exclusively in Canadian waters, will need to meet the discharge standards by September 2030. Vessels built after June 2021 had to meet the performance standards immediately. Vessels that take on board ballast water in the Great Lakes Basin or the Gulf of St. Lawrence, from Montreal to the Gaspe peninsula, are deemed compliant with the new standards if their treatment system was installed following these timelines, the system is operated appropriately, and other requirements (see introductory text for this section). The *Ballast Water Regulations* also outline standards for international vessels that conduct ballast water exchange. For vessels entering the Hudson Bay Complex, ballast water exchange from vessels travelling internationally is required to occur outside of Canadian coastal waters or at a designated alternate ballast water exchange area, the closest of which is >1,000 km away from the AOI (TC 2021). Exclusively domestic vessels are not required to exchange ballast water before entering the Hudson Bay Complex. Untreated ballast water discharge from any vessel may occur in the AOI if necessary for a vessel's safe operation. The majority of vessels entering the AOI are domestic vessels and, though it has happened in the past, none are currently expected to travel directly from international ports to locations within the AOI. Vessels that visited the AOI from 2012-2019 (Maerospace 2020) and vessels that compose the current Canadian fleets of operators that service the AOI include those that were built before and after 2009 (CSL n.d.; Desgagnés n.d.), resulting in vessels required to abide by all three discharge standard timelines outlined above. Of the vessel types that occur

Risk Factor	Score	Rationale
		in the AOI, only a subset (i.e., oil/chemical, cargo/supply, tug, icebreaker, and bulk carrier vessels) would routinely load/discharge ballast water during normal operations, and given that most commercial vessels are transporting cargo to the AOI they will load ballast water as they unload cargo and ballast discharge would not be a regular occurrence. Though expected to be rare under the current management regime, untreated ballast water discharge may occur in the AOI under some circumstances from an exclusively domestic vessel if they were to load cargo or in an emergency situation to ensure safe operation of the vessel. Additionally, in cases where treatment systems are in use, the effectiveness of treatment for the reduction of living organisms can be low (Sayinli et a. 2022; Outinen et al. 2024). Therefore, though untreated ballast water discharge could occur, such occurrences are rare under the current management system, and intensity was scored as 1.
Temporal	1	Common eiders are present in the East Bay priority area from mid-June to September. Adult males depart on their moult migration in July (Abraham and Finney 1986). Eggs hatch in July and the flightless females rear their precocial broods in marine and intertidal waters. Groups of females and young are present until late-September (Abraham and Finney 1986), primarily foraging on benthic invertebrates in waters <20 m deep (Goudie et al. 2020). Vessels are typically present in the East Bay priority area mainly during October, though they are not present throughout that entire period. Although the exchange of untreated ballast water from vessels is prohibited in Canadian waters outside of designated alternate ballast water exchange areas (TC 2021), it is recognized that the discharge of untreated ballast water could occur if required for vessel safety or in the case of certain exclusively domestic vessels that might load cargo (noting that in the majority of cases vessels would be transporting cargo to nearby communities and would thus be unlikely to discharge ballast water). Vessel discharge of ballast water containing pathogens/NIS is presumed possible any time vessels are present in the priority area; however, it is expected to occur in only a small proportion of instances when vessels are present, and not during each trip by a vessel that uses ballast. Considering the above, there is an approximate temporal overlap of <25% between when vessels discharging ballast water and eiders are present, resulting in a score of 1.
Spatial	3	Spatial = Areal x Depth = 1 x 3 = 3
Areal	1	Eider females and broods are expected to be distributed in intertidal and marine waters, primarily <20 m deep, within the East Bay priority area. Pathogens/NIS from vessel discharge of ballast water could be transported beyond the vessel's immediate location via water currents in open, ice-free areas or under the ice. The greatest concentration of ballast water would be localized, and although dispersion could occur, vessel tracks are distant from coastal foraging areas. This results in a score of 1.
Depth	3	Common eider typically dives to a depth of <20 m. If pathogens/NIS from vessel discharge of ballast water sank in the water column, as could be expected given that the majority of reported marine NIS are benthic (Streftaris et al. 2005), they could reach the seabed and occur within the entire depth range of common eiders in the priority area.
Sensitivity	5 (binned)	Sensitivity = (Acute change + Chronic Change) x Recovery Factors = (2 + 3) x 2.6 = 13
Acute Change	2	Though introduction risk and establishment risk vary by species, a vessel discharging ballast water could be a vector for the introduction of pathogens/NIS to the Arctic environment (Chan et al. 2015; Hannah et al. 2020; see likelihood, below).

Risk Factor	Score	Rationale
		Although the specific effects of the introduction of NIS into the Arctic marine environment can be difficult to predict, it is reasonable to presume they can have direct, likely negative, effects on the health of native species. Though many negative effects stemming from NIS are due to establishment and manifest over a longer timeframe (e.g., competition for resources) and are covered under chronic change (below), the introduction of novel pathogens can have widespread effects for species that lack pathogen-specific immunity, potentially including the outbreak of epidemic disease and high mortality (Burek et al. 2008). In other areas where pathogens/NIS have been introduced, the harmful Chaetoceros diatom was shown to cause injury or mortality to fish through gill irritation (Klein et al. 2009), and algal blooms caused mass mortalities (Katsanevakis et al. 2014). Specifically regarding common eiders, avian cholera is a known threat to seabird populations, including the colony in East Bay (Descamps et al. 2012; Henri et al. 2018). Accounting for pathogen outbreaks, measurable changes in mortality rates of common eiders relative to background variability could occur resulting in a score of 2.
Chronic Change	3	Though the number of introductions into the Arctic is expected to be relatively low compared to other regions of the world (e.g., Chan et al. 2015, 2016), higher temperatures, reduced sea ice cover, and intensified vessel traffic in the Canadian Arctic due to climate change are increasing the risk of the introduction and spread of NIS in the region (Goldsmit et al. 2021a). Climate change is also anticipated to alter pathogen transmission or distribution in the Arctic due to increased risk of ballast pollution and other discharges from increased ship traffic (Burek et al. 2008). The establishment of NIS can significantly affect marine ecosystem function and community composition and the economies/lifestyles that depend on them (Drake and Lodge 2007; Bellard et al. 2016; Blackburn et al. 2019; Riley et al. 2022). During the 1960s, the Kamchatka red king crab was deliberately introduced to the Northeast Atlantic, as it was a valuable species in the commercial fisheries of the Bering Sea and North Pacific (Christiansen et al. 2015). Since then, this invasive, benthic top predator has established in the Barents Sea and spread westward to Norway and northeastward to offshore Russian waters, disrupting native biodiversity and biomass throughout its spread (Christiansen et al. 2015; Kourantidou et al. 2015). During 2011, an increase in benthic megafauna biomass was observed in the northeastern Barents Sea due in part to increased abundance of the invasive snow crab, which is one of the greatest threats to biological diversity in the area (Jørgensen et al. 2017). Another effect may be the introduction of a NIS that becomes an abundant food resource for common eider. For example, blue mussels and zebra mussels are quite tolerant of contrasting environmental conditions, including temperature variations and salinity levels ranging form marine to freshwater (Riley et al. 2022). Some bivalve NIS that have been introduced to North America and Europe via ballast water have become abundant and are suitable prey for sea ducks. This has led to large-scale shifts in distribution and potentially increased survival of sea duck species exploiting those NIS (Boyd et al. 2015; Kottsieper et al. 2019). The Hudson Bay Complex was identified as high-risk for the establishment of NIS, particularly by crabs, mollusks, macrozooplankton, and macroalgae (Goldsmit et al. 2020, 2021a). Ballast water is a major vector for the transport of macroalgae propagules and if they become established, can alter the benthic ecosystem by acting as ecosystem engineers (Andreakis and Schaffelke 2012). While in the priority area, common eiders store energy reserves that they require for health and reproductive functions later in the year so any degradation of the benthic community from NIS could cause measurable effects. Further, the introduction of

Risk Factor	Score	Rationale
		novel pathogens can have widespread effects for species that lack pathogen-specific immunity, potentially including the outbreak of epidemic disease and high mortality (Burek et al. 2008) that may continue over time if the pathogen becomes established. For example, avian cholera is a known threat to seabird populations, including the colony in East Bay (Descamps et al. 2012; Henri et al. 2018). If pathogens/NIS were to establish in the East Bay priority area and cause high mortality to common eiders or cause mortality/outcompete native benthic invertebrates that act as prey, it could result in a significant change to overall fitness and/or survival compared to background variability, resulting in a score of 3.
Recovery Factors	2.6	Recovery factors = mean of the factors listed below. Fecundity: 2 (Three to five eggs laid per year; nesting success 0-40% [Goudie et al. 2020]). Early life stage mortality**:** 3 (90-95% in first year [Goudie et al. 2020]). Recruitment pattern**:** 3 (Probability: 0.17-0.47 [Nicol-Harper et al. 2021]). Natural mortality rate**:** 3 (13% [Goudie et al. 2020]). Age at maturity**:** 2 (≥4 years [Goudie et al. 2020]). Life stages affected**:** 3 (All life stages could potentially occur in the East Bay priority area [Goudie et al. 2020]). Population connectivity**:** 3 (High degree of fine-scale spatial population genetic structuring [Talbot et al. 2015]). Population status**:** 2 (Common eider is listed as *near threatened* by IUCN [BirdLife International 2018a] but is not listed under SARA or COSEWIC. However, the population may be declining due to increased polar bear predation in the East Bay priority area [Loewen et al. 2020b]). Also, avian cholera has the potential to cause mass mortality and significantly impact the East Bay population [Descamps et al. 2012; Henri et al. 2018]).
Consequence	2 (binned)	Consequence = Exposure x Sensitivity = 1 x 5 = Low
Likelihood	1	An interaction (i.e., via survival and establishment of NIS) has the potential to occur during summer/fall when untreated ballast water is discharged from vessels in the priority area. Ballast water of commercial vessels is recognized as an important potential transfer mechanism for aquatic NIS in the Arctic (Chan et al. 2015, 2019). The greatest risk for the introduction of NIS into the Canadian Arctic via ballast water likely arises from domestic vessels, which may discharge untreated ballast water in some circumstances and undergo shorter voyages relative to international vessels, thereby increasing the potential survivability of transported NIS (Goldsmit et al. 2021a). Bivalves, gastropods, barnacles, and some bryozoans may survive for weeks to over a month via physical isolation from unfavourable environmental conditions, while soft-bodied taxa (e.g., tunicates, sponges, cnidarians) or those unable to osmoregulate (e.g., echinoderms) may experience rapid mortality (Riley et al. 2022). Planktonic life stages may also survive the journey, particularly where the organism has only one planktonic life stage, such as gastropods and some bivalves (Wonham et al. 2001). Only a subset of introduced species will survive and potentially establish. However, Hudson Bay has been identified as a location with environmental conditions suitable to certain high risk and indicator NIS, increasing the probability of survival and establishment over other areas in the Arctic (Goldsmit et al. 2019, 2020). Additionally, any discharges that may occur would happen in the summer months, which increases the chance of survival and establishment compared with other times of the year (Goldsmit et al. 2019).

Risk Factor	Score	Rationale
		Overall, though some taxa can withstand the harsh environmental changes and establishment risks are increasing due to climate change, NIS in ballast water are generally thought to have poor survivorship after Arctic voyages due to inclement conditions (Goldsmit et al. 2020), and only a small proportion of introduced species can be expected to establish. Therefore, pathogen/NIS survival and establishment is considered rare.
Overall Risk	Low Risk	No additional management measures need to be considered at this time.
Uncertainty		
Exposure	5	No studies have quantitatively investigated the number of ballast water discharges in the area, though operational information from vessels can describe the general pattern. The fate of pathogens/NIS released from a vessel discharge of ballast water is unknown for the priority area. There is a moderate amount of scientific information available regarding the abundance and distribution of common eiders in the East Bay priority area. Environmental DNA and metabarcoding should be used to detect newly arriving NIS into the East Bay priority area, as these methods are currently being successfully used to monitor other remote regions (Goldsmit et al. 2020).
Sensitivity	4	Limited information is available for benthic community diversity and abundance for the East Bay priority area (Loewen et al. 2020b). In addition, there is little information on the effects of pathogens/NIS on existing prey species of common eider in the priority area (Kottsieper et al. 2019; Riley et al. 2022). Pathogen outbreaks are known as an important cause of mortality in common eiders (Henri et al. 2018).
Likelihood	5	Little is known of the risk of pathogen/NIS survival and establishment via vessel discharge of ballast water for the East Bay priority area. Goldsmit et al. (2020, 2021a) did consider the Hudson Bay complex as an invasion hotspot for marine NIS. The resistance and survival time of pathogens/NIS transported into Arctic conditions is largely unknown and likely variable between species (Riley et al. 2022).

Risk Statement: If an interaction occurs involving bearded seals and pathogens/non-indigenous species (NIS) in ballast water discharged from a vessel the consequences could result in a negative impact on the bearded seal population in the Fisher and Evans Straits priority area.

Table 5-72. Bearded Seal – Vessel Discharge (Ballast Water; Fisher and Evans Straits) – Pathogens/Non-Indigenous Species (NIS).

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 6 = 6 (raw score)
Intensity	1	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Fisher and Evans Straits priority area experiences a higher density of vessel traffic relative to other priority areas except Chesterfield Inlet/Narrows (see Figures 5-1 and 5-10), representing 9.5% of total AIS data within the AOI from 2012-2019. The intensity of vessel traffic and the resulting stressor is not uniform, and the density would be higher in areas of higher vessel traffic (e.g., near regular anchorage areas).

Risk Factor	Score	Rationale
		Canada's *Ballast Water Regulations* (2021) apply to all vessels operating in Canadian waters and although past rules relied solely on ballast water exchange to manage the risk, the new regulations include standards regarding the number and size of organisms that can be discharged in ballast water. These new rules are being implemented using a phased approach; all international vessels and vessels operating exclusively in Canadian waters constructed in or after 2009 will have until September 8, 2024 to come into compliance with the performance standard, while those vessels constructed before 2009, operating exclusively in Canadian waters, will need to meet the discharge standards by September 2030. Vessels built after June 2021 had to meet the performance standards immediately. Vessels that take on board ballast water in the Great Lakes Basin or the Gulf of St. Lawrence, from Montreal to the Gaspe peninsula, are deemed compliant with the new standards if their treatment system was installed following these timelines, the system is operated appropriately, and other requirements (see introductory text for this section). The *Ballast Water Regulations* also outline standards for international vessels that conduct ballast water exchange. For vessels entering the Hudson Bay Complex, ballast water exchange from vessels travelling internationally is required to occur outside of Canadian coastal waters or at a designated alternate ballast water exchange area, the closest of which is >1,000 km away from the AOI (TC 2021). Exclusively domestic vessels are not required to exchange ballast water before entering the Hudson Bay Complex. Untreated ballast water discharge from any vessel may occur in the AOI if necessary for a vessel's safe operation. The majority of vessels entering the AOI are domestic vessels and, though it has happened in the past, none are currently expected to travel directly from international ports to locations within the AOI. Vessels that visited the AOI from 2012-2019 (Maerospace 2020) and vessels that compose the current Canadian fleets of operators that service the AOI include those that were built before and after 2009 (CSL n.d.; Desgagnés n.d.), resulting in vessels required to abide by all three discharge standard timelines outlined above. Of the vessel types that occur in the AOI, only a subset (i.e., oil/chemical, cargo/supply, tug, icebreaker, and bulk carrier vessels) would routinely load/discharge ballast water during normal operations, and given that most commercial vessels are transporting cargo to the AOI they will load ballast water as they unload cargo and ballast discharge would not be a regular occurrence. Though expected to be rare under the current management regime, untreated ballast water discharge may occur in the AOI under some circumstances from an exclusively domestic vessel if they were to load cargo or in an emergency situation to ensure safe operation of the vessel. Additionally, in cases where treatment systems are in use, the effectiveness of treatment for the reduction of living organisms can be low (Sayinli et a. 2022; Outinen et al. 2024). Therefore, though untreated ballast water discharge could occur, such occurrences are rare under the current management system, and intensity was scored as 1.
Temporal	1	Bearded seals are expected to be present in the priority area year-round (Idlout 2020; Loewen et al. 2020b). Vessels are typically present in the priority area during July to October, and very occasionally during June and November (Maerospace 2020), though they are not present throughout that entire period. Although the exchange of untreated ballast water from vessels is prohibited in Canadian waters outside of designated alternate ballast water exchange areas (TC 2021), it is recognized that the discharge of untreated ballast water could occur if required for vessel safety or in the case of certain exclusively domestic vessels that might load cargo (noting that in the majority of cases vessels would be transporting cargo to nearby communities and would thus be unlikely to discharge ballast water). Vessel discharge of ballast water containing pathogens/NIS is presumed possible any time vessels are present in the priority

Risk Factor	Score	Rationale
		area; however, it is expected to occur in only a small proportion of instances when vessels are present, and not during each trip by a vessel that uses ballast. Considering the above, there is an approximate temporal overlap of <25% between when vessels discharging ballast water and bearded seals are present, resulting in a score of 1.
Spatial	6	Spatial = Areal x Depth = 2 x 3 = 6
Areal	2	Bearded seal are expected to occur throughout the priority area. Pathogens/NIS from vessel discharge of ballast water could be transported beyond the vessel's immediate location via water currents in open, ice-free areas or under the ice. The greatest concentration of ballast water would be localized, though dispersion could still overlap a small portion of the total bearded seal range in the priority area. This results in a score of 2.
Depth	3	Foraging bearded seals typically dive to depths of <100 m, up to about 500 m (NOAA 2022a). If pathogens/NIS from vessel discharge of ballast water sank in the water column, as could be expected given that the majority of reported marine NIS are benthic (Streftaris et al. 2005), they could reach the seabed and occur within the entire depth range of bearded seals in the priority area.
Sensitivity	5 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (2 + 3) x 2.4 = 12
Acute Change	2	Though introduction risk and establishment risk vary by species, a vessel discharging ballast water could be a vector for the introduction of pathogens/NIS to the Arctic environment (Chan et al. 2015; Hannah et al. 2020; see likelihood, below). Although the specific effects of the introduction of NIS into the Arctic marine environment can be difficult to predict, it is reasonable to presume they can have direct, likely negative, effects on the health of native species. Though many negative effects stemming from NIS are due to establishment and manifest over a longer timeframe (e.g., competition for resources) and are covered under chronic change (below), the introduction of novel pathogens can have widespread effects for species that lack pathogen-specific immunity, potentially including the outbreak of epidemic disease and high mortality (Burek et al. 2008). In other areas where pathogens/NIS have been introduced, the harmful Chaetoceros diatom was shown to cause injury or mortality to fish through gill irritation (Klein et al. 2009), and algal blooms caused mass mortalities (Katsanevakis et al. 2014). Accounting for pathogen outbreaks, measurable changes in mortality rates of bearded seals relative to background variability could occur resulting in a score of 2.
Chronic Change	3	Though the number of introductions into the Arctic is expected to be relatively low compared to other regions of the world (e.g., Chan et al. 2015, 2016), higher temperatures, reduced sea ice cover, and intensified vessel traffic in the Canadian Arctic due to climate change are increasing the risk of the introduction and spread of NIS in the region (Goldsmit et al. 2021a). Climate change is also anticipated to alter pathogen transmission or distribution in the Arctic due to increased risk of ballast pollution and other discharges from increased ship traffic (Burek et al. 2008). The establishment of NIS can significantly affect marine ecosystem function and community composition and the economies/lifestyles that depend on them (Drake and Lodge 2007; Bellard et al. 2016; Blackburn et al. 2019; Riley et al. 2022). During the 1960s, the Kamchatka red king crab was deliberately introduced to the Northeast Atlantic, as it was a valuable species in the commercial fisheries of the Bering Sea and North Pacific (Christiansen et al. 2015). Since then, this invasive,

Risk Factor	Score	Rationale
		benthic top predator has established in the Barents Sea and spread westward to Norway and northeastward to offshore Russian waters, disrupting native biodiversity and biomass throughout its spread (Christiansen et al. 2015; Kourantidou et al. 2015). During 2011, an increase in benthic megafauna biomass was observed in the northeastern Barents Sea due in part to increased abundance of the invasive snow crab, which is one of the greatest threats to biological diversity in the area (Jørgensen et al. 2017). The Hudson Bay Complex was identified as high-risk for the establishment of NIS, particularly by crabs, mollusks, macrozooplankton, and macroalgae (Goldsmit et al. 2020, 2021a). Ballast water is a major vector for the transport of macroalgae propagules and if they become established, can alter the benthic ecosystem by acting as ecosystem engineers (Andreakis and Schaffelke 2012). While in the priority area, bearded seals store energy reserves that they require for health and reproductive functions at other times of year so any degradation of the benthic community from NIS could cause measurable effects. Further, the introduction of novel pathogens can have widespread effects for species that lack pathogen-specific immunity, potentially including the outbreak of epidemic disease and high mortality (Burek et al. 2008) that may continue over time if the pathogen becomes established. If pathogens/NIS were to establish in the Fisher and Evans Straits priority area and cause mortality to bearded seals or cause mortality/outcompete native benthic invertebrates that act as prey, they could result in a significant change to overall fitness and/or survival compared to background variability, resulting in a score of 3.
Recovery Factors	2.4	Recovery factors = mean of the factors listed below. Fecundity: 3 (Females typically give birth to one pup a year). Early life stage mortality: 2 (Mortality could increase in the future as climate change affects the amount and suitability of ice required for important life functions [pupping, nursing; Reeves et al. 1992]). Recruitment pattern: Unknown; excluded from analysis. Natural mortality rate: Unknown; excluded from analysis. Age at maturity: 3 (In general, bearded seals attain sexual maturity at 5-6 years old for females and 6-7 for males [Cameron et al. 2010; Kovacs 2016]; however, some females in the Arctic have been found to attain sexual maturity between 3-7 years of age [Andersen et al. 1999]). Life stages affected: 3 (All stages may be affected). Population connectivity: Unknown; excluded from analysis (It is unknown if bearded seals in the AOI remain there year-round or undertake seasonal movements in and out of the region). Population status: 1 (Bearded seals are considered *data deficient* by COSEWIC [2021] and are not listed under SARA. Bearded seals are listed as *threatened* in the USA [related to potential habitat loss], *not threatened* in Greenland, and *least concern* by IUCN).
Consequence	4 (binned)	Consequence = Exposure x Sensitivity = 2 x 5 = High
Likelihood	1	An interaction (i.e., via survival and establishment of NIS) has the potential to occur during summer/fall when untreated ballast water is discharged from vessels in the priority area. Ballast water of commercial vessels is recognized as an important potential transfer mechanism for aquatic NIS in the Arctic (Chan et al. 2015, 2019). The greatest risk for the introduction of NIS into the Canadian Arctic via ballast water likely arises from domestic vessels, which may discharge untreated ballast water in some circumstances and undergo shorter voyages relative to international vessels, thereby increasing the potential survivability of

Risk Factor	Score	Rationale
		transported NIS (Goldsmit et al. 2021a). Bivalves, gastropods, barnacles, and some bryozoans may survive for weeks to over a month via physical isolation from unfavourable environmental conditions, while soft-bodied taxa (e.g., tunicates, sponges, cnidarians) or those unable to osmoregulate (e.g., echinoderms) may experience rapid mortality (Riley et al. 2022). Planktonic life stages may also survive the journey, particularly where the organism has only one planktonic life stage, such as gastropods and some bivalves (Wonham et al. 2001). Only a subset of introduced species will survive and potentially establish. However, Hudson Bay has been identified as a location with environmental conditions suitable to certain high risk and indicator NIS, increasing the probability of survival and establishment over other areas in the Arctic (Goldsmit et al. 2019, 2020). Additionally, any discharges that may occur would happen in the summer months, which increases the chance of survival and establishment compared with other times of the year (Goldsmit et al. 2019). Overall, though some taxa can withstand the harsh environmental changes and establishment risks are increasing due to climate change, NIS in ballast water are generally thought to have poor survivorship after Arctic voyages due to inclement conditions (Goldsmit et al. 2020), and only a small proportion of introduced species can be expected to establish. Therefore, pathogen/NIS survival and establishment is considered rare.
Overall Risk	Moderately-High Risk	Additional management measures should be considered, including restriction of ballast water discharge in the AOI where possible, engagement with vessel operators to identify and address any barriers to compliance with the latest rules regarding discharge, and monitoring for pathogens/NIS, particularly in habitats identified as important.
Uncertainty		
Exposure	4	No studies have quantitatively investigated the number of ballast water discharges in the area, though operational information from vessels can describe the general pattern. The fate of pathogens/NIS released from a vessel discharge of ballast water is unknown for the priority area. There is limited information about bearded seal distribution and numbers within the priority area. Environmental DNA and metabarcoding should be used to detect newly arriving NIS into the Chesterfield Inlet/Narrows priority area, as these methods are currently being successfully used to monitor other remote regions (Goldsmit et al. 2020).
Sensitivity	5	The impacts of NIS on seals, including bearded seal, are not well understood. How pathogens/NIS may affect individuals and populations is highly uncertain.
Likelihood	4	Little is known of the risk of pathogen/NIS survival and establishment via vessel discharge of ballast water for the priority area, although there is some scientific literature available for other areas. Goldsmit et al. (2020, 2021a) did consider the Hudson Bay complex as an invasion hotspot for marine NIS. The resistance and survival time of pathogens/NIS transported into Arctic conditions is largely unknown and likely variable between species (Riley et al. 2022).

Risk Statement: If an interaction occurs involving walruses and pathogens/non-indigenous species (NIS) in ballast water discharged from a vessel the consequences could result in a negative impact on the walrus population in the Fisher and Evans Straits priority area.

Table 5-73. Walrus – Vessel Discharge (Ballast Water; Fisher and Evans Straits) – Pathogens/Non-Indigenous Species (NIS).

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 6 = 6 (raw score)
Intensity	1	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Fisher and Evans Straits priority area experiences a higher density of vessel traffic relative to other priority areas except Chesterfield Inlet/Narrows (see Figures 5-1 and 5-10), representing 9.5% of total AIS data within the AOI from 2012-2019. The intensity of vessel traffic and the resulting stressor is not uniform, and the density would be higher in areas of higher vessel traffic (e.g., near regular anchorage areas). Canada's *Ballast Water Regulations* (2021) apply to all vessels operating in Canadian waters and although past rules relied solely on ballast water exchange to manage the risk, the new regulations include standards regarding the number and size of organisms that can be discharged in ballast water. These new rules are being implemented using a phased approach; all international vessels and vessels operating exclusively in Canadian waters constructed in or after 2009 will have until September 8, 2024 to come into compliance with the performance standard, while those vessels constructed before 2009, operating exclusively in Canadian waters, will need to meet the discharge standards by September 2030. Vessels built after June 2021 had to meet the performance standards immediately. Vessels that take on board ballast water in the Great Lakes Basin or the Gulf of St. Lawrence, from Montreal to the Gaspe peninsula, are deemed compliant with the new standards if their treatment system was installed following these timelines, the system is operated appropriately, and other requirements (see introductory text for this section). The *Ballast Water Regulations* also outline standards for international vessels that conduct ballast water exchange. For vessels entering the Hudson Bay Complex, ballast water exchange from vessels travelling internationally is required to occur outside of Canadian coastal waters or at a designated alternate ballast water exchange area, the closest of which is >1,000 km away from the AOI (TC 2021). Exclusively domestic vessels are not required to exchange ballast water before entering the Hudson Bay Complex. Untreated ballast water discharge from any vessel may occur in the AOI if necessary for a vessel's safe operation. The majority of vessels entering the AOI are domestic vessels and, though it has happened in the past, none are currently expected to travel directly from international ports to locations within the AOI. Vessels that visited the AOI from 2012-2019 (Maerospace 2020) and vessels that compose the current Canadian fleets of operators that service the AOI include those that were built before and after 2009 (CSL n.d.; Desgagnés n.d.), resulting in vessels required to abide by all three discharge standard timelines outlined above. Of the vessel types that occur in the AOI, only a subset (i.e., oil/chemical, cargo/supply, tug, icebreaker, and bulk carrier vessels) would routinely load/discharge ballast water during normal operations, and given that most commercial vessels are transporting cargo to the AOI they will load ballast water as they unload cargo and ballast discharge would not be a regular occurrence. Though expected to be rare under the current management regime, untreated ballast water discharge may occur in the AOI

Risk Factor	Score	Rationale
		under some circumstances from an exclusively domestic vessel if they were to load cargo or in an emergency situation to ensure safe operation of the vessel. Additionally, in cases where treatment systems are in use, the effectiveness of treatment for the reduction of living organisms can be low (Sayinli et a. 2022; Outinen et al. 2024). Therefore, though untreated ballast water discharge could occur, such occurrences are rare under the current management system, and intensity was scored as 1.
Temporal	1	Based on scientific studies and current Inuit Qaujimajatuqangit, walruses occur in the Fisher and Evans Straits priority area year-round (Idlout 2020; Loewen et al. 2020b). Vessels are typically present in the priority area during July to October, and very occasionally during June and November (Maerospace 2020), though they are not present throughout that entire period. Although the exchange of untreated ballast water from vessels is prohibited in Canadian waters outside of designated alternate ballast water exchange areas (TC 2021), it is recognized that the discharge of untreated ballast water could occur if required for vessel safety or in the case of certain exclusively domestic vessels that might load cargo (noting that in the majority of cases vessels would be transporting cargo to nearby communities and would thus be unlikely to discharge ballast water). Vessel discharge of ballast water containing pathogens/NIS is presumed possible any time vessels are present in the priority area; however, it is expected to occur in only a small proportion of instances when vessels are present, and not during each trip by a vessel that uses ballast. Considering the above, there is an approximate temporal overlap of <25% between when vessels discharging ballast water and walruses are present, resulting in a score of 1.
Spatial	6	Spatial = Areal x Depth = 2 x 3 = 6
Areal	2	Walruses are relatively sedentary in summer (Stewart 2008), tending to remain in areas where their food is most abundant and in water less than 80 m deep (Fay 1982; Reeves et al. 2002; Dehn et al. 2007; Lowry 2016a; COSEWIC 2017). The priority area provides walrus foraging habitat, calving areas, and key terrestrial haul-out sites (on Walrus, Bencas, and Coats Islands). During winter, walruses occur off the floe edge along the south and east coasts of SI and in late spring and summer, walruses use the floating pack ice of Evans Strait (Loewen et al. 2020b). Pathogens/NIS from vessel discharge of ballast water could be transported beyond the vessel's immediate location via water currents in open, ice-free areas or under the ice. The greatest concentration of ballast water would be localized, though dispersion could still overlap a small portion of the total walrus range in the priority area. This results in a score of 2.
Depth	3	Walrus typically feed in waters <80 m deep but sometimes feed in waters up to 200 m (Fay 1982, Outridge et al. 2003; COSEWIC 2017). If pathogens/NIS from vessel discharge of ballast water sank in the water column, as could be expected given that the majority of reported marine NIS are benthic (Streftaris et al. 2005), they could reach the seabed and occur within the entire depth range of walruses in the priority area.
Sensitivity	4 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (2 + 3) x 2.1 = 10.5
Acute Change	2	Though introduction risk and establishment risk vary by species, a vessel discharging ballast water could be a vector for the introduction of pathogens/NIS to the Arctic environment (Chan et al. 2015; Hannah et al. 2020; see likelihood, below). Although the specific effects of the introduction of NIS into the Arctic marine environment can be difficult to predict, it is reasonable to presume they can have

Risk Factor	Score	Rationale
		direct, likely negative, effects on the health of native species. Though many negative effects stemming from NIS are due to establishment and manifest over a longer timeframe (e.g., competition for resources) and are covered under chronic change (below), the introduction of novel pathogens can have widespread effects for species that lack pathogen-specific immunity, potentially including the outbreak of epidemic disease and high mortality (Burek et al. 2008). In other areas where pathogens/NIS have been introduced, the harmful Chaetoceros diatom was shown to cause injury or mortality to fish through gill irritation (Klein et al. 2009), and algal blooms caused mass mortalities (Katsanevakis et al. 2014). Accounting for pathogen outbreaks, measurable changes in mortality rates of walruses relative to background variability could occur resulting in a score of 2.
Chronic Change	3	Though the number of introductions into the Arctic is expected to be relatively low compared to other regions of the world (e.g., Chan et al. 2015, 2016), higher temperatures, reduced sea ice cover, and intensified vessel traffic in the Canadian Arctic due to climate change are increasing the risk of the introduction and spread of NIS in the region (Goldsmit et al. 2021a). Climate change is also anticipated to alter pathogen transmission or distribution in the Arctic due to increased risk of ballast pollution and other discharges from increased ship traffic (Burek et al. 2008). The establishment of NIS can significantly affect marine ecosystem function and community composition and the economies/lifestyles that depend on them (Drake and Lodge 2007; Bellard et al. 2016; Blackburn et al. 2019; Riley et al. 2022). During the 1960s, the Kamchatka red king crab was deliberately introduced to the Northeast Atlantic, as it was a valuable species in the commercial fisheries of the Bering Sea and North Pacific (Christiansen et al. 2015). Since then, this invasive, benthic top predator has established in the Barents Sea and spread westward to Norway and northeastward to offshore Russian waters, disrupting native biodiversity and biomass throughout its spread (Christiansen et al. 2015; Kourantidou et al. 2015). During 2011, an increase in benthic megafauna biomass was observed in the northeastern Barents Sea due in part to increased abundance of the invasive snow crab, which is one of the greatest threats to biological diversity in the area (Jørgensen et al. 2017). The Hudson Bay Complex was identified as high-risk for the establishment of NIS, particularly by crabs, mollusks, macrozooplankton, and macroalgae (Goldsmit et al. 2020, 2021a). Ballast water is a major vector for the transport of macroalgae propagules and if they become established, can alter the benthic ecosystem by acting as ecosystem engineers (Andreakis and Schaffelke 2012). While in the priority area in summer, walruses store energy reserves that they require for health and reproductive functions at other times of year so any degradation of the benthic community from NIS could cause measurable effects. Further, the introduction of novel pathogens can have widespread effects for species that lack pathogen-specific immunity, potentially including the outbreak of epidemic disease and high mortality (Burek et al. 2008) that may continue over time if the pathogen becomes established. If pathogens/NIS were to establish in the Fisher and Evans Straits priority area and cause high mortality to walruses or cause mortality/outcompete native benthic invertebrates that act as prey to walruses, they could result in a significant change to overall fitness and/or survival compared to background variability, resulting in a score of 3.
Recovery Factors	2.1	Recovery factors = mean of the factors listed below. <u>Fecundity</u>: 3 (Adult female walrus have 1 calf every 3 years [Garlich-Miller and Stewart 1999]).

Risk Factor	Score	Rationale
		Early life stage mortality: 1 (The data are sparse but the population structure and relatively high proportion of juveniles in the population suggests low mortality in all juvenile stages [Fay et al. 1997]). Recruitment pattern: 1 (Although annual recruitment is low by some standards, recruitment seems to be consistent among years and because walrus are long lived [40 years; Kovacs and Lydersen 2006], a single female produces a lot of young over her lifetime]). Natural mortality rate: 3 (The data are sparse but the population structure and relatively high proportion of juveniles in the population suggests low mortality in all life stages [Fay et al. 1997]). Age at maturity: 3 (Average age at sexual maturity of females is 7 years [Garlich-Miller and Stewart 1999]). Life stages affected: 3 (It is assumed that all life stages of walrus might be affected). Population connectivity: 2 (Studies suggest that there is some interchange among Canadian Arctic walrus populations [Stewart 2008; Charette et al. 2020; Loewen et al. 2020b]). Population status: 1 (COSEWIC [2017] lists walruses as *special concern* due to threats associated with global warming. The Hudson Bay-Davis Strait stock has increased from a minimum of 3,900 in 1986 to approximately 7,000 and the authors suggest that walruses remain abundant in the Southampton Island area [Hammill et al. 2016a]).
Consequence	3 (binned)	Consequence = Exposure x Sensitivity = 2 x 4 = Moderate
Likelihood	1	An interaction (i.e., via survival and establishment of NIS) has the potential to occur during summer/fall when untreated ballast water is discharged from vessels in the priority area. Ballast water of commercial vessels is recognized as an important potential transfer mechanism for aquatic NIS in the Arctic (Chan et al. 2015, 2019). The greatest risk for the introduction of NIS into the Canadian Arctic via ballast water likely arises from domestic vessels, which may discharge untreated ballast water in some circumstances and undergo shorter voyages relative to international vessels, thereby increasing the potential survivability of transported NIS (Goldsmit et al. 2021a). Bivalves, gastropods, barnacles, and some bryozoans may survive for weeks to over a month via physical isolation from unfavourable environmental conditions, while soft-bodied taxa (e.g., tunicates, sponges, cnidarians) or those unable to osmoregulate (e.g., echinoderms) may experience rapid mortality (Riley et al. 2022). Planktonic life stages may also survive the journey, particularly where the organism has only one planktonic life stage, such as gastropods and some bivalves (Wonham et al. 2001). Only a subset of introduced species will survive and potentially establish. However, Hudson Bay has been identified as a location with environmental conditions suitable to certain high risk and indicator NIS, increasing the probability of survival and establishment over other areas in the Arctic (Goldsmit et al. 2019, 2020). Additionally, any discharges that may occur would happen in the summer months, which increases the chance of survival and establishment compared with other times of the year (Goldsmit et al. 2019). Overall, though some taxa can withstand the harsh environmental changes and establishment risks are increasing due to climate change, NIS in ballast water are generally thought to have poor survivorship after Arctic voyages due to inclement conditions (Goldsmit et al. 2020), and only a small proportion of introduced

Risk Factor	Score	Rationale
		species can be expected to establish. Therefore, pathogen/NIS survival and establishment is considered rare.
Overall Risk	Moderate Risk	Additional management measures should be considered, including restriction of ballast water discharge in the AOI where possible, engagement with vessel operators to identify and address any barriers to compliance with the latest rules regarding discharge, and monitoring for pathogens/NIS, particularly in habitats identified as important (e.g., areas identified during an Inuit Qaujimajatuqangit workshop in February 2020 [Idlout 2020]).
Uncertainty		
Exposure	4	No studies have quantitatively investigated the number of ballast water discharges in the area, though operational information from vessels can describe the general pattern. The fate of pathogens/NIS released from a vessel discharge of ballast water is unknown for the priority area. There is some information about walrus distribution within the priority area, and important haul-out sites are known. Environmental DNA and metabarcoding should be used to detect newly arriving NIS into the Chesterfield Inlet/Narrows priority area, as these methods are currently being successfully used to monitor other remote regions (Goldsmit et al. 2020).
Sensitivity	5	The impacts of NIS on walruses are not well understood. How pathogens/NIS may affect individuals and populations is highly uncertain.
Likelihood	4	Little is known of the risk of pathogen/NIS survival and establishment via vessel discharge of ballast water for the priority area, although there is some scientific literature available for other areas. Goldsmit et al. (2020, 2021a) did consider the Hudson Bay complex as an invasion hotspot for marine NIS. The resistance and survival time of pathogens/NIS transported into Arctic conditions is largely unknown and likely variable between species (Riley et al. 2022).

Risk Statement: If an interaction occurs involving narwhals and pathogens/non-indigenous species (NIS) in ballast water discharged from a vessel the consequences could result in a negative impact on the narwhal population in the Repulse Bay and Frozen Strait priority area.

Table 5-74. Narwhal – Vessel Discharge (Ballast Water; Repulse Bay and Frozen Strait) – Pathogens/Non-Indigenous Species (NIS).

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 6 = 6 (raw score)
Intensity	1	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low absolute density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Repulse Bay/Frozen Strait priority area experiences a low density of vessel traffic relative to other priority areas (see Figures 5-1 and 5-10) representing <1% of total AIS data within the AOI from 2012-2019. Canada's *Ballast Water Regulations* (2021) apply to all vessels operating in Canadian waters and although past rules relied solely on ballast water exchange to manage the risk, the new regulations include standards regarding the number and size of organisms that can be discharged in ballast water. These new rules

Risk Factor	Score	Rationale
		are being implemented using a phased approach; all international vessels and vessels operating exclusively in Canadian waters constructed in or after 2009 will have until September 8, 2024 to come into compliance with the performance standard, while those vessels constructed before 2009, operating exclusively in Canadian waters, will need to meet the discharge standards by September 2030. Vessels built after June 2021 had to meet the performance standards immediately. Vessels that take on board ballast water in the Great Lakes Basin or the Gulf of St. Lawrence, from Montreal to the Gaspe peninsula, are deemed compliant with the new standards if their treatment system was installed following these timelines, the system is operated appropriately, and other requirements (see introductory text for this section). The *Ballast Water Regulations* also outline standards for international vessels that conduct ballast water exchange. For vessels entering the Hudson Bay Complex, ballast water exchange from vessels travelling internationally is required to occur outside of Canadian coastal waters or at a designated alternate ballast water exchange area, the closest of which is >1,000 km away from the AOI (TC 2021). Exclusively domestic vessels are not required to exchange ballast water before entering the Hudson Bay Complex. Untreated ballast water discharge from any vessel may occur in the AOI if necessary for a vessel's safe operation. The majority of vessels entering the AOI are domestic vessels and, though it has happened in the past, none are currently expected to travel directly from international ports to locations within the AOI. Vessels that visited the AOI from 2012-2019 (Maerospace 2020) and vessels that compose the current Canadian fleets of operators that service the AOI include those that were built before and after 2009 (CSL n.d.; Desgagnés n.d.), resulting in vessels required to abide by all three discharge standard timelines outlined above. Of the vessel types that occur in the AOI, only a subset (i.e., oil/chemical, cargo/supply, tug, icebreaker, and bulk carrier vessels) would routinely load/discharge ballast water during normal operations, and given that most commercial vessels are transporting cargo to the AOI they will load ballast water as they unload cargo and ballast discharge would not be a regular occurrence. Though expected to be rare under the current management regime, untreated ballast water discharge may occur in the AOI under some circumstances from an exclusively domestic vessel if they were to load cargo or in an emergency situation to ensure safe operation of the vessel. Additionally, in cases where treatment systems are in use, the effectiveness of treatment for the reduction of living organisms can be low (Sayinli et a. 2022; Outinen et al. 2024). Therefore, though untreated ballast water discharge could occur, such occurrences are rare under the current management system, and intensity was scored as 1.
Temporal	1	Narwhals migrate into Repulse Bay in June and July and out in August and September through Frozen Strait (Westdal et al. 2010). Vessels are typically present in the Repulse Bay/Frozen Strait priority area mainly during September and October, and occasionally in August, though they are not present throughout that entire period. Although the exchange of untreated ballast water from vessels is prohibited in Canadian waters outside of designated alternate ballast water exchange areas (TC 2021), it is recognized that the discharge of untreated ballast water could occur if required for vessel safety or in the case of certain exclusively domestic vessels that might load cargo (noting that in the majority of cases vessels would be transporting cargo to nearby communities and would thus be unlikely to discharge ballast water). Vessel discharge of ballast water containing pathogens/NIS is presumed possible any time vessels are present in the priority area; however, it is expected to occur in only a small proportion of instances when vessels are present, and not during each trip by a vessel that uses ballast. Considering the above, there is an approximate temporal overlap of <25% between when vessels discharging ballast water and narwhals are present, resulting in a score of 1.

Risk Factor	Score	Rationale
Spatial	6	Spatial = Areal x Depth = 2 x 3 = 6
Areal	2	Narwhal preferred habitats are leads in landfast or pack ice (Koski and Davis 1994; Kovacs et al. 2011). Repulse Bay and nearby waters provides important summering habitat for narwhals where they are known to feed and calve (Idlout 2020; Loewen et al. 2020b). Narwhals migrate through Frozen Strait en route to Repulse Bay during spring/early summer break-up and en route to Hudson Strait prior to freeze-up in the fall. Pathogens/NIS from vessel discharge of ballast water could be transported beyond the vessel's immediate location via water currents in open, ice-free areas or under the ice. The greatest concentration of ballast water would be localized, though dispersion could still overlap a small portion of the total narwhal range in the priority area. This results in a score of 2.
Depth	3	Narwhals typically forage in water depths <500 m (Heide-Jørgensen and Dietz 1995; Laidre et al. 2003). If pathogens/NIS from vessel discharge of ballast water sank in the water column, as could be expected given that the majority of reported marine NIS are benthic (Streftaris et al. 2005), they could reach the seabed and occur within the entire depth range of narwhals in the priority area.
Sensitivity	5 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (2 + 3) x 2.5 = 12.5
Acute Change	2	Though introduction risk and establishment risk vary by species, a vessel discharging ballast water could be a vector for the introduction of pathogens/NIS to the Arctic environment (Chan et al. 2015; Hannah et al. 2020; see likelihood, below). Although, for narwhals, direct acute impacts from NIS are unknown and the specific effects of the introduction of NIS into the Arctic marine environment can be difficult to predict, it is reasonable to presume they can have direct, likely negative, effects on the health of native species. Though many negative effects stemming from NIS are due to establishment and manifest over a longer timeframe (e.g., competition for resources) and are covered under chronic change (below), the introduction of novel pathogens can have widespread effects for species that lack pathogen-specific immunity, potentially including the outbreak of epidemic disease and high mortality (Burek et al. 2008). In other areas where pathogens/NIS have been introduced, the harmful Chaetoceros diatom was shown to cause injury or mortality to fish through gill irritation (Klein et al. 2009), and algal blooms caused mass mortalities (Katsanevakis et al. 2014). Accounting for pathogen outbreaks, measurable changes in mortality rates of narwhals relative to background variability could occur resulting in a score of 2.
Chronic Change	3	Though the number of introductions into the Arctic is expected to be relatively low compared to other regions of the world (e.g., Chan et al. 2015, 2016), higher temperatures, reduced sea ice cover, and intensified vessel traffic in the Canadian Arctic due to climate change are increasing the risk of the introduction and spread of NIS in the region (Goldsmit et al. 2021a). Climate change is also anticipated to alter pathogen transmission or distribution in the Arctic due to increased risk of ballast pollution and other discharges from increased ship traffic (Burek et al. 2008). The establishment of NIS can significantly affect marine ecosystem function and community composition and the economies/lifestyles that depend on them (Drake and Lodge 2007; Bellard et al. 2016; Blackburn et al. 2019; Riley et al. 2022). During the 1960s, the Kamchatka red king crab was deliberately introduced to the Northeast Atlantic, as it was a valuable species in the commercial fisheries of the Bering Sea and North Pacific (Christiansen et al. 2015). Since then, this invasive,

Risk Factor	Score	Rationale
		benthic top predator has established in the Barents Sea and spread westward to Norway and northeastward to offshore Russian waters, disrupting native biodiversity and biomass throughout its spread (Christiansen et al. 2015; Kourantidou et al. 2015). During 2011, an increase in benthic megafauna biomass was observed in the northeastern Barents Sea due in part to increased abundance of the invasive snow crab, which is one of the greatest threats to biological diversity in the area (Jørgensen et al. 2017). The Hudson Bay Complex was identified as high-risk for the establishment of NIS, particularly by crabs, mollusks, macrozooplankton, and macroalgae (Goldsmit et al. 2020, 2021a). Ballast water is a major vector for the transport of macroalgae propagules and if they become established, can alter the benthic ecosystem by acting as ecosystem engineers (Andreakis and Schaffelke 2012). While in the priority area in summer, narwhals store energy reserves that they require for health and reproductive functions at other times of year so any degradation of their prey community from NIS could cause measurable effects. Further, the introduction of novel pathogens can have widespread effects for species that lack pathogen-specific immunity, potentially including the outbreak of epidemic disease and high mortality (Burek et al. 2008) that may continue over time if the pathogen becomes established. If pathogens/NIS were to establish in the Repulse Bay/Frozen Strait priority area and cause mortality to narwhals or cause mortality/outcompete native species that act as prey, they could result in a significant change to overall fitness and/or survival compared to background variability, resulting in a score of 3.
Recovery Factors	2.5	Recovery factors = mean of the factors listed below. Fecundity: 3 (Adult female narwhals have a calf about every 3 years [Garde et al. 2015]). Early life stage mortality: 2 (Few data on first year mortality of narwhal calves are available. Koski and Davis [1994] estimated that 17% of calves died when between 1 and 13 months of age; this is lower than for many other marine mammal species]). Recruitment pattern: 2 (Although annual recruitment is low by some standards, recruitment seems to be consistent among years and because narwhals are long lived [80 years; Garde et al. 2015], a single female can produce a lot of young over her lifetime]). Natural mortality rate: 3 (The data are sparse but the stable population size with the removals by subsistence hunters suggests low mortality in all life stages). Age at maturity: 3 (Age at sexual maturity of females is 6-9 years and older for males [Garde et al. 2015]). Life stages affected: 3 (All life stages except for newborn calves are likely to be affected. An adult female accompanied by a yearling was seen in the AOI [Carlyle et al. 2021]). Population connectivity: 3 (Studies suggest that there is limited interchange among Canadian Arctic narwhal populations [Westdal et al. 2010; Heide-Jørgensen et al. 2013a; Doniol-Valcroze et al. 2020]). Population status: 1 (IUCN classifies narwhals as *least concern* [Lowry et al. 2017]. The last COSEWIC assessment is outdated [from 2004]. Narwhal populations are considered stable [Furgal and Laing 2012; Lowry et al. 2017]).
Consequence	4 (binned)	Consequence = Exposure x Sensitivity = 2 x 5 = High
Likelihood	1	An interaction (i.e., via survival and establishment of NIS) has the potential to occur during summer/fall when untreated ballast water is discharged from vessels in the priority area. Ballast water of commercial vessels is recognized as an important potential transfer mechanism for aquatic NIS in the Arctic (Chan et al.

Risk Factor	Score	Rationale
		2015, 2019). The greatest risk for the introduction of NIS into the Canadian Arctic via ballast water likely arises from domestic vessels, which may discharge untreated ballast water in some circumstances and undergo shorter voyages relative to international vessels, thereby increasing the potential survivability of transported NIS (Goldsmit et al. 2021a). Bivalves, gastropods, barnacles, and some bryozoans may survive for weeks to over a month via physical isolation from unfavourable environmental conditions, while soft-bodied taxa (e.g., tunicates, sponges, cnidarians) or those unable to osmoregulate (e.g., echinoderms) may experience rapid mortality (Riley et al. 2022). Planktonic life stages may also survive the journey, particularly where the organism has only one planktonic life stage, such as gastropods and some bivalves (Wonham et al. 2001). Only a subset of introduced species will survive and potentially establish. However, Hudson Bay has been identified as a location with environmental conditions suitable to certain high risk and indicator NIS, increasing the probability of survival and establishment over other areas in the Arctic (Goldsmit et al. 2019, 2020). Additionally, any discharges that may occur would happen in the summer months, which increases the chance of survival and establishment compared with other times of the year (Goldsmit et al. 2019). Overall, though some taxa can withstand the harsh environmental changes and establishment risks are increasing due to climate change, NIS in ballast water are generally thought to have poor survivorship after Arctic voyages due to inclement conditions (Goldsmit et al. 2020), and only a small proportion of introduced species can be expected to establish. Therefore, pathogen/NIS survival and establishment is considered rare.
Overall Risk	Moderately-High Risk	Additional management measures should be considered, including restriction of ballast water discharge in the AOI where possible, engagement with vessel operators to identify and address any barriers to compliance with the latest rules regarding discharge, and monitoring for pathogens/NIS, particularly in habitats identified as important (e.g., areas identified during an Inuit Qaujimajatuqangit workshop in February 2020 [Idlout 2020]).
Uncertainty		
Exposure	4	No studies have quantitatively investigated the number of ballast water discharges in the area, though operational information from vessels can describe the general pattern. The fate of pathogens/NIS released from a vessel discharge of ballast water is unknown for the priority area. There is some information about narwhal distribution within the priority area. Environmental DNA and metabarcoding should be used to detect newly arriving NIS into the Chesterfield Inlet/Narrows priority area, as these methods are currently being successfully used to monitor other remote regions (Goldsmit et al. 2020).
Sensitivity	5	The impacts of NIS on narwhals are not well understood. How pathogens/NIS may affect individuals and populations is highly uncertain.
Likelihood	4	Little is known of the risk of pathogen/NIS survival and establishment via vessel discharge of ballast water for the priority area, although there is some scientific literature available for other areas. Goldsmit et al. (2020, 2021a) did consider the Hudson Bay complex as an invasion hotspot for marine NIS. The resistance and survival time of pathogens/NIS transported into Arctic conditions is largely unknown and likely variable between species (Riley et al. 2022).

Risk Statement: If an interaction occurs involving bowhead whales and pathogens/non-indigenous species (NIS) in ballast water discharged from a vessel the consequences could result in a negative impact on the bowhead whale population in the Fisher and Evans Straits priority area.

Table 5-75. Bowhead Whale – Vessel Discharge (Ballast Water; Fisher and Evans Straits) – Pathogens/Non-Indigenous Species (NIS).

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 2 x 6 = 12 (raw score)
Intensity	1	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Fisher and Evans Straits priority area experiences a higher density of vessel traffic relative to other priority areas except Chesterfield Inlet/Narrows (see Figures 5-1 and 5-10), representing 9.5% of total AIS data within the AOI from 2012-2019. The intensity of vessel traffic and the resulting stressor is not uniform, and the density would be higher in areas of higher vessel traffic (e.g., near regular anchorage areas). Canada's *Ballast Water Regulations* (2021) apply to all vessels operating in Canadian waters and although past rules relied solely on ballast water exchange to manage the risk, the new regulations include standards regarding the number and size of organisms that can be discharged in ballast water. These new rules are being implemented using a phased approach; all international vessels and vessels operating exclusively in Canadian waters constructed in or after 2009 will have until September 8, 2024 to come into compliance with the performance standard, while those vessels constructed before 2009, operating exclusively in Canadian waters, will need to meet the discharge standards by September 2030. Vessels built after June 2021 had to meet the performance standards immediately. Vessels that take on board ballast water in the Great Lakes Basin or the Gulf of St. Lawrence, from Montreal to the Gaspe peninsula, are deemed compliant with the new standards if their treatment system was installed following these timelines, the system is operated appropriately, and other requirements (see introductory text for this section). The *Ballast Water Regulations* also outline standards for international vessels that conduct ballast water exchange. For vessels entering the Hudson Bay Complex, ballast water exchange from vessels travelling internationally is required to occur outside of Canadian coastal waters or at a designated alternate ballast water exchange area, the closest of which is >1,000 km away from the AOI (TC 2021). Exclusively domestic vessels are not required to exchange ballast water before entering the Hudson Bay Complex. Untreated ballast water discharge from any vessel may occur in the AOI if necessary for a vessel's safe operation. The majority of vessels entering the AOI are domestic vessels and, though it has happened in the past, none are currently expected to travel directly from international ports to locations within the AOI. Vessels that visited the AOI from 2012-2019 (Maerospace 2020) and vessels that compose the current Canadian fleets of operators that service the AOI include those that were built before and after 2009 (CSL n.d.; Desgagnés n.d.), resulting in vessels required to abide by all three discharge standard timelines outlined above. Of the vessel types that occur in the AOI, only a subset (i.e., oil/chemical, cargo/supply, tug, icebreaker, and bulk carrier vessels) would routinely load/discharge ballast water during normal operations, and given that most commercial vessels are transporting cargo to the AOI they will load ballast water as they unload cargo and ballast discharge would not be a regular occurrence. Though expected to be rare under the current

Risk Factor	Score	Rationale
		management regime, untreated ballast water discharge may occur in the AOI under some circumstances from an exclusively domestic vessel if they were to load cargo or in an emergency situation to ensure safe operation of the vessel. Additionally, in cases where treatment systems are in use, the effectiveness of treatment for the reduction of living organisms can be low (Sayinli et a. 2022; Outinen et al. 2024). Therefore, though untreated ballast water discharge could occur, such occurrences are rare under the current management system, and intensity was scored as 1.
Temporal	2	Based on scientific studies and current Inuit Qaujimajatuqangit, bowheads occur in the Fisher and Evans Straits priority area from April to November but primarily occur there during summer (Idlout 2020; Loewen et al. 2020b). Vessels are typically present in the priority area during July to October, and very occasionally during June and November (Maerospace 2020), though they are not present throughout that entire period. Although the exchange of untreated ballast water from vessels is prohibited in Canadian waters outside of designated alternate ballast water exchange areas (TC 2021), it is recognized that the discharge of untreated ballast water could occur if required for vessel safety or in the case of certain exclusively domestic vessels that might load cargo (noting that in the majority of cases vessels would be transporting cargo to nearby communities and would thus be unlikely to discharge ballast water). Vessel discharge of ballast water containing pathogens/NIS is presumed possible any time vessels are present in the priority area; however, it is expected to occur in only a small proportion of instances when vessels are present, and not during each trip by a vessel that uses ballast. Considering the above, there is an approximate temporal overlap of 25-50% between when vessels discharging ballast and bowhead whales are present, resulting in a score of 2.
Spatial	6	Spatial = Areal x Depth = 2 x 3 = 6
Areal	2	Bowhead whales are expected to primarily occur in the Fisher and Evans Straits priority area during the summer and can occur throughout the priority area. Nearshore areas around SE SI in Evans Strait are known calving and nursery grounds (DFO 2020; Idlout 2020; Loewen et al. 2020b). Pathogens/NIS from vessel discharge of ballast water could be transported beyond the vessel's immediate location via water currents in open, ice-free areas or under the ice. The greatest concentration of ballast water would be localized, though dispersion could still overlap a small portion of the total bowhead range in the priority area. This results in a score of 2.
Depth	3	Bowheads in the eastern Canadian Arctic routinely conduct foraging dives >100 m with maximum depths exceeding 650 m (Fortune et al. 2020). If pathogens/NIS from vessel discharge of ballast water sank in the water column, as could be expected given that the majority of reported marine NIS are benthic (Streftaris et al. 2005), they could occur within the entire depth range of bowheads in the priority area.
Sensitivity	4 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (2 + 3) x 2.3 = 11.5
Acute Change	2	Though introduction risk and establishment risk vary by species, a vessel discharging ballast water could be a vector for the introduction of pathogens/NIS to the Arctic environment (Chan et al. 2015; Hannah et al. 2020; see likelihood, below). Although for bowhead whales direct acute impacts from NIS are unknown and the specific effects of the introduction of NIS into the Arctic marine environment can be difficult to predict, it is reasonable to presume they can have direct, likely

Risk Factor	Score	Rationale
		negative, effects on the health of native species. Though many negative effects stemming from NIS are due to establishment and manifest over a longer timeframe (e.g., competition for resources) and are covered under chronic change (below), the introduction of novel pathogens can have widespread effects for species that lack pathogen-specific immunity, potentially including the outbreak of epidemic disease and high mortality (Burek et al. 2008). In other areas where pathogens/NIS have been introduced, the harmful Chaetoceros diatom was shown to cause injury or mortality to fish through gill irritation (Klein et al. 2009), and algal blooms caused mass mortalities (Katsanevakis et al. 2014). Accounting for pathogen outbreaks, measurable changes in mortality rates of bowhead whales relative to background variability could occur, resulting in a score of 2.
Chronic Change	3	Though the number of introductions into the Arctic is expected to be relatively low compared to other regions of the world (e.g., Chan et al. 2015, 2016), higher temperatures, reduced sea ice cover, and intensified vessel traffic in the Canadian Arctic due to climate change are increasing the risk of the introduction and spread of NIS in the region (Goldsmit et al. 2021a). Climate change is also anticipated to alter pathogen transmission or distribution in the Arctic due to increased risk of ballast pollution and other discharges from increased ship traffic (Burek et al. 2008). The establishment of NIS can significantly affect marine ecosystem function and community composition and the economies/lifestyles that depend on them (Drake and Lodge 2007; Bellard et al. 2016; Blackburn et al. 2019; Riley et al. 2022). During the 1960s, the Kamchatka red king crab was deliberately introduced to the Northeast Atlantic, as it was a valuable species in the commercial fisheries of the Bering Sea and North Pacific (Christiansen et al. 2015). Since then, this invasive, benthic top predator has established in the Barents Sea and spread westward to Norway and northeastward to offshore Russian waters, disrupting native biodiversity and biomass throughout its spread (Christiansen et al. 2015; Kourantidou et al. 2015). During 2011, an increase in benthic megafauna biomass was observed in the northeastern Barents Sea due in part to increased abundance of the invasive snow crab, which is one of the greatest threats to biological diversity in the area (Jørgensen et al. 2017). The Hudson Bay Complex was identified as high-risk for the establishment of NIS, particularly by crabs, mollusks, macrozooplankton, and macroalgae (Goldsmit et al. 2020, 2021a). Ballast water is a major vector for the transport of macroalgae propagules and if they become established, can alter the benthic ecosystem by acting as ecosystem engineers (Andreakis and Schaffelke 2012). While in the priority area in summer, bowhead whales store energy reserves that they require for health and reproductive functions at other times of year so any degradation of their prey community from NIS could cause measurable effects. Further, the introduction of novel pathogens can have widespread effects for species that lack pathogen-specific immunity, potentially including the outbreak of epidemic disease and high mortality (Burek et al. 2008) that may continue over time if the pathogen becomes established. If pathogens/NIS were to establish in the Fisher and Evans Straits priority area and cause mortality to bowhead whales or cause mortality/outcompete native species that act as prey, they could result in a significant change to overall fitness and/or survival compared to background variability, resulting in a score of 3.
Recovery Factors	2.3	Recovery factors = mean of the factors listed below. Fecundity: 3 (Adult female bowheads have 1 calf every 3-4 years [Miller et al. 1992; Koski et al. 1993; Tarpley et al. 2016, 2021]). Early life stage mortality: Unknown; excluded from consideration (There are no data on mortality rates in juvenile bowheads).

Risk Factor	Score	Rationale
		<u>Recruitment pattern</u>: 1 (Although annual recruitment is low by some standards, bowhead pregnancies seem to be determined by the health of the prospective mother to maximize survival of the calf [W. Koski, pers. comm., 2022]. Because bowheads live to be about 200 years old, a single female produces a lot of young over her lifetime [Tarpley et al. 2016, 2021]). <u>Natural mortality rate</u>: 3 (The mortality rate of adult bowheads is extremely low, possibly the lowest of any animal. Survival has been estimated as 0.984 [0.948-1.00; Zeh et al. 2002] to 0.996 [0.976-1.00, Givens et al. 2018]). <u>Age at maturity</u>: 3 (Average age at sexual maturity of female bowheads is about 25 years [Koski et al. 1993; George et al. 1999] and appears to have declined in recent years [Tarpley et al. 2021]). <u>Life stages affected</u>: 3 (It is assumed that all bowhead life stages could be affected.) <u>Population connectivity</u>: 2 (The EC-WG population of bowhead whales occur in the AOI. Until recently, the geographic distributions of the EC-WG and BCB bowhead populations were significantly different so that there was little or no overlap between the populations [Zeh et al. 1995]. With the opening of the NW passage resulting from climate change, interchange between these two populations is possible, as suggested by a sighting of two satellite tagged bowheads from the two populations in the same general area in the High Arctic [Heide-Jørgensen et al. 2011]). <u>Population status</u>: 1 (IUCN classifies the EC-WG bowhead whale population as *least concern* [Cooke and Reeves 2018]. COSEWIC (2009) classifies them as *threatened*; however, that status report is out of date and is currently being reviewed. Recent surveys indicate that the population has increased since commercial overharvesting ended in the early 1900s. They may have increased to the point where this population has reached the carrying capacity of their habitat, based on sightings of skinny whales and apparent natural mortality in Cumberland Sound [Young et al. 2019] and recent cases of apparent natural mortality in other areas [DFO unpublished data]).
Consequence	3 (binned)	Consequence = Exposure x Sensitivity = 2 x 4 = Moderate
Likelihood	1	An interaction (i.e., via survival and establishment of NIS) has the potential to occur during summer/fall when untreated ballast water is discharged from vessels in the priority area. Ballast water of commercial vessels is recognized as an important potential transfer mechanism for aquatic NIS in the Arctic (Chan et al. 2015, 2019). The greatest risk for the introduction of NIS into the Canadian Arctic via ballast water likely arises from domestic vessels, which may discharge untreated ballast water in some circumstances and undergo shorter voyages relative to international vessels, thereby increasing the potential survivability of transported NIS (Goldsmit et al. 2021a). Bivalves, gastropods, barnacles, and some bryozoans may survive for weeks to over a month via physical isolation from unfavourable environmental conditions, while soft-bodied taxa (e.g., tunicates, sponges, cnidarians) or those unable to osmoregulate (e.g., echinoderms) may experience rapid mortality (Riley et al. 2022). Planktonic life stages may also survive the journey, particularly where the organism has only one planktonic life stage, such as gastropods and some bivalves (Wonham et al. 2001). Only a subset of introduced species will survive and potentially establish. However, Hudson Bay has been identified as a location with environmental conditions suitable to certain high risk and indicator NIS, increasing the probability of survival and establishment over other areas in the Arctic (Goldsmit et al. 2019, 2020). Additionally, any discharges that may occur would happen in the summer

Risk Factor	Score	Rationale
		months, which increases the chance of survival and establishment compared with other times of the year (Goldsmit et al. 2019). Overall, though some taxa can withstand the harsh environmental changes and establishment risks are increasing due to climate change, NIS in ballast water are generally thought to have poor survivorship after Arctic voyages due to inclement conditions (Goldsmit et al. 2020), and only a small proportion of introduced species can be expected to establish. Therefore, pathogen/NIS survival and establishment is considered rare.
Overall Risk	Moderate Risk	Additional management measures should be considered, including restriction of ballast water discharge in the AOI where possible, engagement with vessel operators to identify and address any barriers to compliance with the latest rules regarding discharge, and monitoring for pathogens/NIS, particularly in habitats identified as important (e.g., areas identified during an Inuit Qaujimajatuqangit workshop in February 2020 [Idlout 2020]).
Uncertainty		
Exposure	4	No studies have quantitatively investigated the number of ballast water discharges in the area, though operational information from vessels can describe the general pattern. The fate of pathogens/NIS released from a vessel discharge of ballast water is unknown for the priority area. There is some information about bowhead distribution within the priority area. Environmental DNA and metabarcoding should be used to detect newly arriving NIS into the Chesterfield Inlet/Narrows priority area, as these methods are currently being successfully used to monitor other remote regions (Goldsmit et al. 2020).
Sensitivity	5	The impacts of NIS on bowheads are not well understood. How pathogens/NIS may affect individuals and populations is highly uncertain.
Likelihood	4	Little is known of the risk of pathogen/NIS survival and establishment via vessel discharge of ballast water for the priority area, although there is some scientific literature available for other areas. Goldsmit et al. (2020, 2021a) did consider the Hudson Bay complex as an invasion hotspot for marine NIS. The resistance and survival time of pathogens/NIS transported into Arctic conditions is largely unknown and likely variable between species (Riley et al. 2022).

5.5.3 Petroleum Product Spills

Both small and large vessel source oil spills pose a risk to the marine environment. Regular operation of vessels leads to spills (e.g., bilge water and small fuel leaks) that are generally small in volume but can occur frequently (i.e., chronically), while large accidental spills can occur as a result of rarer events such as collisions, groundings, structural failure, or other instances of vessels in distress at sea (Haggarty et al. 2003; GESAMP 2007). Impacts to marine and coastal ecosystems will depend on volume, location, type of oil spilled, and environmental factors, such as time of year and weather conditions (DFO 2011a; GENIVAR 2013; WSP 2014a). For this assessment, two scenarios have been considered: 1) frequent but small-volume oil spills, and 2) a large heavy fuel oil spill from a vessel operating in the AOI.

5.5.3.1 Small Spills

Small-volume oil spills have been estimated to be the largest source of anthropogenic oil in the marine environment (GESAMP 2007). Though low volumes and typical high product volatility mean that most ESC subcomponents in the AOI area would not be exposed to significant oil levels, seabirds are particularly susceptible to even small volumes and very low concentrations of oil, and alcids are especially sensitive due to the amount of time they spend on and in the water (Irons et al.

2000; Wiese and Robertson 2004; Lieske et al. 2019). As a result, thick-billed murres were assessed and serves as a proxy for other seabird ESC subcomponents (Table 5-76).

Table 5-76. Vessel Discharge − Small Spill: ESC Subcomponents and Priority Areas Assessed.

ESC Subcomponent	Priority Area	Assessed by Proxy
Thick-billed murre	Fisher and Evans Straits	
Other seabirds		Via thick-billed murre

Risk Statement: If an interaction occurs between thick-billed murres and small, operational petroleum product spills the consequences could result in a negative impact on the thick-billed murre population in the Fisher and Evans Straits priority area.

Table 5-77. Thick-billed murre – Vessel Discharge (Fisher and Evans Straits) – Petroleum Product Spills (Small Operational).

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 2 x 2 x 3 = 12 (raw score)
Intensity	2	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Fisher and Evans Straits priority area experiences a higher density of vessel traffic relative to other priority areas except Chesterfield Inlet/Narrows (see Figures 5-1 and 5-10), representing 9.5% of total AIS data within the AOI from 2012-2019. The intensity of vessel traffic and the resulting stressor is not uniform, and the density would be higher in areas of higher vessel traffic (e.g., on regular shipping routes). Because abiotic weathering (e.g., dispersion, evaporation) and bioremediation occurs slowly in cold and/or ice-covered seawater a small, operational spill of petroleum product from a vessel discharge is expected to persist in the environment (WWF n.d.; WSP 2014a; Garneau et al. 2016; Gomes et al. 2022). The combination of low-density vessel traffic and high persistence of petroleum products in cold conditions result in a score of 2.
Temporal	2	Thick-billed murres are present in the Fisher and Evans Straits priority area from mid-May to October (Patterson et al. 2021). Murres would be present at the nesting cliffs on Coats Island from mid-May through July. Foraging adults capable of flight would be present at sea from June to July and in October, whereas chicks and flightless adults would be present at sea from August to September. Vessels are typically present in the priority area during July to October, and very occasionally during June and November (Maerospace 2020), though they are not present throughout that entire period. Thus, there is some overlap between when vessels and thick-billed murres occur in the priority area, resulting in a score of 2.
Spatial	3	Spatial = Areal x Depth = 1 x 3 = 3
Areal	1	Thick-billed murre distribution in the study area would primarily be in open water areas and the nesting cliffs on the north coast of Coats Island west of Cape Pembroke (Latour et al. 2008; Mallory et al. 2019). Murres nesting at these

Risk Factor	Score	Rationale
		colonies forage primarily within Fisher and Evans Straits (Brisson-Curadeau and Elliott 2019; Patterson et al. 2022). Based on available AIS data, vessel activity (see Figures 5-1 and 5-10) is typically focused along two primary paths that occur north and south of Coats Island. Spilled petroleum product from a small, operational discharge would likely remain in the vessel's immediate vicinity and, due to low dispersion in the Arctic environment (Gomes et al. 2022), the greatest concentration of petroleum product would occur at a few restricted locations within the total seabird range in the priority area. This results in a score of 1.
Depth	3	Thick-billed murres at sea spend much of their time on or under the surface and undertake deep foraging dives in the water column (Gaston and Hipfner 2020). Depending on the product and environmental conditions, oil can remain in a thin sheen at the water surface for a prolonged period of time (Lee et al. 2015). Considering the interaction at the water surface and that this species would be forced to pass through a slick at some point before or after a dive results in a depth score of 3.
Sensitivity	1 (binned)	Sensitivity = (Acute Change + Chronic Change) X Recovery Factors = (1+1) x 2.4 = 4.8
Acute Change	1	Petroleum spills have a strong potential for negative effects on seabirds, especially species that spend most of their time on water, like thick-billed murres (Irons et al. 2000; Wiese and Robertson 2004; Lieske et al. 2019; Gaston and Hipfner 2020). These effects include hypothermia and drowning caused by plumage contamination and lethal or sub-lethal toxicity caused by ingestion of the petroleum product during preening or feeding. Such spills cause increased mortality rates, physiological impairment (anemia), damage to internal organs, reduced flight efficiency, and reduced reproductive success (Morandin and O'Hara 2016; Bursian et al. 2017; Maggini et al. 2017a,b,c; Burger 2018; Matcott et al. 2019). However, only a small number of individuals would come into contact with the small operational spills that would result from the low density of vessel traffic. This is expected to result in an insignificant or undetectable change to thick-billed murre mortality rates against background variability in the Fisher and Evans Straits priority area. Thus, a score of 1 was assigned.
Chronic Change	1	Petroleum spills may cause chronic effects on seabirds such as physiological impairment, damaged internal organs, and reduced reproductive success, which in turn may result in chronic population declines (Esler et al. 2002; Wiese and Robertson 2004; Montevecchi et al. 2012; Morandin and O'Hara 2016). However, because of the low density of vessel traffic in the Fisher and Evans Straits priority area, individual murres would be unlikely to experience repeat exposure to small operational spills. Consequently, such a spill is not expected to have measurable impacts on overall fitness and population dynamics compared with background variation, resulting in a score of 1.
Recovery Factors	2.4	Recovery factors = mean of the factors listed below. Fecundity: 2 (One egg laid per year [Gaston and Hipfner 2020]). Early life stage mortality**:** 3 (63-76% before breeding age [Gaston and Hipfner 2020]). Recruitment pattern**:** 3 (Attempted breeding: 3-year olds: 0-2%; 4-year olds: 7-16%; 5-year olds: 0-31% [Noble et al. 1991]). Natural mortality rate**:** 3 (14% [Gaston et al. 1994]). Age at maturity**:** 3 (5.7 years [Gaston and Hipfner 2020]). Life stages affected**:** 3 (All life stages could potentially occur in the priority area [Gaston 2002]). Population connectivity**:** 1 (Very little genetic population structuring [Tigano et al. 2017]).

Risk Factor	Score	Rationale
		Population status**:** 1 (Thick-billed murre is listed as *least concern* by IUCN [BirdLife International 2018b] and is not listed under SARA or COSEWIC).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 2 x 1 = Negligible
Likelihood	4	An interaction could occur in the Fisher and Evans Straits priority area between thick-billed murres and small operational spills of petroleum products. Such spills are a common occurrence during normal vessel operation (Lee et al. 2015). Additionally, seabirds are susceptible to very low concentrations of oil (Morandin and O'Hara 2016). The likelihood of an interaction occurring will depend on the type of petroleum product, weather, variation in distribution and abundance of prey (Wiese et al. 2001, Montevecchi et al. 2012), the size of the spill, the time of year of the spill relative to the flightless period (flight-feather moult), and the location of murre flocks and chick-parent pairs relative to the vessel's track, such that the correlation between the volume of oil released and the number of seabirds oiled is weak (Burger 1993). Considering the information above, likelihood was scored as 4.
Overall Risk	Low Risk	No additional management measures need to be considered at this time.
Uncertainty		
Exposure	3	There is a substantial amount of scientific information available regarding the abundance and distribution of thick-billed murres in the Fisher and Evans Straits priority area (Mallory et al. 2019; Patterson et al. 2022). General vessel traffic patterns are known and were used to inform vessel discharge exposure parameters. Uncertainty is moderate.
Sensitivity	2	There is substantial scientific information on sensitivity of thick-billed murres to the negative effects of petroleum product spills (Irons et al. 2000; Wiese and Robertson 2004; Lieske et al. 2019; Gaston and Hipfner 2020).
Likelihood	2	There is a substantial amount of scientific information on the likelihood of an interaction between an oil spill and thick-billed murres (Irons et al. 2000; Wiese and Robertson 2004; Lieske et al. 2019; Mallory et al. 2019; Patterson et al. 2022).

5.5.3.2 Large Spill

For the purposes of this assessment of a large oil spill and based on the approximate size and fuel storage capacity of the vessels that regularly travel through the AOI (Hughes 2017; Maerospace 2020), we have assumed the scenario of an accidental spill of 1,000 t (~990 m^3 at a density of 1,010 kg/m^3) of heavy fuel oil in the AOI in summer. This is the volume of fuel transported by a typical dry cargo community resupply vessel, and the vast majority of vessels transit within the AOI in summer. Crude oil is not transported through the Canadian Arctic at present (WSP 2014a; Hughes 2017). For the large heavy fuel oil spill scenario, Arctic cod and Arctic char were assessed and the Arctic cod assessment will act as a proxy for the other forage fish assessment (Table 5-78). The physiological and physical effects of a large oil spill are expected to result in similar negative effects on ringed and bearded seals (Helm et al. 2015); however, both seal species have been assessed due to their different habitat preferences and foraging behaviour. Walruses, narwhals, belugas, bowhead whales, and polar bears were also assessed individually. The sensitivity of alcids to oil spills is well-documented (Mead and Baillie 1981; Piatt and Ford 1996), and thus thick-billed murre were selected to represent all seabird ESC subcomponents for this analysis. Zooplankton were assessed by proxy through the assessment on phytoplankton, as discussed in section 3.0. Spilled oil can disperse though the water column to the benthic environment and certain compounds from oil can remain within the substrate for years (Serrano et al. 2006; Yang et al. 2018); therefore, benthic invertebrates were assessed. Polynya habitat and sea ice were also assessed.

Table 5-78. Vessel Discharge − Large Spill: ESC Subcomponents and Priority Areas Assessed.

ESC Subcomponent	Priority Area or AOI	Assessed by Proxy
Kelp beds and other macroalgae	Chesterfield Inlet/Narrows	
Phytoplankton	Chesterfield Inlet/Narrows	
Zooplankton		Via phytoplankton
Benthic invertebrates	Chesterfield Inlet/Narrows	
Arctic cod	Fisher and Evans Straits	
Arctic Char	Duke of York Bay/White Island	
Other forage fish		Via Arctic cod
Thick-billed murre	Fisher and Evans Straits	
Other seabirds		Via thick-billed murre
Ringed seal	Fisher and Evans Straits	
Bearded seal	Fisher and Evans Straits	
Walrus	Fisher and Evans Straits	
Beluga	East Bay	
Narwhal	Repulse Bay/Frozen Strait	
Bowhead whale	Fisher and Evans Straits	
Polar bear	Fisher and Evans Straits	
Polynya habitat	Chesterfield Inlet/Narrows	
Sea ice	Roes Welcome Sound	

Risk Statement: If an interaction occurs involving kelp beds/other macroalgae and a large accidental spill of heavy fuel oil from a vessel the consequence could result in a negative impact on the ecosystem function of kelp bed/other macroalgae habitat in the Chesterfield Inlet/Narrows priority area

Table 5-79. Kelp beds and other macroalgae – Vessel Discharge (Chesterfield Inlet/Narrows) – Petroleum Product (Large Accidental Spill of Heavy Fuel Oil).

Risk Factor	Score	Rationale
Exposure	4 (binned)	Exposure = Intensity x Temporal x Spatial = 3 x 3 x 4 = 36 (raw score)
Intensity	3	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low absolute density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Chesterfield Inlet/Narrows priority area experiences a high density of vessel traffic relative to other portions of the AOI (see Figures 5-1 and 5-10) representing approximately 61% of total AIS data within the AOI from 2012-2019. As abiotic weathering (e.g., dispersion, evaporation) and bioremediation occurs slowly in cold/ice-covered seawater and oil spill clean-up measures are challenging to conduct in remote and/or ice-filled regions, a large, accidental spill of petroleum product from a vessel would persist in the environment (WWF n.d.; WSP 2014a; Garneau et al. 2016; Gomes et al. 2022). Although the number of large, vessel-source accidental petroleum product spills is expected to be low (WSP 2014a), the petroleum product would have a high persistence in the priority area; therefore, intensity was scored as 3.

Risk Factor	Score	Rationale
Temporal	3	Macroalgae are present in the Chesterfield Inlet/Narrows priority area year-round, though photosynthetic activity, important in advance of the growth phase which largely occurs under ice (Chapman and Lindley 1980), is restricted to the ice-free season. Vessels are typically present in the priority area during July to September, and occasionally during June (Maerospace 2020), though they may not be present throughout that entire period. There is an approximate temporal overlap of 33-50% between when vessels and macroalgae are present and a large, accidental vessel spill event is presumed possible any time vessels are present in the priority area. However, because oil would remain in the water beyond the initial accident, this could reasonably result in a large amount of overlap and a temporal score of 3.
Spatial	4	Spatial = Areal x Depth = 2 x 2 = 4
Areal	2	Macroalgae typically occurs in water depths between 5-50 m in the AOI, with higher densities at 10 and 15 m compared with 5 m (Krause-Jensen et al 2012; Filbee-Dexter et al. 2022). Spilled petroleum product from a large, accidental vessel discharge could be transported beyond the vessel's immediate location via water currents in open, ice-free areas or under the ice, but, due to low dispersion in the Arctic environment (Gomes et al. 2022), the greatest concentration of petroleum product would likely be localized, thereby overlapping a small portion of the macroalgal range in the priority area.
Depth	2	Macroalgae inhabit surficial seabed substrate. Petroleum product can sink with suspended particulate matter and/or may congeal into tar balls (Lee et al. 2015). Therefore, petroleum product from spills from a large, accidental vessel discharge could occur within the entire depth range for macroalgae in the priority area. However, petroleum products would be expected to attenuate with depth; thus, depth was scored as 2.
Sensitivity	3 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (2 + 2) x 2.0 = 8.0
Acute Change	2	The input of polycyclic aromatic hydrocarbons (PAHs) from petroleum product can cause substantial local pollution in the Arctic marine ecosystem (Szczybelski et al. 2016). Modelling for Arctic Norwegian regions indicate that macroalgae inhabiting sheltered and/or moderately exposed rocky shores near areas that have been overgrazed by urchins (urchin barrens) are the most sensitive to oil spill pollution (Christie et al. 2019). Seaweeds are covered in a mucilaginous film that provides some protection from petroleum product spills by repelling oil; however, they are vulnerable to smothering effects from large spills, particularly of heavy crude or fuel oils (Nelson-Smith 1982; Shata 2010). Smothering by petroleum products prevents light penetration and respiratory gas exchange necessary for macroalgal survival (Nelson-Smith 1982). By virtue of inhabiting deeper water than seaweeds, kelps are seldom coated with spilled oil but do absorb hydrocarbons from the water column (Shata 2010). Sublethal effects of spilled petroleum products on seaweeds and kelps may include leaf loss, colour changes, reduced reproduction/growth, and accumulation of hydrocarbons (Shata 2010). Laboratory studies of macroalgae in tanks observed an inhibition of reproduction by cell division when exposed to 0.01 ppm of crude and light fuel oils, and reduced photosynthesis at concentrations of ~0.02 ppm; however, effects in a natural environment are expected to be less severe (Nelson-Smith 1982). In clean water, seaweeds and kelps can cleanse themselves of hydrocarbons (Shata 2010). Experimental exposure of *Fucus distichus* tips to Grane, ANS, IFO30, and Marine Gasoil oil types revealed self-cleansing/oil removal half-times of 0.8-4.5 days; Grane oil generally inhibited photosynthesis while the other three oil types stimulated it (Wegeberg et al. 2020). Macroalgae sampled at 3 m depth following an experimental subsurface release of chemically dispersed oil off northern Baffin

Risk Factor	Score	Rationale
		Island did not exhibit negative effects on biomass, species diversity, or reproduction from oil in the sediment or water column; two (*Stictyosiphon tortilis* and *Pilayella littoralis*) of the three species analyzed did not experience any effects, while the third species (*Dictyosiphon foeniculaceus*) experienced increased growth during the year following release (Cross et al. 1987). *Laminaria saccharina* and *L.digitata* kelps did not experience any detectable negative effects following the 922-tonne spill of No. 2 fuel oil due to the 1989 grounding of the *World Prodigy* tanker off Rhode Island, USA; no necrotic or bleached tissues were observed and there were no significant differences in growth rates relative to previous years (Peckol et al. 1990). Depending on the macroalgal species, a measurable change to habitat function could occur, particularly if smothering were involved. This results in a score of 2.
Chronic Change	2	Biodegradation of petroleum products occurs slowly in cold water environments and is limited by nutrient availability, and dispersion and evaporation are slow processes in cold and icy seawater (Gomes et al. 2022). Chronic effects can result from a large heavy fuel oil spill given its persistence in the environment (Lee et al. 2015). Kelps experienced minimal effects from the large *Exxon Valdez* 1989 oil spill and recovery was swift; most kelp forest components fully recovered within two years or less (Dean and Jewett 2001; Steneck et al. 2002). Seven years after a 270,000-litre oil spill from the 1987 grounding of the *Nella Dan* at the sub-Antarctic Macquarie Island, there were no significant differences between oiled and unoiled intertidal sites, although holdfast macrofauna within heavily oiled sites showed only moderate recovery in species sensitive to oiling (Smith and Simpson 1998). However, there was little recovery at Secluded Bay, which had been moderately oiled; there, holdfasts contained sediment with traces of diesel oil (Smith and Simpson 1998). Kelp density increased for at least six years following the untreated spill of light fuel oils from the 1957 *Tampico* tanker stranding off California, USA due to a two-year-long decimation of grazers that would normally have controlled the kelp population (Nelson-Smith 1982). Grazers were similarly depleted following a crude oil spill from the 1967 *Torrey Canyon* tanker stranding on the coast of west Cornwall that was improperly treated with toxic cleansing mixtures, and within one to two months, green algae covered the rock substrate. The following year, the green algae were replaced by a dense cover of perennial brown fucoids. Recovery to the original ecosystem balance took six to seven years (Nelson-Smith 1982). Measurable changes to long-term viability of the habitat could be expected for macroalgae exposed to a large fuel oil spill. This results in a score of 2.
Recovery Factors	2.0	At least 19 species/taxonomic groups of macroalgae have been documented to occur within or near the AOI (DFO 2020; Loewen et al. 2020a, b; Filbee-Dexter et al. 2022). At least 8 species/taxonomic groups have been reported for the Chesterfield Inlet/Narrows priority area. Of these macroalgae, three kelp species, *Laminaria solidungula*, edible kelp and sugar kelp are among the most abundant in the AOI, creating extensive kelp forests reaching up to 3-4 m in height and spreading several kilometers from shore (DFO 2020; Loewen et al. 2020b; Filbee-Dexter et al. 2022). *L. solidungula* is an Arctic endemic species (Roleda 2016). Biomasses of up to 34 kg/m^2 were observed for these kelp forests in the AOI, the highest ever reported for the eastern Canadian Arctic (Filbee-Dexter et al. 2022). Other types of macroalgae also occur amongst these kelp species, including coralline encrusting algae, and are important to create the structural complexity beneficial to its inhabitants (Wharton and Mann 1981; Christie et al. 1998; Steen et al. 2016; Misiuk and Aitken 2020). Habitat recovery factors were used. Recovery factors = mean of the factors listed below.

Risk Factor	Score	Rationale
		Growth rate (biogenic)/rate of structural rebuilding (abiotic): 1 (Kelp sporophyte growth rates are high compared to other organisms [Mann 1973]). Resistance: 3 (Kelp can easily be disturbed physically, known to break apart during physical duress such as sample collection [Mundy 2020]. A change in ecosystem structure, such as an increase in urchin populations [e.g., Filbee-Dexter and Scheibling 2014] can lead to rapid and extensive defoliation of kelp). Regenerative potential: 2 (The regeneration of kelp forests after destructive events highly depends on the strength and duration of the event(s). Different clearing experiments in the northern Atlantic have shown that a full kelp regrowth can be observed after 1-3 years when environmental pressures are removed (Scheibling 1986; Christie et al. 1998; Steen et al. 2016). However, fully grown kelp forests also host a great variety of understorey algae along with many fish and invertebrates, that can take over 5 years to recolonize the habitat (Wharton and Mann 1981; Christie et al. 1998; Steen et al. 2016). In the Arctic, many authors have concurred that coastal recovery processes should be much slower than in temperate waters (Dunton et al. 1982; Conlan 2005; Keck et al. 2020). Several experiments and measurements done in the Beaufort Sea's Boulder Patch have shown that following a major disturbance on the site, it could take more than a decade for the sessile community, including kelp, to fully recover (Konar 2013; Bonsell and Dunton 2021). External stress: 2 (Climate change and warming waters add to stress [e.g., Filbee-Dexter et al. 2020]).
Consequence	4 (binned)	Consequence = Exposure x Sensitivity = 4 x 3 = High
Likelihood	1	Due to the robust oil spill prevention regime in this country, based on existing oil spill response frameworks and standards (WWF n.d.) and historical spill records, the probability of a large, accidental vessel discharge of petroleum product is very low in Canada (WSP 2014b; Lee et al. 2015). Though data are limited for Arctic waters, a fuel oil spill of 990 m^3 is estimated to occur every 920 years, with larger spill volumes occurring more rarely (WSP 2014a). Thus, an oil spill of this nature is expected to occur in only exceptional circumstances.
Overall Risk	Moderately-High Risk	Management measures, such as the development of an oil spill response plan that includes a macroalgae sampling and monitoring program, should be considered.
Uncertainty		
Exposure	4	General vessel traffic patterns are known and were used to inform vessel discharge exposure parameters. Macroalgal documentation in the priority area is limited (e.g., DFO 2020; Loewen et al. 2020a, b), although macroalgae and coastal kelp beds have been identified near the mouth of Chesterfield Inlet and it is known that the Western Hudson Bay Coastline EBSA features dense coastal kelp beds and macroalgae (DFO 2020). Spill modelling should be conducted for the Chesterfield Inlet/Narrows priority area to better understand the fate of petroleum product release via vessel discharge during different times of year.
Sensitivity	4	Relatively little scientific information exists for the response of Arctic macroalgae to petroleum product exposure in their natural environments; most of the available literature features temperate locales/species or laboratory studies. Life history information is generally limited for macroalgae species that occur in/near the priority area.
Likelihood	4	Large oil spill return period estimates exist for the Canadian Arctic, including the study area, though uncertainty remains due to a lack of historic spill data.

Risk Statement: If an interaction occurs involving phytoplankton and a large accidental spill of heavy fuel oil from a vessel the consequence could result in a negative impact on phytoplankton populations in the Chesterfield Inlet/Narrows priority area.

Table 5-80. Phytoplankton – Vessel Discharge (Chesterfield Inlet/Narrows) – Petroleum Product (Large Accidental Spill of Heavy Fuel Oil).

Risk Factor	Score	Rationale
Exposure	4 (binned)	Exposure = Intensity x Temporal x Spatial = 3 x 4 x 4 = 48 (raw score)
Intensity	3	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low absolute density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Chesterfield Inlet/Narrows priority area experiences a high density of vessel traffic relative to other portions of the AOI (see Figures 5-1 and 5-10) representing approximately 61% of total AIS data within the AOI from 2012-2019. As abiotic weathering (e.g., dispersion, evaporation) and bioremediation occurs slowly in cold/ice-covered seawater and oil spill clean-up measures are challenging to conduct in remote and/or ice-filled regions, a large, accidental spill of petroleum product from a vessel would persist in the environment (WWF n.d.; WSP 2014a; Garneau et al. 2016; Gomes et al. 2022). Although the number of large, vessel-source accidental petroleum product spills is expected to be low (WSP 2014a), the petroleum product would have a high persistence in the priority area; therefore, intensity was scored as 3.
Temporal	4	Phytoplankton may occur in the Chesterfield Inlet/Narrows priority area year-round; however, phytoplankton abundance/density is significantly greater during open-water periods and the spring bloom relative to other times of year (Matthes et al. 2021). Matthes et al. (2021) found that the highly abundant sub ice diatom, *Melosira artica*, plays an important role in local production. The area that encompasses the mouth of the Chesterfield Inlet/Narrows priority area is part of the northwestern polynya of the Hudson Bay that has been known to be the largest contributor to annual production in Hudson Bay (Matthes et al. 2021). Vessels are typically present in the priority area during July to September, and occasionally during June (Maerospace 2020), though they may not be present throughout that entire period. For the purposes of this risk assessment, a large, accidental vessel spill event is presumed possible any time vessels are present. As oil would remain in the water beyond the initial accident, this could reasonably result in complete overlap during the spring bloom and a temporal score of 4.
Spatial	4	Spatial = Areal x Depth = 2 x 2 = 4
Areal	2	Phytoplankton are expected to be distributed throughout the Chesterfield Inlet/Narrows priority area, though localized areas of higher density are likely. Spilled petroleum product from a large, accidental vessel discharge could be transported beyond the vessel's immediate location via water currents, winds, and river flow, but, due to low dispersion in the Arctic environment (Gomes et al. 2022), the greatest concentration of petroleum product would likely be localized,

Risk Factor	Score	Rationale
		thereby overlapping a small portion of the phytoplankton range in the priority area. This results in a score of 2.
Depth	2	Phytoplankton are limited to the euphotic zone, which is generally limited to the upper ~200 m of open marine water in sub-tropical regions (WHOI 2022) but is restricted to the upper approximately 50 m in Hudson Bay (Matthes et al. 2021). Water depths in the Chesterfield Inlet/Narrows priority area are ≤100 m (see Figure 2-3). Petroleum product can sink with suspended particulate matter and/or may congeal into tar balls (Lee et al. 2015). Therefore, petroleum product from spills from a large, accidental vessel discharge could occur within the entire depth range for phytoplankton in the priority area. However, petroleum products would be expected to attenuate with depth; thus, depth was scored as 2.
Sensitivity	2 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (2 + 2) x 1.5 = 6.0
Acute Change	2	The input of PAHs from petroleum product can cause substantial local pollution in the Arctic marine ecosystem (Szczybelski et al. 2016). Following a release of petroleum product into Arctic seawater, the concentrations of semi-volatile compounds can be at least temporarily increased near the release site due to low rates of evaporation at low temperatures and sea ice presence (Gomes et al. 2022). Some phytoplankton species are resistant to acute exposure to oil spills while others are more sensitive and experience declines in abundance (e.g., Brussaard et al. 2016). Experimental exposure of phytoplankton that were isolated and cultured from the southern Beaufort Sea to crude oils (10 mg/L of Atkinson Point, Norman Wells, Pembina, or Venezuela) in a laboratory setting for ten days resulted in differing impacts on mortality between species. Following an initial moderate reduction in survival for the first two days of exposure, the green flagellate *Chlamydomonas pulsatilla* recovered to near initial levels, while the diatoms *Chaetoceros septentrionalis*, *Navicula bahusiensis*, and *Nitzschia delicatissima* all experienced increased mortality with no indication of recovery (Hsiao 1978). Marine Arctic phytoplankton experimentally and acutely exposed to three concentrations (total hydrocarbon contents of 0.07 mg/L, 0.28 mg/L, 0.55 mg/L) of the water accommodated fraction (WAF) of heavy fuel oil experienced decreased biomass-specific primary production by 6%, 52%, and 73% for the three WAF concentrations, respectively; phototoxic effects of exposing the WAF to sunlight also reduced primary production in the two higher WAF concentration treatments by 71% and 91%, respectively (Lemcke et al. 2018). Some phytoplankton species are capable of utilizing petroleum hydrocarbons as a carbon source (AMAP 2010). Adams (1975) conducted small, experimental spills (64 m^3) of Norman Wells and Swan Hills crude oils into areas under the ice in Balaena Bay, Northwest Territories and although the spills resulted in lower light levels below ice containing entrapped oil, primary productivity was somewhat enhanced near the oil. The abundance and diversity of phytoplankton was also slightly increased (Adams 1975). During October 1977, the grounding of the tanker *Tsesis* in the Baltic Sea caused a spill of ~1,100 t of fuel oil (mostly No.5), of which ~600-700 t were recovered and ~400 t remained in the environment; acute exposure resulted in an increase in phytoplankton primary production and biomass (Linden et al. 1979; Johansson et al. 1980). When dissolved oil from the spill reached the shoreline two to five days after the grounding (with a concentration of 50-60 µg/L), the phytoplankton community composition remained unchanged and continued to predominantly consist of microflagellates (Johansson et al. 1980). Phytoplankton blooms were also observed following the 1979 IXTOG-I and 2010 *Deepwater Horizon* well blowout oil spills in the Gulf of Mexico and the 2011 Bohai Sea spill (Quigg et al. 2021). The Bohai Sea bloom occurred within two weeks of the spill (Tang et al. 2019). Out of 21 oil spills around the world examined by Tang et al. (2019),

Risk Factor	Score	Rationale
		phytoplankton blooms were observed for 14 spills, with 11 of these blooms occurring within 3-10 months post-spill. Conversely, coastal photosynthetic efficiency was negatively correlated with oil concentrations following exposure to oil and dispersed oil in the short-term after the *Deepwater Horizon* spill (Quigg et al. 2021). Depending on the phytoplankton taxa, a measurable change to mortality rates against background variability could occur following a large accidental discharge of heavy fuel oil. This results in a score of 2.
Chronic Change	2	Biodegradation of petroleum products occurs slowly in cold water environments and is limited by nutrient availability, and dispersion and evaporation are slow processes in cold/icy seawater (Gomes et al. 2022). Chronic effects can result from a large heavy fuel oil spill given its persistence in the environment (Lee et al. 2015). An oil spill in Arctic waters could cause community composition changes to favour phytoplankton species more tolerant of petroleum products. There is also some indication that the presence of crude oil may alter water chemical compositions and marine food web interactions such that increases in phytoplankton growth and biomass are promoted (Ozhan et al. 2014). Dinoflagellates and green algae tend to be more tolerant of exposure to petroleum products, while cyanobacteria are generally more sensitive, and diatoms vary in robustness (Buskey et al. 2016; Quigg et al. 2021). Hsiao (1978) observed higher growth inhibition from experimental exposure to crude oils at colder temperatures for the diatom *C. septentrionalis* and lower inhibition for the diatoms *N. bahusiensis* and *N. delicatissima* and the green flagellate *C. pulsatilla*. Primary productivity can change following exposure to petroleum products. Long-term exposure experiments (70 days) to oil products (concentrations of 0.05-0.5 mg/L) resulted in a 50% decrease in production by marine phytoplankton (Patin 1999 *in* AMAP 2010). The *Deepwater Horizon* oil spill in the Gulf of Mexico in 2010 appeared to enhance the growth of some phytoplankton species while proving toxic to others, and the level of tolerance to oil and dispersants varied between species (Ozhan et al. 2014). Although there was wide spatial variability in phytoplankton taxa diversity, taxa dominance, and overall responses to the *Deepwater Horizon* spill (likely due to a combination of factors, such as habitat type, location, riverine and other environmental influences, circulation, and oil exposure), there were no significant changes to the phytoplankton community (Quigg et al. 2021). There were limited effects on phytoplankton following the heavy fuel oil spill caused by the *Full City* wreck off Norway during July 2009 and no long-term affects on abundance or species composition (Fritt-Rasmussen et al. 2018). Depending on the phytoplankton taxa, measurable changes to overall fitness relative to background variability and/or changes to population dynamics could be expected for phytoplankton exposed to a large, accidental discharge of heavy fuel oil. This results in a score of 2.
Recovery Factors	1.5	Recovery Factors = mean of the factors listed below. Growth rate (biogenic)/rate of structural rebuilding (abiotic): 1 (A phytoplankton bloom can develop rapidly when irradiance conditions are favourable and last until growth becomes limited by factors such as nutrient supply. Increased irradiance due to snow melt during June 2014 allowed phytoplankton under ice cover in Arctic waters of the Beaufort Sea/Barrow Canyon/Hanna Shoal to experience a bloom within approximately one week, with increased growth rates continuing for nearly two weeks before being halted by nutrient limitation [Hill et al. 2018]). Resistance: 1 (As the base of the marine food chain, phytoplankton are subject to regular biological disturbance in the form of predation by herbivorous grazers. During a spring bloom in 2011, phytoplankton communities in Disko Bay, West Greenland were observed to experience high mortality [up to 0.58 d^{-1}] from herbivorous predators [Menden-Deuer et al. 2018]. In polar waters, phytoplankton biomass appears to experience more intense fluctuations due to natural factors,

Risk Factor	Score	Rationale
		such as temperature changes, than to continual grazing losses [Menden-Deuer et al. 2018]. Regenerative potential: 2 (Phytoplankton communities go through seasonal succession in terms of species composition/biomass and they also adapt to seasonally changing environmental conditions, particularly temperature, light, and/or nutrients [e.g., Lewis et al. 2019]. Arctic phytoplankton from West Greenland experienced significantly greater growth rates at higher temperatures during short-term temperature change incubation experiments and did not exhibit any growth rate limitations at low temperatures [Menden-Deuer et al. 2018]. Arctic phytoplankton are adapted to function in even extreme low-light conditions; during 2017-2019, net phytoplankton growth occurred under complete ice cover as early as February in Baffin Bay, which is ice-covered during seven months of the year [Randelhoff et al. 2020]. Such adaptations would compensate for biota loss from disturbance at discrete locations). External Stress: 2 (Climate change is a major stressor for primary producers in the Arctic, as loss of snow cover and/or ice results in drastic increases in the transmission of surface irradiance to the water column which can quickly trigger phytoplankton growth [Hill et al. 2018] and may shift community composition towards taxa more tolerant of increased light levels. Thinning Arctic ice has increased the occurrence of favourable conditions for the formation of under-ice phytoplankton blooms [Hill et al. 2018]. Recent studies indicate that Arctic phytoplankton growth can now sustainably begin underneath seasonal ice cover, in some instances as deep as 100 km from the ice edge [Hill et al. 2018]).
Consequence	3 (binned)	Consequence = Exposure x Sensitivity = 4 x 2 = Moderate
Likelihood	1	Due to the robust oil spill prevention regime in this country, based on existing oil spill response frameworks and standards (WWF n.d.) and historical spill records, the probability of a large, accidental vessel discharge of petroleum product is very low in Canada (WSP 2014b; Lee et al. 2015). Though data are limited for Arctic waters, a fuel oil spill of 990 m^3 is estimated to occur every 920 years, with larger spill volumes occurring more rarely (WSP 2014a). Thus, an oil spill of this nature is expected to occur in only exceptional circumstances.
Overall Risk	Moderate Risk	Additional management measures should be considered, such as the development of an oil spill response plan that includes a phytoplankton sampling and monitoring program.
Uncertainty		
Exposure	4	General vessel traffic patterns are known and were used to inform vessel discharge exposure parameters. Primary productivity and the phytoplankton community have recently been studied and there are pockets of high primary productivity in Repulse Bay and Frozen Strait, Roes Welcome Sound, and Chesterfield Inlet (Matthes et al. 2021; Kitching 2022). Spill modelling should be conducted for the priority area to better understand the fate of petroleum product release via vessel discharge during different times of year.
Sensitivity	4	There is a large amount of scientific literature available regarding the response of phytoplankton to petroleum products, with studies ranging from Arctic species/environments (although not the Chesterfield Inlet/Narrows priority area or AOI) to subtropical habitats and laboratory settings (e.g., AMAP 2010; Quigg et al. 2021). However, uncertainty exists.
Likelihood	4	Large oil spill return period estimates exist for the Canadian Arctic, including the study area, though uncertainty remains due to a lack of historic spill data.

Risk Statement: If an interaction occurs involving benthic invertebrates and a large accidental spill of heavy fuel oil from a vessel the consequence could result in a negative impact on benthic invertebrate populations in the Chesterfield Inlet/Narrows priority area.

Table 5-81. Benthic Invertebrates – Vessel Discharge (Chesterfield Inlet/Narrows) – Petroleum Product (Large Accidental Spill of Heavy Fuel Oil).

Risk Factor	Score	Rationale
Exposure	4 (binned)	Exposure = Intensity x Temporal x Spatial = 3 x 3 x 4 = 36 (raw score)
Intensity	3	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low absolute density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Chesterfield Inlet/Narrows priority area experiences a high density of vessel traffic relative to other portions of the AOI (see Figures 5-1 and 5-10) representing approximately 61% of total AIS data within the AOI from 2012-2019. As abiotic weathering (e.g., dispersion, evaporation) and bioremediation occurs slowly in cold/ice-covered seawater and oil spill clean-up measures are challenging to conduct in remote and/or ice-filled regions, a large, accidental spill of petroleum product from a vessel would persist in the environment (WWF n.d.; WSP 2014a; Garneau et al. 2016; Gomes et al. 2022). Although the number of large, vessel-source accidental petroleum product spills is expected to be low (WSP 2014a), the petroleum product would have a high persistence in the priority area; therefore, intensity was scored as 3.
Temporal	3	Benthic invertebrates are present in the Chesterfield Inlet/Narrows priority area year-round. Vessels are typically present in the priority area during July to September, and occasionally during June (Maerospace 2020), though they may not be present throughout that entire period. For the purposes of this risk assessment, a large, accidental vessel spill event is presumed possible any time vessels are present. As oil would remain in the water beyond the initial accident, this could reasonably result in a large amount of overlap when benthic invertebrates are present and a temporal score of 3.
Spatial	4	Spatial = Areal x Depth = 2 x 2 = 4
Areal	2	Benthic invertebrates are anticipated to occur throughout the Chesterfield Inlet/Narrows priority area. Spilled petroleum product from a large, accidental vessel discharge could be transported beyond the vessel's immediate location via water currents in open, ice-free areas or under the ice, but, due to low dispersion in the Arctic environment (Gomes et al. 2022), the greatest concentration of petroleum product would be localized, thereby overlapping a small portion of the total benthic invertebrate range in the priority area. This results in a score of 2.
Depth	2	Benthic invertebrates inhabit the seabed. Petroleum product from a large spill would occur at the water surface but could disperse into the water column, sink with suspended particulate matter, and/or congeal into tar balls that may sink (Lee et al. 2015). Therefore, petroleum product from spills from a large, accidental vessel discharge could occur within the entire depth range for benthic

Risk Factor	Score	Rationale
		invertebrates in the Chesterfield Inlet/Narrows priority area. However, petroleum products would be expected to attenuate with depth; thus, depth was scored as 2.
Sensitivity	4 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (2 + 2) x 2.3 = 9.2
Acute Change	2	The input of PAHs from petroleum product can cause substantial local pollution in the Arctic marine ecosystem (Szczybelski et al. 2016). The release of petroleum product may directly impact benthic invertebrates via contact with product that sinks to the seabed or indirectly through the consumption of sunken, contaminated algae/phytoplankton and zooplankton by benthic organisms (Szczybelski et al. 2016). Little is known regarding the impacts of petroleum product release on deep-sea corals (Ragnarsson et al. 2016) and much of the current research on coral susceptibility to oil spills has been opportunistic sampling following the *Deepwater Horizon* event in 2010. The unprecedented volume of oil, amounting to a major oil spill daily for 87 days, the use of chemical dispersants, and the subsea location of the spill all contributed to increase the exposure of oil to corals. Cold-water corals are sessile, fragile, slow-growing organisms that are susceptible to anthropogenic disturbance (Girard et al. 2018; Montagna and Girard 2020). It is known that some species of coral can sense and react to oil. For example, exposure to sub-lethal concentrations caused polyps to contract partially after two days and completely after four to five days, remaining shut for the remainder of the experiment (Ducklow and Mitchell 1979). The authors suggested possible inhibition of feeding behaviour although normal polyp activity resumed upon removal from oiled water (Ducklow and Mitchell 1979). It is also known that they are more susceptible to smothering from oil compounds than mobile benthic biota (Elmgren et al. 1983; DHNRDAT 2016). During the *Deepwater Horizon* spill, deep-water corals at several sites in the Gulf of Mexico experienced stress induced by the release of oil and oil dispersants following the blowout, including partial tissue loss, excessive mucus production, retracted polyps, petroleum residue on the branches, and/or death (Ragnarsson et al. 2016). Several months after the blowout, corals were observed to have lost >20% of their tissue and were subject to heavy hydroid colonization on bare skeleton patches (Ragnarsson et al. 2016). Three to four months after the well was capped, White et al. (2012) observed tissue loss in 86% of coral colonies 11 km from the well site; an impacted coral community was also discovered 22 km from the well site, although the effects were less severe (Fisher et al. 2014). Deep-sea corals may experience increased growth rates to compensate for damage received from an oil spill, although this may occur at a cost of energy diversion from other activities, such as reproduction (Girard et al. 2019). Laboratory experiments examining energy use/allocation of Arctic benthic invertebrates observed decreased cellular energy allocation and increased energy consumption by the amphipod *Gammarus setosus* upon exposure to water-accommodated fraction of crude oil, but no change in the energy budget of the bivalve *Liocyma fluctuosa* (Olsen et al. 2007). The differences in responses were likely due to differences in feeding/burrowing behaviour and species-specific sensitivity to petroleum products (Olsen et al. 2007). A measurable change to mortality rates against background variability would be expected for benthic invertebrate species intolerant of petroleum products, resulting in a score of 2.
Chronic Change	2	Biodegradation of petroleum products occurs slowly in cold water environments and is limited by nutrient availability, and dispersion and evaporation are slow processes in cold and icy seawater (Gomes et al. 2022). Chronic effects can result from a large heavy fuel oil spill given its persistence in the environment (Lee et al. 2015). Due to low rates of natural attenuation in cold marine ecosystems, petroleum products can persist in benthic sediments for over 20 years (Tomasino et al. 2021). Much of the current research on coral susceptibility to oil spills has

Risk Factor	Score	Rationale
		been opportunistic sampling following the *Deepwater Horizon* event in 2010. The unprecedented volume of oil, amounting to a major oil spill daily for 87 days, the use of chemical dispersants, and the subsea location of the spill all contributed to increase the exposure of oil to corals. Coral recovery was low following the 2010 *Deepwater Horizon* blowout in the Gulf of Mexico; several months after the blowout, corals were observed to have lost >20% of their tissue and were subject to heavy hydroid colonization on bare skeleton patches (Ragnarsson et al. 2016). Three to four months after the well was capped, White et al. (2012) observed tissue loss in 86% of coral colonies 11 km from the well site; an impacted coral community was also discovered 22 km from the well site, although the effects were less severe (Fisher et al. 2014). During 17 months of post-spill observations, visible signs of spill impacts on the coral communities diminished over time (Hsing et al. 2013), although coral tissues and branch loss continued to be significantly negatively affected at some impacted sites seven years after the spill (Girard and Fisher 2018). Coral regeneration is a complex combination of intrinsic (e.g., coral size and age) and extrinsic (e.g., food availability) factors and it is suggested that negative impacts to growth and sexual reproduction can affect long-term community viability (Henry and Hart 2005). There is evidence that lightly impacted coral colonies can recover completely in approximately 1.5 years (Hsing et al. 2013). Additionally, Girard and authors (2019) found that more heavily impacted corals demonstrated higher growth rates; it was suggested that growth was compensatory for damage sustained and may have diverted energy from other activities, such as reproduction. Importantly, although growth rates were not affected negatively at most sites following *Deepwater Horizon*, acute branch loss resulted in an overall decrease of coral tissue. Models of long-term recovery concluded that most colonies would appear completely healthy after a decade, though with a cumulative biomass loss of 3-14% (Girard et al. 2018). Recovery of heavily impacted colonies to the point that all tissue appeared healthy was estimated to take 37 years, though by that time only 17% of initial coral biomass would remain. Measurable changes to overall fitness relative to background variability and/or changes to population dynamics could be expected for benthic invertebrates exposed to a large fuel oil spill, resulting in a score of 2.
Recovery Factors	2.3	At least 430 benthic invertebrate species have been identified within or near the AOI, including corals (e.g., the soft coral *Gersemia rubiformis*), sponges, sea stars, brittle stars, sea urchins, bivalves, cephalopods, crinoids, gastropods, holothuroids (sea cucumbers), hydrozoans, amphipods, cumaceans, decapods, euphausiids, isopods, Leptostracans, ostracods, sea spiders, polychaetes, barnacles, and chitons (DFO 2020; Loewen et al. 2020a, b). Corals and sponges are the most sensitive benthic invertebrate groups identified for the priority area and were used for the determination of Recovery Factors. There have been limited benthic invertebrate studies for the Chesterfield Inlet/Narrows priority area (e.g., GN 2010; Misiuk and Aitken 2020; Pierrejean et al. 2020). Recovery factors = mean of the factors listed below. Fecundity: 1 (*Geodia phlegraei* sponges from the North Atlantic were observed to produce ~16 million oocytes/sponge and ~30 billion spermatozoa/sponge [Koutsouveli et al. 2020]. It is currently unknown whether *Geodia* sponges occur in the AOI, but the information presented here may be generally used for the Porifera Phylum reported for the AOI). Early life stage mortality: 3 (During four years of observations in water depths >650 m in the Gulf of Maine, the deep-water gorgonian coral *Primnoa resedaeformis* experienced high mortality during its early benthic stage, possibly due to biological disturbance, such as by suspension-feeding brittle stars, and

Risk Factor	Score	Rationale
		limited food supply [Lacharité and Metaxas 2013]. Larvae of the cold-water coral *Lophelia pertusa* had an average survival rate of 60% during three months of laboratory observations and a maximum longevity of one year [Strömberg and Larsson 2017]. Although neither of these species have been reported for the AOI (Loewen et al. 2020a), their habitat conditions may be considered analogous to those of the AOI and the information presented here is applied in a precautionary manner for species within the AOI, for which no specific early life stage mortality information could be found). Recruitment pattern: 2 (Of two deep-water gorgonian corals observed in the Gulf of Maine, the broadcast spawner *P. resedaeformis* had high recruit abundance while the brooder spawner *Paragorgia arborea* had few recruits [Lacharité and Metaxas 2013]. The life span and rates of asexual and sexual reproduction in the soft coral *G. rubiformis* are unknown; however, asexual reproduction can be stimulated by physical disturbance [Henry et al. 2003; Iken et al. 2012]. The lifespan of *Geodia* spp. sponges is unknown, but they are likely to be slow growing [Last et al. 2019]. Although the corals *P. resedaeformis* and *P. arborea* and *Geodia* sponges have not been reported for the AOI, the information provided here has been applied for the AOI, for which no specific information could be found). Natural mortality rate: Unknown; excluded from consideration. Age at maturity: Unknown (DFO 2015b); excluded from consideration. Life stages affected: 3 (All life stages are expected to be affected). Population connectivity: Unknown; excluded from consideration. Population status: Unknown (The population size of the soft coral *G. rubiformis* is unknown [Boutillier et al. 2019] and corals/sponges are not considered under Sara or COSEWIC); excluded from consideration.
Consequence	5 (binned)	Consequence = Exposure x Sensitivity = 4 x 4 = Very High
Likelihood	1	Due to the robust oil spill prevention regime in this country, based on existing oil spill response frameworks and standards (WWF n.d.) and historical spill records, the probability of a large, accidental vessel discharge of petroleum product is very low in Canada (WSP 2014b; Lee et al. 2015). Though data are limited for Arctic waters, a fuel oil spill of 990 m^3 is estimated to occur every 920 years, with larger spill volumes occurring more rarely (WSP 2014a). Thus, an oil spill of this nature is expected to occur in only exceptional circumstances.
Overall Risk	Moderately-High Risk	Management measures, such as the development of an oil spill response plan that includes a benthic invertebrate sampling and monitoring program, should be considered.
Uncertainty		
Exposure	5	General vessel traffic patterns are known and were used to inform vessel discharge exposure parameters. The distribution of benthic invertebrates, particularly sensitive taxonomic groups like corals and sponges, is poorly studied. Spill modelling should be conducted for the priority area to better understand the fate of petroleum product release via vessel discharge during different times of year.
Sensitivity	5	There is a large amount of scientific literature available regarding the response of benthic invertebrates to petroleum products, with studies ranging from Arctic species/environments (although not the Chesterfield Inlet/Narrows priority area or AOI) to subtropical habitats and laboratory settings. Life history information is generally limited for sensitive benthic invertebrate species that may occur within the priority area. Uncertainty is very high.

Risk Factor	Score	Rationale
Likelihood	4	Large oil spill return period estimates exist for the Canadian Arctic, including the study area, though uncertainty remains due to a lack of historic spill data.

Risk Statement: If an interaction occurs involving Arctic cod and a large accidental spill of heavy fuel oil from a vessel the consequence could result in a negative impact on Arctic cod populations in the Fisher and Evans Straits priority area.

Table 5-82. Arctic cod – Vessel Discharge (Fisher and Evans Straits) – Petroleum Product (Large Accidental Spill of Heavy Fuel Oil).

Risk Factor	Score	Rationale
Exposure	4 (binned)	Exposure = Intensity x Temporal x Spatial (Depth x Areal) = 3 x 3 x 4 = 36 (raw score)
Intensity	3	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low absolute density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Fisher and Evans Straits priority area experiences a higher density of vessel traffic relative to other priority areas except Chesterfield Inlet/Narrows (see Figures 5-1 and 5-10), representing approximately 9.5% of total AIS data within the AOI from 2012-2019. As abiotic weathering (e.g., dispersion, evaporation) and bioremediation occurs slowly in cold/ice-covered seawater and oil spill clean-up measures are challenging to conduct in remote and/or ice-filled regions, a large, accidental spill of petroleum product from a vessel would persist in the environment (WWF n.d.; WSP 2014a; Garneau et al. 2016; Gomes et al. 2022). Although the number of large, vessel-source accidental petroleum product spills is expected to be low (WSP 2014a), the petroleum product would have a high persistence in the priority area; therefore, intensity was scored as 3.
Temporal	3	Arctic cod are expected to occur in the priority area year-round. Vessels are typically present in the priority area during July to October, and very occasionally during June and November (Maerospace 2020), though they may not be present throughout that entire period. There is an approximate temporal overlap of 50% between when vessels and Arctic cod are present in the priority area. For the purposes of this risk assessment, a large, accidental vessel spill event is presumed possible any time vessels are present in the priority area. Because oil would remain in the water beyond the initial accident, this could reasonably result in a large amount of overlap and a temporal score of 3.
Spatial	4	Spatial = Areal x Depth = 2 x 2 = 4
Areal	2	A ubiquitous species, Arctic cod occupy coastal and offshore waters in areas with and without sea ice and are expected to be widespread throughout the Arctic Ocean (Coad and Reist 2018). Based on Loewen et al. (2020a), most records for Arctic cod within the AOI are for Evans Strait though Loewen et al. (2020b) also noted the occurrence of Arctic cod around small islands in Fisher Strait. Based on available AIS data, vessel activity (see Figures 5-1 and 5-10) is typically focused

Risk Factor	Score	Rationale
		along two primary paths that occur north and south of Coats Island. Petroleum product from a large, accidental discharge could be transported beyond the vessel's immediate location via water currents in open, ice-free areas or under the ice, but, due to low dispersion in the Arctic environment (Gomes et al. 2022), the greatest concentration of petroleum product would be localized, thereby overlapping a small portion of the total Arctic cod range in the Fisher and Evans Straits priority area. This results in a score of 2.
Depth	2	Arctic cod are widespread across the circumpolar Arctic, but they occur at different depths throughout the water column based on factors such as life history stage (e.g., Geoffroy et al. 2016), seasonal diet (e.g., Majewski et al. 2016), and light regime (e.g., Benoit et al. 2010). Eggs and larvae concentrate under the sea ice. Petroleum product from a large spill would occur at the water surface but could disperse into the water column, can sink with suspended particulate matter, and/or may congeal into tar balls that may sink (Lee et al. 2015). Therefore, some oil could occur within the entire depth range for pelagic biota in the priority area but would be expected to attenuate with depth, resulting in a depth score of 2.
Sensitivity	3 (binned)	Sensitivity = (Acute change + Chronic Change) x Recovery Factors = (2+2) x 1.9 = 7.6
Acute Change	2	Following a release of petroleum product into Arctic seawater, the concentrations of semi-volatile compounds can be at least temporarily increased near the release site due to low rates of evaporation at low temperatures and sea ice presence (Gomes et al. 2022). Under the ice, buoyant petroleum product components can accumulate in high concentrations and be subject to photo enhanced toxicity (Lee et al. 2015). Hydrocarbon spills can have short- and long-term negative impacts on the environment (Suchanek 1993; USFWS 2010), including on fish (Peterson et al. 2003; Bender et al. 2021). Fish may feed on contaminated organisms or they may experience direct toxic effects (US FWS 2010). Plankton and planktonic larval stages of fish and invertebrates are very sensitive to the toxicological effects of oil (Hutchinson et al. 1998). Lee et al. (2015) reported that fish are at risk of acute toxic effects from oil within 24- to 48-hours after a spill, but fish kills are typically localized as adults are mobile and generally able to leave the area. No Arctic cod mortality occurred during a 48-hour experimental exposure to burned oil residue, mechanically dispersed oil, or chemically dispersed oil (Camus 2017). Laurel et al. (2019) found that Arctic cod embryos and larvae that were briefly (i.e., for 3 days) exposed to oil exhibited acute toxic effects. Some embryos died before hatching and some individuals that survived were smaller and had jaw and heart malformations. Pink salmon (*Oncorhynchus gorbuscha*) eggs experienced mortality during the *Exxon Valdez* spill in Alaska (Rice et al. 2001). Similar effects as demonstrated in the preceding two examples could be expected in the younger life stages of other fish species as well. Considering the information above, a measurable change to fish mortality rates against background variability would be expected, resulting in a score of 2.
Chronic Change	2	Biodegradation of petroleum products occurs slowly in cold water environments and is limited by nutrient availability, and dispersion and evaporation are slow processes in cold and icy seawater (Gomes et al. 2022; WWF n.d.). Chronic effects can result from a large heavy fuel oil spill given its persistence in the environment (Lee et al. 2015). Hydrocarbon spills can have long-term negative impacts on fish (Peterson et al. 2003). Exposure to oil can affect fish feeding behaviour and efficiency, disease resistance, growth, reproduction, and survival (Bue et al. 1998; Peterson et al. 2003; Thorne and Thomas 2008; Lee et al. 2015). Camus (2017) experimentally exposed wild Arctic cod to burned oil residue, mechanically dispersed oil, or chemically dispersed oil for 48 hours; during the month following exposure, growth rates were significantly lower for cod exposed to the burned oil residue relative to those exposed to chemically

Risk Factor	Score	Rationale
		dispersed oil, but there were no other significant growth differences during that time or for the remaining five months of the study. The exposure to burnt oil residue resulted in the interruption of egg yolk formation in female fish, though there were no significant differences between treatment and control groups for female oocyte development or male testis development (Camus 2017). Laurel et al. (2019) found that brief (3-day) oil exposure caused acute toxic effects in embryos and larvae of Arctic cod, with some embryos dying before hatching when exposure was medium or high. Additionally, individuals were smaller and had jaw and heart malformation, and experienced delayed mortality due to impaired blood flow and the inability to feed; similar negative effects can reasonably be expected in embryonic/larval life stages of other species as well. Fish that were exposed to low oil concentrations were also smaller and showed critical delayed impacts; they were not able to effectively process and store fat. Pink salmon eggs and larvae experienced mortality and reduced growth rate, respectively, during the *Exxon Valdez* spill in Alaska (Rice et al. 2001). These effects were following long-term exposure to low concentrations of weathered crude oil. Growth rate among migrating fry was reduced, and the population decreased via size-dependent mortality (Rice et al. 2001). Thus, a heavy fuel oil spill could result in a measurable change to overall fitness of fish, including Arctic cod, compared with background variability, resulting in a score of 2.
Recovery Factors	1.9	Recovery factors = mean of the factors listed below. Fecundity: 2 (Spawn only once in their lifetime with a relatively low number of eggs; between 9,000 to 21,000 eggs are produced, with an average of 11,900 per female [Cohen et al. 1990]). Early life stage mortality: 3 (R-selected species with high mortality [Coad and Reist 2018]). Recruitment pattern: 2 (Increased recruitment expected with climate change [LeBlanc et al. 2019]). Natural mortality rate: 1 (Mortality is high [Coad and Reist 2018]). Age at maturity: 2 (2-3 years for males and 3-4 years for females [Coad and Reist 2018]). Life stages affected: 3 (All life stages could potentially occur in the area). Population connectivity: 1 (Arctic cod range widely throughout the Arctic). Population status: 1 (IUCN classification is *least concern* [Fernandes et al. 2015], but population trend is unknown. Abundant in Arctic marine waters [Coad and Reist 2018]).
Consequence	4 (binned)	Consequence = Exposure x Sensitivity = 4 x 3 = High
Likelihood	1	Due to the robust oil spill prevention regime in this country, based on existing oil spill response frameworks and standards (WWF n.d.) and historical spill records, the probability of a large, accidental vessel discharge of petroleum product is very low in Canada (WSP 2014b; Lee et al. 2015). Though data are limited for Arctic waters, a fuel oil spill of 990 m^3 is estimated to occur every 920 years, with larger spill volumes occurring more rarely (WSP 2014a). Thus, an oil spill of this nature is expected to occur in only exceptional circumstances.
Overall Risk	Moderately-High Risk	Management measures, such as the development of an oil spill response plan that includes a fish sampling program, should be considered.
Uncertainty		
Exposure	5	General vessel traffic patterns are known and were used to inform vessel discharge exposure parameters. General information exists regarding the distribution of Arctic cod, as well as some information specific to the priority area, though it is limited. Spill modelling should be conducted for the priority area to

Risk Factor	Score	Rationale
		better understand the fate of petroleum product release via vessel discharge during different times of year.
Sensitivity	4	There is a large amount of scientific literature available regarding the response of fishes to petroleum products, with studies ranging from Arctic species/environments (including on Arctic cod) to subtropical habitats and laboratory settings. Uncertainty is high.
Likelihood	4	Large oil spill return period estimates exist for the Canadian Arctic, including the study area, though uncertainty remains due to a lack of historic spill data.

Risk Statement: If an interaction occurs involving Arctic char and a large accidental spill of heavy fuel oil from a vessel the consequence could result in a negative impact on Arctic char populations in the Duke of York Bay/White Island priority area.

Table 5-83. Arctic Char – Vessel Discharge (Duke of York Bay/White Island) – Petroleum Product (Large Accidental Spill of Heavy Fuel Oil).

Risk Factor	Score	Rationale
Exposure	5 (binned)	Exposure = Intensity x Temporal x Spatial = 3 x 4 x 9 = 108 (raw score)
Intensity	3	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low absolute density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Duke of York Bay/White Island priority area experiences a low density of vessel traffic relative to other portions of the AOI (see Figures 5-1 and 5-10) representing approximately 1% of total AIS data within the AOI from 2012-2019. As abiotic weathering (e.g., dispersion, evaporation) and bioremediation occurs slowly in cold/ice-covered seawater and oil spill clean-up measures are challenging to conduct in remote and/or ice-filled regions, a large, accidental spill of petroleum product from a vessel would persist in the environment (WWF n.d.; WSP 2014a; Garneau et al. 2016; Gomes et al. 2022). Although the number of large, vessel-source accidental petroleum product spills is expected to be low (WSP 2014a), the petroleum product would have a high persistence in the priority area; therefore, intensity was scored as 3.
Temporal	4	Arctic char primarily occur in coastal waters during summer (June-August). Vessels are typically present in the priority area during October, and occasionally during August and September (Maerospace 2020), though they are not present throughout that entire period. For the purposes of this risk assessment, a large, accidental vessel spill event is presumed possible any time vessels are present in the Duke of York Bay/White Bay priority area, and the oil would remain in the water beyond the initial accident. This could reasonably result in complete overlap with the time Arctic char are in the priority area and a temporal score of 4.
Spatial	9	Spatial = Areal x Depth = 3 x 3 = 9

Risk Factor	Score	Rationale
Areal	3	Arctic char are expected to occur in the coastal waters of the Duke of York Bay/White Island priority area (GN 2012; Idlout 2020; Loewen et al. 2020a, b), generally within 1,500 m from shore (Moore et al. 2016). Vessels typically travel a consistent path to the east and north of White Island (Figure 5-1). Spilled petroleum product from a large, accidental vessel discharge could be transported beyond the vessel's immediate location via water currents in open, ice-free areas or under the ice, but, due to low dispersion in the Arctic environment (Gomes et al. 2022), the greatest concentration of petroleum product would be localized; however it is still possible that a large oil spill would overlap a large portion of Arctic char habitat in the priority area, resulting in a score of 3.
Depth	3	Arctic char are distributed in shallow coastal waters. Petroleum product from a large spill would occur at the water surface but could disperse into the water column, sink with suspended particulate matter, and/or congeal into tar balls that may sink (Lee et al. 2015). As the waters where char are present are shallow, it is expected that oil would occur throughout the entire depth range of Arctic char in the priority area, resulting in a score of 3.
Sensitivity	4 (binned)	Sensitivity = (Acute change + Chronic Change) x Recovery Factors = (2+2) x 2.5 = 10.0
Acute Change	2	Following a release of petroleum product into Arctic seawater, the concentrations of semi-volatile compounds can be at least temporarily increased near the release site due to low rates of evaporation at low temperatures and sea ice presence (Gomes et al. 2022). Under the ice, buoyant petroleum product components can accumulate in high concentrations and be subject to photo-enhanced toxicity (Lee et al. 2015). Oil spills can have short- and long-term negative impacts on the environment (Suchanek 1993; US FWS 2010), including on fish (Peterson et al. 2003; Bender et al. 2021). Fish may feed on contaminated organisms, or they may experience direct toxic effects (USFWS 2010). Plankton and planktonic larval stages of fish and invertebrates are very sensitive to the toxicological effects of oil (Hutchinson et al. 1998). Lee et al. (2015) reported that fish are at risk of acute toxic effects from oil within 24-48 hours after a spill, but fish kills are typically localized as adults are mobile and generally able to leave the area. Laurel et al. (2019) found that Arctic cod embryos and larvae that were briefly (i.e., for 3 days) exposed to oil exhibited acute toxic effects. Some embryos died before hatching and some individuals that survived were smaller and had jaw and heart malformations. Pink salmon eggs experienced mortality during the *Exxon Valdez* spill in Alaska (Rice et al. 2001). Similar effects as demonstrated in the preceding two examples could be expected in the younger life stages of other fish species as well. A measurable change to fish mortality rates against background variability would be expected, resulting in a score of 2.
Chronic Change	2	Biodegradation of petroleum products occurs slowly in cold water environments and is limited by nutrient availability, and dispersion and evaporation are slow processes in cold and icy seawater (Gomes et al. 2022; WWF n.d.). Chronic effects can result from a large heavy fuel oil spill given its persistence in the environment (Lee et al. 2015). Hydrocarbon spills can have long-term negative impacts on fish (Peterson et al. 2003). Exposure to oil can affect fish feeding behaviour and efficiency, disease resistance, growth, reproduction, and survival (Bue et al. 1998; Peterson et al. 2003; Thorne and Thomas 2008; Lee et al. 2015). Camus (2017) experimentally exposed wild Arctic cod to burned oil residue, mechanically dispersed oil, or chemically dispersed oil for 48 hours; during the month following exposure, growth rates were significantly lower for cod exposed to the burned oil residue relative to those exposed to chemically dispersed oil, but there were no other significant growth differences during that time or for the remaining five months of the study. The exposure to burnt oil residue resulted in the interruption of egg yolk formation in female fish, though

Risk Factor	Score	Rationale
		there were no significant differences between treatment and control groups for female oocyte development or male testis development (Camus 2017). Laurel et al. (2019) found that brief (3-day) oil exposure caused acute toxic effects in embryos and larvae of Arctic cod, with some embryos dying before hatching when exposure was medium or high. Additionally, individuals were smaller and had jaw and heart malformation, and experienced delayed mortality due to impaired blood flow and the inability to feed; similar negative effects can reasonably be expected in embryonic/larval life stages of other species as well. Fish that were exposed to low oil concentrations were also smaller and showed critical delayed impacts; they were not able to effectively process and store fat. Pink salmon eggs and larvae experienced mortality and reduced growth rate, respectively, during the *Exxon Valdez* spill in Alaska (Rice et al. 2001). These effects were following long-term exposure to low concentrations of weathered crude oil. Growth rate among migrating fry was reduced, and the population decreased via size-dependent mortality (Rice et al. 2001). Thus, a heavy fuel oil spill could result in a measurable change to overall fitness of fish, including Arctic char, compared with background variability, resulting in a score of 2.
Recovery Factors	2.5	Recovery factors = mean of the factors listed below. Fecundity: 2 (Fecundity declines with latitude, but Arctic char spawn several times throughout their life [Coad and Reist 2018]). Early life stage mortality: 3 (High mortality likely associated with environmental factors, as well as density-dependent factors [Coad and Reist 2018]). Recruitment pattern: 2 (Anadromous Arctic char are not as long lived as lake-dwelling populations but may live 20+ years and spawn multiple times throughout their lives [Coad and Reist 2018]). Natural mortality rate: 2 (Mean annual mortality for Canadian anadromous populations is 30-45%, for age classes 6-15 years [Coad and Reist 2018]). Age at maturity: 3 (Age at maturity is 3-10 years [Coad and Reist 2018]). Life stages affected: 3 (All stages). Population connectivity: 3 (Discrete stocks/populations occur in rivers and lakes [Coad and Reist 2018]). Population status: 2 (IUCN classification is *least concern* [Freyhof and Kottelat 2008], but many discrete stocks exist, and the population trends are unknown).
Consequence	5 (binned)	Consequence = Exposure x Sensitivity = 5 x 4 = Very High
Likelihood	1	Due to the robust oil spill prevention regime in this country, based on existing oil spill response frameworks and standards (WWF n.d.) and historical spill records, the probability of a large, accidental vessel discharge of petroleum product is very low in Canada (WSP 2014b; Lee et al. 2015). Though data are limited for Arctic waters, a fuel oil spill of 990 m^3 is estimated to occur every 920 years, with larger spill volumes occurring more rarely (WSP 2014a). Thus, an oil spill of this nature is expected to occur in only exceptional circumstances.
Overall Risk	Moderately-High Risk	Management measures, such as the development of an oil spill response plan that includes a fish sampling program, should be considered.
Uncertainty		
Exposure	4	General vessel traffic patterns are known and were used to inform vessel discharge exposure parameters. General information exists regarding the distribution of Arctic char, though specific information for the priority area is limited. Spill modelling should be conducted for the priority area to better understand the fate of petroleum product release via vessel discharge during different times of year.

Risk Factor	Score	Rationale
Sensitivity	4	There is a large amount of scientific literature available regarding the response of fishes to petroleum products, with studies ranging from Arctic species/environments to subtropical habitats and laboratory settings (including salmonids), though little is known for Arctic char specifically. Uncertainty is high.
Likelihood	4	Large oil spill return period estimates exist for the Canadian Arctic, including the study area, though uncertainty remains due to a lack of historic spill data.

Risk Statement: If an interaction occurs between thick-billed murres and large, accidental spill of heavy fuel oil from a vessel the consequences could result in a negative impact on the thick-billed murre population in the Fisher and Evans Straits priority area.

Table 5-84. Thick-billed murre – Vessel Discharge (Fisher and Evans Straits) – Petroleum Product (Large Accidental Spill of Heavy Fuel Oil).

Risk Factor	Score	Rationale
Exposure	5 (binned)	Exposure = Intensity x Temporal x Spatial = 3 x 4 x 6 = 72 (raw score)
Intensity	3	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Fisher and Evans Straits priority area experiences a higher density of vessel traffic relative to other priority areas except Chesterfield Inlet/Narrows (see Figures 5-1 and 5-10), representing 9.5% of total AIS data within the AOI from 2012-2019. As abiotic weathering (e.g., dispersion, evaporation) and bioremediation occurs slowly in cold/ice-covered seawater and oil spill clean-up measures are challenging to conduct in remote and/or ice-filled regions, a large, accidental spill of petroleum product from a vessel would persist in the environment (WWF n.d.; WSP 2014a; Garneau et al. 2016; Gomes et al. 2022). Although the number of large, vessel-source accidental petroleum product spills is expected to be low (WSP 2014a), the petroleum product would have a high persistence in the priority area; therefore, intensity was scored as 3.
Temporal	4	Thick-billed murres are present in the Fisher and Evans Straits priority area from mid-May to October (Patterson et al. 2021). Murres would be present at the nesting cliffs on Coats Island from mid-May to through July. Foraging adults capable of flight would be present at sea from June to July and in October, whereas chicks and flightless adults would be present at sea from August to September. Vessels are typically present in the priority area during July to October, and very occasionally during June and November (Maerospace 2020), though they may not be present during that entire period. For the purposes of this risk assessment, it is presumed that a large, accidental vessel-source spill is possible any time vessels are present in the study area and that the oil would remain in the water beyond the initial accident. This could reasonably result in complete overlap with the time seabirds are in the area and a temporal score of 4.
Spatial	6	Spatial = Areal x Depth = 2 x 3 = 6

Risk Factor	Score	Rationale
Areal	2	Thick-billed murre distribution in the study area would primarily be open water areas and the nesting cliffs on the north coast of Coats Island west of Cape Pembroke (Latour et al. 2008; Mallory et al. 2019). Murres nesting at these colonies forage primarily within Fisher and Evans Straits (Brisson-Curadeau and Elliott 2019; Patterson et al. 2022). Based on available AIS data, vessel activity (see Figures 5-1 and 5-10) is typically focused along two primary paths that occur north and south of Coats Island. Petroleum product from a large, accidental vessel discharge could be transported beyond the vessel's immediate location via water currents in open, ice-free areas or under the ice, but, due to low dispersion in the Arctic environment (Gomes et al. 2022), the greatest concentration of petroleum product would be localized, thereby overlapping a small portion of the total thick-billed murre range in the Fisher and Evans Straits priority area. This results in a score of 2.
Depth	3	Thick-billed murres at sea spend much of their time on or under the surface and undertake deep foraging dives in the water column (Gaston and Hipfner 2020). Depending on the product, spill volume, and environmental conditions, oil can remain in a slick or sheen at the water surface for a prolonged period of time and also disperse deeper into the water column (Lee et al. 2015). Considering the interaction at the water surface and that this species would be forced to pass through a slick at some point before or after a dive results in a depth score of 3.
Sensitivity	4 (binned)	Sensitivity = (Acute Change + Chronic Change) X Recovery Factors = (2+2) x 2.4 = 9.6
Acute Change	2	Petroleum spills have a strong potential for negative effects on seabirds, especially species that spend most of their time on water, like thick-billed murres, and this interaction has been well-studied (Irons et al. 2000; Wiese and Robertson 2004; Lieske et al. 2019; Gaston and Hipfner 2020). These effects include hypothermia and drowning caused by plumage contamination and lethal or sub-lethal toxicity caused by ingestion of the petroleum product during preening or feeding. Such spills cause increased mortality rates, physiological impairment (anemia), damage to internal organs, reduced flight efficiency, and reduced reproductive success (Morandin and O'Hara 2016; Bursian et al. 2017; Maggini et al. 2017a,b,c; Burger 2018; Matcott et al. 2019). A large number of individuals could come into contact with a large heavy fuel oil spill driven by wind. This would result in a measurable change to thick-billed murre mortality rates against background variability in the Fisher and Evans Straits priority area. A score of 2 was assigned.
Chronic Change	2	Biodegradation of petroleum products occurs slowly in cold water environments and is limited by nutrient availability, and dispersion and evaporation are slow processes in cold and icy seawater (Gomes et al. 2022). Chronic effects can result from a large heavy fuel oil spill given its persistence in the environment (Lee et al. 2015). Petroleum spills may cause chronic effects on seabirds such as physiological impairment, damaged internal organs, and reduced reproductive success, which in turn may result in chronic population declines (Esler et al. 2002; Wiese and Robertson 2004; Montevecchi et al. 2012; Morandin and O'Hara 2016). In addition, hydrocarbons may persist in the priority area for years, causing repeated exposure to thick-billed murres (e.g., Esler et al. 2010). Consequently, such a spill may have a measurable change on overall fitness and population dynamics compared with background variation, resulting in a score of 2.
Recovery Factors	2.4	Recovery factors = mean of the factors listed below. Fecundity: 2 (One egg laid per year [Gaston and Hipfner 2020]). Early life stage mortality**:** 3 (63-76% before breeding age [Gaston and Hipfner 2020]).

Risk Factor	Score	Rationale
		Recruitment pattern: 3 (Attempted breeding: 3-year olds: 0-2%; 4-year olds: 7-16%; 5-year olds: 0-31% [Noble et al. 1991]). Natural mortality rate: 3 (14% [Gaston et al. 1994]). Age at maturity: 3 (5.7 years [Gaston and Hipfner 2020]). Life stages affected: 3 (All life stages could potentially occur in the priority area [Gaston 2002]). Population connectivity: 1 (Very little genetic population structuring [Tigano et al. 2017]). Population status: 1 (Thick-billed murre is listed as *least concern* by IUCN [BirdLife International 2018b] and is not listed under SARA or COSEWIC).
Consequence	5 (binned)	Consequence = Exposure x Sensitivity = 5 x 4 = Very High
Likelihood	1	Due to the robust oil spill prevention regime in this country, based on existing oil spill response frameworks and standards (WWF n.d.) and historical spill records, the probability of a large, accidental vessel discharge of petroleum product is very low in Canada (WSP 2014b; Lee et al. 2015). Though data are limited for Arctic waters, a fuel oil spill of 990 m^3 is estimated to occur every 920 years, with larger spill volumes occurring more rarely (WSP 2014a). Thus, an oil spill of this nature is expected to occur in only exceptional circumstances.
Overall Risk	Moderately-High Risk	Management measures, such as the development of an oil spill response plan that includes a fish sampling program, should be considered.
Uncertainty		
Exposure	3	There is a moderate amount of scientific information available regarding the abundance and distribution of thick-billed murres in the Fisher and Evans Straits priority area. General vessel traffic patterns are known and were used to inform vessel discharge exposure parameters. Spill modelling should be conducted for the priority area to better understand the fate of petroleum product release via vessel discharge during different times of year.
Sensitivity	2	There is substantial scientific information on sensitivity of thick-billed murres to the negative effects of a large oil spill (Irons et al. 2000; Wiese and Robertson 2004; Lieske et al. 2019; Gaston and Hipfner 2020).
Likelihood	4	Large oil spill return period estimates exist for the Canadian Arctic, including the study area, though uncertainty remains due to a lack of historic spill data.

Risk Statement: If an interaction occurs involving ringed seals and a large accidental spill of heavy fuel oil from a vessel the consequence could result in a negative impact on the ringed seal population in the Fisher and Evans Straits priority area.

Table 5-85. Ringed Seal – Vessel Discharge (Fisher and Evans Straits) – Petroleum Product (Large Accidental Spill of Heavy Fuel Oil).

Risk Factor	Score	Rationale
Exposure	4 (binned)	Exposure = Intensity x Temporal x Spatial = 3 x 3 x 6 = 54 (raw score)
Intensity	3	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel

Risk Factor	Score	Rationale
		traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Fisher and Evans Straits priority area experiences a higher density of vessel traffic relative to other priority areas except Chesterfield Inlet/Narrows (see Figures 5-1 and 5-10), representing 9.5% of total AIS data within the AOI from 2012-2019. As abiotic weathering (e.g., dispersion, evaporation) and bioremediation occurs slowly in cold/ice-covered seawater and oil spill clean-up measures are challenging to conduct in remote and/or ice-filled regions, a large, accidental spill of petroleum product from a vessel would persist in the environment (WWF n.d.; WSP 2014a; Garneau et al. 2016; Gomes et al. 2022). Although the number of large, vessel-source accidental petroleum product spills is expected to be low (WSP 2014a), the petroleum product would have a high persistence in the priority area; therefore, intensity was scored as 3.
Temporal	3	Ringed seals are expected to occur in the priority area year-round. Vessels are typically present in the priority area during July to October, and very occasionally during June and November (Maerospace 2020), though they are not present during that entire period. There is an approximate temporal overlap of 33-50% between when vessels and ringed seals are present and for the purposes of this risk assessment, a large, accidental vessel spill event is presumed possible any time vessels are present in the priority area. However, because oil would remain in the water beyond the initial accident, this could reasonably result in a large amount of overlap and a temporal score of 3.
Spatial	6	Spatial = Areal x Depth = 2 x 3 = 6
Areal	2	Ringed seal are expected to occur throughout the priority area. Based on available AIS data, vessel activity (see Figures 5-1 and 5-10) is typically focused along two primary paths that occur north and south of Coats Island. Oil from a large, accidental vessel-source spill could be transported beyond the vessel's immediate location via water currents in open, ice-free areas or under the ice, but, due to low dispersion in the Arctic environment (Gomes et al. 2022), the greatest concentration of oil would be localized, thereby overlapping a small portion of the total ringed seal range in the Fisher and Evans Straits priority area. This results in a score of 2.
Depth	3	Ringed seals may be found throughout the water column (maximum dive depth for ringed seals is >500 m; Ogloff et al. 2021). Petroleum product from a large spill would occur at the water surface but could disperse into the water column, can sink with suspended particulate matter, and/or may congeal into tar balls that may sink (Lee et al. 2015). Although oil is expected to attenuate with depth, considering the interaction at the water surface and that this species would be forced to pass through a slick at some point before or after a dive results in a depth score of 3.
Sensitivity	4 (binned)	Sensitivity = (Acute Change + Chronic Change) X Recovery Factors = (2+2) × 2.3 = 9.2
Acute Change	2	Following a release of petroleum product into Arctic seawater, the concentrations of semi-volatile compounds can be at least temporarily increased near the release site due to low rates of evaporation at low temperatures and sea ice presence (Gomes et al. 2022). Under the ice, buoyant petroleum product components can accumulate in high concentrations and be subject to photo-enhanced toxicity (Lee et al. 2015). Oil has little effect on thermoregulation in seals since pinnipeds rely on a subcutaneous layer of blubber for insulation (Geraci 1990). The exception is seal pups that have not yet developed insulating blubber (Kooyman et al. 1976 in Helm et al. 2015); mortality has been reported in seals fouled with oil, particularly in seal pups in colder waters who have yet to develop adequate blubber (St. Aubin

Risk Factor	Score	Rationale
		1990). Heavily fouled seals can experience reduced locomotion and drowning (Davis and Anderson 1976; Sergeant 1991). Harbour seals observed immediately after oiling appeared lethargic and disoriented, a response that may be attributed to lesions observed in the thalamus of the brain (Spraker et al. 1994). Seals may ingest oil by consuming contaminated prey or by nursing contaminated milk. Once ingested, oil absorbed into the tissues can result in minor kidney, liver, or brain lesions (Geraci and Smith 1976; Spraker et al. 1994). A measurable change to ringed seal mortality rates against background variability and possible behavioural changes would be expected, resulting in a score of 2.
Chronic Change	2	Biodegradation of petroleum products occurs slowly in cold water environments and is limited by nutrient availability, and dispersion and evaporation are slow processes in cold and icy seawater (Gomes et al. 2022). Chronic effects can result from a large heavy fuel oil spill given its persistence in the environment (Lee et al. 2015). Exposure of seals to oil can result in conjunctivitis (Spraker et al. 1994), corneal abrasion and swollen nictitating membranes, or permanent eye damage (St. Aubin 1990) and therefore reduced foraging ability (Levenson and Schusterman 1997) which may affect a population over the long-term. Spraker et al. (1994) found lesions characteristic of hydrocarbon toxicity in the brains of oiled seals collected several months after the *Exxon Valdez* spill. Given that oil exposure can result in mortality (especially to seal pups) which may affect population structure (Davis and Anderson 1976; St. Aubin 1990; Sergeant 1991; Kooyman et al. 1976 in Helm et al. 2015), and there may be long-term effects on the reproductive capacity of adults (Helm et al. 2015), there could be a measurable change to overall fitness relative to background variability for ringed seals exposed to a large, heavy fuel oil spill, resulting in a score of 2.
Recovery Factors	2.3	Recovery factors = mean of the factors listed below. Fecundity: 3 (Females typically give birth to one pup a year) Early life stage mortality: 2 (Reeves et al. 1992). Recruitment pattern: 2 (Recruitment is variable depending on prevailing environmental conditions [Ferguson et al. 2005; Stirling 2005; Chambellant et al. 2010]). Natural mortality rate: 3 (Mortality rates have been reported low in adult ringed seals with survivorship of 0.89 for age 6+ seals. Survivorship of age 0+ seals is reported to be much lower [0.59] [Smith 1975; Reimer et al. 2019]). Age at maturity: 3 (Best estimate of the population-wide average age at maturity is 4-7 years old [in most areas; can range from 3-9; see COSEWIC 2019]). Life stages affected: 3 (All stages). Population connectivity: 1 (Ringed seals in the Canadian Arctic are known to move extensively to different arctic regions, regularly making annual journeys that are 1,000s of kilometers). Population status: 1 (Ringed seals are considered s*pecial concern* by COSEWIC (2019) and are not listed under SARA. The COSEWIC report does not offer insight into population trend. Ringed seals are listed as *threatened* in the USA (related to potential habitat loss), *least concern* in Greenland, no listing in Russia, and *least concern* by IUCN.)
Consequence	5 (binned)	Consequence = Exposure x Sensitivity = 4 x 4 = Very High
Likelihood	1	Due to the robust oil spill prevention regime in this country, based on existing oil spill response frameworks and standards (WWF n.d.) and historical spill records, the probability of a large, accidental vessel discharge of petroleum product is very low in Canada (WSP 2014b; Lee et al. 2015). Though data are limited for Arctic waters, a fuel oil spill of 990 m^3 is estimated to occur every 920 years, with larger

Risk Factor	Score	Rationale
		spill volumes occurring more rarely (WSP 2014a). Thus, an oil spill of this nature is expected to occur in only exceptional circumstances.
Overall Risk	Moderately-High Risk	Management measures, such as the development of an oil spill response plan that includes a marine mammal monitoring program, should be considered.
Uncertainty		
Exposure	5	Some information exists on the general distribution of ringed seals, including in the priority area. General vessel traffic patterns are known and were used to inform vessel discharge exposure parameters. Spill modelling should be conducted for the priority area to better understand the fate of a large, accidental petroleum product release via vessel discharge during different times of year.
Sensitivity	4	Certain aspects of ringed seal biology have been reported in other areas of the Arctic, and there is some literature on the effects of oil exposure on seals. There is uncertainty if ringed seals would avoid a spill.
Likelihood	4	Large oil spill return period estimates exist for the Canadian Arctic, including the study area, though uncertainty remains due to a lack of historic spill data.

Risk Statement: If an interaction occurs involving bearded seals and a large accidental spill of heavy fuel oil from a vessel the consequence could result in a negative impact on the bearded seal population in the Fisher and Evans Straits priority area.

Table 5-86. Bearded Seal – Vessel Discharge (Fisher and Evans Straits) – Petroleum Product (Large Accidental Spill of Heavy Fuel Oil).

Risk Factor	Score	Rationale
Exposure	4 (binned)	Exposure = Intensity x Temporal x Spatial = 3 x 3 x 6 = 54 (raw score)
Intensity	3	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Fisher and Evans Straits priority area experiences a higher density of vessel traffic relative to other priority areas except Chesterfield Inlet/Narrows (see Figures 5-1 and 5-10), representing 9.5% of total AIS data within the AOI from 2012-2019. As abiotic weathering (e.g., dispersion, evaporation) and bioremediation occurs slowly in cold/ice-covered seawater and oil spill clean-up measures are challenging to conduct in remote and/or ice-filled regions, a large, accidental spill of petroleum product from a vessel would persist in the environment (WWF n.d.; WSP 2014a; Garneau et al. 2016; Gomes et al. 2022). Although the number of large, vessel-source accidental petroleum product spills is expected to be low (WSP 2014a), the petroleum product would have a high persistence in the priority area; therefore, intensity was scored as 3.
Temporal	3	Bearded seals are expected to occur in the priority area year-round. Vessels are typically present in the priority area during July to October, and very occasionally during June and November (Maerospace 2020), though they are not present during that entire period. There is an approximate temporal overlap of 33-50% between when vessels and bearded seals are present and for the purposes of this risk assessment, a large, accidental vessel spill event is presumed possible any

Risk Factor	Score	Rationale
		time vessels are present in the priority area. However, because oil would remain in the water beyond the initial accident, this could reasonably result in a large amount of overlap and a temporal score of 3.
Spatial	6	Spatial = Areal x Depth = 2 x 3 = 6
Areal	2	Bearded seal are expected to occur throughout the priority area. Based on available AIS data, vessel activity (see Figures 5-1 and 5-10) is typically focused along two primary paths that occur north and south of Coats Island. Oil from a large vessel-source spill could be transported beyond the vessel's immediate location via water currents in open, ice-free areas or under the ice, but, due to low dispersion in the Arctic environment (Gomes et al. 2022), the greatest concentration of petroleum product would be localized, thereby overlapping a small portion of the total bearded seal range in the Fisher and Evans Straits priority area. This results in a score of 2.
Depth	3	Foraging bearded seals typically dive to depths of <100 m, up to about 500 m (NOAA 2022a). Oil from a large spill would occur at the water surface but could disperse into the water column, can sink with suspended particulate matter, and/or may congeal into tar balls that may sink (Lee et al. 2015). Although oil is expected to attenuate with depth, considering the interaction at the water surface and that this species would be forced to pass through a slick at some point before or after a dive results in a depth score of 3.
Sensitivity	4 (binned)	Sensitivity = (Acute Change + Chronic Change) X Recovery Factors = (2+2) × 2.4 = 9.6
Acute Change	2	Following a release of petroleum product into Arctic seawater, the concentrations of semi-volatile compounds can be at least temporarily increased near the release site due to low rates of evaporation at low temperatures and sea ice presence (Gomes et al. 2022). Under the ice, buoyant petroleum product components can accumulate in high concentrations and be subject to photo-enhanced toxicity (Lee et al. 2015). Oil has little effect on thermoregulation in seals since pinnipeds rely on a subcutaneous layer of blubber for insulation (Geraci 1990). The exception is seal pups that have not yet developed insulating blubber (Kooyman et al. 1976 in Helm et al. 2015); mortality has been reported in seals fouled with oil, particularly in seal pups in colder waters who have yet to develop adequate blubber (St. Aubin 1990). Heavily fouled seals can experience reduced locomotion and drowning (Davis and Anderson 1976; Sergeant 1991). Harbour seals observed immediately after oiling appeared lethargic and disoriented, a response that may be attributed to lesions observed in the thalamus of the brain (Spraker et al. 1994). Seals may ingest oil by consuming contaminated prey or by nursing contaminated milk. Once ingested, oil absorbed into the tissues can result in minor kidney, liver, or brain lesions (Geraci and Smith 1976; Spraker et al. 1994). A measurable change to bearded seal mortality rates against background variability and possible behavioural changes may occur. This results in a score of 2.
Chronic Change	2	Biodegradation of petroleum products occurs slowly in cold water environments and is limited by nutrient availability, and dispersion and evaporation are slow processes in cold and icy seawater (Gomes et al. 2022). Chronic effects can result from a large heavy fuel oil spill given its persistence in the environment (Lee et al. 2015). Exposure of seals to oil can result in conjunctivitis (Spraker et al. 1994), corneal abrasion and swollen nictitating membranes, or permanent eye damage (St. Aubin 1990) and therefore reduced foraging ability (Levenson and Schusterman 1997) which may affect a population over the long-term. Spraker et al. (1994) found lesions characteristic of hydrocarbon toxicity in the brains of oiled seals collected several months after the *Exxon Valdez* spill. Given that oil exposure can result in mortality (especially to seal pups) which may affect

Risk Factor	Score	Rationale
		population structure (Davis and Anderson 1976; St. Aubin 1990; Sergeant 1991; Kooyman et al. 1976 in Helm et al. 2015), and there may be long-term effects on the reproductive capacity of adults (Helm et al. 2015), there could be a measurable change to overall fitness relative to background variability for bearded seals exposed to a large, heavy fuel oil spill, resulting in a score of 2.
Recovery Factors	2.4	Recovery factors = mean of the factors listed below. Fecundity: 3 (Females typically give birth to one pup a year). Early life stage mortality: 2 (Mortality could increase in the future as climate change affects the amount and suitability of ice required for important life functions [pupping, nursing; Reeves et al. 1992]). Recruitment pattern: Unknown; excluded from analysis. Natural mortality rate: Unknown; excluded from analysis. Age at maturity: 3 (In general, bearded seals attain sexual maturity at 5-6 years old for females and 6-7 for males [Cameron et al. 2010; Kovacs 2016]; however, some females in the Arctic have been found to attain sexual maturity between 3-7 years of age [Andersen et al. 1999]). Life stages affected: 3 (All stages may be affected). Population connectivity: Unknown; excluded from analysis (It is unknown if bearded seals in the AOI remain there year-round or undertake seasonal movements in and out of the region). Population status: 1 (Bearded seals are considered *data deficient* by COSEWIC [2021] and are not listed under SARA. Bearded seals are listed as *threatened* in the USA [related to potential habitat loss], *not threatened* in Greenland, and *least concern* by IUCN).
Consequence	5 (binned)	Consequence = Exposure x Sensitivity = 4 x 4 = Very High
Likelihood	1	Due to the robust oil spill prevention regime in this country, based on existing oil spill response frameworks and standards (WWF n.d.) and historical spill records, the probability of a large, accidental vessel discharge of petroleum product is very low in Canada (WSP 2014b; Lee et al. 2015). Though data are limited for Arctic waters, a fuel oil spill of 990 m^3 is estimated to occur every 920 years, with larger spill volumes occurring more rarely (WSP 2014a). Thus, an oil spill of this nature is expected to occur in only exceptional circumstances.
Overall Risk	Moderately-High Risk	Management measures, such as the development of an oil spill response plan that includes a marine mammal monitoring program, should be considered.
Uncertainty		
Exposure	5	Some information exists on the general distribution of bearded seals, including in the priority area. General vessel traffic patterns are known and were used to inform vessel discharge exposure parameters. Spill modelling should be conducted for the priority area to better understand the fate of a large, accidental petroleum product release via vessel discharge during different times of year.
Sensitivity	4	Certain aspects of bearded seal biology have been reported in other areas of the Arctic, and there is some literature on the effects of oil exposure on seals. There is uncertainty if bearded seals would avoid a spill.
Likelihood	4	Large oil spill return period estimates exist for the Canadian Arctic, including the study area, though uncertainty remains due to a lack of historic spill data.

Risk Statement: If an interaction occurs involving walruses and a large accidental spill of heavy fuel oil from a vessel the consequence could result in a negative impact on the walrus population in the Fisher and Evans Straits priority area.

Table 5-87. Walrus – Vessel Discharge (Fisher and Evans Straits) – Petroleum Product (Large Accidental Spill of Heavy Fuel Oil).

Risk Factor	Score	Rationale
Exposure	5 (binned)	Exposure = Intensity x Temporal x Spatial = 3 x 3 x 9 = 81 (raw score)
Intensity	3	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Fisher and Evans Straits priority area experiences a higher density of vessel traffic relative to other priority areas except Chesterfield Inlet/Narrows (see Figures 5-1 and 5-10), representing 9.5% of total AIS data within the AOI from 2012-2019. As abiotic weathering (e.g., dispersion, evaporation) and bioremediation occurs slowly in cold/ice-covered seawater and oil spill clean-up measures are challenging to conduct in remote and/or ice-filled regions, a large, accidental spill of petroleum product from a vessel would persist in the environment (WWF n.d.; WSP 2014a; Garneau et al. 2016; Gomes et al. 2022). Although the number of large, vessel-source accidental petroleum product spills is expected to be low (WSP 2014a), the petroleum product would have a high persistence in the priority area; therefore, intensity was scored as 3.
Temporal	3	Based on scientific studies and current Inuit Qaujimajatuqangit walruses occur in the Fisher and Evans Straits priority area year-round (Idlout 2020; Loewen et al. 2020b). Vessels are typically present in the priority area during July to October, and very occasionally during June and November (Maerospace 2020), though they may not be present during that entire period. For the purposes of this risk assessment, a large, accidental vessel spill event is presumed possible any time vessels are present in the priority area. However, because oil would remain in the water beyond the initial accident, this could reasonably result in a large amount of overlap with walrus occurrence and a temporal score of 3.
Spatial	9	Spatial = Areal x Depth = 3 x 3 = 9
Areal	3	Walruses are relatively sedentary in summer (Stewart 2008), tending to remain in areas where their food is most abundant and in water less than 80 m deep (Fay 1982; Reeves et al. 2002; Dehn et al. 2007; Lowry 2016a; COSEWIC 2017). The priority area provides walrus foraging habitat, calving areas, and key terrestrial haul-out sites (on Walrus, Bencas, and Coats Islands). During winter, walruses occur off the floe edge along the south and east coasts of Southampton Island and in late spring and summer, walruses use the floating pack ice of Evans Strait (Loewen et al. 2020b). Based on available AIS data, vessel activity (see Figures 5-1 and 5-10) is typically focused along two primary paths that occur north and south of Coats Island. A large fuel oil spill could be transported beyond the vessel's immediate location via water currents in open, ice-free areas or under the ice, but, due to low dispersion in the Arctic environment (Gomes et al. 2022), the greatest concentration of petroleum product would be localized; however, it is still possible that a large portion of the total walrus range in the priority area (particularly haul-outs) may be affected resulting in a score of 3.

Risk Factor	Score	Rationale
Depth	3	Walruses spend time on the water surface and undertake foraging dives up to 200m deep (Fay 1982; COSEWIC 2017). Depending on the product, spill volume, and environmental conditions, oil can remain in a slick or sheen at the water surface for a prolonged period of time and also disperse deeper into the water column (Lee et al. 2015). Although oil is expected to attenuate with depth, considering the interaction at the water surface and that this species would be forced to pass through a slick at some point before or after a dive results in a depth score of 3.
Sensitivity	3 (binned)	Sensitivity = (Acute Change + Chronic Change) X Recovery Factors = (2+2) × 2.1 = 8.4
Acute Change	2	Following a release of petroleum product into Arctic seawater, the concentrations of semi-volatile compounds can be at least temporarily increased near the release site due to low rates of evaporation at low temperatures and sea ice presence (Gomes et al. 2022). Under the ice, buoyant petroleum product components can accumulate in high concentrations and be subject to photo-enhanced toxicity (Lee et al. 2015). Though the research specifically on walruses is limited, parallels can be drawn with the effects on other pinnipeds. Oil is expected to have little effect on thermoregulation in walruses since pinnipeds rely on a subcutaneous layer of blubber for insulation (Geraci 1990). Walruses that come into contact with crude or refined oil could experience acute and long-lasting effects including irritation to eyes, mouth, and mucus membranes, irritation and damage to respiratory organs from inhalation, and kidney and liver damage from ingestion of contaminated prey, and mortality in extreme cases (BOEM 2018). Heavily fouled pinnipeds can experience reduced locomotion and drowning (Davis and Anderson 1976; Sergeant 1991). Harbour seals observed immediately after oiling appeared lethargic and disoriented, a response that may be attributed to lesions observed in the thalamus of the brain (Spraker et al. 1994). Walruses may ingest oil by consuming contaminated prey or by nursing contaminated milk. Once ingested, oil absorbed into the tissues can result in minor kidney, liver, or brain lesions (Geraci and Smith 1976; Spraker et al. 1994). Considering the above, a score of 2 was assigned.
Chronic Change	2	Biodegradation of petroleum products occurs slowly in cold water environments and is limited by nutrient availability, and dispersion and evaporation are slow processes in cold and icy seawater (Gomes et al. 2022). Chronic effects can result from a large heavy fuel oil spill given its persistence in the environment (Lee et al. 2015). Exposure of pinnipeds to oil can result in conjunctivitis (Spraker et al. 1994), corneal abrasion and swollen nictitating membranes, or permanent eye damage (St. Aubin 1990) and therefore reduced foraging ability (Levenson and Schusterman 1997) which may affect a population over the long-term. Spraker et al. (1994) found lesions characteristic of hydrocarbon toxicity in the brains of oiled pinnipeds collected several months after the *Exxon Valdez* spill. Walruses could also consume contaminated prey which could lead to reduced health and reproduction (Geraci and St Aubin 1990). Given that oil exposure can result in mortality (especially in young life stages) which may affect population structure (Davis and Anderson 1976; St. Aubin 1990; Sergeant 1991; Kooyman et al. 1976 in Helm et al. 2015), and there may be long-term effects on the reproductive capacity of adults (Helm et al. 2015), there could be a measurable change to overall fitness relative to background variability for walruses exposed to a large, heavy fuel oil spill, resulting in a score of 2.
Recovery Factors	2.1	Recovery factors = mean of the factors listed below. Fecundity: 3 (Adult female walrus have 1 calf every 3 years [Garlich-Miller and Stewart 1999]).

Risk Factor	Score	Rationale
		Early life stage mortality: 1 (The data are sparse but the population structure and relatively high proportion of juveniles in the population suggests low mortality in all juvenile stages [Fay et al. 1997]). Recruitment pattern: 1 (Although annual recruitment is low by some standards, recruitment seems to be consistent among years and because walrus are long lived [40 years; Kovacs and Lydersen 2006], a single female produces a lot of young over her lifetime]). Natural mortality rate: 3 (The data are sparse but the population structure and relatively high proportion of juveniles in the population suggests low mortality in all life stages [Fay et al. 1997]). Age at maturity: 3 (Average age at sexual maturity of females is 7 years [Garlich-Miller and Stewart 1999]). Life stages affected: 3 (All life stages may be affected). Population connectivity: 2 (Studies suggest that there is some interchange among Canadian Arctic walrus populations [Stewart 2008; Charette et al. 2020; Loewen et al. 2020b]). Population status: 1 (COSEWIC [2017] lists walruses as *special concern* due to threats associated with global warming. The Hudson Bay-Davis Strait stock has increased from a minimum of 3,900 in 1986 to approximately 7,000 and the authors suggest that walruses remain abundant in the Southampton Island area [Hammill et al. 2016a]).
Consequence	4 (binned)	Consequence = Exposure x Sensitivity = 5 x 3 = High
Likelihood	1	Due to the robust oil spill prevention regime in this country, based on existing oil spill response frameworks and standards (WWF n.d.) and historical spill records, the probability of a large, accidental vessel discharge of petroleum product is very low in Canada (WSP 2014b; Lee et al. 2015). Though data are limited for Arctic waters, a fuel oil spill of 990 m^3 is estimated to occur every 920 years, with larger spill volumes occurring more rarely (WSP 2014a). Thus, an oil spill of this nature is expected to occur in only exceptional circumstances.
Overall Risk	Moderately-High Risk	Management measures, such as the development of an oil spill response plan that includes a marine mammal monitoring program, should be considered.
Uncertainty		
Exposure	4	There is some information about walrus distribution within the priority area, and important haul-out sites are known. General vessel traffic patterns are known and were used to inform vessel discharge exposure parameters. Spill modelling should be conducted for the priority area to better understand the fate of a large, accidental petroleum product release via vessel discharge during different times of year.
Sensitivity	5	Certain aspects of walrus biology have been reported in other areas of the Arctic, and there is some literature on the effects of oil exposure on pinnipeds. There is uncertainty if walrus would avoid a spill. Uncertainty is very high.
Likelihood	4	Large oil spill return period estimates exist for the Canadian Arctic, including the study area, though uncertainty remains due to a lack of historic spill data.

Risk Statement: If an interaction occurs involving belugas and a large accidental spill of heavy fuel oil from a vessel the consequence could result in a negative impact on the beluga population in the East Bay priority area.

Table 5-88. Beluga – Vessel Discharge (East Bay) – Petroleum Product (Large Accidental Spill of Heavy Fuel Oil).

Risk Factor	Score	Rationale
Exposure	5 (binned)	Exposure = Intensity x Temporal x Spatial = 3 x 3 x 9 = 81 (raw score)
Intensity	3	It should be noted that relative to other areas that experience shipping and vessel traffic and for which biological effects literature is largely based, the AOI receives a low density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9). The East Bay priority area experiences a low density of vessel traffic relative to other priority areas (see Figures 5-1 and 5-10) representing <1% of total AIS data within the AOI from 2012-2019. As abiotic weathering (e.g., dispersion, evaporation) and bioremediation occurs slowly in cold/ice-covered seawater and oil spill clean-up measures are challenging to conduct in remote and/or ice-filled regions, a large, accidental spill of petroleum product from a vessel would persist in the environment (WWF n.d.; WSP 2014a; Garneau et al. 2016; Gomes et al. 2022). Although the number of large, vessel-source accidental petroleum product spills is expected to be low (WSP 2014a), the petroleum product would have a high persistence in the priority area; therefore, intensity was scored as 3.
Temporal	3	Belugas are expected to migrate into the AOI and presumably the East Bay priority area in May and June and occur in the priority area during summer, with migration out of the priority area beginning in early to late September (Loewen et al. 2020b). Vessels are typically present in the East Bay priority area during October and very occasionally in September, though they are not present throughout that entire period (Maerospace 2020). For the purposes of this risk assessment, a large, accidental vessel spill event is presumed possible any time vessels are present in the priority area. However, because oil would remain in the water beyond the initial accident, this could reasonably result in a large amount of overlap with beluga occurrence and a temporal score of 3.
Spatial	9	Spatial = Areal x Depth = 3 x 3 = 9
Areal	3	Belugas migrate into the priority area in spring/early summer, congregate in the shallow waters of East Bay during summer, and migrate out of East Bay by end of September. Available AIS data indicate that vessels have occurred in the northern portion of the East Bay priority area. A large fuel oil spill could be transported beyond the vessel's immediate location via water currents in open, ice-free areas or under the ice, but, due to low dispersion in the Arctic environment (Gomes et al. 2022), the greatest concentration of petroleum product would be localized; however, it is possible that a large portion of the total beluga range in the priority area may be affected, resulting in a score of 3.
Depth	3	Belugas regularly forage at depths of 100s of meters (Martin et al. 1998; Watt et al. 2016), with some dives to depths greater than 800 m (Heide-Jørgensen et al. 1998; Richard et al. 2001). Petroleum product from a large spill would occur at the water surface but could disperse into the water column, can sink with suspended particulate matter, and/or may congeal into tar balls that may sink (Lee et al. 2015). Although oil is expected to attenuate with depth, considering the interaction at the water surface and that this species would be forced to pass through a slick at some point before or after a dive results in a depth score of 3.
Sensitivity	4	Sensitivity = (Acute Change + Chronic Change) X Recovery Factors

Risk Factor	Score	Rationale
	(binned)	= (2+2) × 2.4 = 9.6
Acute Change	2	Following a release of petroleum product into Arctic seawater, the concentrations of semi-volatile compounds can be at least temporarily increased near the release site due to low rates of evaporation at low temperatures and sea ice presence (Gomes et al. 2022). Under the ice, buoyant petroleum product components can accumulate in high concentrations and be subject to photo-enhanced toxicity (Lee et al. 2015). Though the effects of oil on belugas has been poorly studied, parallels can be drawn to research on other small cetaceans and marine mammals in general. The effects of oil on marine mammals depend on the extent of exposure to toxic components. Exposure may occur due to external coatings of oil (e.g., interaction with surface slicks when animals surface for air), inhalation of aerosols of particulate oil and hydrocarbons, and ingestion of contaminated prey (Helm et al. 2015; Lee et al. 2015; NRDA 2016; Ruberg et al. 2021). Studies to date have shown variable results regarding the ability of marine mammals to detect and/or avoid oil-contaminated waters (Engelhardt 1983; St. Aubin et al. 1985; Smultea and Würsig 1995; Ackleh et al. 2012; Wilkin et al. 2017). According to Geraci and St. Aubin (1980, 1982, 1990), whales exposed to an oil spill are unlikely to ingest enough oil to cause serious internal damage. Marine mammal species that feed in restricted areas or within restricted ranges may be at greater risk of ingesting oil (Würsig 1990; Helm et al. 2015). However, when returning to clean water, Engelhardt (1978, 1982) indicated that contaminated animals can depurate this internal oil. Numerous studies of dolphin populations inhabiting areas of the Gulf of Mexico that were affected by the *Deepwater Horizon* oil spill have indicated that elevated petroleum compounds contributed to increased numbers of dolphin mortalities due to oil-related injury and chronic and potentially progressive diseases (Schwacke et al. 2021; Venn-Watson et al. 2015; NOAA 2022b). A measurable change to beluga mortality rates against background variability and possible behavioural changes may occur, resulting in a score of 2.
Chronic Change	2	Biodegradation of petroleum products occurs slowly in cold water environments and is limited by nutrient availability, and dispersion and evaporation are slow processes in cold and icy seawater (Gomes et al. 2022). Chronic effects can result from a large heavy fuel oil spill given its persistence in the environment (Lee et al. 2015). Based on longer-term studies of marine mammal health in the Gulf of Mexico following the *Deepwater Horizon* spill, there is growing evidence that suggests exposure to oil spills have chronic effects on marine mammals. Hydrocarbons consumed via contaminated prey can be metabolized and excreted, but some is stored in blubber and other fat deposits (Lee et al. 2015). Absorbed oil can cause toxic effects such as liver, kidney, and brain lesions (Geraci and Smith 1976; Geraci 1990; Spraker et al. 1994), as well as other cell and tissue abnormalities and organ dysfunction (Ruberg et al. 2021; Takeshita et al. 2021). Along with increased mortality rates, pregnancy success rates of dolphins inhabiting the exposed area were depressed (Lane et al. 2015; Kellar et al. 2017). Poor reproductive success may have been caused by increased concentrations of genotoxic metals in these animals (Wise et al. 2018). Long-term acoustic monitoring in the Gulf of Mexico suggests local declines in marine mammal presence (e.g., sperm whale *Physeter macroephalus*, beaked whales *Kogia* spp.), possibly due to reduced reproductive success as a result of oil exposure (Frasier et al. 2020). Considering the information above, there could be a measurable change to overall fitness relative to background variability for belugas exposed to a large, heavy fuel oil spill, resulting in a score of 2.
Recovery Factors	2.4	Recovery factors = mean of the factors listed below.

Risk Factor	Score	Rationale
		Fecundity: 3 (Adult female belugas have 1 calf every 3 years [Sergeant 1973; Matthews and Ferguson 2015]). Early life stage mortality: Unknown; excluded from analyses (There are no data on mortality rates in juvenile belugas). Recruitment pattern: 2 (Although annual recruitment is low by some standards, belugas live to be about 70 years old assuming a single growth layer is formed in their teeth in a year [Waugh et al. 2018: Vos et al. 2020]. The maximum longevity may be 100 years [Harwood 2002]. Because of their longevity, a single female could produce a lot of young over her lifetime even if they become reproductively senescent at 35-40 years old, as suggested by Hobbs et al. [2015] and Ellis et al. [2018]). Natural mortality rate: 3 (The natural mortality rate of belugas must be low if they live to ~70 years old. Ice entrapments of belugas are known to recur in the Canadian High Arctic and in northern Foxe Basin [Smith and Sjare 1990]. Polar bears and Inuit hunters take advantage of these incidents to harvest belugas. The proportion of mortality in these situations that is attributable to predation is not well documented and remains debatable [Kilabuk 1998]. Age at maturity: 3 (Average age at sexual maturity of female beluga is 6-14 years [COSEWIC 2020]). Life stages affected: 3 (It is likely that all life stages of belugas will be affected). Population connectivity: 2 (The Western Hudson Bay population that occurs in the AOI overlaps with the Eastern Hudson Bay and Ungava Bay beluga populations in Hudson Strait during winter.) Population status: 1 (IUCN classifies the beluga whale as *near threatened*. COSEWIC [2020] lists the Western Hudson Bay population that occurs in the AOI as *least concern*]).
Consequence	5 (binned)	Consequence = Exposure x Sensitivity = 5 x 4 = Very High
Likelihood	1	Due to the robust oil spill prevention regime in this country, based on existing oil spill response frameworks and standards (WWF n.d.) and historical spill records, the probability of a large, accidental vessel discharge of petroleum product is very low in Canada (WSP 2014b; Lee et al. 2015). Though data are limited for Arctic waters, a fuel oil spill of 990 m^3 is estimated to occur every 920 years, with larger spill volumes occurring more rarely (WSP 2014a). Thus, an oil spill of this nature is expected to occur in only exceptional circumstances.
Overall Risk	Moderately-High Risk	Management measures, such as the development of an oil spill response plan that includes a marine mammal monitoring program, should be considered.
Uncertainty		
Exposure	5	There is some information on beluga distribution and temporal occurrence in the priority area. General vessel traffic patterns are known and were used to inform vessel discharge exposure parameters. Spill modelling should be conducted for the priority area to better understand the fate of a large, accidental petroleum product release via vessel discharge during different times of year.
Sensitivity	4	Certain aspects of beluga biology have been reported in other areas of the arctic, and there is some literature on the effects of oil exposure on small cetaceans. There is uncertainty if belugas would avoid a spill.
Likelihood	4	Large oil spill return period estimates exist for the Canadian Arctic, including the study area, though uncertainty remains due to a lack of historic spill data.

Risk Statement: If an interaction occurs involving narwhals and a large accidental spill of heavy fuel oil from a vessel the consequence could result in a negative impact on the narwhal population in the Repulse Bay and Frozen Strait priority area.

Table 5-89. Narwhal – Vessel Discharge (Repulse Bay and Frozen Strait) – Petroleum Product (Large Accidental Spill of Heavy Fuel Oil).

Risk Factor	Score	Rationale
Exposure	5 (binned)	Exposure = Intensity x Temporal x Spatial = 3 x 3 x 9 = 81 (raw score)
Intensity	3	It should be noted that relative to other areas that experience shipping and vessel traffic and for which biological effects literature is largely based, the AOI receives a low density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9). The Repulse Bay/Frozen Strait priority area experiences a low density of vessel traffic relative to other priority areas (see Figures 5-1 and 5-10) representing <1% of total AIS data within the AOI from 2012-2019. As abiotic weathering (e.g., dispersion, evaporation) and bioremediation occurs slowly in cold/ice-covered seawater and oil spill clean-up measures are challenging to conduct in remote and/or ice-filled regions, a large, accidental spill of petroleum product from a vessel would persist in the environment (WWF n.d.; WSP 2014a; Garneau et al. 2016; Gomes et al. 2022). Although the number of large, vessel-source accidental petroleum product spills is expected to be low (WSP 2014a), the petroleum product would have a high persistence in the priority area; therefore, intensity was scored as 3.
Temporal	3	Narwhals migrate into Repulse Bay in June and July and out in August and September through Frozen Strait (Westdal et al. 2010). Vessels are typically present in the Repulse Bay/Frozen Strait priority area mainly during September and October, and occasionally in August, though they are not present throughout that entire period. For the purposes of this risk assessment, a large, accidental vessel-source spill event is presumed possible any time vessels are present in the priority area. However, because oil would remain in the water beyond the initial accident, this could reasonably result in a large amount of overlap with narwhal occurrence and a temporal score of 3.
Spatial	9	Spatial = Areal x Depth = 3 x 3 = 9
Areal	3	Narwhals preferred habitats are leads in landfast or pack ice (Koski and Davis 1994; Kovacs et al. 2011). Repulse Bay and nearby waters provides important summering habitat for narwhals where they are known to feed and calve (Idlout 2020; Loewen et al. 2020b). Narwhals migrate through Frozen Strait en route to Repulse Bay during spring/early summer break-up and en route to Hudson Strait prior to freeze-up in the fall. A large fuel oil spill could be transported beyond the vessel's immediate location via water currents in open, ice-free areas or under the ice, but, due to low dispersion in the Arctic environment (Gomes et al. 2022), the greatest concentration of petroleum product would be localized; however, it is still possible that a large portion of the total narwhal range in the priority area may be affected, resulting in a score of 3.
Depth	3	Narwhals typically forage in water depths <500 m (Heide-Jørgensen and Dietz 1995; Laidre et al. 2003). Petroleum product from a large spill would occur at the

Risk Factor	Score	Rationale
		water surface but could disperse into the water column, can sink with suspended particulate matter, and/or may congeal into tar balls that may sink (Lee et al. 2015). Although oil is expected to attenuate with depth, considering the interaction at the water surface and that this species would be forced to pass through a slick at some point before or after a dive results in a depth score of 3.
Sensitivity	4 (binned)	Sensitivity = (Acute Change + Chronic Change) X Recovery Factors = (2+2) × 2.5 = 10.0
Acute Change	2	Following a release of petroleum product into Arctic seawater, the concentrations of semi-volatile compounds can be at least temporarily increased near the release site due to low rates of evaporation at low temperatures and sea ice presence (Gomes et al. 2022). Under the ice, buoyant petroleum product components can accumulate in high concentrations and be subject to photo-enhanced toxicity (Lee et al. 2015). Though the effects of oil on narwhals has not been studied, parallels can be drawn to research on other small cetaceans and marine mammals in general. The effects of oil on marine mammals depend on the extent of exposure to toxic components. Exposure may occur due to external coatings of oil (e.g., interaction with surface slicks when animals surface for air), inhalation of aerosols of particulate oil and hydrocarbons, and ingestion of contaminated prey (Helm et al. 2015; Lee et al. 2015; NRDA 2016; Ruberg et al. 2021). Studies to date have shown variable results regarding the ability of marine mammals to detect and/or avoid oil-contaminated waters (Engelhardt 1983; St. Aubin et al. 1985; Smultea and Würsig 1995; Ackleh et al. 2012; Wilkin et al. 2017). According to Geraci and St. Aubin (1980, 1982, 1990), whales exposed to an oil spill are unlikely to ingest enough oil to cause serious internal damage. Marine mammal species that feed in restricted areas or within restricted ranges may be at greater risk of ingesting oil (Würsig 1990; Helm et al. 2015). However, when returning to clean water, Engelhardt (1978, 1982) indicated that contaminated animals can depurate this internal oil. Numerous studies of dolphin populations inhabiting areas of the Gulf of Mexico that were affected by the *Deepwater Horizon* oil spill have indicated that elevated petroleum compounds contributed to increased numbers of dolphin mortalities (Schwacke et al. 2021; Venn-Watson et al. 2015; NOAA 2022b). A measurable change to narwhal mortality rates against background variability and possible behavioural changes may occur, resulting in a score of 2.
Chronic Change	2	Biodegradation of petroleum products occurs slowly in cold water environments and is limited by nutrient availability, and dispersion and evaporation are slow processes in cold and icy seawater (Gomes et al. 2022). Chronic effects can result from a large heavy fuel oil spill given its persistence in the environment (Lee et al. 2015). Based on longer-term studies of marine mammal health in the Gulf of Mexico following the *Deepwater Horizon* spill, there is growing evidence that suggests exposure to oil spills have chronic effects on marine mammals. Hydrocarbons consumed via contaminated prey can be metabolized and excreted, but some is stored in blubber and other fat deposits (Lee et al. 2015). Absorbed oil can cause toxic effects such as liver, kidney, and brain lesions (Geraci and Smith 1976; Geraci 1990; Spraker et al. 1994), as well as other cell and tissue abnormalities and organ dysfunction (Ruberg et al. 2021; Takeshita et al. 2021). Along with increased mortality rates, pregnancy success rates of dolphins inhabiting the exposed area were depressed (Lane et al. 2015; Kellar et al. 2017). Poor reproductive success may have been caused by increased concentrations of genotoxic metals in these animals (Wise et al. 2018). Long-term acoustic monitoring in the Gulf of Mexico suggests local declines in marine mammal presence (e.g., sperm whale, beaked whales), possibly due to reduced reproductive success as a result of oil exposure (Frasier et al. 2020). Considering

Risk Factor	Score	Rationale
		the information above, there could be a measurable change to overall fitness relative to background variability for narwhal exposed to a large, heavy fuel oil spill, resulting in a score of 2.
Recovery Factors	2.5	Recovery factors = mean of the factors listed below. Fecundity: 3 (Adult female narwhals have a calf about every 3 years [Garde et al. 2015]). Early life stage mortality: 2 (Few data on first year mortality of narwhal calves are available. Koski and Davis [1994] estimated that 17% of calves died when between 1 and 13 months of age; this is lower than for many other marine mammal species]). Recruitment pattern: 2 (Although annual recruitment is low by some standards, recruitment seems to be consistent among years and because narwhals are long lived [80 years; Garde et al. 2015], a single female can produce a lot of young over her lifetime]). Natural mortality rate: 3 (The data are sparse but the stable population size with the removals by subsistence hunters suggests low mortality in all life stages). Age at maturity: 3 (Age at sexual maturity of females is 6-9 years and older for males [Garde et al. 2015]). Life stages affected: 3 (All life stages except for newborn calves are likely to be affected. An adult female accompanied by a yearling was seen in the AOI [Carlyle et al. 2021]). Population connectivity: 3 (Studies suggest that there is limited interchange among Canadian Arctic narwhal populations [Westdal et al. 2010; Heide-Jørgensen et al. 2013a; Doniol-Valcroze et al. 2020]). Population status: 1 (IUCN classifies narwhals as *least concern* [Lowry et al. 2017]. The last COSEWIC assessment is outdated [from 2004]. Narwhal populations are considered stable [Furgal and Laing 2012; Lowry et al. 2017]).
Consequence	5 (binned)	Consequence = Exposure x Sensitivity = 5 x 4 = Very High
Likelihood	1	Due to the robust oil spill prevention regime in this country, based on existing oil spill response frameworks and standards (WWF n.d.) and historical spill records, the probability of a large, accidental vessel discharge of petroleum product is very low in Canada (WSP 2014b; Lee et al. 2015). Though data are limited for Arctic waters, a fuel oil spill of 990 m^3 is estimated to occur every 920 years, with larger spill volumes occurring more rarely (WSP 2014a). Thus, an oil spill of this nature is expected to occur in only exceptional circumstances.
Overall Risk	Moderately-High Risk	Management measures, such as the development of an oil spill response plan that includes a marine mammal monitoring program, should be considered.
Uncertainty		
Exposure	5	Some information exists about narwhal spatial and temporal distribution from the priority area. General vessel traffic patterns are known and were used to inform vessel discharge exposure parameters. Spill modelling should be conducted for the priority area to better understand the fate of a large, accidental petroleum product release via vessel discharge during different times of year.
Sensitivity	4	Certain aspects of narwhal biology have been reported in other areas of the arctic, and there is some literature on the effects of oil exposure on small cetaceans. There is uncertainty if narwhals would avoid a spill.
Likelihood	4	Large oil spill return period estimates exist for the Canadian Arctic, including the study area, though uncertainty remains due to a lack of historic spill data.

Risk Statement: If an interaction occurs involving bowhead whales and a large accidental spill of heavy fuel oil from a vessel the consequence could result in a negative impact on the bowhead whale population in the Fisher and Evans Straits priority area.

Table 5-90. Bowhead Whale – Vessel Discharge (Fisher and Evans Straits) – Petroleum Product (Large Accidental Spill of Heavy Fuel Oil).

Risk Factor	Score	Rationale
Exposure	5 (binned)	Exposure = Intensity x Temporal x Spatial = 3 x 3 x 9 = 81 (raw score)
Intensity	3	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Fisher and Evans Straits priority area experiences a higher density of vessel traffic relative to other priority areas except Chesterfield Inlet/Narrows (see Figures 5-1 and 5-10), representing 9.5% of total AIS data within the AOI from 2012-2019. As abiotic weathering (e.g., dispersion, evaporation) and bioremediation occurs slowly in cold/ice-covered seawater and oil spill clean-up measures are challenging to conduct in remote and/or ice-filled regions, a large, accidental spill of petroleum product from a vessel would persist in the environment (WWF n.d.; WSP 2014a; Garneau et al. 2016; Gomes et al. 2022). Although the number of large, vessel-source accidental petroleum product spills is expected to be low (WSP 2014a), the petroleum product would have a high persistence in the priority area; therefore, intensity was scored as 3.
Temporal	3	Based on scientific studies and current Inuit Qaujimajatuqangit bowheads occur in the Fisher and Evans Straits priority area from April to November but primarily occur there during summer (Idlout 2020; Loewen et al. 2020b). Vessels are typically present in the priority area during July to October, and very occasionally during June and November (Maerospace 2020), though they may not occur during that entire period. For the purposes of this risk assessment, a large, accidental vessel spill event is presumed possible any time vessels are present in the priority area. However, because oil would remain in the water beyond the initial accident, this could reasonably result in a large amount of overlap with bowhead whale occurrence and a temporal score of 3.
Spatial	9	Spatial = Areal x Depth = 3 x 3 = 9
Areal	3	Bowhead whales are expected to primarily occur in the Fisher and Evans Straits priority area during the summer and can occur throughout the priority area. Nearshore areas around SE SI in Evans Strait are known calving and nursery grounds (DFO 2020; Idlout 2020; Loewen et al. 2020b). Based on available AIS data, vessel activity (see Figures 5-1 and 5-10) is typically focused along two primary paths that occur north and south of Coats Island. A large fuel oil spill could be transported beyond the vessel's immediate location via water currents in open, ice-free areas or under the ice, but, due to low dispersion in the Arctic environment (Gomes et al. 2022), the greatest concentration of petroleum product would be localized. However, it is still possible that a large portion of the total bowhead range in the priority area may be affected, resulting in a score of 3.

Risk Factor	Score	Rationale
Depth	3	Though bowhead whales undertake foraging dives (e.g., Fortune et al. 2020), they spend a considerable amount of time at or near the water surface. Oil from a large spill would occur at the water surface but could disperse into the water column, can sink with suspended particulate matter, and/or may congeal into tar balls that may sink (Lee et al. 2015). Although oil is expected to attenuate with depth, considering the interaction at the water surface and that this species would be forced to pass through a slick at some point before or after a dive results in a depth score of 3.
Sensitivity	4 (binned)	Sensitivity = (Acute Change + Chronic Change) X Recovery Factors = (2+2) × 2.3 = 9.2
Acute Change	2	Following a release of petroleum product into Arctic seawater, the concentrations of semi-volatile compounds can be at least temporarily increased near the release site due to low rates of evaporation at low temperatures and sea ice presence (Gomes et al. 2022). Under the ice, buoyant petroleum product components can accumulate in high concentrations and be subject to photo-enhanced toxicity (Lee et al. 2015). The effects of oil on marine mammals depend on the extent of exposure to toxic components. Exposure may occur due to external coatings of oil (e.g., interaction with surface slicks when animals surface for air), inhalation of aerosols of particulate oil and hydrocarbons, and ingestion of contaminated prey (Helm et al. 2015; Lee et al. 2015; NRDA 2016; Ruberg et al. 2021). Studies to date have shown variable results regarding the ability of marine mammals to detect and/or avoid oil-contaminated waters (Engelhardt 1983; St. Aubin et al. 1985; Smultea and Würsig 1995; Ackleh et al. 2012; Wilkin et al. 2017). According to Geraci and St. Aubin (1980, 1982, 1990), whales exposed to an oil spill are unlikely to ingest enough oil to cause serious internal damage. Marine mammal species that feed in restricted areas or within restricted ranges may be at greater risk of ingesting oil (Würsig 1990; Helm et al. 2015). However, when returning to clean water, Engelhardt (1978, 1982) indicated that contaminated animals can depurate this internal oil. Oil can coat the baleen of mysticetes and reduce filtration, thereby reducing feeding efficiency (Geraci 1990). This effect is considered reversible once adherent oil is removed (Geraci 1990). Numerous studies of dolphin populations inhabiting areas of the Gulf of Mexico that were affected by the *Deepwater Horizon* oil spill have indicated that elevated petroleum compounds contributed to increased numbers of dolphin mortalities (Schwacke et al. 2021; Venn-Watson et al. 2015; NOAA 2022b). A measurable change to bowhead mortality rates against background variability and possible behavioural changes may occur, resulting in a score of 2.
Chronic Change	2	Biodegradation of petroleum products occurs slowly in cold water environments and is limited by nutrient availability, and dispersion and evaporation are slow processes in cold and icy seawater (Gomes et al. 2022). Chronic effects can result from a large heavy fuel oil spill given its persistence in the environment (Lee et al. 2015). Based on longer-term studies of marine mammal health in the Gulf of Mexico following the *Deepwater Horizon* spill, there is growing evidence that suggests exposure to oil spills have chronic effects on marine mammals. Hydrocarbons consumed via contaminated prey can be metabolized and excreted, but some is stored in blubber and other fat deposits (Lee et al. 2015). Absorbed oil can cause toxic effects such as liver, kidney, and brain lesions (Geraci and Smith 1976; Geraci 1990; Spraker et al. 1994), as well as other cell and tissue abnormalities and organ dysfunction (Ruberg et al. 2021; Takeshita et al. 2021). Along with increased mortality rates, pregnancy success rates of dolphins inhabiting the exposed area were depressed (Lane et al. 2015; Kellar et al. 2017). Poor reproductive success may have been caused by increased concentrations of genotoxic metals in these animals (Wise et al. 2018). Long-term acoustic

Risk Factor	Score	Rationale
		monitoring in the Gulf of Mexico suggests local declines in marine mammal presence (e.g., sperm whale, beaked whales), possibly due to reduced reproductive success as a result of oil exposure (Frasier et al. 2020). Considering the information above, there could be a measurable change to overall fitness relative to background variability for bowhead whales exposed to a large, heavy fuel oil spill, resulting in a score of 2.
Recovery Factors	2.3	Recovery factors = mean of the factors listed below. Fecundity: 3 (Adult female bowheads have 1 calf every 3-4 years [Miller et al. 1992; Koski et al. 1993; Tarpley et al. 2016, 2021]). Early life stage mortality: Unknown; excluded from consideration (There are no data on mortality rates in juvenile bowheads). Recruitment pattern: 1 (Although annual recruitment is low by some standards, bowhead pregnancies seem to be determined by the health of the prospective mother to maximize survival of the calf [W. Koski, pers. comm., 2022]. Because bowheads live to be about 200 years old, a single female produces a lot of young over her lifetime [Tarpley et al. 2016, 2021]). Natural mortality rate: 3 (The mortality rate of adult bowheads is extremely low, possibly the lowest of any animal. Survival has been estimated as 0.984 [0.948-1.00; Zeh et al. 2002] to 0.996 [0.976-1.00, Givens et al. 2018]). Age at maturity: 3 (Average age at sexual maturity of female bowheads is about 25 years [Koski et al. 1993; George et al. 1999] and appears to have declined in recent years [Tarpley et al. 2021]). Life stages affected: 3 (It is assumed that all life stages could be susceptible to oiling effects). Population connectivity: 2 (The EC-WG population of bowhead whales occur in the AOI. Until recently, the geographic distributions of the EC-WG and BCB bowhead populations were significantly different so that there was little or no overlap between the populations [Zeh et al. 1995]. With the opening of the NW passage resulting from climate change, interchange between these two populations is possible, as suggested by a sighting of two satellite tagged bowheads from the two populations in the same general area in the High Arctic [Heide-Jørgensen et al. 2011]). Population status: 1 (IUCN classifies the EC-WG bowhead whale population as *least concern* [Cooke and Reeves 2018]. COSEWIC (2009) classifies them as *threatened*; however, that status report is out of date and is currently being reviewed. Recent surveys indicate that the population has increased since commercial overharvesting ended in the early 1900s. They may have increased to the point where this population has reached the carrying capacity of their habitat, based on sightings of skinny whales and apparent natural mortality in Cumberland Sound [Young et al. 2019] and recent cases of apparent natural mortality in other areas [DFO unpublished data]).
Consequence	5 (binned)	Consequence = Exposure x Sensitivity = 5 x 4 = Very High
Likelihood	1	Due to the robust oil spill prevention regime in this country, based on existing oil spill response frameworks and standards (WWF n.d.) and historical spill records, the probability of a large, accidental vessel discharge of petroleum product is very low in Canada (WSP 2014b; Lee et al. 2015). Though data are limited for Arctic waters, a fuel oil spill of 990 m^3 is estimated to occur every 920 years, with larger spill volumes occurring more rarely (WSP 2014a). Thus, an oil spill of this nature is expected to occur in only exceptional circumstances.
Overall Risk	Moderately-High Risk	Management measures, such as the development of an oil spill response plan that includes a marine mammal monitoring program, should be considered.

Risk Factor	Score	Rationale
Uncertainty		
Exposure	4	Some information exists about bowhead whale distribution in the priority area. General vessel traffic patterns are known and were used to inform vessel discharge exposure parameters. Spill modelling should be conducted for the priority area to better understand the fate of a large, accidental petroleum product release via vessel discharge during different times of year.
Sensitivity	4	Certain aspects of bowhead whale biology have been reported in other areas of the arctic, and there is some literature on the effects of oil exposure on cetaceans. There is uncertainty if bowheads would avoid a spill.
Likelihood	4	Large oil spill return period estimates exist for the Canadian Arctic, including the study area, though uncertainty remains due to a lack of historic spill data.

Risk Statement: If an interaction occurs involving polar bears and a large accidental spill of heavy fuel oil from a vessel the consequence could result in a negative impact on polar bear populations in the Fisher and Evans Straits priority area.

Table 5-91. Polar Bear – Vessel Discharge (Fisher and Evans Straits) – Petroleum Product (Large Accidental Spill of Heavy Fuel Oil).

Risk Factor	Score	Rationale
Exposure	4 (binned)	Exposure = Intensity x Temporal x Spatial (Depth x Areal) = 3 x 3 x 6 = 54 (raw score)
Intensity	3	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Fisher and Evans Straits priority area experiences a higher density of vessel traffic relative to other priority areas except Chesterfield Inlet/Narrows (see Figures 5-1 and 5-10), representing 9.5% of total AIS data within the AOI from 2012-2019. As abiotic weathering (e.g., dispersion, evaporation) and bioremediation occurs slowly in cold/ice-covered seawater and oil spill clean-up measures are challenging to conduct in remote and/or ice-filled regions, a large, accidental spill of petroleum product from a vessel would persist in the environment (WWF n.d.; WSP 2014a; Garneau et al. 2016; Gomes et al. 2022). Although the number of large, vessel-source accidental petroleum product spills is expected to be low (WSP 2014a), the petroleum product would have a high persistence in the priority area; therefore, intensity was scored as 3.
Temporal	3	Polar bears are expected to occur in the Fisher and Evans Strait priority area year-round, although the bears move onto land when the ice breaks up in the summer. No known denning habitat exists in the area so females are cubs are less likely to be present in this area during spring and summer. Vessels are typically present in the priority area during July to October, and very occasionally during June and November (Maerospace 2020), though they may not occur during that entire period. For the purposes of this risk assessment, a large, accidental vessel spill event is presumed possible any time vessels are present in the priority area. Because oil would remain in the water beyond the initial

Risk Factor	Score	Rationale
		accident, this could reasonably result in a large amount of overlap and a temporal score of 3.
Spatial	6	Spatial = Areal x Depth = 2 x 3 = 6
Areal	2	Polar bears are likely widely distributed and occur at low densities of 1-11 bears/1,000 km^2 throughout their range (Taylor and Lee 1995; Evans et al. 2003; Aars et al. 2009). They are known to occur in the Fisher and Evans Straits priority area (Peacock et al. 2009; Sahanatien et al. 2015). Polar bears are frequently found in areas of landfast ice or consolidated pack ice (Stirling et al. 1993); during the summer, they are often found on land (Durner et al. 2009). Based on available AIS data, vessel activity (see Figures 5-1 and 5-10) is typically focused along two primary paths that occur north and south of Coats Island. Heavy fuel oil from a large, accidental discharge could be transported beyond the vessel's immediate location via water currents in open, ice-free areas or under the ice, but, due to low dispersion in the Arctic environment (Gomes et al. 2022), the greatest concentration of petroleum product would be localized, thereby overlapping a small portion of the total polar bear range in the Fisher and Evans Straits priority area. This results in a score of 2.
Depth	3	Polar bears spend most of their time on the ice surface and not in the water. However, when polar bears are in the water, they are typically at the surface where oil could contaminate their fur. This results in a depth score of 3.
Sensitivity	4 (binned)	Sensitivity = (Acute change + Chronic Change) x Recovery Factors = (2+2) x 2.4 = 9.6
Acute Change	2	Polar bears are known to be attracted to petroleum products and may actively investigate oil spills; they also are known to consume foods fouled with petroleum products (St. Aubin 1990; Derocher and Stirling 1991). Oiled polar bears would likely ingest oil during grooming and would be susceptible to hypothermia (Engelhardt 1981; Geraci and St. Aubin. 1990). Polar bears that encounter oil could experience acute (and long-lasting) effects, including irritation to eyes, mouth, and mucus membranes, irritation and damage to respiratory organs from inhalation, and kidney and liver damage from ingestion of contaminated prey (Øritsland et al. 1981). Heavily oiled bears would not survive unless capture and cleaning efforts were successful (Øritsland et al. 1981). A measurable change to polar bear mortality rates against background variability is expected, resulting in a score of 2.
Chronic Change	2	Polar bears exposed to oil can experience long-term effects such as changes in reproductive capacity (Øritsland et al. 1981). Contact with and ingestion of oil by polar bears can also cause hair loss, anemia, anorexia, increased metabolic rate, elevated skin temperatures, and stress response (St. Aubin 1990; Derocher and Stirling 1991). Hydrocarbons consumed via contaminated prey can be metabolized and excreted, but some is stored in fat deposits (Lee et al. 2015). Absorbed oil can cause toxic effects in other marine mammals such as liver, kidney, and brain lesions (Geraci and Smith 1976; Geraci 1990; Spraker et al. 1994), as well as other cell and tissue abnormalities and organ dysfunction (Ruberg et al. 2021; Takeshita et al. 2021), and similar effects would be expected in polar bears. Combined with the effects of mortality on population structure, these effects could result in a measurable change to fitness of populations in the priority area, particularly given the expected persistence of oil from a spill. This results in a score of 2.
Recovery Factors	2.4	Recovery factors = mean of the factors listed below. Fecundity: 3 (Adult female polar bears have an average of 2 [range 1-3] cubs every 3 years [Stirling 1988a]).

Risk Factor	Score	Rationale
		Early life stage mortality: 2 (Polar bear cubs experience moderate mortality [43%; Taylor et al. 2005; Aars et al. 2006]). Recruitment pattern: 2 (Polar bears have a moderate level of recruitment due to long life span and have an average of two cubs at regular intervals). Natural mortality rate: 3 (Tagging studies from other areas suggest a high level of survival for adult bears [e.g., adult female survival ranges: 0.91-1.00; see Regehr et al. 2015 for review]. Most populations are stable or increasing and have sustainable levels of harvest allowed under regulated quotas). Age at maturity: 3 (Earliest age at sexual maturity of females is 4 years with most females not reproducing until 5 or 6 years of age [Ramsay and Stirling 1988; Stirling 1988a]. Males reach sexual maturity as early as 2 years of age [Richardson et al. 2020]). Life stages affected: 3 (All life stages may be affected). Population connectivity: 2 (Studies suggest that there is little interchange between Canadian Arctic polar bear populations, but there is some exchange within the AOI, including the Fisher and Evans Straits priority area [Paetkau et al. 1999; Sahanatien et al. 2015]). Population status: 1 (IUCN classifies polar bears as *vulnerable* [Wiig et al. 2015], and COSEWIC [2018] classifies them as *special concern* due to threats by global warming. However, aerial surveys of the Foxe Basin area suggest that populations are stable [Stapleton et al. 2016] despite a well-documented decline in cub production and survival in western Hudson Bay [Stirling et al. 1999]).
Consequence	5 (binned)	Consequence = Exposure x Sensitivity = 4 x 4 = Very High
Likelihood	1	Due to the robust oil spill prevention regime in this country, based on existing oil spill response frameworks and standards (WWF n.d.) and historical spill records, the probability of a large, accidental vessel discharge of petroleum product is very low in Canada (WSP 2014b; Lee et al. 2015). Though data are limited for Arctic waters, a fuel oil spill of 990 m^3 is estimated to occur every 920 years, with larger spill volumes occurring more rarely (WSP 2014a). Thus, an oil spill of this nature is expected to occur in only exceptional circumstances.
Overall Risk	Moderately-High Risk	Management measures, such as the development of an oil spill response plan that includes a marine mammal monitoring program, should be considered.
Uncertainty		
Exposure	5	There is some information about polar bear distribution and numbers for the priority area. General vessel traffic patterns are known and were used to inform vessel discharge exposure parameters. Spill modelling should be conducted for the priority area to better understand the fate of a large, accidental petroleum product release via vessel discharge during different times of year.
Sensitivity	3	The impacts of a large discharge of petroleum products on polar bears can be reasonably predicted based on information and studies conducted elsewhere (e.g., Engelhardt 1981; Geraci and St. Aubin 1990).
Likelihood	4	Large oil spill return period estimates exist for the Canadian Arctic, including the study area, though uncertainty remains due to a lack of historic spill data.

Risk Statement: If an interaction occurs involving polynya habitat and a large accidental spill of heavy fuel oil from a vessel the consequence could result in a negative impact on the ecosystem function of polynya habitat in the Chesterfield Inlet/Narrows priority area.

Table 5-92. Polynya Habitat – Vessel Discharge (Chesterfield Inlet/Narrows) – Petroleum Product (Large Accidental Spill of Heavy Fuel Oil).

Risk Factor	Score	Rationale
Exposure	5 (binned)	Exposure = Intensity x Temporal x Spatial = 3 x 3 x 9 = 81 (raw score)
Intensity	3	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low absolute density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Chesterfield Inlet/Narrows priority area experiences a high density of vessel traffic relative to other portions of the AOI (see Figures 5-1 and 5-10) representing approximately 61% of total AIS data within the AOI from 2012-2019. As abiotic weathering (e.g., dispersion, evaporation) and bioremediation occurs slowly in cold/ice-covered seawater and oil spill clean-up measures are challenging to conduct in remote and/or ice-filled regions, a large, accidental spill of petroleum product from a vessel would persist in the environment (WWF n.d.; WSP 2014a; Garneau et al. 2016; Gomes et al. 2022). Although the number of large, vessel-source accidental petroleum product spills is expected to be low (WSP 2014a), the petroleum product would have a high persistence in the priority area; therefore, intensity was scored as 3.
Temporal	3	The Western Hudson Bay polynya in the Chesterfield Inlet/Narrows priority area opens up in December and merges with adjacent open water during summer (Gunn 2014). Vessels are typically present in the priority area during July to September, and occasionally during June (Maerospace 2020), though they may not be present throughout that entire period. As vessel traffic mainly occurs during summer to fall and the polynya occurs from December through late June/early July, there would be very little temporal overlap (<25%) between vessels and the polynya. However, because oil would remain in the water beyond the initial accident, this could reasonably result in a large amount of overlap and a temporal score of 3.
Spatial	9	Spatial = Areal x Depth = 3 x 3 = 9
Areal	3	The Western Hudson Bay polynya is a recurring coastal polynya that reforms annually along the coast within the Chesterfield Inlet/Narrows priority area and is characterized by the recurrence of lower sea ice concentration and extent, and surface wind forcing (DFO 2020a; Bruneau et al. 2021). During summer, when the ice melts, this open water area merges with open water in the rest of region. A large heavy fuel oil spill could be transported beyond the vessel's immediate location via water currents in open, ice-free areas or under the ice, but, due to low dispersion in the Arctic environment and sea ice impeding the ability of oil to rapidly disperse across the water surface (Gomes et al. 2022), the greatest concentration of petroleum product would be localized. Nonetheless, if a spill were to occur, the area of overlap is likely to be widespread, perhaps throughout the entire polynya, resulting in a score of 3.
Depth	3	A spill would occur at the water/ice surface and petroleum product could get trapped under the ice or could be incorporated into the ice via encapsulation and/or movement through brine channels (Brakstad et al. 2008; Lee et al. 2015) resulting in a depth score of 3.

Risk Factor	Score	Rationale
Sensitivity	4 (binned)	Sensitivity = (Acute change + Chronic Change) x Recovery Factors = (2 + 3) x 2.0 = 10.0
Acute Change	2	Following a release of petroleum product into Arctic seawater, the concentrations of semi-volatile compounds can be at least temporarily increased near the release site due to low rates of evaporation at low temperatures and sea ice presence (Gomes et al. 2022). Under the ice, buoyant petroleum product components can accumulate in high concentrations and be subject to photo-enhanced toxicity (Lee et al. 2015). Oil spilled in sea ice can become trapped under the ice, at the surface between floes, and within cracks and brine channels in the ice (Fingas and Hollebone 2003; Boehm et al. 2007; Dickins 2011; Lee et al. 2015; Desmond et al. 2021). As close pack ice prevents oil from spreading, oil trapped in the ice through the winter remains largely in a fresh state, and trapped oil is exposed on the ice surface in the spring (Dickins 2011). Petroleum products trapped in or on ice can reduce the surface albedo and increase melt rates (see Fingas and Hollebone 2014). The presence of a polynya can increase productivity and influence food web structures, supporting increased numbers of upper trophic level species such as marine mammals and birds (Arrigo and van Dijken 2004); however, the use of this habitat would be negatively impacted by a spill. For example, the phytoplanktonic community can underdo compositional changes within days of a spill and ice algae occurs at greatest concentration at the ice-water interface (Brussaard et al. 2016; Lemcke et al. 2018); plankton and planktonic larval stages of fish and invertebrates are very sensitive to the toxicological effects of oil (Hutchinson et al. 1998); though mass mortalities of adult fish via acute toxicity are not known, they are likely to avoid a contaminated area which may result in vacating important habitat (Lee et al. 2015); and oil can cause mortality in seals, with pups being more sensitive than adults due to their thinner layers of blubber (Davis and Anderson 1976; St. Aubin 1990; Sergeant 1991). Thus, an oil spill could have significant impact on habitat function of the polynya for various trophic levels, resulting in a score of 2.
Chronic Change	3	Oil degrades slowly in the Arctic, due to molecular processes occurring more slowly at lower temperatures and oil entrapped in ice being less exposed to wave action (Lee et al. 2015; Garneau et al. 2016; Gomes et al. 2022). Oil becomes encapsulated in sea ice over a matter of days and begins to migrate upwards through sea ice in brine channels when temperatures begin to warm, eventually appearing on the surface of the sea ice (NORCOR 1975; Dome Petroleum 1981). Movement through brine channels can occur rapidly when temperatures are warm enough (NORCOR 1975). There was no observed difference in sea ice growth rate when oil was encapsulated in the ice, unless significant pools were present (Fingas and Holleborne 2003). However, Glaeser and Vance (1971) found that oil on the ice surface absorbed 30% more heat from the sun than did ice and this corroborated a finding that oiled ice had half the albedo of unoiled ice (NORCOR 1975). Furthermore, oil on the surface of ice has been found to increase melt rates associated with reduced surface albedo (see Fingas and Hollebone 2014). It is suggested that oil can persist in this way on the upper surface of the ice for 2-5 melt seasons (Fingas and Holleborne 2003). As it relates to habitat function, Garneau et al. (2016) observed that microbial communities in sea ice and at the water-ice interface changed when exposed to hydrocarbons, favouring oil-degrading organisms. Additional negative effects on various trophic levels are expected due to degradation of habitat (e.g., oil compounds can persist in sediments for years; Elmgren et al. 1983; Yang et al. 2018), avoidance behaviour (e.g., in adult fish; Lee et al. 2015), and the effects of repeated oil exposure on individual animals (e.g., internal lesions, cell and tissue abnormalities and organ dysfunction in marine mammals (Geraci and Smith 1976; Spraker et al. 1994; Ruberg et al. 2021;

Risk Factor	Score	Rationale
		Takeshita et al. 2021). Thus, a significant change in the long-term viability of the polynya to function as habitat would be expected resulting in a score of 3.
Recovery Factors	2.0	Recovery factors for sea ice = mean of the factors listed below. Growth rate (biogenic)/rate of structural rebuilding (abiotic): 2 (Sea ice refreezes during fall). Resistance: 2 (Sea ice is relatively hard and durable). Regenerative potential: 1 (Sea ice grows each year and any removal of it will be met by its replacement if temperatures are below freezing). External stress: 3 (Climate change adds to stress).
Consequence	5 (binned)	Consequence = Exposure x Sensitivity = 5 x 4 = Very high
Likelihood	1	Due to the robust oil spill prevention regime in this country, based on existing oil spill response frameworks and standards (WWF n.d.) and historical spill records, the probability of a large, accidental vessel discharge of petroleum product is very low in Canada (WSP 2014b; Lee et al. 2015). Though data are limited for Arctic waters, a fuel oil spill of 990 m^3 is estimated to occur every 920 years, with larger spill volumes occurring more rarely (WSP 2014a). Thus, an oil spill of this nature is expected to occur in only exceptional circumstances.
Overall Risk	Moderately-High Risk	Management measures, such as the development of an oil spill emergency response plan that includes a sampling program, should be considered.
Uncertainty		
Exposure	4	General vessel traffic patterns are known and were used to inform vessel discharge exposure parameters. Some investigation has occurred regarding the spatial and temporal occurrence of the Western Hudson Bay polynya. Spill modeling should be conducted for the priority area to better understand the fate of a large, accidental vessel-source spill during different times of year.
Sensitivity	3	There is a little scientific information available regarding impact of oil spills on polynyas, though literature exists for sea ice and for many organisms that use polynyas as habitat. Uncertainty is moderate.
Likelihood	4	Large oil spill return period estimates exist for the Canadian Arctic, including the study area, though uncertainty remains due to a lack of historic spill data.

Risk Statement: If an interaction occurs involving sea ice and a large accidental spill of heavy fuel oil from a vessel the consequence could result in a negative impact on the ecosystem function of sea ice in the Roes Welcome Sound priority area.

Table 5-93. Sea Ice – Vessel Discharge (Roes Welcome Sound) – Petroleum Product (Large Accidental Spill of Heavy Fuel Oil).

Risk Factor	Score	Rationale
Exposure	4 (binned)	Exposure = Intensity x Temporal x Spatial = 3 x 3 x 6 = 54 (raw score)
Intensity	3	It should be noted that relative to other areas that experience shipping and vessel traffic and for which biological effects literature is largely based, the AOI receives a low density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9). The Roes Welcome Sound priority area experiences a low density of vessel traffic relative

Risk Factor	Score	Rationale
		to other priority areas (see Figures 5-1 and 5-10) representing <1% of total AIS data within the AOI from 2012-2019. As abiotic weathering (e.g., dispersion, evaporation) and bioremediation occurs slowly in cold/ice-covered seawater and oil spill clean-up measures are challenging to conduct in remote and/or ice-filled regions, a large, accidental spill of petroleum product from a vessel would persist in the environment (WWF n.d.; WSP 2014a; Garneau et al. 2016; Gomes et al. 2022). Although the number of large, vessel-source accidental petroleum product spills is expected to be low (WSP 2014a), the petroleum product would have a high persistence in the priority area; therefore, intensity was scored as 3.
Temporal	3	Sea ice occurs in the Roes Welcome sound priority area from late fall through late spring (~8 months of the year); it melts during the summer. Vessels are typically present in the priority area during September and October, and occasionally in August, with the entirety of June activity accounted for by one research cruise in 2018 (Maerospace 2020); vessels may not be present throughout that entire period. For the purposes of this risk assessment, a large, accidental spill event is presumed possible any time vessels are present in the priority area and the oil would remain in the water beyond the initial accident. Therefore, although the temporal overlap between vessels and sea ice in the priority area is low, a spill could remain over a prolonged period of time, resulting in a temporal score of 3.
Spatial	6	Spatial = Areal x Depth = 2 x 3 = 6
Areal	2	Sea ice occurs throughout the Roes Welcome Sound priority area for ~8 months of the year consisting of landfast ice and mobile pack ice. Additionally, an ice arch also forms across Roes Welcome Sound south of Wager Bay every ~4 years. A large heavy fuel oil spill could be transported beyond the vessel's immediate location via water currents in open, ice-free areas or under the ice, but, due to low dispersion in the Arctic environment and sea ice impeding the ability of oil to rapidly disperse across the water surface (Gomes et al. 2022), the greatest concentration of petroleum product would be localized. This results in an areal score of 2.
Depth	3	A spill would occur at the water/ice surface and petroleum product could get trapped under the ice or could be incorporated into the ice via encapsulation and/or movement through brine channels (Brakstad et al. 2008; Lee et al. 2015) resulting in a depth score of 3.
Sensitivity	4 (binned)	Sensitivity = (Acute change + Chronic Change) x Recovery Factors = (2 + 3) x 2.0 = 10.0
Acute Change	2	Following a release of petroleum product into Arctic seawater, the concentrations of semi-volatile compounds can be at least temporarily increased near the release site due to low rates of evaporation at low temperatures and sea ice presence (Gomes et al. 2022). Under the ice, buoyant petroleum product components can accumulate in high concentrations and be subject to photo-enhanced toxicity (Lee et al. 2015). Oil spilled in sea ice can become trapped under the ice, at the surface between floes, and within cracks and brine channels in the ice (Fingas and Hollebone 2003; Boehm et al. 2007; Dickins 2011; Lee et al. 2015; Desmond et al. 2021). As close pack ice prevents oil from spreading, oil trapped in the ice through the winter remains largely in a fresh state, and trapped oil is exposed on the ice surface in the spring (Dickins 2011). Petroleum products trapped in or on ice can reduce the surface albedo and increase melt rates (see Fingas and Hollebone 2014). The use of this habitat would be negatively impacted by a spill. For example, the phytoplanktonic

Risk Factor	Score	Rationale
		community can underdo compositional changes within days of a spill and ice algae occurs at greatest concentration at the ice-water interface (Brussaard et al. 2016; Lemcke et al. 2018); plankton and planktonic larval stages of fish and invertebrates are very sensitive to the toxicological effects of oil (Hutchinson et al. 1998); though mass mortalities of adult fish via acute toxicity are not known, they are likely to avoid a contaminated area which may result in vacating important habitat (Lee et al. 2015); and oil can cause mortality in seals, with pups being more sensitive than adults due to their thinner layers of blubber (Davis and Anderson 1976; St. Aubin 1990; Sergeant 1991). An oil spill is expected to have a measurable impact on the habitat function of sea ice in the Roes Welcome Sound priority area for various trophic levels, resulting in a score of 2.
Chronic Change	3	Oil degrades slowly in the Arctic, due to molecular processes occurring more slowly at lower temperatures and oil entrapped in ice being less exposed to wave action (Lee et al. 2015; Garneau et al. 2016; Gomes et al. 2022). Oil becomes encapsulated in sea ice over a matter of days and begins to migrate upwards through sea ice in brine channels when temperatures begin to warm, eventually appearing on the surface of the sea ice (NORCOR 1975; Dome Petroleum 1981). Movement through brine channels can occur rapidly when temperatures are warm enough (NORCOR 1975). There was no observed difference in sea ice growth rate when oil was encapsulated in the ice, unless significant pools were present (Fingas and Holleborne 2003). However, Glaeser and Vance (1971) found that oil on the ice surface absorbed 30% more heat from the sun than did ice and this corroborated a finding that oiled ice had half the albedo of unoiled ice (NORCOR 1975). Furthermore, oil on the surface of ice has been found to increase melt rates associated with reduced surface albedo (see Fingas and Hollebone 2014). It is suggested that oil can persist in this way on the upper surface of the ice for 2-5 melt seasons (Fingas and Holleborne 2003). As it relates to habitat function, Garneau et al. (2016) observed that microbial communities in sea ice and at the water-ice interface changed when exposed to hydrocarbons, favouring oil-degrading organisms. Additional negative effects on various trophic levels are expected due to avoidance behaviour (e.g., in adult fish; Lee et al. 2015) and the effects of repeated oil exposure on individual animals (e.g., internal lesions, cell and tissue abnormalities and organ dysfunction in marine mammals (Geraci and Smith 1976; Spraker et al. 1994; Ruberg et al. 2021; Takeshita et al. 2021). Thus, a significant change in the ability of sea ice to function as habitat over the long-term would be expected resulting in a score of 3.
Recovery Factors	2.0	Recovery factors for sea ice = mean of the factors listed below. <u>Growth rate (biogenic)/rate of structural rebuilding (abiotic)</u>: 2 (Sea ice refreezes during fall). <u>Resistance:</u> 2 (Sea ice is relatively hard and durable). <u>Regenerative potential:</u> 1 (Sea ice grows each year and any removal of it will be met by its replacement if temperatures are below freezing). <u>External stress:</u> 3 (Climate change adds to stress).
Consequence	5 (binned)	Consequence = Exposure x Sensitivity = 4 x 4 = Very high
Likelihood	1	Due to the robust oil spill prevention regime in this country, based on existing oil spill response frameworks and standards (WWF n.d.) and historical spill records, the probability of a large, accidental vessel discharge of petroleum product is very low in Canada (WSP 2014b; Lee et al. 2015). Though data are limited for Arctic waters, a fuel oil spill of 990 m^3 is estimated to occur every 920 years, with

Risk Factor	Score	Rationale
		larger spill volumes occurring more rarely (WSP 2014a). Thus, an oil spill of this nature is expected to occur in only exceptional circumstances.
Overall Risk	Moderately-High Risk	Management measures, such as the development of an oil spill emergency response plan that includes a sampling program, should be considered.
Uncertainty		
Exposure	4	Spill modeling should be conducted for the Roes Welcome Sound priority area to better understand the fate of a large, accidental petroleum-product release via vessel discharge during different times of year.
Sensitivity	4	There is a little scientific information available regarding impact of oil spills on ice within the Roes Welcome Sound priority area.
Likelihood	4	Large oil spill return period estimates exist for the Canadian Arctic, including the study area, though uncertainty remains due to a lack of historic spill data.

5.5.4 Contaminants (Scrubber Effluent)

As of 1 January 2020, in an effort to reduce harmful air emissions from vessels, the *Vessel Pollution and Dangerous Chemicals Regulations* (2012) limits the sulphur content of marine fuels to 0.5%. Alternatively, vessels can employ exhaust gas cleaning systems, or scrubbers, to ensure an equivalent reduction in sulphur content in emitted exhaust. These scrubbers use large volumes of seawater in their operation, and the output is cleaning residue and wash water. Though the residue must be offloaded at a shore facility, the wash water can be discharged at sea and may contain pollutants such as PAHs and heavy metals, including arsenic, lead, cadmium, copper, mercury, nickel, vanadium, and zinc (Kjøholt et al. 2012; Lange 2015; Teuchies et al. 2020); these contaminants can be harmful to the marine environment (Lange 2015). Though research on the impacts of scrubber effluent on the marine environment is limited, especially in the Arctic context, initial findings indicate that certain ESC subcomponents may be impacted. In direct exposures to scrubber effluent, Koski et al. (2017) observed uptake of certain compounds into a microalgal species eaten by copepods and impacts on the growth rates of these species. Considering the information outlined above, phytoplankton were assessed (Table 5-94) and acted as a proxy for the assessment of zooplankton as discussed in Section 3.0.

Table 5-94. Vessel Discharge − Contaminants: ESC Subcomponents and Priority Areas Assessed.

ESC Subcomponent	Priority Area	Assessed by Proxy
Phytoplankton	Chesterfield Inlet/Narrows	
Zooplankton		Via phytoplankton

Risk Statement: If an interaction occurs involving phytoplankton and scrubber effluent discharged from a vessel the consequence could result in a negative impact on phytoplankton populations in the Chesterfield Inlet/Narrows priority area.

Table 5-95. Phytoplankton – Vessel Discharge (Chesterfield Inlet/Narrows) – Contaminants (Scrubber Effluent).

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 3 x 4 = 12 (raw score)
Intensity	1	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low absolute density of vessel traffic. Vessel traffic in

Risk Factor	Score	Rationale
		the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Chesterfield Inlet/Narrows priority area experiences a high density of vessel traffic relative to other portions of the AOI (see Figures 5-1 and 5-10) representing approximately 61% of total AIS data within the AOI from 2012-2019. The intensity of vessel traffic and the resulting stressor is not uniform, and the density would be higher in areas of higher vessel traffic (e.g., near regular anchorage areas at Helicopter Island or near Chesterfield Inlet). Vessels that utilize exhaust gas cleaning systems/scrubbers to reduce sulfur output are permitted to discharge wash water (i.e., scrubber effluent) at sea. It is not expected that vessels will be discharging scrubber effluent constantly. Considering the low density of vessel traffic and discharge occurring occasionally, intensity was scored as 1.
Temporal	3	Phytoplankton may occur in the Chesterfield Inlet/Narrows priority area year-round; however, phytoplankton abundance/density is significantly greater during open-water periods and the spring bloom relative to other times of year (Matthes et al. 2021). Matthes et al. (2021) found that the highly abundant sub ice diatom, *Melosira arctica,* plays an important role in local primary production. The area that encompasses the mouth of the Chesterfield Inlet/Narrows priority area is part of the northwestern polynya of the Hudson Bay that has been known to be the largest contributor to annual production in Hudson Bay (Matthes et al. 2021). Vessels are typically present in the priority area during July to September, and occasionally during June (Maerospace 2020), though they may not be present throughout that entire period. For the purposes of this risk assessment, scrubber effluent discharge is presumed possible any time vessels are present in the priority area though is not expected that vessels will be discharging scrubber effluent constantly. To account for overlap during the time of the year with highest phytoplankton densities (i.e., summer open water period), a score of 3 was assigned.
Spatial	4	Spatial = Areal x Depth = 2 x 2 = 4
Areal	2	Phytoplankton are expected to be distributed throughout the Chesterfield Inlet/Narrows priority area, though localized areas of higher density are likely. Scrubber effluent from vessel discharge could be transported beyond the vessel's immediate location via water currents and winds, but the greatest concentration of contaminants would be localized, thereby overlapping a small portion of the total phytoplankton range in the priority area resulting in a score of 2.
Depth	2	Phytoplankton are limited to the euphotic zone, which is generally limited to the upper ~200 m of open marine water in sub-tropical regions (WHOI 2022) but is restricted to the upper approximately 50 m in Hudson Bay (Matthes et al. 2021). Scrubber effluents are less dense than seawater and, therefore, will occur at its highest concentration near the air-sea interface, attenuating with depth. Scrubber effluents are anticipated to occur over a small to moderate portion of the depth range of phytoplankton in the Chesterfield Inlet/Narrows priority area; thus, depth was scored as 2.
Sensitivity	2 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (2 + 2) x 1.5 = 6.0
Acute Change	2	Scrubber wash water is acidic and contains a mixture of contaminants including PAHs, and heavy metals, such as arsenic, lead, cadmium, copper, mercury,

Risk Factor	Score	Rationale
		nickel, vanadium, and zinc (Kjøholt et al. 2012; Lange 2015; Teuchies et al. 2020). The complex mixtures of contaminants and generally low pH of scrubber effluent could have synergistic effects on biota (Koski et al. 2017). Although there has been very little direct research on the environmental effects of scrubber effluent, there is a large body of evidence showing effects of other petroleum-based contaminants discharged into marine environments, as well as *in vitro* evidence of effects of many individual chemical compounds that are contained in scrubber effluent (Endres et al. 2018). Although little is known regarding the interaction between Arctic phytoplankton and scrubber effluent, some taxa are known to be capable of metabolizing n-alkanes, isoalkanes, aromatic hydrocarbons, and/or naphthalene (Das and Chandran 2011; Garneau et al. 2016). Some phytoplankton species may be tolerant of high lead levels from scrubber effluent discharge and could potentially benefit from the mortality of lead-intolerant grazers (Endres et al. 2018). A significant increase in chlorophyll *a*, particulate organic phosphorus, carbon, and nitrogen were observed when a Baltic Sea microplankton community was experimentally exposed to 10% scrubber effluent for 13 days; the filamentous cyanobacteria *Nodularia spumigena* responded with a decrease in photosynthesis while the chain-forming diatom *Melosira arctica* exhibited increased primary productivity, further supporting species-specific responses to scrubber effluent discharge (Ytreberg et al. 2019). Growth rates for *Rhodomonas* spp. phytoplankton were nil for cultures exposed to 100% scrubber effluent (Koski et al. 2017). Ytreberg et al. (2021) experimentally exposed *in situ* Baltic Sea microplankton to scrubber effluent of 1%, 3%, and 10% concentrations for 14 days during a summer bloom and observed significant increases in biovolume for diatoms, flagellates *Incertae sedis*, chlorophytes, and ciliates, while there was no effect on cyanobacteria. An acute response to exposure to scrubber effluent from vessel discharge may include a measurable localized change in mortality rates against background variability and/or reduced biomass of some phytoplankton species (Fiala and Delille 1999) and an increase in abundance for taxa capable of metabolizing scrubber effluent products, resulting in a score of 2.
Chronic Change	2	Aquatic organisms can be subject to toxic effects from compounds in scrubber effluent released via vessel discharge (Lee et al. 2015; Endres et al. 2018; Honda and Suzuki 2020). Biodegradation of organic contaminants, such as those contained in scrubber effluent, occurs slowly in cold water environments and is limited by nutrient availability, and dispersion and evaporation are slow processes in cold/icy seawater (Gomes et al. 2022). Some phytoplankton species may be tolerant of high lead levels from scrubber effluent discharge and could potentially benefit from the mortality of lead-intolerant grazers (Endres et al. 2018), which could result in a long-term decrease in abundance of intolerant species and/or a shift in community composition towards scrubber effluent-tolerant species. Perturbation studies examining the effects of PAH addition observed decreased phytoplankton growth rates, particularly on picophytoplankton such as *Prochlorococus* sp. and *Synechococcus* sp. (Endres et al. 2018). Based on the above information there could be a measurable change to overall fitness compared with background variability or impacts on population dynamics, resulting in a score of 2.
Recovery Factors	1.5	Recovery Factors = mean of the factors listed below. Growth rate (biogenic)/rate of structural rebuilding (abiotic): 1 (A phytoplankton bloom can develop rapidly when irradiance conditions are favourable and last until growth becomes limited by factors such as nutrient supply. Increased irradiance due to snow melt during June 2014 allowed phytoplankton under ice cover in Arctic waters of the Beaufort Sea/Barrow Canyon/Hanna Shoal to experience a bloom within approximately one week, with increased growth rates continuing for nearly two weeks before being halted by nutrient limitation [Hill et al. 2018]).

Risk Factor	Score	Rationale
		Resistance: 1 (As the base of the marine food chain, phytoplankton are subject to regular biological disturbance in the form of predation by herbivorous grazers. During a spring bloom in 2011, phytoplankton communities in Disko Bay, West Greenland were observed to experience high mortality [up to 0.58 d^{-1}] from herbivorous predators [Menden-Deuer et al. 2018]. In polar waters, phytoplankton biomass appears to experience more intense fluctuations due to natural factors, such as temperature changes, than to continual grazing losses [Menden-Deuer et al. 2018]. Regenerative potential: 2 (Phytoplankton communities go through seasonal succession in terms of species composition/biomass and they also adapt to seasonally changing environmental conditions, particularly temperature, light, and/or nutrients [e.g., Lewis et al. 2019]. Arctic phytoplankton from West Greenland experienced significantly greater growth rates at higher temperatures during short-term- temperature change incubation experiments and did not exhibit any growth rate limitations at low temperatures [Menden-Deuer et al. 2018]. Arctic phytoplankton are adapted to function in even extreme low-light conditions; during 2017-2019, net phytoplankton growth occurred under complete ice cover as early as February in Baffin Bay, which is ice-covered during seven months of the year [Randelhoff et al. 2020]. Such adaptations would compensate for biota loss from disturbance at discrete locations). External Stress: 2 (Climate change is a major stressor for primary producers in the Arctic, as loss of snow cover and/or ice results in drastic increases in the transmission of surface irradiance to the water column which can quickly trigger phytoplankton growth [Hill et al. 2018] and may shift community composition towards taxa more tolerant of increased light levels. Thinning Arctic ice has increased the occurrence of favourable conditions for the formation of under-ice phytoplankton blooms [Hill et al. 2018]. Recent studies indicate that Arctic phytoplankton growth can now sustainably begin underneath seasonal ice cover, in some instances as deep as 100 km from the ice edge [Hill et al. 2018]).
Consequence	2 (binned)	Consequence = Exposure x Sensitivity = 2 x 2 = Low
Likelihood	3	An interaction could occur between scrubber effluent discharged by vessels and phytoplankton taxa that are intolerant of the discharge products or taxa that may be able to metabolize them (e.g., Das and Chandran 2011; Garneau et al. 2016; Koski et al. 2017). An interaction may not occur for phytoplankton taxa that are simply tolerant of scrubber effluent (e.g., Endres et al. 2018). An interaction may occur in some but not all circumstances.
Overall Risk	Moderate Risk	Additional management measures should be considered, such as limitations on permissible vessel discharges and the development of a phytoplankton sampling and monitoring program.
Uncertainty		
Exposure	4	General vessel traffic patterns are known and were used to inform vessel discharge exposure parameters. Primary productivity and the phytoplankton community have recently been studied and there are pockets of high primary productivity in Repulse Bay and Frozen Strait, Roes Welcome Sound, and Chesterfield Inlet (Matthes et al. 2021; Kitching 2022). Uncertainty is high.
Sensitivity	5	Little scientific information exists for the effects of scrubber effluent on phytoplankton. Information on primary productivity and the phytoplankton community has been researched recently and has found high primary productivity in Frozen Strait and Repulse bay, Roes Welcome Sound, and Chesterfield Inlet (DFO 2020; Loewen et al. 2020b; Matthes et al. 2021; Kitching 2022). There is little scientific information available examining the sensitivity of phytoplankton to scrubber effluent outside of laboratory conditions.

Risk Factor	Score	Rationale
Likelihood	5	Research is needed on the response of Arctic phytoplankton to scrubber effluent released via vessel discharge and the parameters that contribute to an interaction.

5.5.5 Atmospheric Emissions

Emissions from marine vessels include carbon dioxide, black carbon, sulfur oxides, nitrogen oxides, particulate matter, heavy metals, volatile organic compounds, and ozone-depleting compounds (Eyring et al. 2005; Corbett et al. 2010; Poplawski et al. 2011). Some of these compounds reside in the air for a short time and are then absorbed at the ocean surface (Endres et al. 2018) or are deposited onto sea ice and terrestrial environments through precipitation or dry deposition (Aksoyoglu et al. 2016; Raut et al. 2016).

The incomplete combustion of diesel fuels results in the release of particulate matter, including black carbon (Arctic Council 2009). The release and deposition of black carbon that falls with precipitation has been identified as a particular concern in the Arctic because it has been shown to reduce the albedo of snow and sea ice and accelerate ice melt rates (Quinn et al. 2008; Arctic Council 2009; Eckhardt et al. 2013; Meinander et al. 2013). Shipping is a significant source of black carbon in the Arctic (European Commission 2021). The quality of fuel burned by marine vessels varies and affects the composition of atmospheric emissions. For instance, heavy fuel oil produces significantly higher black carbon emissions than lighter fuels (International Maritime Organization [IMO] 2015). Additionally, Lack and Corbett (2012) stated that vessels operating in Arctic waters can emit up to 50% more black carbon when encountering challenging sea and ice conditions than under regular sea conditions, due to the increased emission of black carbon under very low or variable engine loads. Most of the fuel burned by large vessels in the Arctic is currently heavy fuel oil. New regulations intended to limit heavy fuel oil use by Arctic vessels were introduced by the IMO in 2021; however, their implementation is expected to be phased in over a decade and there are concerns from the Inuit Circumpolar Council, some Arctic countries, and environmental non-government organizations (ENGOs) that these regulations will be insufficient to mitigate the disproportionate impact black carbon has on Arctic warming (Koperqualuk and Ell-Kanayuk 2022). Emissions Control Areas (ECAs) exist around the world, where fuel quality and emissions standards are more environmentally stringent; however, the North American Emissions Control Area does not include the AOI or other Arctic waters (US EPA 2010). Given that there is concern about the timeliness and effectiveness of new IMO fuel content regulations, vessels traveling in and near the AOI will continue to be a source of black carbon. Polynya habitat was assessed as it contains features that may be susceptible to decreased albedo (i.e., sea ice). Reduced albedo associated with black carbon can also affect sea ice that is not associated with a polynya; therefore, this interaction was assessed (Table 5-96).

Table 5-96. Vessel Discharge − Atmospheric Emissions: ESC Subcomponents and Priority Areas Assessed.

ESC Subcomponent	Priority Area	Assessed by Proxy
Polynya habitat	Chesterfield Inlet/Narrows	
Sea ice	Roes Welcome Sound	

Risk Statement: If an interaction occurs involving polynya habitat and black carbon emissions discharged by vessels the consequence could result in a negative impact on the ecosystem function of polynya habitat in the Chesterfield Inlet/Narrows priority area.

Table 5-97. Polynya Habitat – Vessel Discharge (Chesterfield Inlet/Narrows) – Atmospheric Emissions.

Risk Factor	Score	Rationale
Exposure	1 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 2 = 2 (raw score)
Intensity	1	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low absolute density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Chesterfield Inlet/Narrows priority area experiences a high density of vessel traffic relative to other portions of the AOI (see Figures 5-1 and 5-10) representing approximately 61% of total AIS data within the AOI from 2012-2019. The intensity of vessel traffic and the resulting stressor is not uniform, and the density would be higher in areas of higher vessel traffic (e.g., near regular anchorage areas at Helicopter Island or near Chesterfield Inlet). Vessels emit particulate matter containing black carbon, which may be deposited on snow, ice, and open water in the Western Hudson Bay polynya at the mouth of Chesterfield Inlet. The Canadian Arctic is not within an Emission Control Area (US EPA 2010), so as of 2022, heavy fuel oil is allowed as a primary fuel for vessels in the area. Heavy fuel oil typically generates higher black carbon emissions than lighter marine diesels (IMO 2015), and vessels emit greater concentrations of black carbon during active icebreaking (Lack and Corbette 2012). Despite the lack of regulations controlling fuel content and emissions criteria, the low density of vessel traffic that occurs when the polynya is formed results in an intensity score of 1.
Temporal	1	The Western Hudson Bay polynya in the Chesterfield Inlet/Narrows priority area opens up in December and merges with adjacent open water during summer (Gunn 2014). Vessels are typically present in the priority area during July to September, and occasionally during June (Maerospace 2020), though they may not be present throughout that entire period. As vessel traffic mainly occurs during summer to fall and the polynya occurs from December through late June/early July, there would be very little temporal overlap (<25%) between vessels and the polynya. This results in a score of 1.
Spatial	2	Spatial = Areal x Depth = 1 x 2 = 2
Areal	1	The Western Hudson Bay polynya is a recurring coastal polynya that reforms annually along the coast within the Chesterfield Inlet/Narrows priority area and is characterized by the recurrence of lower sea ice concentration and extent, and surface wind forcing (DFO 2020a; Bruneau et al. 2021). During summer, when the ice melts, this open water area merges with open water in the rest of region. Vessel traffic actively avoids the area during the time the polynya persists (DFO 2024). Therefore, deposition of black carbon from vessels would overlap a few restricted locations of polynya habitat resulting in a score of 1.
Depth	2	The melting of sea ice driven by black carbon deposition is expected to affect a relatively large proportion of the overall thickness of sea ice in polynya habitat, resulting in a score of 2.
Sensitivity	1 (binned)	Sensitivity = (Acute change + Chronic Change) x Recovery Factors = (1 + 1) x 2.0 = 4.0

Risk Factor	Score	Rationale
Acute Change	1	Emissions from vessels include carbon dioxide, black carbon, sulfur oxides, nitrogen oxides, particulate matter, heavy metals, volatile organic compounds, and ozone-depleting compounds (Eyring et al. 2005; Corbett et al. 2010; Poplawski et al. 2011). Some of these compounds stay in the air for a short period and are then absorbed at the ocean surface (Endres et al. 2018), which can affect water quality. Other compounds are deposited onto sea ice through precipitation or dry deposition. Shipping is a major source of overall black carbon in the Arctic (European Commission 2021); the incomplete combustion of diesel fuels results in the release of particulate matter, such as black carbon (Arctic Council 2009). The release and deposition of black carbon is of concern in the Arctic because it can reduce the albedo of snow and sea ice and accelerate the rate at which the ice melts (Quinn et al. 2008; Arctic Council 2009; Eckhardt et al. 2013; Meinander et al. 2013). The quality of fuel used by vessels varies, with heavy oil producing significantly higher black carbon emissions than lighter fuels (IMO 2015); most of the fuel burned by large vessels in the Arctic is heavy fuel. Though the discharge of black carbon is known to negatively impact sea ice and would be concerning if the level of vessel traffic were to increase in the future, the current low level of vessel traffic results in a score of 1.
Chronic Change	1	International regulations are being implemented in a phased approach, but there is concern that they may not be effective at mitigating the effects of heavy fuels in the Arctic within the expected time frame (Koperqualuk and Ell-Kanayuk 2022). Lack and Corbett (2012) reported that vessels in the Arctic can emit up to 50% more black carbon when icebreaking than while underway in regular sea conditions. Since sea ice (and therefore, polynyas) grows and melts over an annual cycle, localized and temporally-confined activities impacting the ice should not have a long-lasting impact. Based on current vessel intensity in polynya habitat within the priority area and the annual recurrence of sea ice, chronic change from black carbon emissions is not expected to be measurable, resulting in a score of 1.
Recovery Factors	2.0	Recovery factors = mean of the factors listed below based on ice. <u>Growth rate (biogenic)/rate of structural rebuilding (abiotic):</u> 2 (Sea ice can regenerate each year starting in fall). <u>Resistance:</u> 2 (All ice and snow is susceptible to decreased albedo from black carbon deposition; landfast (first-year) ice is more susceptible to decreased albedo from black carbon than multi-year ice [Marks and King 2014]). <u>Regenerative potential:</u> 1 (Ice can regenerate annually). <u>External stress:</u> 3 (Climate change adds to stress).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 1 x 1 = Negligible
Likelihood	3	An interaction has the potential to occur when black carbon emissions from vessels are deposited on sea ice and the sea surface in polynya habitat. An interaction may occur in some but not all circumstances.
Overall Risk	Low Risk	No additional management actions need to be considered at this time.
Uncertainty		
Exposure	4	General vessel traffic patterns are known and were used to inform vessel discharge exposure parameters. Some investigation has occurred regarding the spatial and temporal occurrence of the Western Hudson Bay polynya. Modeling for vessel atmospheric emissions should be conducted for polynya habitat to better understand pollution concentrations at various temporal and spatial scales in the Arctic environment. The uncertainty is high.

Risk Factor	Score	Rationale
Sensitivity	5	There is little scientific information available regarding the impact of vessel air emissions on sea ice and the sea surface within polynya habitat, though some is available from other areas. The uncertainty is very high.
Likelihood	4	Research is needed on vessel air emission and black carbon effects on sea ice and the sea surface, though some has occurred in other areas. The uncertainty is high.

Risk Statement: If an interaction occurs involving sea ice and black carbon emissions discharged by vessels the consequence could result in a negative impact on the ecosystem function of sea ice habitat in the Roes Welcome Sound priority area.

Table 5-98. Sea Ice – Vessel Discharge (Roes Welcome Sound) – Atmospheric Emissions.

Risk Factor	Score	Rationale
Exposure	1 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 2 = 4 (raw score)
Intensity	1	It should be noted that relative to other areas that experience shipping and vessel traffic in Canada and worldwide and for which biological effects literature is largely based, the AOI receives a low absolute density of vessel traffic. Vessel traffic in the AOI consists of oil/chemical, cargo/supply, tug, military/patrol, icebreaker, passenger/pleasure, research, and bulk carrier vessels (Maerospace 2020). An increase in the transmission frequency of AIS messages indicates that vessel traffic has been increasing in recent years (Maerospace 2020; Figures 5-2 to 5-9), a trend corroborated by others (Dawson et al. 2018). The Roes Welcome Sound priority area experiences a low density of vessel traffic relative to other portions of the AOI (see Figure 2 in Maerospace 2020) representing <1% of total AIS data within the AOI from 2012-2019. Vessels emit particulate matter containing black carbon, which may be deposited on snow, ice, and open water in the Roes Welcome Sound priority area. The Canadian Arctic is not within an Emission Control Area (US EPA 2010), so as of 2022, heavy fuel oil is allowed as a primary fuel for vessels in the area. Heavy fuel oil typically generates higher black carbon emissions than lighter marine diesels (IMO 2015), and vessels emit greater concentrations of black carbon during active icebreaking (Lack and Corbett 2012). Despite the lack of regulations controlling fuel content and emissions criteria, the low density of vessel traffic that occurs in the area when sea ice is present results in an intensity score of 1.
Temporal	1	Sea ice occurs in the Roes Welcome sound priority area from late fall through late spring (~8 months of the year). Vessels (with available AIS data) are typically present in the AOI during September and October and occasionally during August, with the entirety of June traffic occurring during a single voyage of a research vessel in 2018 (Maerospace 2020). Thus, there is little temporal overlap with sea ice, which would primarily form after vessels have left the area in fall, resulting in a score of 1.
Spatial	2	Spatial = Areal x Depth = 1 x 2 = 2
Areal	1	Sea ice occurs throughout the Roes Welcome Sound priority area for ~8 months of the year consisting of landfast ice and mobile pack ice. Additionally, an ice arch also forms across Roes Welcome Sound south of Wager Bay every ~4 years. Given vessel traffic patterns, deposition of black carbon from vessels

Risk Factor	Score	Rationale
		would overlap a few restricted locations of the sea ice extent, resulting in a score of 1.
Depth	2	The melting of sea ice driven by black carbon deposition is expected to affect a relatively large proportion of the overall thickness of sea ice in the Roes Welcome Sound priority area, resulting in a score of 2.
Sensitivity	1 (binned)	Sensitivity = (Acute change + Chronic Change) x Recovery Factors = (1 + 1) x 2.0 = 4.0
Acute Change	1	Emissions from vessels include carbon dioxide, black carbon, sulfur oxides, nitrogen oxides, particulate matter, heavy metals, volatile organic compounds, and ozone-depleting compounds (Eyring et al. 2005; Corbett et al. 2010; Poplawski et al. 2011). Some of these compounds stay in the air for a short period and are then absorbed at the ocean surface (Endres et al. 2018) or they are deposited onto sea ice through precipitation or dry deposition. Shipping is a major source of overall black carbon in the Arctic (European Commission 2021); the incomplete combustion of diesel fuels results in the release of particulate matter, such as black carbon (Arctic Council 2009). The release and deposition of black carbon is of concern in the Arctic because it can reduce the albedo of snow and sea ice and accelerate the rate at which the ice melts (Quinn et al. 2008; Arctic Council 2009; Eckhardt et al. 2013; Meinander et al. 2013). The quality of fuel used by vessels varies, with heavy oil producing significantly higher black carbon emissions than lighter fuels (IMO 2015); most of the fuel burned by large vessels in the Arctic is heavy fuel. Though the discharge of black carbon is known to negatively impact sea ice and would be concerning if the level of vessel traffic were to increase in the future, the current low level of vessel traffic results in a score of 1.
Chronic Change	1	International regulations are being implemented in a phased approach, but there is concern that they may not be effective at mitigating the effects of heavy fuels in the Arctic within the expected time frame (Koperqualuk and Ell-Kanayuk 2022). Lack and Corbett (2012) reported that vessels in the Arctic can emit up to 50% more black carbon when icebreaking than while underway in regular sea conditions. Since sea ice grows and melts over an annual cycle, localized and temporally-confined activities impacting the ice should not have a long-lasting impact. Based on current vessel intensity in the priority area and the annual recurrence of sea ice, chronic change from black carbon emissions is not expected to be measurable, resulting in a score of 1.
Recovery Factors	2.0	Recovery factors = mean of the factors listed below. Growth rate (biogenic)/rate of structural rebuilding (abiotic): 2 (Sea ice can regenerate each year starting in fall). Resistance: 2 (All ice and snow is susceptible to decreased albedo from black carbon deposition; landfast (first-year) ice is more susceptible to decreased albedo from black carbon than multi-year ice [Marks and King 2014]). Regenerative potential: 1 (Can regenerate annually). External stress: 3 (Climate change adds to stress).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 1 x 1 = Negligible
Likelihood	3	An interaction has the potential to occur when black carbon emissions from vessels are deposited on sea ice. An interaction may occur in some but not all circumstances.
Overall Risk	Low Risk	No additional management actions need to be considered at this time.
Uncertainty		

Risk Factor	Score	Rationale
Exposure	4	General vessel traffic patterns are known and were used to inform vessel discharge exposure parameters. Some investigation has occurred regarding the spatial and temporal occurrence of sea ice in the priority area. Modeling for vessel atmospheric emissions should be conducted for the Roes Welcome Sound priority area to better understand pollution concentrations at various temporal and spatial scales in the Arctic environment. The uncertainty is high.
Sensitivity	5	There is little scientific information available regarding the impact of vessel air emissions on sea ice within the Roes Welcome Sound priority area, though some is available from other areas. The uncertainty is very high.
Likelihood	4	Though some literature exists on the topic, additional research is needed on vessel air emission and black carbon effects on sea ice. The uncertainty is high.

6.0 Submarine Cables

Submarine cables are installed on the seafloor to enable telecommunications or the transfer of electricity across ocean spaces. In general, each cable has an expected lifespan of 20-25 years (Carter et al. 2014). With the increased reliance on digital media, a desire for faster and more reliable service has resulted in a greater number of submarine cable projects, and demand is still growing (Oslo/Paris Convention for the Protection of the Marine Environment of the North-east Atlantic [OSPAR] Commission 2008). Within the AOI, no submarine cables have been installed, although a proposed fibre optic cable linking the communities of western Hudson Bay, including Chesterfield Inlet and Coral Harbour, with a high-speed network is in the early planning stages.

Telecommunications cable technology has improved since its inception, with a concurrent reduction in cable size; fiber optic technology is now used, and cables are approximately 2-5 cm in diameter (OSPAR Commission 2008). In comparison, power cables, used to transfer electricity from offshore installations to the terrestrial electricity grid or across relatively shorter oceanic stretches, are generally thicker, up to 15 cm in diameter (OSPAR Commission 2008). Before installation, proponents undertake a series of surveys (e.g., side-scan sonar, Remotely Operated Vehicle [ROV] video transects, geophysical) to explore possible routes and the physical or ecological impediments that may be encountered (Kraus and Carter 2018). Where possible, routes are planned with an attempt to avoid hard substrate, steep slopes, boulder fields, and ecologically sensitive areas (NOAA 2018). Submarine cables can be installed using different methods. For deeper-water installations located beyond the reach of human activities that might interact with the cables (e.g., vessel anchoring or fishing gear deployment), cables may be laid directly on the seabed without burying. Alternatively, and in shallower waters where cables may be exposed to fishing gear or anchors, cables are routinely buried. This can occur using a variety of methods, including a tread-mounted plough pulled behind a vessel, or by spraying streams of water (i.e., water jetting) from a tread-mounted vehicle or ROV. They may also be installed using a tread-mounted rock-cutting wheel or chain excavator, although this method is more expensive and laborious, and routes are often chosen to avoid hard substrates (Kraus and Carter 2018). Before the cable itself is buried, a pre-lay grapnel run is often conducted. This consists of a grapnel towed along the route to clear any obstructions; the grapnel can penetrate the sediment to a depth of 0.5-1 m (Carter et al. 2014), disturbing bottom sediments and bottom-dwelling organisms (CSRIC 2014; NOAA 2018).

Though rare, repairs may need to be conducted throughout the lifespan of a cable. This process may cause similar impacts to the marine environment as the initial installation. For example, this activity may require the use of a grapnel for cutting and/or collecting the cable during repair. Once the damaged portion of the cable is located, a cut is made and each end is brought to the water surface, resulting in a length of cable being removed and disturbing sediment and organisms that may have recolonized the area after initial installation (Carter et al. 2014; NOAA 2018). After repairs, extra cable (generally twice the water depth) is used to splice the cut ends together and the damaged cable needs to be re-buried or re-laid back in place (CSRIC 2014). This extra cable is installed in a loop extending from the original path and thus requires more trenching for buried sections (NOAA 2018).

The process of laying submarine cable can also cause an increase in suspended sediments with the level of impact on the benthic biota dependent on the method used to bury the cable, sediment type, habitat, and the ability of the biota to respond to periods of high turbidity (Kraus and Carter 2018). Ploughing produces less suspended sediment when compared to jetting, and mud/clay substrates may produce larger plumes compared with coarser substrates that settle more quickly, such as sand and gravel. The sediment mobilized by ploughing generally falls back in place and covers the cable. Although research has not examined mortality linked to sediment suspension during ploughing, it is expected that effects will be negligible to the benthic community (BERR 2008; Kraus and Carter 2018). Though not focused on the Arctic environment, modelling has suggested that typical cable burial activities can increase suspended sediment levels in the water column up to 50 mg/L, with higher concentrations (>100 mg/L) of sedimentation lasting <2 hours. These effects were reduced with distance from the site of burial and approached background levels beyond 100 m (Swanson and Isaji 2006). The authors emphasized that the background level of suspended sediment is important to consider and that organisms may regularly interact with heightened sediment levels over short time periods due to natural processes (e.g., storms and tidal currents).

Submarine cable installation and maintenance occurs rarely (perhaps a few times per decade), so noticeable increases in the general effects of vessel traffic are not expected and are covered by analyses conducted in the section on shipping and vessel traffic (Section 5.0).

6.1 Acoustic Surveying – Noise Disturbance

Prior to cable installation, a corridor where the cable will be installed is surveyed to determine bottom type and obstructions. Multibeam echo sounder (MBES), sub-bottom profiler, and side-scan sonar are commonly used survey methods and though the particular frequency range varies by instrument these sources produce high frequency sounds (MacGillivray et al. 2014). It is expected that these surveys would occur in the summer months for logistical reasons. These sound sources may affect marine mammals depending on their auditory range (Southall et al. 2019). Bowhead whales, whose auditory range covers low frequency sound (i.e., 0.02-6 kHz; Southall et al. 2019), migrate through a possible survey route (i.e., through Fisher and Evans Straits and to Chesterfield Inlet) in late summer, and may feed, calve, and rest along the southeast coast of Southampton Island, so were assessed (Table 6-1). Narwhals feed and likely rear calves in Chesterfield Inlet in the summer (Higdon 2017; Roff et al. 2020) and were assessed. Beluga also occur in the area; however, the majority are expected to not remain in the AOI over summer and known calving areas are more towards the north side of Southampton Island (i.e., Duke of York Bay, East Bay) for this species instead of along a possible survey route. As belugas and narwhals are closely related odontocetes, and narwhals are expected to use the area along a possible survey route for rearing in addition to feeding and migration, the risk is expected to be greater to narwhals and that assessment covered belugas by proxy. Ringed and bearded seals were also assessed. Fishes in the family Gadidae are known to use sound in communication and reproduction (Popper and Hawkins 2019) and demonstrate sensitivity to vessel noise (Stanley et al. 2017). Arctic cod were chosen for assessment, acting as a proxy for other forage fish and Arctic char. Though seabirds have known sensitivities to noise disturbance, acoustic surveys will predominantly generate sound underwater and the effects on seabirds are not expected to be measurable; therefore, they were not assessed.

Table 6-1. Acoustic Surveys − Noise Disturbance: ESC Subcomponents and Priority Areas Assessed.

ESC Subcomponent	Priority Area	Assessed by Proxy
Arctic cod	Fisher and Evans Straits	
Arctic char		Via Arctic cod
Other forage fish		Via Arctic cod
Ringed seal	Fisher and Evans Straits	
Bearded seal	Fisher and Evans Straits	
Walrus	Fisher and Evans Straits	
Beluga		Via narwhal

ESC Subcomponent	**Priority Area**	**Assessed by Proxy**
Narwhal	Chesterfield Inlet/Narrows	
Bowhead whale	Fisher and Evans Straits	

Risk Statement: If an interaction occurs involving Arctic cod and noise disturbance from acoustic surveying associated with submarine cables the consequence could result in a negative impact on Arctic cod populations in the Fisher and Evans Straits priority area.

Table 6-2. Arctic cod – Submarine Cables (Fisher and Evans Straits) – Noise Disturbance from Acoustic Surveying.

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 6 = 6 (raw score)
Intensity	1	There could be future acoustic surveys (i.e., multibeam echo sounder, sub-bottom profiler, side-scan sonar) conducted in the Fisher and Evans Straits priority area in preparation for proposed submarine cable installation, including for Phase 3 of Quintillion Global Communication's Asia & Europe Subsea Fibre Optic Cable System, which may include the easternmost portion of the AOI (Quintillion 2022); the Kivalliq Hydro-Fibre Link if the project extends into marine areas between the mainland and Coral Harbour (Nukik Corporation 2023); and a submarine fibre optic system that would connect Iqaluit to Quebec, extending from east of the AOI into Coral Harbour and then southwest towards Chesterfield Inlet (DFO unpublished[17]; E. Devereaux, pers. comm., 2020). In general, submarine cable installation occurs rarely, perhaps a few times per decade. Thus, the number of acoustic surveys associated with submarine cables that may occur in the future in Fisher and Evans Straits priority area is likely to be low. Considering that the stressor would occur at low density and that sounds produced by multibeam echosounders typically dissipate quickly (i.e., have limited persistence; AECOM and Arctic Fibre Inc. 2013), an intensity score of 1 was assigned.
Temporal	1	Arctic cod are expected to occur in the area year-round. Acoustic surveys associated with submarine cables would most likely occur during summer when ice cover is at its lowest extent and vessel traffic is possible, approximately 7-8 weeks of the year. However, active days of surveying would not cover this entire period. Thus, there would be little temporal overlap (<25%) between the stressor and Arctic cod, resulting in a score of 1.
Spatial	6	Spatial = Areal x Depth = 2 x 3 = 6
Areal	2	A ubiquitous species, Arctic cod occupy coastal and offshore waters in areas with and without sea ice and are expected to be widespread throughout the Arctic Ocean (Coad and Reist 2018). Based on Loewen et al. (2020a), most records for Arctic cod within the AOI are for Evans Strait though Loewen et al. (2020b) also noted the occurrence of Arctic cod around small islands in Fisher Strait. If an acoustic survey associated with submarine cables were to be conducted in the Straits (e.g., between Chesterfield Inlet and Coral Harbour), it would occur along the entire linear cable route. Systems used during subsea cable surveys produce high-frequency sounds in a narrow beam and apart from side-scan sonars, sound is directed vertically downward. The combination of these two factors limits the horizontal propagation of noise to a matter of kilometers (Lurton and DeRuiter 2011). Considering the above, the area of overlap would be localized and occur

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[17] DFO. 2024. Southampton Island Area of Interest socio-economic overview report. 45 p. + annexes.

Risk Factor	Score	Rationale
		within a small proportion of the total Arctic cod range in the Fisher and Evans Straits priority area, resulting in a score of 2.
Depth	3	Arctic cod are widespread across the circumpolar Arctic, but they occur at different depths throughout the water column based on factors such as life history stage (e.g., Geoffroy et al. 2016), seasonal diet (e.g., Majewski et al. 2016) and light regime (e.g., Benoit et al. 2010). Noise from acoustic surveys would propagate in water and could potentially cover the entire depth range of Arctic cod in the Fisher and Evans Straits priority areas. This results in a score of 3.
Sensitivity	1 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (1 + 1) x 1.9 = 3.8
Acute Change	1	As with all members of the Gadidae family, Arctic cod have swim bladders positioned close to their ears, their hearing is more sensitive to a wider range of frequencies compared to other fish species that do not have a swim bladder; however, they are less sensitive than fish that have swim bladders linked to their ears (Popper and Hawkins 2019). Gadids are sensitive to sound pressure as well as particle motion, giving them the ability to locate sound sources and discriminate sounds against background noise (Popper and Hawkins 2019). Gadids can hear frequencies up to 500 Hz (Popper and Hawkins 2019), which overlap with low frequencies emitted by some acoustic surveys (e.g., airgun surveys) but not with higher frequencies emitted by most multibeam echo sounders, sub-bottom profilers, and side-scan sonars. The risk factors for using these types of acoustic devices are considered low with little to no impact (Boebel et al. 2005; Carter et al. 2014). Gadids also produce sounds (Riera et al. 2018). Fish use sound for mating behaviour and to communicate, avoid predators, and select habitat (see Popper and Hawkins 2019). Noise can impact fish behaviour, physiology, and hearing (Popper and Hawkins 2019), mask natural sounds and decrease communication space (e.g., Stanley et al. 2017; Pine et al. 2018), and impact spawning success (e.g., de Jong et al. 2018, 2020). Several studies have shown changes in behaviour and physiology of gadids exposed to noise, including reduced spawning success (e.g., Nedelec et al. 2015; Sierra-Flores et al. 2015; Ivanova et al. 2020), but most studies have been conducted on fish in laboratories, not free-ranging animals in natural conditions. It is noted that the acoustic survey technologies discussed here are similar to those used in fishfinders and if negative effects (e.g., avoidance) were demonstrated in a technology used to find fish, it would not have gone unnoticed (SCAR 2002). Although there could be limited behavioural impacts such as avoidance of acoustic surveys by Arctic cod, no mortality is expected and short-term harm was deemed to be insignificant or undetectable relative to naturally occurring mortality and behaviour, resulting in a score of 1.
Chronic Change	1	Noise can impact fish behaviour, physiology, and hearing (Popper and Hawkins 2019), and mask natural sounds and decrease communication space (e.g., Stanley et al. 2017; Pine et al. 2018). If critical life functions, such as spawning success (e.g., de Jong et al. 2018, 2020) are compromised by sound or avoidance responses result from sound, fitness consequences could result (Slabbekoorn et al. 2010). There is a risk that noise from acoustic surveys could mask Gadid sounds and interfere with the production and detection of important acoustic signals or cause behavioural changes such as avoidance, possibly leading to further impacts such as interruptions to spawning behaviour. Although long-term effects associated with reduced spawning success and prolonged avoidance are possible, this has not been shown to occur in naturally occurring environments where fish are able to swim away from loud sources.

Risk Factor	Score	Rationale
		Based on the low number of acoustic surveys expected in the Fisher and Evans Straits priority area and the limited overlap in frequency ranges between survey equipment and Gadids, no detectable changes to overall fitness or impact on population dynamics would be expected, resulting in a score of 1.
Recovery Factors	1.9	Recovery factors = mean of the factors listed below. Fecundity: 2 (Spawn only once in their lifetime with a relatively low number of eggs; between 9,000 to 21,000 eggs are produced, with an average of 11,900 per female [Cohen et al. 1990]). Early life stage mortality: 3 (R-selected species with high mortality [Coad and Reist 2018]). Recruitment pattern: 2 (Increased recruitment expected with climate change [LeBlanc et al. 2019]). Natural mortality rate: 1 (Mortality is high [Coad and Reist 2018]). Age at maturity: 2 (2-3 years for males and 3-4 years for females [Coad and Reist 2018]). Life stages affected: 3 (All life stages could potentially occur in the area). Population connectivity: 1 (Arctic cod range widely throughout the Arctic). Population status: 1 (IUCN classification is *least concern* [Fernandes et al. 2015], but population trend is unknown. Abundant in Arctic marine waters [Coad and Reist 2018]).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 2 x 1 = Negligible
Likelihood	3	An interaction has the potential to occur when Arctic cod and an acoustic survey are present at the same time in the Fisher and Evans Straits priority area and within close enough proximity for the noise to cause a disturbance to the animal. Gadids can hear frequencies up to 500 Hz (Popper and Hawkins 2019), which overlap with low frequencies emitted by some acoustic surveys (e.g., airgun surveys) but not with higher frequencies emitted by most multibeam echo sounders, sub-bottom profilers, and side-scan sonars. Depending on the behavioural state of the animal and the distance to the sound source, an interaction may occur in some but not all circumstances.
Overall Risk	Low Risk	No additional management actions need to be considered at this time.
Uncertainty		
Exposure	5	How noise may affect individuals and populations over different spatial and temporal scales is uncertain. General information exists regarding the distribution of Arctic cod, as well as some information specific to the priority area, though it is limited. The particular parameters of acoustic survey equipment (e.g., frequency) that might be used in the area are not known, which influences the exposure of animals to this stressor. Since little scientific information is available on the topic and assumptions were made from other areas, the uncertainty is very high.
Sensitivity	4	The impacts of anthropogenic noise on fish, including Arctic cod, are not well understood, in particular how particle motion rather than sound pressure may affect their behaviour and physiology (Popper and Hawkins 2018). In addition, most studies on fish hearing and sound production have focused on laboratory experiments and results may differ if experiments were conducted in natural settings (Popper and Hawkins 2019). However, there is widespread use of similar acoustic equipment (i.e., fishfinders) without known negative effects on fishes. Thus, the uncertainty is high.
Likelihood	5	Research is needed on the response of Arctic cod to noise from acoustic surveys, both in open water and ice-covered habitats. Responses of other Gadids to acoustic surveys that used airguns are variable and depend on the cod's behavioural state, life stage, distance from the sound source, and received sound

Risk Factor	Score	Rationale
		levels. Since little scientific information is available on the topic and assumptions were made from other areas, the uncertainty is very high.

Risk Statement: If an interaction occurs involving ringed seals and noise disturbance from acoustic surveying associated with submarine cables the consequence could result in a negative impact on the ringed seal population in the Fisher and Evans Straits priority area.

Table 6-3. Ringed Seal – Submarine Cables (Fisher and Evans Straits) – Noise Disturbance from Acoustic Surveying.

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 6 = 6 (raw score)
Intensity	1	There could be future acoustic surveys (i.e., multibeam echo sounder, sub-bottom profiler, side-scan sonar) conducted in the Fisher and Evans Straits priority area in preparation for proposed submarine cable installation, including for Phase 3 of Quintillion Global Communication's Asia & Europe Subsea Fibre Optic Cable System, which may include the easternmost portion of the AOI (Quintillion 2022); the Kivalliq Hydro-Fibre Link if the project extends into marine areas between the mainland and Coral Harbour (Nukik Corporation 2023); and a submarine fibre optic system that would connect Iqaluit to Quebec, extending from east of the AOI into Coral Harbour and then southwest towards Chesterfield Inlet (DFO unpublished[18]; E. Devereaux, pers. comm., 2020). In general, submarine cable installation occurs rarely, perhaps a few times per decade. Thus, the number of acoustic surveys associated with submarine cables that may occur in the future in Fisher and Evans Straits priority area is likely to be low. Considering that the stressor would occur at low density and that sounds produced by multibeam echosounders typically dissipate quickly (i.e., have limited persistence; AECOM and Arctic Fibre Inc. 2013), an intensity score of 1 was assigned.
Temporal	1	Ringed seals are expected to occur in the priority area year-round. Acoustic surveys associated with submarine cables would most likely occur during summer when ice cover is at its lowest extent and vessel traffic is possible, approximately 7-8 weeks of the year. However, active days of surveying would not cover this entire period. Thus, there would be little temporal overlap (<25%) between the stressor and ringed seals, resulting in a score of 1.
Spatial	6	Spatial = Areal x Depth = 2 x 3 = 6
Areal	2	Ringed seals are expected to be widely distributed throughout the priority area. If an acoustic survey associated with submarine cables were to be conducted in the priority area (e.g., between Chesterfield Inlet and Coral Harbour), in would occur along the entire linear cable route. Systems used during subsea cable surveys produce high-frequency sounds in a narrow beam and apart from side-scan sonars, sound is directed vertically downward. The combination of these two factors limits the horizontal propagation of noise to a matter of kilometers (Lurton and DeRuiter 2011). The area of overlap would be localized and occur within a small proportion of the total ringed seal range in the Fisher and Evans Straits priority area, resulting in a score of 2.
Depth	3	The maximum dive depth for ringed seals is >500 m (Ogloff et al. 2021). Depending on the routing of the acoustic survey in the priority area, ringed seals

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Risk Factor	Score	Rationale
		may be found throughout the water column. Noise from acoustic surveys would propagate through water and could potentially cover the entire depth range of ringed seals in the Fisher and Evans Straits priority areas. This results in a score of 3.
Sensitivity	1 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (1 + 1) x 2.3 = 4.6
Acute Change	1	Best estimates of the frequency range of ringed seal social calls in water are from 0.02-30 kHz (Southall et al. 2019). Behavioural audiometry data (i.e., direct measurements conducted in captivity) for this species indicates that the auditory range spans from <0.1 to >72.4 kHz (Southall et al. 2019). MBES produce sound at frequencies ranging from 12 to several hundred kHz with frequencies of 70-150 kHz for water depths over the continental shelf and higher frequencies for very shallow applications (Lurton and DeRuiter 2011). Seals are known to have a broad hearing range in water, and it is suggested that they would perceive sounds produced by MBES and demonstrate a response in some circumstances (Lurton and DeRuiter 2011; MacGillivray et al. 2014). Thus, there is overlap between the audible range of ringed seals and sounds produced by seafloor mapping equipment. There is little information on ringed or other seal behavioural response to acoustic surveys. During monitoring (14.3 hours of effort over two days) of a Canadian Hydrographic Service seafloor mapping program in the nearshore waters of the Canadian Beaufort Sea, a ringed seal was observed during operation of the side-scan sonar and sub-bottom profiler (MacGillivray et al. 2004); its behaviour was not reported. Modelling of sensation levels by MacGillivray et al. (2014) indicates that seals would likely respond to MBES and side-scan sonar only within 500 m from source. Based on the source levels and operational frequencies of acoustic survey equipment, there is limited risk that ringed seals could incur hearing impairment particularly if standard mitigation measures are implemented (e.g., MacGillivray et al. 2004; LGL Ltd. 2014). It is suggested that seals are at highest risk from equipment with an output below 50 kHz and that pathological effects are possible, though unlikely, as avoidance generally occurs before impacts are felt (SCAR 2002). It is possible that some of the acoustic survey equipment will operate above the frequencies that ringed seals can hear, particularly in shallower water depths (Lurton and DeRuiter 2011). Although there could be limited behavioural impacts such as avoidance of acoustic surveys by ringed seals, considering the incomplete overlap of frequency ranges, the limited behavioural effects noted where exposure does occur, expected lack of mortality, and existing mitigation measures, effects are deemed to be insignificant or undetectable relative to naturally occurring mortality and behaviour, resulting in a score of 1.
Chronic Change	1	Based on the low number of acoustic surveys expected in the Fisher and Evans Straits priority area and the limited behavioural effects on ringed seals (see *Acute Change*, above), no detectable changes to overall fitness or impact on population dynamics would be expected, resulting in a score of 1.
Recovery Factors	2.3	Recovery factors = mean of the factors listed below. Fecundity: 3 (Females typically give birth to one pup a year) Early life stage mortality: 2 (Reeves et al. 1992). Recruitment pattern: 2 (Recruitment is variable depending on prevailing environmental conditions [Ferguson et al. 2005; Stirling 2005; Chambellant et al. 2010]).

Risk Factor	Score	Rationale
		Natural mortality rate: 3 (Mortality rates have been reported low in adult ringed seals with survivorship of 0.89 for age 6+ seals. Survivorship of age 0+ seals is reported to be much lower [0.59] [Smith 1975; Reimer et al. 2019]). Age at maturity: 3 (Best estimate of the population-wide average age at maturity is 4-7 years old [in most areas; can range from 3-9; see COSEWIC 2019]). Life stages affected: 3 (All stages). Population connectivity: 1 (Ringed seals in the Canadian Arctic are known to move extensively to different arctic regions, regularly making annual journeys that are 1,000s of kilometers). Population status: 1 (Ringed seals are considered *special concern* by COSEWIC (2019) and are not listed under SARA. The COSEWIC report does not offer insight into population trend. Ringed seals are listed as *threatened* in the USA (related to potential habitat loss), *least concern* in Greenland, no listing in Russia, and *least concern* by IUCN.)
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 2 x 1 = Negligible
Likelihood	3	An interaction has the potential to occur when ringed seals and an acoustic survey are present at the same time in the Fisher and Evans Straits priority area and within close enough proximity for the noise to cause a disturbance to the animal. The frequency ranges of most MBES, sub-bottom profilers, and side-scan sonars overlap with the audible ranges of ringed seals. Depending on the behavioural state of the animal and the distance to the sound source, an interaction may occur in some but not all circumstances.
Overall Risk	Low Risk	No additional management actions need to be considered at this time.
Uncertainty		
Exposure	4	There is some information about ringed seal distribution and numbers for the Fisher and Evans Straits priority area. There is no known information describing the ranges at which ringed seals could perceive sounds from acoustic surveys such as MBES, though information exists pertaining to pinnipeds from other areas (Southall et al. 2019). The particular parameters of acoustic survey equipment (e.g., frequency) that might be used in the area are not known, which influences the exposure of animals to this stressor. Uncertainty is high.
Sensitivity	5	Certain aspects of ringed seal biology have been reported in other areas of the arctic. The particular parameters of acoustic survey equipment (e.g., frequency) that might be used in the area are not known, which influences the sensitivity of animals to this stressor. There is limited scientific information available on effects of acoustic surveys on ringed seals though information exists pertaining to other pinnipeds (Southall et al. 2019); the uncertainty is very high.
Likelihood	5	Research is needed on the response of ringed seals to noise from acoustic surveys. Since little scientific information is available on the topic and assumptions were made from other areas and the parameters of typical acoustic survey equipment, the uncertainty is very high.

Risk Statement: If an interaction occurs involving bearded seals and noise disturbance from acoustic surveying associated with submarine cables the consequence could result in a negative impact on the bearded seal population in the Fisher and Evans Straits priority area.

Table 6-4. Bearded Seal – Submarine Cables (Fisher and Evans Straits) – Noise Disturbance from Acoustic Surveying.

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 6 = 6 (raw score)
Intensity	1	There could be future acoustic surveys (i.e., multibeam echo sounder, sub-bottom profiler, side-scan sonar) conducted in the Fisher and Evans Straits priority area in preparation for proposed submarine cable installation, including for Phase 3 of Quintillion Global Communication's Asia & Europe Subsea Fibre Optic Cable System, which may include the easternmost portion of the AOI (Quintillion 2022*)*; the Kivalliq Hydro-Fibre Link if the project extends into marine areas between the mainland and Coral Harbour (Nukik Corporation 2023); and a submarine fibre optic system that would connect Iqaluit to Quebec, extending from east of the AOI into Coral Harbour and then southwest towards Chesterfield Inlet (DFO unpublished[19]; E. Devereaux, pers. comm., 2020). In general, submarine cable installation occurs rarely, perhaps a few times per decade. Thus, the number of acoustic surveys associated with submarine cables that may occur in the future in Fisher and Evans Straits priority area is likely to be low. Considering that the stressor would occur at low density and that sounds produced by multibeam echosounders typically dissipate quickly (i.e., have limited persistence; AECOM and Arctic Fibre Inc. 2013), an intensity score of 1 was assigned.
Temporal	1	Bearded seals are expected to occur in the priority area year-round. Acoustic surveys associated with submarine cables would most likely occur during summer when ice cover is at its lowest extent and vessel traffic is possible, approximately 7-8 weeks of the year. However, active days of surveying would not cover this entire period. Thus, there would be little temporal overlap (<25%) between the stressor and bearded seals, resulting in a score of 1.
Spatial	6	Spatial = Areal x Depth = 2 x 3 = 6
Areal	2	Bearded seals are expected to be widely distributed in low densities throughout the priority area. If an acoustic survey associated with submarine cables were to be conducted in the priority area (e.g., between Chesterfield Inlet and Coral Harbour), in would occur along the entire linear cable route. Systems used during subsea cable surveys produce high-frequency sounds in a narrow beam and apart from side-scan sonars, sound is directed vertically downward. The combination of these two factors limits the horizontal propagation of noise to a matter of kilometers (Lurton and DeRuiter 2011). The area of overlap would be localized and occur within a small proportion of the total bearded seal range in the Fisher and Evans Straits priority area, resulting in a score of 2.
Depth	3	Foraging bearded seals typically dive to depths of <100 m, up to about 500 m (NOAA 2022a). Depending on the routing of the acoustic survey in the priority area, bearded seals may be found throughout the water column. Noise from acoustic surveys would propagate through water and could potentially cover the entire depth range of bearded seals in the Fisher and Evans Straits priority areas. This results in a score of 3.
Sensitivity	1 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (1 + 1) x 2.4 = 4.8
Acute Change	1	Best estimates of the frequency range of bearded seal social calls in water are from 0.08-22 kHz (Southall et al. 2019). Behavioural audiometry data (i.e., direct measurements conducted in captivity) are not available for this species, though

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Risk Factor	Score	Rationale
		data for ringed seals indicates that their auditory range spans from <0.1 to >72.4 kHz (Southall et al. 2019). MBES produce sound at frequencies ranging from 12 to several hundred kHz with frequencies of 70-150 kHz for water depths over the continental shelf and higher frequencies for very shallow applications (Lurton and DeRuiter 2011). Seals are known to have a broad hearing range in water, and it is suggested that they would perceive sounds produced by MBES and demonstrate a response in some circumstances (Lurton and DeRuiter 2011; MacGillivray et al. 2014). Thus, there is overlap between the audible range of bearded seals and sounds produced by seafloor mapping equipment. There is little to no information on bearded or other seal behavioural response to acoustic surveys. During monitoring (14.3 hours of effort over two days) of a Canadian Hydrographic Service seafloor mapping program in the nearshore waters of the Canadian Beaufort Sea, a ringed seal was observed during operation of the side-scan sonar and sub-bottom profiler (MacGillivray et al. 2004); its behaviour was not reported. Modelling of sensation levels by MacGillivray et al. (2014) indicates that seals would likely respond to MBES and side-scan sonar only within 500 m from source. Based on the source levels and operational frequencies of acoustic survey equipment, there is limited risk that bearded seals could incur hearing impairment particularly if standard mitigation measures are implemented (e.g., MacGillivray et al. 2004; LGL Ltd. 2014). It is suggested that seals are at highest risk from equipment with an output below 50 kHz and that pathological effects are possible, though unlikely, as avoidance generally occurs before impacts are felt (SCAR 2002). It is possible that some of the acoustic survey equipment will operate above the frequencies that bearded seals can hear, particularly in shallower water depths (Lurton and DeRuiter 2011). Although there could be limited behavioural impacts such as avoidance of acoustic surveys by bearded seals, considering the incomplete overlap of frequency ranges, the limited behavioural effects noted where exposure does occur, expected lack of mortality, and existing mitigation measures, effects are deemed to be insignificant or undetectable relative to naturally occurring mortality and behaviour, resulting in a score of 1.
Chronic Change	1	Based on the low number of acoustic surveys expected in the Fisher and Evans Straits priority area and the limited behavioural effects on seals (see *Acute Change*, above), no detectable changes to overall fitness or impact on population dynamics would be expected, resulting in a score of 1.
Recovery Factors	2.4	Recovery factors = mean of the factors listed below. Fecundity: 3 (Females typically give birth to one pup a year). Early life stage mortality: 2 (Mortality could increase in the future as climate change affects the amount and suitability of ice required for important life functions [pupping, nursing; Reeves et al. 1992]). Recruitment pattern: Unknown; excluded from analysis. Natural mortality rate: Unknown; excluded from analysis. Age at maturity: 3 (In general, bearded seals attain sexual maturity at 5-6 years old for females and 6-7 for males [Cameron et al. 2010; Kovacs 2016]; however, some females in the Arctic have been found to attain sexual maturity between 3-7 years of age [Andersen et al. 1999]). Life stages affected: 3 (All stages may be affected). Population connectivity: Unknown; excluded from analysis (It is unknown if bearded seals in the AOI remain there year-round or undertake seasonal movements in and out of the region).

Risk Factor	Score	Rationale
		Population status: 1 (Bearded seals are considered *data deficient* by COSEWIC [2021] and are not listed under SARA. Bearded seals are listed as *threatened* in the USA [related to potential habitat loss], *not threatened* in Greenland, and *least concern* by IUCN).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 2 x 1 = Negligible
Likelihood	3	An interaction has the potential to occur when bearded seals and an acoustic survey are present at the same time in the Fisher and Evans Straits priority area and within close enough proximity for the noise to cause a disturbance to the animal. The frequency ranges of most MBES, sub-bottom profilers, and side-scan sonars overlap with the audible ranges of bearded seals. Depending on the behavioural state of the animal and the distance to the sound source, an interaction may occur in some but not all circumstances.
Overall Risk	Low Risk	No additional management actions need to be considered at this time.
Uncertainty		
Exposure	4	Some information exists on the general distribution of bearded seals, including in the priority area. There is no known information describing the ranges at which bearded seals could perceive sounds from acoustic surveys such as MBES, though information exists pertaining to pinnipeds from other areas (Southall et al. 2019). The particular parameters of acoustic survey equipment (e.g., frequency) that might be used in the area are not known, which influences the exposure of animals to this stressor. Uncertainty is high.
Sensitivity	5	Certain aspects of bearded seal biology have been reported in other areas of the arctic. The particular parameters of acoustic survey equipment (e.g., frequency) that might be used in the area are not known, which influences the sensitivity of animals to this stressor. There is no scientific information available on effects of acoustic surveys on bearded seals though information exists pertaining to other pinnipeds (Southall et al. 2019); the uncertainty is very high.
Likelihood	5	Research is needed on the response of bearded seals to noise from acoustic surveys. Since little scientific information is available on the topic and assumptions were made from other areas and the parameters of typical acoustic survey equipment, the uncertainty is very high.

Risk Statement: If an interaction occurs involving walruses and noise disturbance from acoustic surveying associated with submarine cables the consequence could result in a negative impact on the walrus population in the Fisher and Evans Straits priority area.

Table 6-5. Walrus – Submarine Cables (Fisher and Evans Straits) – Noise Disturbance from Acoustic Surveying.

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 6 = 6 (raw score)
Intensity	1	There could be future acoustic surveys (i.e., multibeam echo sounder, sub-bottom profiler, side-scan sonar) conducted in the Fisher and Evans Straits priority area in preparation for proposed submarine cable installation, including for Phase 3 of Quintillion Global Communication's Asia & Europe Subsea Fibre Optic Cable System, which may include the easternmost portion of the AOI (Quintillion 2022); the Kivalliq Hydro-Fibre Link if the project extends into marine areas between the mainland and Coral Harbour (Nukik Corporation 2023); and a submarine fibre optic system that would connect Iqaluit to Quebec, extending from east of the AOI

Risk Factor	Score	Rationale
		into Coral Harbour and then southwest towards Chesterfield Inlet (DFO unpublished[20]; E. Devereaux, pers. comm., 2020). In general, submarine cable installation occurs rarely, perhaps a few times per decade. Thus, the number of acoustic surveys associated with submarine cables that may occur in the future in the priority area is likely to be low. Considering that the stressor would occur at low density and that sounds produced by multibeam echosounders and other acoustic survey equipment typically dissipate quickly (AECOM and Arctic Fibre Inc. 2013), an intensity score of 1 was assigned.
Temporal	1	Based on scientific studies and current Inuit Qaujimajatuqangit, walruses occur in the Fisher and Evans Straits priority area year-round (Idlout 2020; Loewen et al. 2020b). Acoustic surveys associated with submarine cables would most likely occur during summer when ice cover is at its lowest extent and vessel traffic is possible, approximately 7-8 weeks of the year. However, active days of surveying would not cover this entire period. Thus, there would be little temporal overlap (<25%) between the stressor and walruses, resulting in a score of 1.
Spatial	6	Spatial = Areal x Depth = 2 x 3 = 6
Areal	2	Walruses are relatively sedentary in summer (Stewart 2008), tending to remain in areas where their food is most abundant and in water less than 80 m deep (Fay 1982; Reeves et al. 2002; Dehn et al. 2007; Lowry 2016a; COSEWIC 2017). The priority area provides walrus foraging habitat, calving areas, and key terrestrial haul-out sites (on Walrus, Bencas, and Coats Islands). If an acoustic survey associated with submarine cables were to be conducted in the priority area, it would occur along the entire linear cable route. Systems used during subsea cable surveys produce high-frequency sounds in a narrow beam and apart from side-scan sonars, sound is directed vertically downward. The combination of these two factors limits the horizontal propagation of noise to a matter of kilometers (Lurton and DeRuiter 2011). The area of overlap would be localized and occur within a small proportion of the total walrus distribution in the priority area.
Depth	3	Walruses spend time on the water surface and undertake foraging dives up to 200 m deep (Fay 1982; COSEWIC 2017). Depending on the routing of the acoustic survey in the priority area, walruses may be found throughout the water column. Noise from acoustic surveys would propagate through water and could potentially cover the entire depth range of walrus in the priority area. This results in a score of 3.
Sensitivity	1 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (1 + 1) x 2.1 = 4.2
Acute Change	1	Best estimates of the frequency range of walrus social calls in water are from 0.2-20 kHz (Southall et al. 2019). Behavioural audiometry data (i.e., direct measurements conducted in captivity) for this species indicates that the auditory range spans from <0.125 to >15 kHz (Southall et al. 2019). MBES produce sound at frequencies ranging from 12 to several hundred kHz with frequencies of 70-150 kHz for water depths over the continental shelf and higher frequencies for very shallow applications (Lurton and DeRuiter 2011). Pinnipeds are known to have a broad hearing range in water, and it is suggested that they would perceive sounds produced by MBES and demonstrate a response in some circumstances (Lurton and DeRuiter 2011; MacGillivray et al. 2014). Thus, there is expected overlap between the audible range of walruses and sounds produced by seafloor mapping equipment.

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[20] DFO. 2024. Southampton Island Area of Interest socio-economic overview report. 45 p. + annexes.

Risk Factor	Score	Rationale
		There are no studies on walrus behavioural responses to acoustic surveys and limited information for pinnipeds generally. During monitoring (14.3 hours of effort over two days) of a Canadian Hydrographic Service seafloor mapping program in the nearshore waters of the Canadian Beaufort Sea, a ringed seal was observed during operation of the side-scan sonar and sub-bottom profiler (MacGillivray et al. 2004); its behaviour was not reported. Modelling of sensation levels by MacGillivray et al. (2014) indicates that pinnipeds would likely respond to MBES and side-scan sonar only within 500 m from source. Based on the source levels and operational frequencies of acoustic survey equipment, there is limited risk that pinnipeds could incur hearing impairment particularly if standard mitigation measures are implemented (e.g., MacGillivray et al. 2004; LGL Ltd. 2014). It is suggested that pinnipeds are at highest risk from equipment with an output below 50 kHz and that pathological effects are possible, though unlikely, as avoidance generally occurs before impacts are felt (SCAR 2002). It is possible that some of the acoustic survey equipment will operate above the frequencies that walruses can hear, particularly in shallower water depths (Lurton and DeRuiter 2011). Although there could be limited behavioural impacts such as avoidance of acoustic surveys by walruses, considering the incomplete overlap of frequency ranges, expected lack of mortality, and existing mitigation measures, effects are deemed to be insignificant or undetectable relative to naturally occurring mortality and behaviour, resulting in a score of 1.
Chronic Change	1	Based on the low number of acoustic surveys expected in the priority area and the limited expected behavioural effects on walruses (see *Acute Change*, above), no detectable changes to overall fitness or impact on population dynamics would be expected, resulting in a score of 1.
Recovery Factors	2.1	Recovery factors = mean of the factors listed below. Fecundity: 3 (Adult female walrus have 1 calf every 3 years [Garlich-Miller and Stewart 1999]). Early life stage mortality: 1 (The data are sparse but the population structure and relatively high proportion of juveniles in the population suggests low mortality in all juvenile stages [Fay et al. 1997]). Recruitment pattern: 1 (Although annual recruitment is low by some standards, recruitment seems to be consistent among years and because walrus are long lived [40 years; Kovacs and Lydersen 2006], a single female produces a lot of young over her lifetime]). Natural mortality rate: 3 (The data are sparse but the population structure and relatively high proportion of juveniles in the population suggests low mortality in all life stages [Fay et al. 1997]). Age at maturity: 3 (Average age at sexual maturity of females is 7 years [Garlich-Miller and Stewart 1999]). Life stages affected: 3 (It is assumed all life stages may be affected). Population connectivity: 2 (Studies suggest that there is some interchange among Canadian Arctic walrus populations [Stewart 2008; Charette et al. 2020; Loewen et al. 2020b]). Population status: 1 (COSEWIC [2017] lists walruses as *special concern* due to threats associated with global warming. The Hudson Bay-Davis Strait stock has increased from a minimum of 3,900 in 1986 to approximately 7,000 and the authors suggest that walruses remain abundant in the Southampton Island area [Hammill et al. 2016a]).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 2 x 1 = Negligible

Risk Factor	Score	Rationale
Likelihood	3	An interaction has the potential to occur when walruses and an acoustic survey are present at the same time in the priority area and within close enough proximity for the noise to cause a disturbance to the animal. The frequency ranges of most MBES, sub-bottom profilers, and side-scan sonars overlap with the audible ranges of walruses. Depending on the behavioural state of the animal and the distance to the sound source, an interaction may occur in some but not all circumstances.
Overall Risk	Low Risk	No additional management measures need to be considered at this time.
Uncertainty		
Exposure	4	There is some information about walrus distribution within the priority area, and important haul-out sites are known. There is no known information describing the ranges at which walruses could perceive sounds from acoustic surveys such as MBES, though knowledge exists pertaining to other pinnipeds (Southall et al. 2019). The particular parameters of acoustic survey equipment (e.g., frequency) that might be used in the area are not known, which influences the exposure of animals to this stressor. Uncertainty is high.
Sensitivity	5	Certain aspects of walrus biology have been reported in other areas of the arctic and within the AOI. The particular parameters of acoustic survey equipment (e.g., frequency) that might be used in the area are not known, which influences the sensitivity of animals to this stressor. There is no scientific information available on effects of acoustic surveys on walruses though information exists pertaining to other pinnipeds (Southall et al. 2019); the uncertainty is very high.
Likelihood	5	Research is needed on the response of walrus to noise from acoustic surveys. Since little scientific information is available on the topic and assumptions were made from other areas and pinniped species, the uncertainty is very high.

Risk Statement: If an interaction occurs involving narwhals and noise disturbance from acoustic surveying associated with submarine cables the consequence could result in a negative impact on the narwhal population in the Chesterfield Inlet/Narrows priority area.

Table 6-6. Narwhal – Submarine Cables (Chesterfield Inlet/Narrows) – Noise Disturbance from Acoustic Surveying.

Risk Factor	Score	Rationale
Exposure	3 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 3 x 6 = 18 (raw score)
Intensity	1	There could be future acoustic surveys (i.e., multibeam echo sounder, sub-bottom profiler, side-scan sonar) conducted in the Fisher and Evans Straits priority area in preparation for proposed submarine cable installation, including for Phase 3 of Quintillion Global Communication's Asia & Europe Subsea Fibre Optic Cable System, which may include the easternmost portion of the AOI (Quintillion 2022); the Kivalliq Hydro-Fibre Link if the project extends into marine areas between the mainland and Coral Harbour (Nukik Corporation 2023); and a submarine fibre optic system that would connect Iqaluit to Quebec, extending from east of the AOI into Coral Harbour and then southwest towards Chesterfield Inlet (DFO unpublished[21]; E. Devereaux, pers. comm., 2020). In general, submarine cable installation occurs rarely, perhaps a few times per decade. Thus, the number of acoustic surveys associated with submarine cables that may occur in the future in Fisher and Evans Straits priority area is likely to be low. Considering that the stressor would occur at low density and that sounds produced by multibeam

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Risk Factor	Score	Rationale
		echosounders typically dissipate quickly (i.e., have limited persistence; AECOM and Arctic Fibre Inc. 2013), an intensity score of 1 was assigned.
Temporal	3	Narwhals migrate into Repulse Bay in June and July, with some continuing down the west coast of Hudson Bay, and leave the area in August and September through Frozen Strait (Westdal et al. 2010); some narwhal are expected to occur in the Chesterfield Inlet/Narrows priority area during summer (DFO 2020a). Acoustic surveys associated with submarine cables would most likely occur during summer when ice cover is at its lowest extent and vessel traffic is possible, approximately 7-8 weeks of the year. However, active days of surveying would not cover this entire period. Thus, there would be a large amount of temporal overlap between the stressor and narwhals, resulting in a score of 3.
Spatial	6	Spatial = Areal x Depth = 2 x 3 = 6
Areal	2	Narwhals may occur throughout the priority area with the exception of most of the Narrows. If an acoustic survey associated with submarine cables were to be conducted in the priority area (e.g., between Chesterfield Inlet and Coral Harbour), it would occur along the entire linear cable route. Systems used during subsea cable surveys produce high-frequency sounds in a narrow beam and apart from side-scan sonars, sound is directed vertically downward. The combination of these two factors limits the horizontal propagation of noise to a matter of kilometers (Lurton and DeRuiter 2011). The area of overlap would be localized and occur within a small proportion of the total narwhal range in the Chesterfield Inlet/Narrows priority area, resulting in a score of 2.
Depth	3	Narwhals typically forage in water depths <500 m (Heide-Jørgensen and Dietz 1995; Laidre et al. 2003). Depending on the routing of the acoustic survey in the priority area, narwhals may be found throughout the water column. Noise from acoustic surveys would propagate through water and could potentially cover the entire depth range of narwhals in the Chesterfield Inlet/Narrows priority area. This results in a score of 3.
Sensitivity	2 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (1 + 1) x 2.5 = 5.0
Acute Change	1	Best estimates of the frequency range of narwhal social calls are from 0.3-24 kHz with calls used in echolocation demonstrating a mean frequency of 54 kHz (Southall et al. 2019). Behavioural audiometry data (i.e., direct measurements conducted in captivity) for the closely related beluga spans from 0.04-130 kHz (Southall et al. 2019). MBES produce sound at frequencies ranging from 12 to several hundred kHz with frequencies of 70-150 kHz for water depths over the continental shelf and higher frequencies for very shallow applications (Lurton and DeRuiter 2011). Thus, there is overlap between the audible range of narwhals and sounds produced by seafloor mapping equipment. Based on the source levels and operational frequencies of acoustic survey sound sources, there is limited risk that narwhals could incur hearing impairment particularly if standard mitigation measures are implemented (e.g., MacGillivray et al. 2004; LGL Ltd. 2014). There is no known information on narwhal behavioural response to acoustic surveys; however, there are some studies pertinent to other “high-frequency cetaceans” as grouped by Southall et al. (2019) and those data are included here. Modelling indicates that sounds produced by MBES would cause a reaction to belugas only within 100 m from the source due to the rapid attenuation of high-frequency sound (MacGillivray et al. 2014). Beaked whales apparently ceased echolocation transmissions in response to the use of single-beam scientific echosounders (Simrad EK60, operated simultaneously at frequencies of 18, 38, 70, 120, and 200 kHz (Cholewiak et al. 2017). Short-finned

Risk Factor	Score	Rationale
		pilot whales exhibited no evidence of a change in foraging behavior but heading variance increased in response to the operation of a single-beam echosounder, which the authors attributed to possible increased vigilance (Quick et al. 2017). Cuvier's beaked whales exhibited no obvious change in the level of detected foraging during MBES surveys (12 kHz operational frequency), and most foraging remained in known and well-utilized foraging habitat (Kates Varghese et al. 2021). In 2008, there was a stranding event of melon-headed whales off of Madagascar that was associated temporally with an offshore MBES (12 kHz) operating 65 km away from the stranding site, though it was never conclusively determined to be the cause of the stranding (Southall et al. 2013). It is possible that some of the acoustic survey equipment will operate above the frequencies that narwhals can hear particularly in shallower water depths (Lurton and DeRuiter 2011). Although there could be behavioural impacts such as avoidance of acoustic surveys by narwhals, considering the incomplete overlap of frequency ranges, the limited behavioural effects noted where exposure does occur, and existing mitigation measures, impacts are deemed to be insignificant or undetectable relative to naturally occurring mortality and behaviour. This results in a score of 1.
Chronic Change	1	Based on the limited behavioural impacts, a lack of expected mortality (see *Acute Change*, above), and the low number of acoustic surveys expected in the Chesterfield Inlet/Narrows priority area, no detectable changes to overall fitness or impact on population dynamics would be expected, resulting in a score of 1.
Recovery Factors	2.5	Recovery factors = mean of the factors listed below. Fecundity: 3 (Adult female narwhals have a calf about every 3 years [Garde et al. 2015]). Early life stage mortality: 2 (Few data on first year mortality of narwhal calves are available. Koski and Davis [1994] estimated that 17% of calves died when between 1 and 13 months of age; this is lower than for many other marine mammal species]). Recruitment pattern: 2 (Although annual recruitment is low by some standards, recruitment seems to be consistent among years and because narwhals are long lived [80 years; Garde et al. 2015], a single female can produce a lot of young over her lifetime]). Natural mortality rate: 3 (The data are sparse but the stable population size with the removals by subsistence hunters suggests low mortality in all life stages). Age at maturity: 3 (Age at sexual maturity of females is 6-9 years and older for males [Garde et al. 2015]). Life stages affected: 3 (All life stages except for newborn calves are likely to be affected. An adult female accompanied by a yearling was seen in the AOI [Carlyle et al. 2021]). Population connectivity: 3 (Studies suggest that there is limited interchange among Canadian Arctic narwhal populations [Westdal et al. 2010; Heide-Jørgensen et al. 2013a; Doniol-Valcroze et al. 2020]). Population status: 1 (IUCN classifies narwhals as *least concern* [Lowry et al. 2017]. The last COSEWIC assessment is outdated [from 2004]. Narwhal populations are considered stable [Furgal and Laing 2012; Lowry et al. 2017]).
Consequence	3 (binned)	Consequence = Exposure x Sensitivity = 3 x 2 = Moderate
Likelihood	3	An interaction has the potential to occur when narwhals and an acoustic survey are present at the same time in the Chesterfield Inlet/Narrows priority area and within close enough proximity for the noise to cause a disturbance to the animal.

Risk Factor	Score	Rationale
		The frequency ranges of most MBES, sub-bottom profilers, and side-scan sonars overlap with the audible ranges of narwhals. Depending on the behavioural state of the animal and the distance to the sound source, an interaction may occur in some but not all circumstances.
Overall Risk	Moderately-high Risk	Additional management measures should be considered, such as avoidance of known narwhal migratory pathways during the time of year they are present.
Uncertainty		
Exposure	4	There is some information about narwhal distribution for the Chesterfield Inlet/Narrows priority area. There is no known information describing the distances at which narwhals could perceive sounds from acoustic surveys such as MBES, and limited knowledge exists pertaining to other similar cetaceans (Southall et al. 2019). The particular parameters of acoustic survey equipment (e.g., frequency) that might be used in the area are not known, which influences the exposure of animals to this stressor.
Sensitivity	5	Certain aspects of narwhal biology have been reported in other areas of the arctic. The particular parameters of acoustic survey equipment (e.g., frequency) that might be used in the area are not known, which influences the sensitivity of animals to this stressor. There is no scientific information available on effects of acoustic surveys on narwhals and limited knowledge pertaining to other similar cetaceans (Southall et al. 2019); the uncertainty is very high.
Likelihood	5	Research is needed on the response of narwhals to noise from acoustic surveys. Since little scientific information is available on the topic and assumptions were made from other areas and the parameters of typical acoustic survey equipment, the uncertainty is very high.

Risk Statement: If an interaction occurs involving bowhead whales and noise disturbance from acoustic surveying associated with submarine cables the consequence could result in a negative impact on the bowhead whale population in the Fisher and Evans Straits priority area.

Table 6-7. Bowhead Whale – Submarine Cables (Fisher and Evans Straits) – Noise Disturbance from Acoustic Surveying.

Risk Factor	Score	Rationale
Exposure	3 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 3 x 6 = 18 (raw score)
Intensity	1	There could be future acoustic surveys (i.e., multibeam echo sounder, sub-bottom profiler, side-scan sonar) conducted in the Fisher and Evans Straits priority area in preparation for proposed submarine cable installation, including for Phase 3 of Quintillion Global Communication's Asia & Europe Subsea Fibre Optic Cable System, which may include the easternmost portion of the AOI (Quintillion 2022); the Kivalliq Hydro-Fibre Link if the project extends into marine areas between the mainland and Coral Harbour (Nukik Corporation 2023); and a submarine fibre optic system that would connect Iqaluit to Quebec, extending from east of the AOI into Coral Harbour and then southwest towards Chesterfield Inlet (DFO unpublished[22]; E. Devereaux, pers. comm., 2020). In general, submarine cable installation occurs rarely, perhaps a few times per decade. Thus, the number of acoustic surveys associated with submarine cables that may occur in the future in Fisher and Evans Straits priority area is likely to be low. Considering that the stressor would occur at low density and that sounds produced by multibeam

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Risk Factor	Score	Rationale
		echosounders typically dissipate quickly (i.e., have limited persistence; AECOM and Arctic Fibre Inc. 2013), an intensity score of 1 was assigned.
Temporal	3	Based on scientific studies and current Inuit Qaujimajatuqangit, bowheads occur in the Fisher and Evans Straits priority area from April to November but primarily occur there during summer (Idlout 2020; Loewen et al. 2020b). Acoustic surveys associated with submarine cables would most likely occur during summer when ice cover is at its lowest extent and vessel traffic is possible, approximately 7-8 weeks of the year. However, active days of surveying would not cover this entire period. Thus, there would be a large amount of temporal overlap between the stressor and bowheads, resulting in a score of 3.
Spatial	6	Spatial = Areal x Depth = 2 x 3 = 6
Areal	2	Bowhead whales are expected to primarily occur in the Fisher and Evans Straits priority area during the summer and can occur throughout the priority area. Nearshore areas around SE Southampton Island in Evans Strait are known calving and nursery grounds (DFO 2020; Idlout 2020; Loewen et al. 2020b). If an acoustic survey associated with submarine cables were to be conducted in the priority area, it would occur along the entire linear cable route. Systems used during subsea cable surveys produce high-frequency sounds in a narrow beam and apart from side-scan sonars, sound is directed vertically downward. The combination of these two factors limits the horizontal propagation of noise to a matter of kilometers (Lurton and DeRuiter 2011). The area of overlap would be localized and occur within a small proportion of the total bowhead range in the priority area.
Depth	3	Depending on the routing of the acoustic survey in the priority area, bowheads may be found throughout the water column. Noise from acoustic surveys could propagate through water and potentially cover the entire depth range of bowheads in the priority area. This results in a score of 3.
Sensitivity	1 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (1 + 1) x 2.3 = 4.6
Acute Change	1	Best estimates of the frequency range of bowhead social calls are from 0.02-6 kHz, with this species being identified as adapted to low frequency communication (Southall et al. 2019). Auditory modelling suggests a range from 0.6-32 kHz (Southall et al. 2019). MBES produce sound at frequencies ranging from 12 to several hundred kHz with frequencies of 70-150 kHz for water depths over the continental shelf and higher frequencies for very shallow applications (Lurton and DeRuiter 2011). Thus, there is limited overlap between the audible range of bowheads and sounds produced by seafloor mapping equipment (Blue Planet Marine 2016). Although there are no studies on bowhead behavioural response to acoustic surveys, based on the source levels and operational frequencies of acoustic survey sound sources, it is expected that mysticetes are unlikely to detect the frequencies used by MBES, sub-bottom profilers, and side-scan sonars (Lurton and DeRuiter 2011; MacGillivray et al. 2014; Blue Planet Marine 2016). Thus, there is limited risk that bowheads could incur hearing impairment or behavioural impacts. It is likely that acoustic survey equipment will operate above the frequencies that bowheads can hear, particularly in shallower water depths (Lurton and DeRuiter 2011) such as those present in the AOI. Considering the lack of overlap between frequency ranges, and the limited behavioural effects expected where exposure

Risk Factor	Score	Rationale
		might occur, impacts are deemed to be insignificant or undetectable relative to naturally occurring mortality and behaviour. This results in a score of 1.
Chronic Change	1	Based on the lack of overlap between frequency ranges, and the limited behavioural effects expected where exposure might occur (see *Acute Change*, above), no detectable changes to overall fitness or impact on population dynamics would be expected, resulting in a score of 1.
Recovery Factors	2.3	Recovery factors = mean of the factors listed below. Fecundity: 3 (Adult female bowheads have 1 calf every 3-4 years [Miller et al. 1992; Koski et al. 1993; Tarpley et al. 2016, 2021]). Early life stage mortality: Unknown; excluded from consideration (there are no data on mortality rates in juvenile bowheads). Recruitment pattern: 1 (Although annual recruitment is low by some standards, bowhead pregnancies seem to be determined by the health of the prospective mother to maximize survival of the calf [W. Koski, pers. comm., 2022]. Because bowheads live to be about 200 years old, a single female produces a lot of young over her lifetime [Tarpley et al. 2016, 2021]). Natural mortality rate: 3 (The mortality rate of adult bowheads is extremely low, possibly the lowest of any animal. Survival has been estimated as 0.984 [0.948-1.00; Zeh et al. 2002] to 0.996 [0.976-1.00, Givens et al. 2018]). Age at maturity: 3 (Average age at sexual maturity of female bowheads is about 25 years [Koski et al. 1993; George et al. 1999] and appears to have declined in recent years [Tarpley et al. 2021]). Life stages affected: 3 (It is assumed that all life stages could be affected by acoustic survey noise). Population connectivity: 2 (The EC-WG population of bowhead whales occur in the AOI. Until recently, the geographic distributions of the EC-WG and BCB bowhead populations were significantly different so that there was little or no overlap between the populations [Zeh et al. 1995]. With the opening of the NW passage resulting from climate change, interchange between these two populations is possible, as suggested by a sighting of two satellite tagged bowheads from the two populations in the same general area in the High Arctic [Heide-Jørgensen et al. 2011]). Population status: 1 (IUCN classifies the EC-WG bowhead whale population as *least concern* [Cooke and Reeves 2018]. COSEWIC (2009) classifies them as *threatened*; however, that status report is out of date and is currently being reviewed. Recent surveys indicate that the population has increased since commercial overharvesting ended in the early 1900s. They may have increased to the point where this population has reached the carrying capacity of their habitat, based on sightings of skinny whales and apparent natural mortality in Cumberland Sound [Young et al. 2019] and recent cases of apparent natural mortality in other areas [DFO unpublished data]).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 3 x 1 = Negligible
Likelihood	1	Based on a lack of overlap between frequencies used by acoustic survey equipment (i.e., MBES, sub-bottom profilers, and side-scan sonars) and the audible ranges of bowhead whales (Southall et al. 2019), likelihood was scored as a 1 (Lurton and DeRuiter 2011; MacGillivray et al. 2014).
Overall Risk	Low Risk	No additional management measures need to be considered at this time.
Uncertainty		
Exposure	4	There is some information about bowhead distribution for the Fisher and Evans Straits priority area. There is no known information describing the distances at which bowheads could perceive sounds from acoustic surveys such as MBES,

Risk Factor	Score	Rationale
		and some knowledge exists pertaining to other similar cetaceans (Southall et al. 2019). The particular parameters of acoustic survey equipment (e.g., frequency) that might be used in the area are not known, which influences the exposure of animals to this stressor. Uncertainty is high.
Sensitivity	5	Certain aspects of bowhead biology have been reported in other areas of the arctic. The particular parameters of acoustic survey equipment (e.g., frequency) that might be used in the area are not known, which influences the sensitivity of animals to this stressor. There is no scientific information available on effects of acoustic surveys on bowheads and some knowledge pertaining to other similar cetaceans (Southall et al. 2019); the uncertainty is very high.
Likelihood	5	Research is needed on the response of bowheads to noise from acoustic surveys. Since little scientific information is available on the topic and assumptions were made from other areas and marine mammal species, the uncertainty is very high.

6.2 Installation – Habitat Alteration/Removal

The plough blade used for cable burial generally disturbs an area of seabed <1 m wide and up to 3 m deep, while the entire assembly operates on treads that can range from 2-8 m wide (Kraus and Carter 2018). Mobile organisms (e.g., fish and some benthic invertebrates) could avoid the assembly and any disturbance would be short in duration; mobile benthic organisms are expected to resume their normal abundance levels even before the substrate itself returns to the pre-disturbance state (Carter et al. 2014). No known studies have investigated the impacts of cable installation in Arctic marine environments and recovery in these systems occurs slowly (Al-Habahbeh et al. 2020). However, multiple studies (Andrulewicz et al. 2003; Kogan et al. 2006; Auster et al. 2013; NOAA 2018) have failed to document negative impacts of cable installation on mobile organisms, and some positive impacts have been reported, likely due to increased habitat heterogeneity (Kogan et al. 2006). Therefore, this stressor will not be assessed for fish or mobile benthic invertebrate species. The plough blade and installation vehicle treads would impact the substrate and although this would occur over a limited spatial area, sessile organisms would likely be damaged where they exist in the path of the vehicle; therefore, macroalgae, and immobile benthic invertebrates (specifically, corals and sponges) were assessed for this stressor (Table 6-8). Although corals, sponges, or other sensitive sessile benthic organisms are not known to exist in significant densities in the AOI, it is acknowledged that there is a data gap for this ESC in the AOI (DFO 2020b), these organisms are susceptible to this stressor, and their distribution would need to be considered during any future cable installations.

Table 6-8. Submarine Cable Installation − Habitat Alteration/Removal: ESC Subcomponents and Priority Areas Assessed.

ESC Subcomponent	Priority Area	Assessed by Proxy
Kelp beds and other macroalgae	Chesterfield Inlet/Narrows	
Benthic invertebrates (corals and sponges)	Fisher and Evans Straits	

Risk Statement: If an interaction occurs involving kelp beds/other macroalgae and habitat alteration/removal due to the installation of submarine cables the consequence could result in a negative impact on the ecosystem function of kelp beds/other macroalgae habitat in the Chesterfield Inlet/Narrows priority area.

Table 6-9. Kelp beds and other macroalgae – Submarine Cables (Installation; Chesterfield Inlet/Narrows) – Habitat Alteration/Removal.

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 2 x 6 = 12 (raw score)
Intensity	1	Several submarine cable installations have been discussed or proposed in the Chesterfield Inlet/Narrows priority area, including for the Kivalliq Hydro-Fibre Link (Nukik Corporation 2023) and a potential submarine fibre optic system that would connect Iqaluit to Quebec, extending from east of the AOI into Coral Harbour and then southwest towards Chesterfield Inlet (DFO unpublished[23]; E. Devereaux, pers. comm., 2020). Submarine cables are expected to have a lifespan of 20-25 years (Carter et al. 2014) and therefore the density of cable installations is not expected to be >1 at a time; thus, intensity was scored as 1.
Temporal	2	Kelp beds and other macroalgae are present in the Chesterfield Inlet/Narrows priority area year-round, though photosynthetic activity, important in advance of the growth phase which largely occurs under ice (Chapman and Lindley 1980), is restricted to the ice-free season. Although the planned duration for a submarine cable installation project in the priority area is currently unknown, it would most likely occur during summer when ice cover is at its lowest extent and vessel traffic is possible, approximately 7-8 weeks of the year. Thus, a score of 2 was assigned.
Spatial	6	Spatial = Areal x Depth = 2 x 3 = 6
Areal	2	Macroalgae typically occurs in water depths between 5-50 m in the AOI, with higher densities at 10 and 15 m compared with 5 m (Krause-Jensen et al 2012; Filbee-Dexter et al. 2022). Cable installation equipment operates on treads from 2-8 m wide with the plough approximately 1 m wide (Kraus and Carter 2018). The area of overlap would be localized to planned submarine cable routes and consist of a small portion of the total macroalgal range in the priority area, resulting in a score of 2.
Depth	3	Macroalgae inhabit surficial seabed substrate. At the depths for which macroalgae occurs, submarine cables are buried in the seabed and thus would cover the entire depth range of macroalgae in the Chesterfield Inlet/Narrows priority area. This results in a score of 3.
Sensitivity	2 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (2 + 1) x 2.0 = 6.0
Acute Change	2	A plough blade used for cable burial typically disturbs an area of the seabed <1 m wide and ≤3 m deep and the cable deployment assembly operates on treads that vary between 2-8 m wide (Kraus and Carter 2018). The process of ploughing and subsequent cable burial can increase suspended sediment (Kraus and Carter 2018). Modelling for non-Arctic environments suggests that cable burial can cause an acute increase of 50 mg/L of suspended sediment in the water column and a short-term (<2 h) increase of >100 mg/L (Swanson and Isaji 2006). These effects would decrease with increasing distance from the burial site and would be near background concentrations beyond 100 m (Swanson and Isaji 2006). Suspended sediment can decrease available light for macroalgae, and resettled sediment can cause smothering or inhibit substrate attachment (Traiger and Konar 2017). For one month, a backhoe excavated a 1.3 m wide, 1.3 m deep, 10,300 m long cable trench for the Nysted offshore wind farm in Denmark, and monitoring indicated that eelgrass shoot density and rhizome biomass decreased near the trench due

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Risk Factor	Score	Rationale
		to sediment spill during excavation, back filling, and temporary burial by sediment deposited along the cable trench (Zucco et al. 2006). Macroalgae accumulated within the trench, which may have prevented recolonization by other local fauna; however, the overall impact on the local environment was considered negligible (Zucco et al. 2006). Benthic organisms that inhabit areas with naturally heightened background levels of suspended sediment (e.g., due to storms of tidal currents) would likely be less affected by increased sedimentation than those in habitats with routinely low concentrations of suspended sediment (Swanson and Isaji 2006). Some species are intolerant of increased sedimentation, such as the kelp *Nereocystis luetkeana*, while others thrive, albeit with potentially shorter growing seasons, such as the kelp *Saccharina latissima* (Traiger and Konar 2017). Although there are no known studies that have investigated the impacts of cable installation in Arctic marine environments (Al-Habahbeh et al. 2020), it is expected that habitat alteration/removal via physical cable installation activities and increased sedimentation would result in measurable changes to habitat function in the ecosystem over an acute timeframe, resulting in a score of 2..
Chronic Change	1	Kelp distribution, abundance, and species composition vary with sedimentation, substrate type, wave exposure, temperature, and light (Traiger and Konar 2017). The community structure of Arctic kelp beds could be altered to favour species with sediment-tolerant gametophytes, such as *S. latissima* (DFO 2020), if the ecosystem experienced long-term increased sedimentation rates, such as from increased glacial melt (e.g., Traiger and Konar 2017). Reproductive success may also be affected by long-term increases in turbidity, although this was not found to be the case during laboratory studies with *S. latissima* and *N. luetkeana* (Traiger and Konar 2017). Balata et al. (2007) and Spurkland and Iken (2011) observed decreased macroalgal diversity and kelp recruitment in areas with high increases in sedimentation rates during field studies off the coasts of Tuscany and Alaska, respectively. However, modelling for non-Arctic environments has suggested that cable burial activities can increase suspended sediment levels in the water column typically amounting to 50 mg/L, with higher concentrations of >100 mg/L lasting <2 hours (Swanson and Isaji 2006) and long-term increases in turbidity are not expected. This study emphasized that the background level of suspended sediment is important to consider and that organisms may regularly interact with heightened sediment levels over short time periods due to natural processes, which are expected in the priority area given the dynamic tides (Roff et al. 1980). Nearshore environmental effects from submarine cable installations in the North Puget Sound region during 1990-2000 ranged from no apparent damage to total loss of seagrass (*Zostera marina*) cover (Austin et al. 2004). Underwater video surveys conducted after the installation of a High Voltage Direct Current submarine cable across Bass Strait, southeast Australia indicated that visible evidence of trenching and cable laying was gone within two years at over one third of transects at deeper water sites (32-72 m), while at other deeper sites, drift material was trapped in the residual trench that provided habitat for the benthos (Sherwood et al. 2016). Surveys in shallower sites (<15 m) found no detectable evidence of the cable route within one year. Within 3.5 years of installation, nearshore portions of the cable that traversed hard basalt rock and were encased in a protective cast iron half shell were colonized by the same species that occupied hard substrates elsewhere on the reef (Sherwood et al. 2016). Cast iron half shells and concrete masses associated with the 2012 installation of a submarine power cable in an energetic coastal environment in France were similarly colonized and supported an increase in local biodiversity; underwater surveys suggested the macroalgal ecological succession was ongoing five years after cable installation and the deployment of these artificial reef structures (Taormina 2019).

Risk Factor	Score	Rationale
		Considering the information above, it is not expected that increased sedimentation would result in a measurable change in habitat function and although installation equipment would impact macroalgae over a small area, it is not expected to result in a change to long-term viability of the habitat within the priority area, resulting in a score of 1.
Recovery Factors	2.0	At least 19 species/taxonomic groups of macroalgae have been documented to occur within or near the AOI (DFO 2020; Loewen et al. 2020a, b; Filbee-Dexter et al. 2022). At least 8 species/taxonomic groups have been reported for the Chesterfield Inlet/Narrows priority area. Of these macroalgae, three kelp species, *Laminaria solidungula*, edible kelp and sugar kelp are among the most abundant in the AOI, creating extensive kelp forests reaching up to 3-4 m in height and spreading several kilometers from shore (DFO 2020; Loewen et al. 2020b; Filbee-Dexter et al. 2022). *L. solidungula* is an Arctic endemic species (Roleda 2016). Biomasses of up to 34 kg/m^2 were observed for these kelp forests in the AOI, the highest ever reported for the eastern Canadian Arctic (Filbee-Dexter et al. 2022). Other types of macroalgae also occur amongst these kelp species, including coralline encrusting algae, and are important to create the structural complexity beneficial to its inhabitants (Wharton and Mann 1981; Christie et al. 1998; Steen et al. 2016; Misiuk and Aitken 2020). Habitat recovery factors were used. Recovery factors = mean of the factors listed below. Growth rate (biogenic)/rate of structural rebuilding (abiotic): 1 (Kelp sporophyte growth rates are high compared to other organisms [Mann 1973]). Resistance: 3 (Kelp can easily be disturbed physically, known to break apart during physical duress such as sample collection [Mundy 2020]. A change in ecosystem structure, such as an increase in urchin populations [e.g., Filbee-Dexter and Scheibling 2014] can lead to rapid and extensive defoliation of kelp). Regenerative potential: 2 (The regeneration of kelp forests after destructive events highly depends on the strength and duration of the event(s). Different clearing experiments in the northern Atlantic have shown that a full kelp regrowth can be observed after 1-3 years when environmental pressures are removed (Scheibling 1986; Christie et al. 1998; Steen et al. 2016). However, fully grown kelp forests also host a great variety of understorey algae along with many fish and invertebrates, that can take over 5 years to recolonize the habitat (Wharton and Mann 1981; Christie et al. 1998; Steen et al. 2016). In the Arctic, many authors have concurred that coastal recovery processes should be much slower than in temperate waters (Dunton et al. 1982; Conlan 2005; Keck et al. 2020). Several experiments and measurements done in the Beaufort Sea's Boulder Patch have shown that following a major disturbance on the site, it could take more than a decade for the sessile community, including kelp, to fully recover (Konar 2013; Bonsell and Dunton 2021). External stress: 2 (Climate change and warming waters add to stress [e.g., Filbee-Dexter et al. 2020]).
Consequence	2 (binned)	Consequence = Exposure x Sensitivity = 2 x 2 = Moderate
Likelihood	4	An interaction may not occur beyond the direct path of the cable installation route (i.e., in the area influenced by increased suspended sediment load) for macroalgae species that are tolerant of increased sedimentation. However, as kelp and other macroalgae are benthic organisms and cable installation equipment is designed to interact with the seabed, an interaction is certain to occur for macroalgae present directly on the installation route. Thus, an interaction is likely to occur.

Risk Factor	Score	Rationale
Overall Risk	Moderate Risk	Additional management measures should be considered, such as the development of a sedimentation study and minimizing permissible cable routing in portions of the Chesterfield Inlet/Narrows priority area identified as important kelp areas (see areas identified during an Inuit Qaujimajatuqangit workshop in February 2020 [Idlout 2020]).
Uncertainty		
Exposure	5	Macroalgal documentation in the priority area is limited (e.g., DFO 2020; Loewen et al. 2020a, b), although macroalgae and coastal kelp beds have been identified near the mouth of Chesterfield Inlet and it is known that the Western Hudson Bay Coastline EBSA features dense coastal kelp beds and macroalgae (DFO 2020). The extent, duration, and concentration/rates of sedimentation induced by submarine cable installation is uncertain, though study has been conducted in other areas.
Sensitivity	4	No studies have examined the impacts of cable installation in Arctic marine environments, though investigation has occurred for kelp/other macroalgae in other areas (Al-Habahbeh et al. 2020). Life history information is generally limited for macroalgae species that occur in/near the priority area.
Likelihood	5	Research is needed on how different species of Arctic macroalgae respond to increased sedimentation and turbidity, though some investigation has occurred in other areas.

Risk Statement: If an interaction occurs involving corals and sponges and habitat alteration/removal due to the installation of submarine cables the consequence could result in a negative impact on coral and sponge benthic invertebrate populations in the Fisher and Evans Straits priority area.

Table 6-10. Benthic Invertebrates (Corals and Sponges) – Submarine Cables (Installation; Fisher and Evans Straits) – Habitat Alteration/Removal.

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 2 x 3 = 6 (raw score)
Intensity	1	Several submarine cable installations have been discussed or proposed in the Chesterfield Inlet/Narrows priority area, including for the Kivalliq Hydro-Fibre Link (Nukik Corporation 2023) and a potential submarine fibre optic system that would connect Iqaluit to Quebec, extending from east of the AOI into Coral Harbour and then southwest towards Chesterfield Inlet (DFO unpublished[24]; E. Devereaux, pers. comm., 2020). Submarine cables are expected to have a lifespan of 20-25 years (Carter et al. 2014) and therefore the density of cable installations is not expected to be >1 at a time; thus, intensity was scored as 1.
Temporal	2	Corals and sponges are present in the Fisher and Evans Straits priority area year-round. Although the planned duration for a submarine cable installation project in the priority area is currently unknown, it would most likely occur during summer when ice cover is at its lowest extent and vessel traffic is possible, approximately 7-8 weeks of the year. Thus, a score of 2 was assigned.
Spatial	3	Spatial = Areal x Depth = 1 x 3 = 3
Areal	1	Coral and sponge distribution information in the Fisher and Evans Straits priority area is poorly studied (DFO 2020; Loewen et al. 2020b), but as a conservative minimum, they are anticipated to occur throughout at least the deeper portions of

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Risk Factor	Score	Rationale
		the priority area. Cable installation equipment operates on treads from 2-8 m wide with the plough approximately 1 m wide (Kraus and Carter 2018). The area of overlap would be localized to planned submarine cable routes, resulting in a score of 1.
Depth	3	Corals and sponges inhabit surficial seabed substrate. At the depths that occur in the priority area, submarine cables are buried in the seabed and thus would cover the entire depth range of corals and sponges. This results in a score of 3.
Sensitivity	5 (binned)	Sensitivity = (Acute change + Chronic Change) X Recovery Factors = (3 + 3) x 2.3 = 13.8
Acute Change	3	A plough blade used for cable burial typically disturbs an area of the seabed <1 m wide and ≤3 m deep and the cable deployment assembly operates on treads that vary between 2-8 m wide (Kraus and Carter 2018). It is known that where corals are exposed to physical disturbance, such as mobile bottom-contacting fishing gear, they can be damaged or destroyed (DFO 2006; Fuller et al. 2008; Althaus et al. 2009); similarly, submarine cable burial methods drag heavy objects along the seafloor. Physical disturbance, such as damaging, crushing, or dislodging, can reduce colony size, percent cover, architectural complexity, and diversity of coral species (Broad et al. 2020). Some colonial cnidarians, such as the soft coral *Gersemia rubiformis*, can survive some degree of crushing or abrasion—these organisms inflate or retract their polyps and may react to disturbance by enacting reproduction; however, these potential survival responses occur at the cost of lost time spent feeding, performing waste exchange, or propagating clonally (Henry et al. 2003). Corals and sponges can be easily detached from their substrate (Henry et al. 2003). Once dislodged, corals and large sponges generally do not reattach to the substrate and ultimately die (McMurray and Pawlik 2009). The process of ploughing and subsequent cable laying/burial can also increase suspended sediment (Kraus and Carter 2018). Modelling for non-Arctic environments suggests that cable burial can cause an acute increase of 50 mg/L of suspended sediment in the water column and a very short-term (<2 h) increase of >100 mg/L (Swanson and Isaji 2006). These effects would decrease with increasing distance from the burial site and would be near background concentrations beyond 100 m (Swanson and Isaji 2006). Benthic biota, such as corals and sponges, may be smothered by the resettling of sediments (WWF 2020). Suspension of sediment may decrease light availability for regions where light penetrates to the seabed, and the resuspension of sediments can rerelease nutrients from the substrate, altering the surrounding nutrient concentrations (WWF 2020). Increases in suspended sediment can cause a decrease or complete stop in filter feeding pumping rates of some sponge species (Grant et al. 2019). During 1993, a sediment slumping event at McMurdo Sound, Antarctica resulted in 84% colony mortality for the soft coral *Alcyonium paessleri* compared to an average annual mortality rate of 14% in the region (Slattery and Bockus 1997). Benthic organisms that inhabit areas with naturally heightened background levels of suspended sediment (e.g., due to storms or tidal currents) would likely be less affected by increased sedimentation than those in habitats with routinely low concentrations of suspended sediment (Swanson and Isaji 2006). Although there are no known studies that have investigated the impacts of cable installation in Arctic marine environments (Al-Habahbeh et al. 2020) and corals/sponges are able to cope with increased suspended sediment levels over the short-term, it is expected that habitat alteration/removal via physical cable installation activities would result in significant changes to mortality rates of corals and sponges in the path of a plough/cable laying vehicle. This results in a score of 3.

Risk Factor	Score	Rationale
Chronic Change	3	Although the soft coral *G. rubiformis* can withstand some physical pressure, such as temporary crushing, via colony retraction, the long lifespan, slow growth, and overall fragility of cold-water corals (and sponges) renders them highly vulnerable to chronic disturbance (Henry et al. 2003). Though the effects of cable installation via burial have not been studied empirically on corals, it is known that where corals are exposed to physical disturbance, such as mobile bottom-contacting fishing gear, they can be damaged or destroyed (DFO 2006; Fuller et al. 2008; Althaus et al. 2009). The degree of impact has been related to the depth of sediment penetration and the amount of bottom contact (Gass and Willison 2005; Campbell and Simms 2009). Similarly, submarine cable burial methods drag heavy objects along the seafloor. ROV surveys conducted twice annually for four years following the installation of a surface-laid (i.e., non-trenched) submarine power transmission cable and during its operation on a glass sponge reef between Vancouver Island and the Canadian mainland demonstrated decreased (~55%) live sponge cover along cable transects and at cable index sites 1.5 years post-installation and near complete (~85%) recovery during the proceeding two years; there was no evidence that the cable was moving across the reef surface (Dunham et al. 2015). Survey data suggested 100% mortality of glass sponges along the direct cable footprint and 15% mortality within 1.5-m of the cable 3.5 years post-installation (Dunham et al. 2015). Significant and long-lasting damage to sponges, gorgonians, and scleractinian corals was reported in the path of a seabed surface fiber optic cable array laid on a coral reef nearshore Florida, USA (Sultzmann et al. 2002). *G. rubiformis* may respond to disturbance by propagating new daughter colonies; however, the long-term survival rate of the daughter colonies may be low (e.g., Henry et al. 2003). Cable installation can also impact seabed habitat, though the abiotic environment can recover within years. Underwater video surveys conducted after the installation of a submarine cable across Bass Strait, southeast Australia indicated that visible evidence of trenching and cable laying was gone within two years at over one third of transects at deeper water sites (32-72 m), while at other deeper sites, drift material was trapped in the residual trench that provided habitat for various benthic species (Sherwood et al. 2016). Surveys in shallower sites (<15 m) found no detectable evidence of the cable route within one year. There were limited impacts from two cables for the Pacific Crossing fiber optic telecommunications system installed through the Olympic Coast National Marine Sanctuary via plow burial during 1999 and 2000; seabed recovery was relatively swift, with the longest lasting trenches occurring where the substrate primarily consisted of sand, mud, or clay; there were no visible trenches within 4.5 years post-installation (Antrim et al. 2018). The introduction of hard substrate onto the seabed surface, such as the submarine cable itself or protective, cast-iron half shells or concrete masses associated with the cable, may serve as suitable substrate for colonization by corals/sponges, similar to the macroalgal ecological succession that was observed following the deployment of such artificial reef structures during 2012 in France (Taormina 2019). Persistent sedimentation of the benthic habitat due to prolonged cable installation activities may alter community dynamics towards species more tolerant of such disturbance and may require lengthy periods for ecosystem recovery (Broad et al. 2020; WWF 2020), though this is note expected given the short period of time installation would occur in a given area. Considering the information above, especially the fragility, and slow growth and recovery rates for corals and sponges after disturbance, a significant change to overall fitness for corals and sponges in the priority area is expected. This results in a score of 3.

Risk Factor	Score	Rationale
Recovery Factors	2.3	At least 430 benthic invertebrate species have been identified within or near the AOI, including corals (e.g., the soft coral *Gersemia rubiformis*), sponges, sea stars, brittle stars, sea urchins, bivalves, cephalopods, crinoids, gastropods, holothuroids (sea cucumbers), hydrozoans, amphipods, cumaceans, decapods, euphausiids, isopods, Leptostracans, ostracods, sea spiders, polychaetes, barnacles, and chitons (DFO 2020; Loewen et al. 2020a, b). Corals and sponges are the most sensitive benthic invertebrate groups identified for the priority area and were used for the determination of Recovery Factors. There have been no dedicated baseline studies for the Fisher and Evans Straits priority area though limited benthic invertebrate studies for the Chesterfield Inlet/Narrows priority area exist (e.g., GN 2010; Misiuk and Aitken 2020; Pierrejean et al. 2020). Recovery factors = mean of the factors listed below. <u>Fecundity</u>: 1 (*Geodia phlegraei* sponges from the North Atlantic were observed to produce ~16 million oocytes/sponge and ~30 billion spermatozoa/sponge [Koutsouveli et al. 2020]. It is currently unknown whether *Geodia* sponges occur in the AOI, but the information presented here may be generally used for the Porifera Phylum reported for the AOI). <u>Early life stage mortality</u>: 3 (During four years of observations in water depths >650 m in the Gulf of Maine, the deep-water gorgonian coral *Primnoa resedaeformis* experienced high mortality during its early benthic stage, possibly due to biological disturbance, such as by suspension-feeding brittle stars, and limited food supply [Lacharité and Metaxas 2013]. Larvae of the cold-water coral *Lophelia pertusa* had an average survival rate of 60% during three months of laboratory observations and a maximum longevity of one year [Strömberg and Larsson 2017]. Although neither of these species have been reported for the AOI (Loewen et al. 2020a), their habitat conditions may be considered analogous to those of the AOI and the information presented here is applied in a precautionary manner for species within the AOI, for which no specific early life stage mortality information could be found). <u>Recruitment pattern</u>: 2 (Of two deep-water gorgonian corals observed in the Gulf of Maine, the broadcast spawner *P. resedaeformis* had high recruit abundance while the brooder spawner *Paragorgia arborea* had few recruits [Lacharité and Metaxas 2013]. The life span and rates of asexual and sexual reproduction in the soft coral *G. rubiformis* are unknown; however, asexual reproduction can be stimulated by physical disturbance [Henry et al. 2003; Iken et al. 2012]. The lifespan of *Geodia* spp. sponges is unknown, but they are likely to be slow growing [Last et al. 2019]. Although the corals *P. resedaeformis* and *P. arborea* and *Geodia* sponges have not been reported for the AOI, the information provided here has been applied for the AOI, for which no specific information could be found). <u>Natural mortality rate</u>: Unknown; excluded from consideration. <u>Age at maturity</u>: Unknown (DFO 2015b); excluded from consideration. <u>Life stages affected</u>: 3 (All life stages are expected to be affected). <u>Population connectivity</u>: Unknown; excluded from consideration. <u>Population status</u>: Unknown (The population size of the soft coral *G. rubiformis* is unknown [Boutillier et al. 2019] and corals/sponges are not considered under Sara or COSEWIC); excluded from consideration.
Consequence	4 (binned)	Consequence = Exposure x Sensitivity = 2 x 5 = High
Likelihood	4	An interaction may not occur beyond the direct path of the cable installation route (i.e., in the area influenced by increased suspended sediment load) for corals and sponges that are tolerant of increased sedimentation. However, as corals and

Risk Factor	Score	Rationale
		sponges are benthic organisms and cable installation equipment is designed to interact with the seabed, an interaction is certain to occur for these organisms present directly on the installation route. Thus, and interaction is likely to occur.
Overall Risk	High Risk	Additional management measures need to be considered, such as completion of baseline underwater video surveys to determine the community composition and distribution of corals and sponges along a potential survey route, and prohibiting/minimizing cable routes through portions of the priority area that host coral/sponge concentrations where they are found.
Uncertainty		
Exposure	5	Very limited information is available for coral and sponge diversity, distribution, and abundance for the Fisher and Evans Strait priority area (DFO 2020; Loewen et al. 2020b). The extent, duration, and concentration/rates of sedimentation induced by submarine cable installation is uncertain, though study has been conducted in other areas.
Sensitivity	5	Life history information is generally limited for coral and sponge species that may occur within the priority area. No studies have examined the impacts of cable installation in Arctic marine environments though studies have been conducted in other areas (Al-Habahbeh et al. 2020) and on similar stressors, such as bottom trawling fishing gear.
Likelihood	5	Research is needed on how different species of Arctic corals and sponges respond to cable installation activity, though some investigation has occurred in other areas.

7.0 Scientific Research – Data Collection

Scientific research is an activity that occurs regularly in the AOI and has the potential to impact ESC subcomponents through several pathways. Coral Harbour is home to the Atmospheric Radionuclides Monitoring Station, which monitors radiation in the air and precipitation. The radiation monitoring station consists of passive sampling equipment only, with all analyses performed at a laboratory in Ottawa, so the station does not impact wildlife. In addition, there are several permanent research camps owned by ECCC on Southampton Island. These camps have ongoing research projects monitoring the ecology of various bird species. Scientific research by several other organizations is ongoing in and near the AOI, including DFO, and involves marine baseline data collection, archeology, oceanography, and other studies on marine and terrestrial animals. Depending on the objectives, research in the marine environment may be conducted from large ships, icebreakers, smaller local vessels, helicopters, fixed-wing aircraft, and/or unmanned aerial systems. On-ice research may be conducted from camps established on the ice and accessed via snowmobile. There are two MBS on Southampton Island, Harry Gibbons (Ikkattuaq) and East Bay (Qaqsauqtuuq), and both include marine components and are focal areas for avian research in the area. Some data collection techniques take advantage of animals that are harvested for subsistence purposes (i.e., no additional harvesting or interactions with animals occurs due to sampling) and other techniques are completely non-invasive. Tissues, including tusks, returned as part of long-running community-based sampling programs are being analysed for genetics as well as trace elements, which will be used to evaluate current stock delineations. As well, a satellite image pilot study was recently completed using imagery of Walrus Island, with future plans to use satellite images in long-term monitoring of walrus presence/absence and abundance in the study area (C. Matthews, pers. comm., 2023).

There have been several recent research cruises in the SI AOI, such as the Nuliajuk Cruise (2016), ArcticNet/Hudson Bay System study (BaySys)/Bridging Global change, Inuit Health and the Transforming Arctic Ocean project (BriGHT) cruises (in 2010, 2017, and 2018), Southampton Island Marine Ecosystem Project (SIMEP) Cruise (2018, 2019), and the GenICE Cruise (2019) (Loewen et al. 2020b; DFO 2020b; Filbee-Dexter et al. 2022). The PoE for vessel traffic related to scientific research are generally similar to those from vessel traffic and were assessed in the section on shipping and vessel traffic (Section 5.0). This section focuses on the stressors and effects associated with sampling and surveying for scientific research—namely noise disturbance and biota encounters and handling.

Scientific studies of benthic species can involve the use of bottom trawls. For example, in a study of the benthic invertebrate fauna of the Hudson Bay Complex, Pierrejean et al. (2020) used epibenthic trawls to collect specimens for identification and quantification. In 2018 and 2019, the SIMEP cruise led by the University of Manitoba performed benthic and pelagic trawls from the RV *William Kennedy* at locations around Southampton Island, during which numerous pelagic and benthic invertebrates and fishes were collected to monitor their distribution and abundance, as well as food web dynamics (Filbee-Dexter et al. 2022). These activities could alter the benthic habitat, which was acknowledged in an investigation of the impacts of scientific bottom trawling in protected areas in the Newfoundland and Labrador Region (DFO 2022). Although they are infrequent activities that cover a limited spatial scope and their impacts are not expected to lead to measurable impact on pelagic biota, it is also suggested that impacts are dependent on survey design (e.g., recurrence time and gear type; DFO 2022). Given that the evaluation of impacts of bottom-contacting research trawls will be highly speculative without a detailed project proposal that includes the survey design, this activity was not be assessed here. However, see the following paragraph: any bottom trawl research activity in a future MPA would be subject to an activity plan approval process which would be able to more accurately assess the risks of the activity while remaining consistent with the co-management arrangement of a potential future MPA.

There are a number of other types of research activities that do or could occur in the SI AOI, and it would be impractical to assess each individually at this time. Certain activities are expected to occur in low enough densities or occur over small enough spatial scales that they are not expected to manifest in measurable impacts to the ecological components of the MPA and were not assessed. If an MPA is established in the area, the MPA activity plan approval process will examine any future research activities individually and will be able to more accurately consider impacts of the activity according to additional details provided at that time. Therefore, interactions that were assessed had to meet three criteria: they were known to occur regularly in the AOI, the initial level 1 assessment indicated that there may be measurable impact, and additional details provided through the activity plan approval process were not necessary to complete an assessment of risk.

7.1 Noise Disturbance

This section focuses on sources of noise related to scientific research other than from icebreaking, vessels at rest, and vessels underway in open water, which are covered in the section on shipping and vessel traffic (Section 5.0). Described further below, of the available research platforms, aircraft are most likely to lead to disturbance of ESC subcomponents and therefore assessments focused on the interactions with helicopters and/or fixed-wing aircraft.

Scientific research activities can use a variety of platforms, most of which produce noise. Marine mammal surveys are typically conducted aerially to assess population abundance, habitat use, and behavioral dynamics of Arctic marine mammals, such as Atlantic walruses, bowhead whales, narwhals, belugas, and seals. Marine mammal surveys conducted by DFO do not follow a standard published protocol. However, surveys follow similar methodologies when using similar aircraft. When utilizing manned aircraft such as de Havilland Twin Otters, surveys are typically flown at a target altitude of either 305 m or 610 m and travel at a ground speed of 185-204 km/h (Doniol-Valcroze et al. 2020; Hammill et al. 2016a; Watt et al. 2020b). Surveys utilizing aerial ROVs in marine mammal surveys varied in methodology. In one survey, Mayette et al. (2022) utilized a large aerial ROV called SeaHunter and completed surveys at a target altitude of 610 m and used the same target speed as manned aerial surveys. When using smaller aerial drones (e.g., Phantom 3/4 by DJI) that would take off from a boat, these ROVs flew at a target altitude of at least 30 m above water. Survey duration varies depending on objective, species, weather, location of survey (i.e., accessibility), aircraft used, and survey area covered.

All marine mammal species considered in this risk assessment have been documented to exhibit at least minor behavioural responses to fixed-wing and helicopter overflights, with walruses being most sensitive (e.g., Richardson et al. 1995a; DFO 2019a). Polar bears do not typically exhibit negative responses to anthropogenic noise, although they will occasionally investigate sources of noise (Stirling 1988b; Shideler 1993). Based on observations of polar bears collected during fixed-wing overflights (305 m or 457 m above sea level [asl]) in the Chukchi Sea, bears typically exhibited vigilance behaviour (i.e., looked at aircraft) and occasionally a resting bear would stand up. However, it was very rare for polar bears to move away from the aircraft or enter the water (B. Koski, pers. comm., 2022). Polar bears observed incidentally during aerial surveys for seals in the Alaskan Beaufort Sea during the springs of 1997-2002 exhibited little (i.e., looked at plane) to no reaction to fixed-wing aircraft traveling at a speed of 220 km/h and an altitude of 90 m (Moulton and Williams

2002). Therefore, polar bears are not expected to accrue measurable impacts from this stressor and were not assessed. All other marine mammal species were assessed (Table 7-1). Seabirds were assessed since they can be disturbed by the noise and visual cues from overhead flights, especially helicopters (Olsson and Gabrielsen 1990; Chardine and Mendenhall 1998). ROVs are currently used in a limited capacity, while underwater autonomous vehicle (UAV) use, particularly in Arctic marine mammal studies, is becoming more common and may occur in the AOI in future. The use of UAVs and ROVs have a minimal likelihood of measurable impacts on marine fauna. However, in one survey using small aerial ROVs, Ryan et al. (2002) saw beluga behavioural responses when the ROVs came within 10 to 20 m. The use of ice camps and snowmobiles may have minor effects, particularly on seals. However, of the platforms mentioned above, aircraft are most likely to lead to disturbance of ESC subcomponents; thus, assessments will focus on the interactions with helicopters and/or fixed-wing aircraft.

Table 7-1. Scientific Research − Noise Disturbance: ESC Subcomponents and Priority Areas Assessed.

ESC Subcomponent	**Priority Area**	**Assessed by Proxy**
Common eider	East Bay	
Thick-billed murre	Fisher and Evans Straits	
Thayer's gull	Duke of York Bay/White Island	
Ringed seal	Fisher and Evans Straits	
Bearded seal	Fisher and Evans Straits	
Walrus	Fisher and Evans Straits	
Beluga	East Bay	
Narwhal	Duke of York Bay/White Island	
Bowhead whale	Fisher and Evans Straits	

Risk Statement: If an interaction occurs involving common eiders and noise disturbance from aerial research surveys the consequence could result in a negative impact on the common eider population in the East Bay priority area.

Table 7-2. Common eider – Scientific Research – Data Collection (East Bay) – Noise Disturbance.

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 9 = 9 (raw score)
Intensity	1	This interaction investigates noise disturbance from the fixed-wing aircraft and helicopters involved in animal surveys. De Havilland Twin Otters are the likely platform used for surveys and helicopters may also be used. Surveys for walruses, seals, and polar bears are conducted coastally and may expose common eiders to this stressor while they are present during summer. Surveys for belugas may also contribute as belugas are known to aggregate in this area and are surveyed every five to ten years. Polar bear subpopulations are typically surveyed every ten years and the other marine mammal surveys are conducted every five to ten years. Surveys for seals are less frequent. Individual surveys are conducted over the course of about seven to ten days. Survey design for marine mammals excluding walruses follow a parallel transect pattern with transects separated by a few to tens of kilometers, depending on the field of view covered by the imaging equipment and/or surveyors. Transect line surveys are not designed to pass over the same area multiple times. Considering this information, the intensity of aerial surveys is expected to be low resulting in a score of 1.
Temporal	1	Common eiders are present in the East Bay priority area from mid-June to September. Adult males depart on their moult migration in July (Abraham and Finney 1986). Eggs hatch in July and the flightless females rear their precocial

Risk Factor	Score	Rationale
		broods in marine and intertidal waters. Groups of females and young are present until late-September (Abraham and Finney 1986), primarily foraging on benthic invertebrates in waters <20 m deep (Goudie et al. 2020). Surveys for polar bears and other marine mammals are likely conducted during summer, while seal surveys are more likely in the spring and would not overlap with common eider presence. Polar bear subpopulations are typically surveyed every ten years and the other marine mammal surveys are conducted every five to ten years. Surveys for seals are less frequent. Individual surveys are conducted over the course of about seven to ten days. Due to the speed of the aircraft individual flyovers last from 30-60 seconds and transect surveys are generally not designed to pass over the same area multiple times. Therefore, there would be very little overlap (<25%) between when eiders are present in the priority area and the activity, resulting in a score of 1.
Spatial	9	Spatial = Areal x Depth = 3 x 3 = 9
Areal	3	Common eider females are expected to be on nests on Mitvik Island and part of the south shore of East Bay from mid-June to mid-July. Eiders are expected to be distributed in intertidal and marine waters (Abraham and Finney 1986), primarily <20 m deep (Goudie et al. 2020). The population present will initially be comprised of males and non-breeding females, then will be replaced by females and broods (Abraham and Finney 1986). Eiders on the surface of the bay are expected to show escape behaviour from aircraft within 500 m, but incubating females are not expected to flush from the nest (Johnson et al. 1987; Mallory 2016). Both coastal surveys and those over water (see *Intensity*, above) could overlap with eider habitat; therefore, it is expected that aerial surveys would overlap with a large proportion of eider habitat in the priority area, resulting in a score of 3.
Depth	3	The overlap of sounds produced by an aircraft with habitat used by common eiders would depend on the altitude of the survey (e.g., for cetaceans, typically 305 or 610 m). Common eider flight altitude (over water) is expected to be lower than that of aircraft, except when the latter are landing. This species typically dives to a depth of <20 m, although this species' hearing ability under water is unknown. Considering the above, noise from aircraft covers the entire portion of the depth range of common eider resulting in a score of 3.
Sensitivity	2 (binned)	Sensitivity = (Acute change + Chronic Change) x Recovery Factors = (1 + 1) x 2.6 = 5.2
Acute Change	1	Noise disturbance from aircraft used in data collection could have a negative impact on breeding success through increased physiological stress response, temporary nest abandonment causing increased egg predation or egg mortality from exposure to temperature extremes, and nest desertion, and could decrease colony recruitment (Olsson and Gabrielson 1990; Chardine and Mendenhall 1998; Boersma et al. 2002; Boyd et al. 2015; Mallory 2016). It is not expected to cause direct mortality. Considering the low overall frequency of aerial surveys in the area, noise disturbance from aircraft is expected to result in an insignificant or undetectable change to common eider mortality rates against background variability and limited behavioural impacts, resulting in a score of 1.
Chronic Change	1	In some circumstances noise disturbance from aircraft may negatively impact breeding success in seabirds (see *Acute Change*, above). However, the low frequency of such flights in the priority area would be unlikely to cause repeated effects or, therefore, chronic change in the common eider population. As a result, it is expected there would be an insignificant or undetectable change to overall fitness and no impact on population dynamics, resulting in a score of 1.
Recovery Factors	2.6	Recovery factors = mean of the factors listed below.

Risk Factor	Score	Rationale
		Fecundity: 2 (Three to five eggs laid per year; nesting success 0-40% [Goudie et al. 2020]). Early life stage mortality**:** 3 (90-95% in first year [Goudie et al. 2020]). Recruitment pattern**:** 3 (Probability: 0.17-0.47 [Nicol-Harper et al. 2021]). Natural mortality rate**:** 3 (13% [Goudie et al. 2020]). Age at maturity**:** 2 (≥4 years [Goudie et al. 2020]). Life stages affected**:** 3 (All life stages could potentially occur in the East Bay priority area [Goudie et al. 2020]). Population connectivity**:** 3 (High degree of fine-scale spatial population genetic structuring [Talbot et al. 2015]). Population status**:** 2 (Common eider is listed as *near threatened* by IUCN [BirdLife International 2018a] but is not listed under SARA or COSEWIC. However, the population may be declining due to increased polar bear predation in the East Bay priority area [Loewen et al. 2020b]). Also, avian cholera has the potential to cause mass mortality and significantly impact the East Bay population [Descamps et al. 2012]).
Consequence	2 (binned)	Consequence = Exposure x Sensitivity = 2 x 2 = Low
Likelihood	3	An interaction may occur between aircraft and common eiders in the priority area if the aircraft is in close enough proximity. This will depend on the distance from the aircraft, the behavioural state of the individual eiders, and the eiders' prior experience with human disturbance. Considering the above, an interaction may occur in some but not all circumstances, and a score of 3 was assigned.
Overall Risk	Moderate Risk	Additional management measures should be considered, such as aircraft not actively engaged in data collection observing minimum set-back distances and altitudes from concentrations of common eiders as prescribed by ECCC-CWS.
Uncertainty		
Exposure	3	There is a moderate amount of scientific information available regarding the abundance and distribution of common eiders in the East Bay priority area (Mallory et al. 2019; Patterson et al. 2021), and some information exists on the likely distances at which eiders would be disturbed. Survey protocols and the general frequency and timing of aerial surveys are known, though it is possible not every aerial surveyed was captured. Uncertainty is moderate.
Sensitivity	3	There is a moderate amount of scientific information on the sensitivity of common eiders to noise disturbance, though none known from the priority area.
Likelihood	3	There is a moderate amount of scientific information on the likelihood of noise disturbance interacting with common eiders associated with scientific research, and information exists for this species on noise disturbance from other sources.

Risk Statement: If an interaction occurs involving thick-billed murres and noise disturbance from aerial research surveys the consequence could result in a negative impact on the thick-billed murre population in the Fisher and Evans Straits priority area.

Table 7-3. Thick-billed Murre – Data Collection (Fisher and Evans Straits) – Noise Disturbance.

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 9 = 9 (raw score)
Intensity	1	This interaction investigates noise disturbance from the fixed-wing aircraft and helicopters involved in animal surveys. De Havilland Twin Otters are the likely

Risk Factor	Score	Rationale
		platform used for surveys and helicopters may also be used. Surveys for walruses, seals, and polar bears are conducted coastally and may expose thick-billed murres to this stressor while they are occupying coastal habitat during summer. Walrus surveys in particular are expected to pass over Coats Island as haul-out sites are known nearby. Surveys for other marine mammals, including narwhals, belugas, and bowhead whales, would be conducted over water and may also expose murres to this stressor. Polar bear subpopulations are typically surveyed every ten years and the other marine mammal surveys are conducted every five to ten years. Surveys for seals are less frequent. Individual surveys are conducted over the course of about seven to ten days. Survey design for marine mammals excluding walruses follow a parallel transect pattern with transects separated by a few to tens of kilometers, depending on the field of view covered by the imaging equipment and/or surveyors. Transect line surveys are not designed to pass over the same area multiple times. Considering this information, the intensity of aerial surveys is expected to be low resulting in a score of 1.
Temporal	1	Thick-billed murres are present in this priority area from mid-May to October (Patterson et al. 2021). Murres would be present at the nesting cliffs on Coats Island from mid-May through July. Foraging adults capable of flight would be present at sea from June to July and in October, whereas chicks and flightless adults would be present in marine waters from August to September. Surveys for polar bears and other marine mammals are likely conducted during summer, while seal surveys are more likely in the spring and would not overlap with thick-billed murre presence. Polar bear subpopulations are typically surveyed every ten years and the other marine mammal surveys are conducted every five to ten years. Surveys for seals are less frequent. Individual surveys are conducted over the course of about seven to ten days. Due to the speed of the aircraft individual flyovers last from 30-60 seconds and transect surveys are generally not designed to pass over the same area multiple times. Therefore, there would be very little overlap (<25%) between when thick-billed murres are present in the priority area and the activity, resulting in a score of 1.
Spatial	9	Spatial = Areal x Depth = 3 x 3 = 9
Areal	3	Thick-billed murre distribution in the study area would primarily be the open water areas of Fisher and Evans Straits and the nesting cliffs on the north coast of Coats Island west of Cape Pembroke (Latour et al. 2008; Mallory et al. 2019; Patterson et al. 2022). Murres nesting at these colonies forage primarily within Fisher and Evans Straits (Brisson-Curadeau and Elliott 2019; Patterson et al. 2022). This species flushes from nesting cliffs when a helicopter approaches within 2 km (Olsson and Gabrielsen 1990). Both coastal surveys and those over water (see *Intensity*, above) could overlap with thick-billed murre habitat; therefore, it is expected that aerial surveys would overlap with a large proportion of habitat in the priority area, resulting in a score of 3.
Depth	3	The overlap of sounds produced by an aircraft with habitat used by thick-billed murres would depend on the altitude of the survey (e.g., for cetaceans, typically 305 or 610 m). Thick-billed murres flush from nesting cliffs when helicopters approach within 2 km at altitudes of at least 500 m (Olsson and Gabrielsen 1990). An interaction would be expected to occur over a large portion of the depth range of this species, resulting in a score of 3.
Sensitivity	1 (binned)	Sensitivity = (Acute change + Chronic Change) x Recovery Factors = (1 + 1) x 2.4 = 4.8
Acute Change	1	Noise disturbance from aircraft used in data collection could have a negative impact on thick-billed murre breeding success through increased physiological stress response, eggs or chicks falling from the nesting ledge if breeding birds

Risk Factor	Score	Rationale
		flush (the egg is incubated on the brooding adult's feet), temporary nest abandonment causing increased egg predation or egg mortality from exposure to temperature extremes, and nest desertion, and could decrease colony recruitment (Olsson and Gabrielson 1990; Chardine and Mendenhall 1998; Boersma et al. 2002; Latour et al. 2008; Mallory et al. 2019; Gaston and Hipfner 2020). Murres flush from the nesting cliff at greater distances in response to helicopters vs. fixed-wing aircraft, and when aircraft fly toward the cliff vs. parallel to it (Olsson and Gabrielson 1990). Non-breeding and breeding, off-duty murres show a much stronger response than breeding birds on the nest (Olsson and Gabrielson 1990; Gaston and Hipfner 2020). Murres at sea would be expected to flush or escape dive in response to noise from an aircraft. Considering the low overall frequency of aerial surveys in the area (see *Intensity*, above), noise disturbance from aircraft is expected to result in an insignificant or undetectable change to thick-billed murre mortality rates against background variability and limited behavioural impacts, resulting in a score of 1.
Chronic Change	1	In some circumstances noise disturbance from aircraft may negatively impact breeding success in seabirds (see *Acute Change*, above). A small proportion of thick-billed murres could be affected by noise disturbance associated with data collection in the Fisher and Evans Straits priority area. However, the low frequency of such flights the priority area would be unlikely to cause repeated effects or, therefore, chronic change in the thick-billed murre population. As a result, it is expected there would be an insignificant or undetectable change to overall fitness and no impact on population dynamics, resulting in a score of 1.
Recovery Factors	2.4	Recovery factors = mean of the factors listed below. Fecundity: 2 (One egg laid per year [Gaston and Hipfner 2020]). Early life stage mortality**:** 3 (63-76% before breeding age [Gaston and Hipfner 2020]). Recruitment pattern**:** 3 (Attempted breeding: 3-year olds: 0-2%; 4-year olds: 7-16%; 5-year olds: 0-31% [Noble et al. 1991]). Natural mortality rate**:** 3 (14% [Gaston et al. 1994]). Age at maturity**:** 3 (5.7 years [Gaston and Hipfner 2020]). Life stages affected**:** 3 (All life stages could potentially occur in the priority area [Gaston 2002]). Population connectivity**:** 1 (Very little genetic population structuring [Tigano et al. 2017]). Population status**:** 1 (Thick-billed murre is listed as *least concern* by IUCN [BirdLife International 2018b] and is not listed under SARA or COSEWIC).
Consequence	2 (binned)	Consequence = Exposure x Sensitivity = 2 x 1 = Negligible
Likelihood	3	An interaction may occur between an aircraft and thick-billed murres in the priority area if the aircraft is in close enough proximity. This will depend on the breeding status of the individuals, an aircraft's flight direction (towards vs. parallel to the nesting cliff), the type of aircraft (which determines noise amplitude), the behavioural state of individual birds, and each individual's prior experience with human disturbance. Considering the above, an interaction may occur in some but not all circumstances, and a score of 3 was assigned.
Overall Risk	Low Risk	No additional management measures need to be considered at this time. However, aircraft should observe minimum set-back distances from birds and active nests as prescribed by ECCC-CWS.
Uncertainty		
Exposure	3	There is a substantial amount of scientific information available regarding the thick-billed murres nesting colonies adjacent to the Fisher and Evans Straits priority

Risk Factor	Score	Rationale
		area and their occupation of nearby marine waters. Survey protocols and the general frequency and timing of aerial surveys are known, though it is possible not every aerial surveyed was captured. Uncertainty is moderate.
Sensitivity	3	There is a moderate amount of scientific information on the sensitivity of thick-billed murres to noise, though none is specific to the priority area.
Likelihood	3	There is a substantial amount of scientific information on the likelihood of an interaction between noise and thick-billed murres, though some is for sources other than aircraft. Uncertainty is moderate.

Risk Statement: If an interaction occurs involving Thayer's gulls and noise disturbance from aerial research surveys the consequence could result in a negative impact on Thayer's gull populations in the Duke of York Bay/White Island priority area.

Table 7-4. Thayer's gull – Scientific Research – Data Collection (Duke of York/White Island) – Noise Disturbance.

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 9 = 9 (raw score)
Intensity	1	This interaction investigates noise disturbance from the fixed-wing aircraft and helicopters involved in animal surveys. De Havilland Twin Otters are the likely platform used for surveys and helicopters may also be used. Surveys for walruses, seals, and polar bears are conducted coastally and may expose Thayer's gulls to this stressor while they are in bays feeding during summer. Surveys for other marine mammals, including belugas, narwhals, and bowhead whales, would be conducted over water and may also expose Thayer's gulls to this stressor. Polar bear subpopulations are typically surveyed every ten years and the other marine mammal surveys are conducted every five to ten years. Surveys for seals are less frequent. Individual surveys are conducted over the course of about seven to ten days. Survey design for marine mammals excluding walruses follow a parallel transect pattern with transects separated by a few to tens of kilometers, depending on the field of view covered by the imaging equipment and/or surveyors. Transect line surveys are not designed to pass over the same area multiple times. Considering this information, the intensity of aerial surveys is expected to be low resulting in a score of 1.
Temporal	1	Thayer's gulls are present in the Duke of York/White Island priority area from mid-May to early October (Snell et al. 2020). Surveys for polar bears and other marine mammals are likely conducted during summer, while seal surveys are more likely in the spring and would not overlap fully with Thayer's gull presence. Polar bear subpopulations are typically surveyed every ten years and the other marine mammal surveys are conducted every five to ten years. Surveys for seals are less frequent. Individual surveys are conducted over the course of about seven to ten days. Due to the speed of the aircraft individual flyovers last from 30-60 seconds and transect surveys are generally not designed to pass over the same area multiple times. Therefore, there would be very little overlap (<25%) between when Thayer's gulls are present in the priority area and the activity, resulting in a score of 1.
Spatial	9	Spatial = Areal x Depth = 3 x 3 = 9
Areal	3	Thayer's gulls nest on coastal cliffs and forage over open water among pack ice as well as near shore and in the intertidal area (Richards and Gaston 2018; Loewen et al. 2020b). Both coastal surveys and those over water (see *Intensity*, above)

Risk Factor	Score	Rationale
		could overlap with Thayer's gull habitat. It is expected that aerial surveys would overlap with a large proportion of Thayer's gull habitat in the priority area, resulting in a score of 3.
Depth	3	Thayer's gulls would be expected to fly relatively close to nesting cliffs and the sea surface, except occasionally when soaring upwards on wind deflecting from the cliff face or warm air thermals rising from the island. Noise disturbance from aircraft engaged in aerial studies of nesting colonies would be expected to elicit a response throughout a large proportion of the depth range for Thayer's gulls, resulting in a score of 3.
Sensitivity	1 (binned)	Sensitivity = (Acute change + Chronic Change) x Recovery Factors = (1 + 1) x 2.3 = 4.6
Acute Change	1	Noise disturbance from aircraft used in data collection could have a negative impact on Thayer's gull breeding success through increased physiological stress response, eggs or chicks falling from the nesting ledge if breeding birds flush, temporary nest abandonment causing increased egg predation or egg mortality from exposure to temperature extremes, and nest desertion, and could decrease colony recruitment (Olsson and Gabrielson 1990; Chardine and Mendenhall 1998; Boersma et al. 2002; Latour et al. 2008; Mallory et al. 2019; Gaston and Hipfner 2020). Other cliff-nesting seabird species (i.e., thick-billed murres) flush from the nesting cliff at greater distances in response to helicopters vs. fixed-wing aircraft, and when aircraft fly toward the cliff vs. parallel to it (Olsson and Gabrielson 1990). Non-breeding and breeding, off-duty seabirds show a much stronger response than breeding birds on the nest (Olsson and Gabrielson 1990). Thayer's gulls forage primarily in marine waters (Snell et al. 2020) and when at-sea would be expected to take flight in response to noise from an aircraft. Considering the low overall frequency of aerial surveys in the area (see *Intensity*, above), noise disturbance from aircraft is expected to result in an insignificant or undetectable change to Thayer's gull mortality rates against background variability and limited behavioural impacts, resulting in a score of 1.
Chronic Change	1	In some circumstances noise disturbance from aircraft may negatively impact breeding success in seabirds (see *Acute Change*, above). A small proportion of nesting or foraging Thayer's gulls could be affected by noise disturbance from aircraft. However, the low frequency of aerial surveys near nesting colonies and foraging habitat in the Duke of York Bay/White Island priority area would be unlikely to cause repeated disturbances within a single breeding season and therefore no chronic change in the Thayer's gull nesting population in the priority area. As a result, it is expected there would be insignificant or undetectable change to overall fitness and no impact on population dynamics, resulting in a score of 1.
Recovery Factors	2.3	Recovery factors = mean of the factors listed below. Fecundity: 2 (Two to three eggs laid per year [Snell et al. 2020]). Early life stage mortality**:** 1 (Unknown but thought to be similar to related large, white-headed, North Atlantic *Larus* gulls, e.g., herring gull *L. argentatus* [Snell et al. 2020]). Recruitment pattern**:** 3 (Unknown but thought to be similar to related large, white-headed, North Atlantic *Larus* gulls, e.g., herring gull [Snell et al. 2020]). Natural mortality rate**:** 3 (Unknown but thought to be similar to related large, white-headed, North Atlantic *Larus* gulls, e.g., herring gull [Snell et al. 2020]). Age at maturity**:** 3 (Unknown but thought to be >4 as in related large, white-headed, North Atlantic *Larus* gulls, e.g., herring gull [Snell et al. 2020]).

Risk Factor	Score	Rationale
		Life stages affected**:** 3 (Immature birds do not visit colonies but are present in flocks along Arctic coastlines, so all life stages could potentially occur in the Duke of York/White Island priority area [Snell et al. 2020). Population connectivity**:** 2 (Unknown but thought to be similar to related large, white-headed, North Atlantic *Larus* gulls, e.g., herring gull [Snell et al. 2020]). Population status**:** 1 (Poorly monitored [Snell et al. 2020] but listed as *least concern* by IUCN [BirdLife International 2019]; not listed under SARA or COSEWIC).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 2 x 1 = Negligible
Likelihood	3	An interaction may occur between an aircraft and Thayer's gulls in the priority area if the aircraft is in close enough proximity. This will depend on the breeding status of the individuals, an aircraft's flight direction (towards vs. parallel to the nesting cliff), the type of aircraft (which determines noise amplitude), the behavioural state of individual birds, and each individual's prior experience with human disturbance. Considering the above, an interaction may occur in some but not all circumstances, and a score of 3 was assigned.
Overall Risk	Low Risk	No additional management measures need to be considered at this time. However, aircraft should observe minimum set-back distances from birds and active nests as prescribed by ECCC-CWS.
Uncertainty		
Exposure	3	There is a moderate amount of scientific information available on the abundance and distribution of Thayer's gull in the Duke of York Bay/White Island priority area (Gaston et al.1986, 2012). Survey protocols and the general frequency and timing of aerial surveys are known, though it is possible not every aerial surveyed was captured. Uncertainty is moderate.
Sensitivity	4	There is some scientific information available on the sensitivity of seabirds to noise disturbance, though little is directed at this species and none was undertaken in the priority area.
Likelihood	4	There is some scientific information available on the likelihood of an impact of noise disturbance on seabirds, though little is directed at this species and none was undertaken in the priority area.

Risk Statement: If an interaction occurs involving ringed seals and noise disturbance from aerial research surveys the consequence could result in a negative impact on the ringed seal population in the Fisher and Evans Straits priority area.

Table 7-5. Ringed Seal – Scientific Research (Fisher and Evans Straits) – Noise Disturbance.

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 6 = 6 (raw score)
Intensity	1	This interaction investigates noise disturbance from the fixed-wing aircraft and helicopters involved in animal surveys. De Havilland Twin Otters are the likely platform used for surveys and helicopters may also be used. Surveys for walruses and polar bears are conducted coastally and would expose seals to this stressor. Surveys for other marine mammals, including belugas, narwhals, and bowhead whales, would be conducted over water and may also expose seals to this stressor. Polar bear subpopulations are typically surveyed every ten years and the other marine mammal surveys are conducted every five to ten years. Surveys for seals are less frequent. Individual surveys are conducted over the course of about

Risk Factor	Score	Rationale
		seven to ten days. Survey design for marine mammals excluding walruses follow a parallel transect pattern with transects separated by a few to tens of kilometers, depending on the field of view covered by the imaging equipment and/or surveyors. Transect line surveys are not designed to pass over the same area multiple times. Considering this information, the intensity of aerial surveys is expected to be low resulting in a score of 1.
Temporal	1	Ringed seals are expected to occur in the priority area year-round. Aerial surveys of ringed seals would most likely occur during springtime, when seals are hauled out and visible on the ice surface as they undergo moult. Surveys for polar bears and other marine mammals are likely conducted during summer. Polar bear subpopulations are typically surveyed every ten years and the other marine mammal surveys are conducted every five to ten years. Surveys for seals are less frequent. Individual surveys are conducted over the course of about seven to ten days. Due to the speed of the aircraft individual flyovers last from 30-60 seconds and surveys are generally not designed to pass over the same area multiple times.Therefore, there would be very little overlap (<25%) between when ringed seals are present in the priority area and the activity, resulting in a score of 1.
Spatial	6	Spatial = Areal x Depth = 3 x 2 = 6
Areal	3	Ringed seals are expected to be widely distributed throughout the priority area (but during the ice-covered season more prevalent in areas of fast-ice with water depths >3 m). Aerial surveys for ringed seals would be planned to cover areas where ringed seals might occur or are most abundant, and both coastal surveys and those over water (see *Intensity*, above) could also overlap with seals. It is expected that aerial surveys would overlap with a large proportion of ringed seal habitat in the Fisher and Evans Straits priority area, resulting in a score of 3.
Depth	2	The overlap of sounds produced by a survey aircraft with habitats and water depths used by ringed seals would depend on the habitat occupied and the altitude of the survey (e.g., for cetaceans, typically 305 or 610 m). Received noise levels underwater have been recorded for a few aircraft, including the de Havilland Canada DHC-6 Twin Otter (Richardson et al. 1995a; Patenaude et al. 2002). Ringed seals in water near the surface near the aerial survey track line would be exposed to noise (Patenaude et al. 2002). Ringed seals hauled out on land or ice would be exposed to in-air sounds. A score of 2 was assigned.
Sensitivity	1 (binned)	Sensitivity = (Acute Change + Chronic Change) X Recovery Factors = (1+1) × 2.3 = 4.6
Acute Change	1	Ringed seals can hear aircraft noise (both in-air and in the water). Sounds produced from aircraft overflights are not predicted to cause hearing damage or mortality. Given the temporary nature of aircraft overflight sounds, it is unlikely that masking would affect ringed seals. There have been few systematic studies of the reactions of seals to aircraft overflights, and most of the available data concern seals hauled out on land or ice rather than those in the water (Richardson et al. 1995a). Born et al. (1999) assessed the responses of ringed seals hauled out on the ice to overflights by fixed-wing twin-engine aircraft (Partenavia PN68 Observer) and a helicopter (Bell 206 III). Both flew over seals at an altitude of 150 m. Overall, 6% of 5,040 seals left the ice in reaction to the fixed-wing aircraft and 49% of 227 seals left the ice in response to the helicopter. Similarly, a small percentage of ringed seals (~2.3 % of 2,963) were observed to dive into holes or cracks in response to overflights at 91 m altitude by a fixed-wing Turbo Commander 690A (Moulton et al. 2003). A slightly higher percentage was observed diving into holes or cracks (4.0% of 3,007 seals) during overflights by a Twin Otter at the same altitude. Most seals were observed

Risk Factor	Score	Rationale
		looking (22.9 %) at the aircraft or exhibiting no detectable response (58.6 %; Moulton et al. 2000). Responses of seals inside lairs will likely be lessened, because airborne sound levels from aircraft will be diminished as snow attenuates sound transmission. Given that ringed seal mortality is not expected, that seals are expected to be widely distributed in the priority area and that displacement is considered temporary and localized, and the frequency and duration of aerial surveys would be limited (see *Intensity*, above) the impact of noise from survey overflights on ringed seals at the population level is considered insignificant or undetectable, resulting in a score of 1.
Chronic Change	1	Some ringed seals may exhibit localized and temporary behavioural responses to aircraft and no mortality from this stressor is expected. However, given that the frequency and duration of aerial surveys would be limited (see *Intensity*, above), and that overflights are not expected in spring when ringed seals will be pupping and nursing and presumed to be more sensitive, there would be no expected effect on population dynamics and a score of 1 was assigned.
Recovery Factors	2.3	Recovery factors = mean of the factors listed below. Fecundity: 3 = Low (Females typically give birth to one pup a year) Early life stage mortality: 2 = Moderate (Reeves et al. 1992). Recruitment pattern: 2 (Recruitment is variable depending on prevailing environmental conditions [Ferguson et al. 2005; Stirling 2005; Chambellant et al. 2010]). Natural mortality rate: 3 (Mortality rates have been reported low in adult ringed seals with survivorship of 0.89 for age 6+ seals. Survivorship of age 0+ seals is reported to be much lower [0.59] [Smith 1975; Reimer et al. 2019]). Age at maturity: 3 (Best estimate of the population-wide average age at maturity is 4-7 years old [in most areas; can range from 3-9; see COSEWIC 2019]). Life stages affected: 3 = all stages. Population connectivity: 1 = Regular (Ringed seals in the Canadian Arctic are known to move extensively to different arctic regions, regularly making annual journeys that are 1,000s of kilometers). Population status: 1 = Stable or increasing (Ringed seals are considered s*pecial concern* by COSEWIC (2019) and are not listed under SARA. The COSEWIC report does not offer insight into population trend. Ringed seals are listed as *threatened* in the USA (related to potential habitat loss), *least concern* in Greenland, no listing in Russia, and *least concern* by IUCN.)
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 2 x 1 = Negligible
Likelihood	3	An interaction has the potential to occur when ringed seals occur near the overflight path of an aircraft. The extent of the interaction would depend on the behavioural state of the animal (and whether it is in the water or hauled out on the ice) and the distance to the aircraft overflight path. Considering this information, an interaction may occur in some but not all circumstances, resulting in a score of 3.
Overall Risk	Low Risk	No additional management actions need to be considered at this time. However, scientific studies involving aircraft should use maximum altitudes that can still achieve study objectives.
Uncertainty		
Exposure	4	Some information exists on the general distribution of ringed seals, including in the priority area. Survey protocols and the general frequency and timing of aerial surveys are known, though it is possible not every aerial surveyed was captured. Uncertainty is high.

Risk Factor	Score	Rationale
Sensitivity	3	Certain aspects of ringed seals biology and their response to aircraft overflights have been reported in other areas of the arctic; however, little is known about the impacts of noise disturbance. Uncertainty is moderate.
Likelihood	3	Available information, not specific to the priority area or AOI, indicates that some ringed seals will exhibit a temporary behavioural response to aircraft overflights. The uncertainty is moderate.

Risk Statement: If an interaction occurs involving bearded seals and noise disturbance from aerial research surveys the consequence could result in a negative impact on the bearded seal population in the Fisher and Evans Straits priority area.

Table 7-6. Bearded Seal – Scientific Research (Fisher and Evans Straits) – Noise Disturbance.

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 6 = 6 (raw score)
Intensity	1	This interaction investigates noise disturbance from the fixed-wing aircraft and helicopters involved in animal surveys. De Havilland Twin Otters are the likely platform used for surveys and helicopters may also be used. Surveys for walruses and polar bears are conducted coastally and would expose seals to this stressor. Surveys for other marine mammals, including beluga, narwhals, and bowhead whales, would be conducted over water and may also expose seals to this stressor. Polar bear subpopulations are typically surveyed every ten years and the other marine mammal surveys are conducted every five to ten years. Surveys for seals are less frequent. Individual surveys are conducted over the course of about seven to ten days. Survey design for marine mammals excluding walruses follow a parallel transect pattern with transects separated by a few to tens of kilometers, depending on the field of view covered by the imaging equipment and/or surveyors. Transect line surveys are not designed to pass over the same area multiple times. Considering this information, the intensity of aerial surveys is expected to be low resulting in a score of 1.
Temporal	1	Bearded seals are expected to occur in the priority area year-round. Aerial surveys of bearded seals would most likely occur during springtime, when seals are hauled out and visible on the ice surface. Surveys for polar bears and other marine mammals are likely conducted during summer. Polar bear subpopulations are typically surveyed every ten years and the other marine mammal surveys are conducted every five to ten years. Surveys for seals are less frequent. Individual surveys are conducted over the course of about seven to ten days. Due to the speed of the aircraft individual flyovers last from 30-60 seconds and surveys are generally not designed to pass over the same area multiple times. Therefore, there would be very little overlap (<25%) between when bearded seals are present in the priority area and the activity, resulting in a score of 1.
Spatial	6	Spatial = Areal x Depth = 3 x 2 = 6
Areal	3	Bearded seals are expected to be widely distributed in low densities throughout the priority area. Aerial surveys for bearded seals would be planned to cover areas where bearded seals might occur or are most abundant, and both coastal surveys and those over water (see *Intensity*, above) could also overlap with seals. It is expected that aerial surveys would overlap with a large proportion of bearded seal habitat in the Fisher and Evans Straits priority area, resulting in a score of 3.

Risk Factor	Score	Rationale
Depth	2	The overlap of sounds produced by a survey aircraft with habitats and water depths used by bearded seals would depend on the habitat occupied and the altitude of the survey (e.g., for cetaceans, typically 305 or 610 m). Received noise levels underwater have been recorded for a few aircraft, including the de Havilland Canada DHC-6 Twin Otter (Richardson et al. 1995a; Patenaude et al. 2002). Bearded seals in water near the surface near the aerial survey track line would be exposed to noise (Patenaude et al. 2002). Bearded seals hauled out on land or ice would be exposed to in-air sounds. A score of 2 was assigned.
Sensitivity	1 (binned)	Sensitivity = (Acute Change + Chronic Change) X Recovery Factors = (1+1) × 2.4 = 4.8
Acute Change	1	Bearded seals can hear aircraft noise (both in-air and in the water). Sounds produced from aircraft overflights are not predicted to cause hearing damage or mortality. Given the temporary nature of aircraft overflight sounds, it is unlikely that masking would affect bearded seals. There have been few systematic studies of the reactions of seals to aircraft overflights, and most of the available data concern seals hauled out on land or ice rather than those in the water (Richardson et al. 1995a). Information on the response of other seal species to aircraft overflights are included here to inform the response of bearded seals. Born et al. (1999) assessed the responses of ringed seals hauled out on the ice to overflights by fixed-wing twin-engine aircraft (Partenavia PN68 Observer) and a helicopter (Bell 206 III). Both flew over seals at an altitude of 150 m. Overall, 6% of 5,040 seals left the ice in reaction to the fixed-wing aircraft and 49% of 227 seals left the ice in response to the helicopter. Similarly, a small percentage of ringed seals (~2.3 % of 2,963) were observed to dive into holes or cracks in response to overflights at 91 m altitude by a fixed-wing Turbo Commander 690A (Moulton et al. 2003). A slightly higher percentage was observed diving into holes or cracks (4.0% of 3,007 seals) during overflights by a Twin Otter at the same altitude. Most seals were observed looking (22.9 %) at the aircraft or exhibiting no detectable response (58.6 %; Moulton et al. 2000). Given that bearded seal mortality is not expected, that seal displacement is considered temporary and localized and the frequency and duration of aerial surveys would be limited (see *Intensity*, above), the impact of noise from aircraft overflights on bearded seal behaviour at the population level is considered insignificant or undetectable, resulting in a score of 1.
Chronic Change	1	Some bearded seals may exhibit localized and temporary behavioural responses to aircraft and no mortality from this stressor is expected. However, given that the frequency and duration of aerial surveys would be limited (see *Intensity*, above), and that overflights are not expected when bearded seals will be pupping and nursing and presumed to be more sensitive, there would be no expected effect on population dynamics and a score of 1 was assigned.
Recovery Factors	2.4	Recovery factors = mean of the factors listed below. Fecundity: 3 (Females typically give birth to one pup a year). Early life stage mortality: 2 (Mortality could increase in the future as climate change affects the amount and suitability of ice required for important life functions [pupping, nursing; Reeves et al. 1992]). Recruitment pattern: Unknown; excluded from analysis. Natural mortality rate: Unknown; excluded from analysis. Age at maturity: 3 (In general, bearded seals attain sexual maturity at 5-6 years old for females and 6-7 for males [Cameron et al. 2010; Kovacs 2016]; however, some

Risk Factor	Score	Rationale
		females in the Arctic have been found to attain sexual maturity between 3-7 years of age [Andersen et al. 1999]). Life stages affected: 3 (All stages may be affected). Population connectivity: Unknown; excluded from analysis (It is unknown if bearded seals in the AOI remain there year-round or undertake seasonal movements in and out of the region). Population status: 1 (Bearded seals are considered *data deficient* by COSEWIC [2021] and are not listed under SARA. Bearded seals are listed as *threatened* in the USA [related to potential habitat loss], *not threatened* in Greenland, and *least concern* by IUCN).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 2 x 1 = Negligible
Likelihood	3	An interaction has the potential to occur when bearded seals occur near the overflight path of an aircraft. The extent of the interaction would depend on the behavioural state of the animal (and whether it is in the water or hauled out on the ice) and the distance to the aircraft overflight path. Considering this information, an interaction may occur in some but not all circumstances, resulting in a score of 3.
Overall Risk	Low Risk	No additional management actions need to be considered at this time. However, scientific studies involving aircraft should use maximum altitudes that can still achieve study objectives.
Uncertainty		
Exposure	4	There is some information about bearded seal distribution in the priority area. Exposure assumptions were based primarily on ringed seal literature from other areas and there is little scientific information available on bearded seals. Survey protocols and the general frequency and timing of aerial surveys are known, though it is possible not every aerial surveyed was captured.
Sensitivity	4	Certain aspects of bearded seal biology and seal response to aircraft overflights have been reported in other areas of the arctic; however, little is known about the impacts of noise disturbance. Since assumptions were based primarily on ringed seal literature from other areas and there is little scientific information available for bearded seals, the uncertainty is high.
Likelihood	4	Available information, not specific to bearded seals, the priority area or AOI, indicates that bearded seals may exhibit a temporary behavioural response to aircraft overflights. Since assumptions were based primarily on ringed seal literature from other areas and there is little scientific information available for this species, the uncertainty is high.

Risk Statement: If an interaction occurs involving walruses and noise disturbance from aerial research surveys the consequence could result in a negative impact on the walrus population in the Fisher and Evans Straits priority area.

Table 7-7. Walrus – Scientific Research (Fisher and Evans Straits) – Noise Disturbance.

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 6 = 6 (raw score)
Intensity	1	This interaction investigates noise disturbance from the fixed-wing aircraft and helicopters involved in animal surveys. De Havilland Twin Otters are the likely platform used for surveys and helicopters may also be used. Surveys for walruses, seals, and polar bears are those that are conducted coastally and would

Risk Factor	Score	Rationale
		expose walruses to this stressor. Polar bear subpopulations are typically surveyed every ten years and walrus surveys are conducted every five to ten years. Seal surveys are less frequent. Surveys are conducted for a few days during the course of a few weeks and, for walruses, each individual haul-out site is surveyed one to two times. Considering this information, the intensity of aerial surveys is expected to be low resulting in a score of 1.
Temporal	1	Based on scientific studies and current Inuit Qaujimajatuqangit walruses occur in the Fisher and Evans Straits priority area year-round (Idlout 2020; Loewen et al. 2020b). Aerial surveys would be anticipated to only occur for a number of days over the course of a few weeks during the summer. Due to the speed of the aircraft individual flyovers last from 30-60 seconds. Therefore, there would be very little overlap (<25%) between when walruses are present in priority area and the activity. This results in a score of 1.
Spatial	6	Spatial = Areal x Depth = 3 x 2 = 6
Areal	3	Walruses are relatively sedentary in summer (Stewart 2008), tending to remain in areas where their food is most abundant and in water less than 80 m deep (Fay 1982; Reeves et al. 2002; Dehn et al. 2007; Lowry 2016a; COSEWIC 2017). The priority area provides walrus foraging habitat, calving areas, and key terrestrial haul-out sites (on Walrus, Bencas, and Coats Islands). Surveys for walruses, seals, and polar bears are those that are conducted coastally and would expose walruses to this stressor, with those surveying walruses covering areas where walruses are known to occur and/or are most abundant. It is expected that aerial surveys would cover a large proportion of walrus habitat in the priority area, resulting in a score of 3.
Depth	2	The overlap of sounds produced by a survey aircraft with habitats and water depths used by walruses would depend on the habitat occupied and the altitude of the survey (e.g., for cetaceans, typically 305 or 610 m). During summer, walruses spend on average of 71-74% of their time below the water surface, 16% hauled out on ice or land, and 11-14% in the water near the surface (Garde et al. 2018). Overflights in occupied aircraft (e.g., de Havilland Twin Otter), would expose hauled out walruses or those in the water and near the survey track line (Patenaude et al. 2002). Considering this information, a score of 2 was assigned.
Sensitivity	2 (binned)	Sensitivity = (Acute Change + Chronic Change) X Recovery Factors = (2+1) × 2.1 = 6.3
Acute Change	2	Important walrus haul-out sites, calving, and foraging habitat occur in the Fisher and Evans Straits priority area. Walruses at haul-out sites or on sea ice often react to disturbance such as sounds or a visual stimulus from an aircraft by entering the water (Salter 1979; Brueggeman 1993). Young animals can be injured or killed during these evacuations (Fay et al. 1997; Fischbach et al. 2009; Goertz et al. 2017). Surveys for walruses and polar bears are those that are conducted coastally and would expose walruses to this stressor. Though DFO conducts scientific surveys for walruses every five to ten years and those conducted on polar bear subpopulations are conducted every ten years, a study found that walrus responses to aircraft are variable but dispersal into water is not uncommon. Propeller planes and helicopters flying at ~1370-6100 m AGL at horizontal distances of up to 2.8 km have caused dispersal of walruses at haul-outs and disturbance would be expected to be more severe with decreased distance (DFO 2019a). Walruses have also been documented abandoning haul-out sites after a disturbance for a 3-4 days; Mansfield and St. Aubin 1991). Thus, changes to the health or survival of individual walruses are plausible and behavioural impacts are expected if they are exposed to sounds produced by aircraft, resulting in a score of 2.

Risk Factor	Score	Rationale
Chronic Change	1	Disturbance may cause indirect impacts including interruption of foraging and social interactions (e.g., interference of mother-offspring communication or insufficient nursing of calves) and increased stress and energy expenditure (Born et al. 1995). Walruses may abandon haul-out sites after repeated exposure to disturbance and may shift distribution away from preferred feeding areas (Johnson et al. 1989; Born et al. 1995), which would result in a loss of important habitat and a change in geographic range. However, given that the frequency and duration of aerial surveys would be limited (see *Acute Change*, above), there would be no expected effect on population dynamics and a score of 1 was assigned. To note regarding habituation: Stewart et al. (2012) generally found that evidence of walrus habituation to noise disturbance from vessels and aircraft has not been sufficiently supported. Additionally, observations for walrus haul-out disturbance behaviour from one area may not be transferable to another. For example, since walruses in Canada are hunted, they tend to be more sensitive to human presence compared to other areas where they are not (Higdon et al. 2022). Øren et al. (2018) looked at the effects of tourist visitations on haul-out dynamics and site use by walruses in Svalbard, Norway and found that tourists on land and boats near the haul-out sites did not disturb walrus haul-out behaviour significantly at any of the sites, with a single exception. This perhaps suggests that habituation occurred; however, it has been suggested that this is due to the fact that walruses are not hunted in this area (Higdon et al. 2022). At Round Island, Alaska long-term datasets have suggested that Pacific walruses have not habituated to disturbance from both boats and aircraft as reactions have remained similar over a 20+ year monitoring period (DFO 2019a; Higdon et al. 2022). Habituation may therefore not occur consistently among Pacific and Atlantic walruses, populations, or individuals. Since there is potential for walruses to experience chronic stress whether they were to habituate or not in response to ship noise (Stewart et al. 2012) and since walruses in the Southampton Island AOI may respond differently to sound given that they are hunted for subsistence, the possibility of habituation was not incorporated into the risk score calculations.
Recovery Factors	2.1	Recovery factors = mean of the factors listed below. Fecundity: 3 (Adult female walrus have 1 calf every 3 years [Garlich-Miller and Stewart 1999]). Early life stage mortality: 1 (The data are sparse but the population structure and relatively high proportion of juveniles in the population suggests low mortality in all juvenile stages [Fay et al. 1997]). Recruitment pattern: 1 (Although annual recruitment is low by some standards, recruitment seems to be consistent among years and because walrus are long lived [40 years; Kovacs and Lydersen 2006], a single female produces a lot of young over her lifetime]). Natural mortality rate: 3 (The data are sparse but the population structure and relatively high proportion of juveniles in the population suggests low mortality in all life stages [Fay et al. 1997]). Age at maturity: 3 (Average age at sexual maturity of females is 7 years [Garlich-Miller and Stewart 1999]). Life stages affected: 3 (All life stages may be affected). Population connectivity: 2 (Studies suggest that there is some interchange among Canadian Arctic walrus populations [Stewart 2008; Charette et al. 2020; Loewen et al. 2020b]). Population status: 1 (COSEWIC [2017] lists walruses as *special concern* due to threats associated with global warming. The Hudson Bay-Davis Strait stock has

Risk Factor	Score	Rationale
		increased from a minimum of 3,900 in 1986 to approximately 7,000 [Hammill et al. 2016a]).
Consequence	2 (binned)	Consequence = Exposure x Sensitivity = 2 x 2 = Low
Likelihood	4	Though the extent of the interaction would depend on the behavioural state of the animal (and whether it is in the water or hauled out) and the distance to the aircraft overflight path, given the documented responses of walruses to disturbance from aircraft noise (see *Acute Change*, above), if an aircraft were to enter the priority area and approach close enough an interaction would occur in most circumstances. This results in a likelihood score of 4.
Overall Risk	Moderate Risk	Additional management measures may be considered, such as recommending that survey aircraft do not fly within 2.5 km of a haul-out site.
Uncertainty		
Exposure	3	There is some information about walrus distribution within the priority area, and important haul-out sites are known. Survey protocols and the general frequency and timing of aerial surveys are known, though it is possible not every aerial surveyed was captured. Uncertainty is considered moderate.
Sensitivity	3	Certain aspects of walrus biology have been reported in other areas of the Arctic. Walrus reactions to aircraft have been documented by Salter (1979) and in several anecdotal peer-reviewed publications which have not quantitatively documented rates or factors causing disturbance but have documented the results of severe disturbance. DFO (2019) examined walrus disturbance from aircraft. Uncertainty is considered moderate.
Likelihood	3	Information exists on the likelihood of walruses being disturbed by aircraft. Uncertainty is moderate.

Risk Statement: If an interaction occurs involving belugas and noise disturbance from aerial research surveys the consequence could result in a negative impact on the beluga population in the East Bay priority area.

Table 7-8. Beluga – Scientific Research (East Bay) – Noise Disturbance.

Risk Factor	Score	Rationale
Exposure	1 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 3 = 3 (raw score)
Intensity	1	This interaction investigates noise disturbance from the fixed-wing aircraft and helicopters involved in animal surveys. De Havilland Twin Otters are the likely platform used for surveys and helicopters may also be used. Surveys for walruses, seals, and polar bears are conducted coastally and may expose belugas to this stressor while they are in bays feeding during summer. Surveys for other marine mammals, including narwhals and bowhead whales, would be conducted over water and may also expose belugas to this stressor. Polar bear subpopulations are typically surveyed every ten years and the other marine mammal surveys are conducted every five to ten years. Surveys for seals are less frequent. Individual surveys are conducted over the course of about seven to ten days. Survey design for marine mammals excluding walruses follow a parallel transect pattern with transects separated by a few to tens of kilometers, depending on the field of view covered by the imaging equipment and/or surveyors. Transect line surveys are not designed to pass over the same area multiple times. Considering this information, the intensity of aerial surveys is expected to be low resulting in a score of 1.

Risk Factor	Score	Rationale
Temporal	1	Belugas are expected to migrate into the AOI and presumably the East Bay priority area in May and June and occur in the priority area during summer, with migration out of the priority area beginning in early to late September (Loewen et al. 2020b). Surveys for polar bears and other marine mammals are likely conducted during summer, while seal surveys are more likely in the spring. Polar bear subpopulations are typically surveyed every ten years and the other marine mammal surveys are conducted every five to ten years. Surveys for seals are less frequent. Individual surveys are conducted over the course of about seven to ten days. Due to the speed of the aircraft individual flyovers last from 30-60 seconds and transect surveys are generally not designed to pass over the same area multiple times. Therefore, there would be very little overlap (<25%) between when belugas are present in the priority area and the activity, resulting in a score of 1.
Spatial	3	Spatial = Areal x Depth = 3 x 1 = 3
Areal	3	The East Bay priority area provides summering habitat for belugas where they are known to calve and moult (Idlout 2020; Loewen et al. 2020b). Scientific studies assessed here would be planned to cover areas where belugas are known to occur or are most abundant, and both coastal surveys and those over water (see *Intensity*, above) could also overlap with belugas. It is expected that aerial surveys would overlap with a large proportion of beluga habitat in the priority area, resulting in a score of 3.
Depth	1	The overlap of sounds produced by an occupied aircraft with water depths used by belugas would depend on the altitude of the survey (e.g., for cetaceans, typically 305 or 610 m). Received noise levels underwater have been recorded for a few aircraft, including the de Havilland Canada DHC-6 Twin Otter (Richardson et al. 1995a; Patenaude et al. 2002). Only animals at or near the water surface would be exposed. Belugas regularly forage at depths of 100s of metres (Martin et al. 1998; Watt et al. 2016), with some dives to depths greater than 800 m (Heide-Jørgensen et al. 1998; Richard et al. 2001). Belugas spend some time at and near the water surface where they could hear sounds of the aircraft with the rest of their time spent foraging at depths where the sounds would not be loud enough to disturb the animals. Therefore, depth was scored as 1.
Sensitivity	1 (binned)	Sensitivity = (Acute Change + Chronic Change) X Recovery Factors = (1+1) × 2.4 = 4.8
Acute Change	1	Studies have shown that belugas exhibit variable responses to aircraft overflights. Some belugas ignored aircraft flying at an altitude of 500 m, while with aircraft at altitudes of 150-200 m, they dove for longer periods and sometimes swam away; feeding belugas appeared to be less prone to disturbance (Kleinenberg et al. 1964). Those in summering areas, including the Mackenzie Estuary, often reacted to aircraft by diving or swimming away (e.g., Fraker and Fraker 1979; Caron and Smith 1990). Belugas in Cook Inlet may be habituated to aircraft, as there are several airports in the area; they did not react to repeated overflights by a fixed-wing aircraft (Rugh et al. 2000). During a spring flight that opportunistically examined the short-term behavioural responses of migrating beluga whales to overflights by a Twin Otter fixed-wing aircraft, a small proportion of belugas were observed to react to the aircraft at altitudes of 60-460 m (Patenaude et al. 2002). Considering observations made during all fixed-wing aircraft altitudes, 3.2 % (24 of 760) of beluga individuals or groups reacted overtly, exhibiting behaviours such as diving with tail thrash, changing heading, and twisting to look up at the aircraft; direct overflights generated the most obvious reactions. The proportion of belugas reacting to the Twin Otter at low altitudes (≤182 m) was relatively low at 5.4 % (18 of 336); however, the authors acknowledge this is likely an underestimation as observation opportunities were brief (Patenaude et al. 2002). Overall, most (14 of

Risk Factor	Score	Rationale
		24) reactions by belugas occurred when the Twin Otter was at altitudes ≤182 m and lateral distances ≤250 m (Patenaude et al. 2002). Patenaude et al. (2002) suggested that the mid-frequency components of Twin Otter sounds from overflights at 150 m altitude should be readily audible to belugas just below the surface but overflights at 300 m might be barely detectable. A greater proportion (38% of 40) reacted to helicopters than to fixed-wing aircraft; most reactions (86%) occurred when the helicopter was at altitudes ≤150 m and lateral distances ≤250 m (Patenaude et al. 2002). Seven of 14 beluga groups reacted up to 320 m away when a helicopter was on the ice with its engines running (Patenaude et al. 2002). No mortality is expected from this stressor and considering the results above in relation to aerial survey altitude (i.e., 305 or 610 m), it is not expected that measurable impacts would result. Thus, a score of 1 was assigned.
Chronic Change	1	Overlights of fixed-wing aircraft may result in temporary behavioural responses of belugas and no mortality is expected. Furthermore, any effects of infrequent noise disturbance from aircraft would diminish quickly after the disturbance. Given that the frequency and duration of aerial surveys would be limited (see *Intensity*, above) and the results of overflight impact studies on belugas in relation to survey altitudes (see *Acute Change*, above) there would be no expected effect on population dynamics and a score of 1.
Recovery Factors	2.4	Recovery factors = mean of the factors listed below. Fecundity: 3 (Adult female belugas have 1 calf every 3 years [Sergeant 1973; Matthews and Ferguson 2015]). Early life stage mortality: Unknown; excluded from analyses (There are no data on mortality rates in juvenile belugas). Recruitment pattern: 2 (Although annual recruitment is low by some standards, belugas live to be about 70 years old assuming a single growth layer is formed in their teeth in a year [Waugh et al. 2018: Vos et al. 2020]. The maximum longevity may be 100 years [Harwood 2002]. Because of their longevity, a single female could produce a lot of young over her lifetime even if they become reproductively senescent at 35-40 years old, as suggested by Hobbs et al. [2015] and Ellis et al. [2018]). Natural mortality rate: 3 (The natural mortality rate of belugas must be low if they live to ~70 years old. Ice entrapments of belugas are known to recur in the Canadian High Arctic and in northern Foxe Basin [Smith and Sjare 1990]. Polar bears and Inuit hunters take advantage of these incidents to harvest belugas. The proportion of mortality in these situations that is attributable to predation is not well documented and remains debatable [Kilabuk 1998]. Age at maturity: 3 (Average age at sexual maturity of female beluga is 6-14 years [COSEWIC 2020]). Life stages affected: 3 (It is likely that all life stages of belugas will be affected). Population connectivity: 2 (The Western Hudson Bay population that occurs in the AOI overlaps with the Eastern Hudson Bay and Ungava Bay beluga populations in Hudson Strait during winter.) Population status: 1 (IUCN classifies the beluga whale as *near threatened*. COSEWIC [2020] lists the Western Hudson Bay population that occurs in the AOI as *least concern*]).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 1 x 1 = Negligible
Likelihood	2	An interaction has the potential to occur when belugas occur near aircraft overflights associated with scientific research, although beluga directly overflown at altitudes above 300 m would not be exposed to high sound levels and are not

Risk Factor	Score	Rationale
		likely to react based on a study by Patenaude et al. (2002). Considering this information, an interaction is unlikely to occur, resulting in a score of 2.
Overall Risk	Low Risk	No additional management actions need to be considered at this time. However, scientific studies involving aircraft should use maximum altitudes that can still achieve study objectives.
Uncertainty		
Exposure	4	There is some information on beluga distribution and temporal occurrence in the priority area. Survey protocols and the general frequency and timing of aerial surveys are known, though it is possible not every aerial surveyed was captured. Uncertainty is high.
Sensitivity	3	Certain aspects of beluga biology have been reported in other areas of the arctic. There have been some studies on the impacts of sounds from aircraft on belugas. Uncertainty is moderate.
Likelihood	4	Information exists particular to this species and pathway of effect, though from other areas. Uncertainty is high.

Risk Statement: If an interaction occurs involving narwhals and noise disturbance from aerial research surveys the consequence could result in a negative impact on the narwhal population in the Duke of York Bay/White Island priority area.

Table 7-9. Narwhal – Scientific Research (Duke of York Bay/White Island) – Noise Disturbance.

Risk Factor	Score	Rationale
Exposure	1 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 3 = 3 (raw score)
Intensity	1	This interaction investigates noise disturbance from the fixed-wing aircraft and helicopters involved in animal surveys. De Havilland Twin Otters are the likely platform used for surveys and helicopters may also be used. Surveys for walruses, seals, and polar bears are conducted coastally and may expose narwhals to this stressor while they are in bays feeding during summer. Surveys for other marine mammals, including belugas and bowhead whales, would be conducted over water and may also expose narwhals to this stressor. Polar bear subpopulations are typically surveyed every ten years and the other marine mammal surveys are conducted every five to ten years. Surveys for seals are less frequent. Individual surveys are conducted over the course of about seven to ten days. Survey design for marine mammals excluding walruses follow a parallel transect pattern with transects separated by a few to tens of kilometers, depending on the field of view covered by the imaging equipment and/or surveyors. Transect line surveys are not designed to pass over the same area multiple times. Considering this information, the intensity of aerial surveys is expected to be low, resulting in a score of 1.
Temporal	1	Narwhals migrate into the priority area in June and July and out in August and September through Frozen Strait (Westdal et al. 2010). Surveys for polar bears and other marine mammals are likely conducted during summer, while seal surveys are more likely in the spring. Polar bear subpopulations are typically surveyed every ten years and the other marine mammal surveys are conducted every five to ten years. Surveys for seals are less frequent. Individual surveys are conducted over the course of about seven to ten days. Due to the speed of the aircraft individual flyovers last from 30-60 seconds and transect surveys are generally not designed to pass over the same area multiple times. Therefore, there would be very little overlap (<25%) between when narwhals are present in the priority area and the activity, resulting in a score of 1.
Spatial	3	Spatial = Areal x Depth

Risk Factor	Score	Rationale
		= 3 x 1 = 3
Areal	3	The Duke of York/White Island priority area provides important summering habitat for narwhals where they are known to feed and calve (Idlout 2020; Loewen et al. 2020b). Narwhals migrate through Frozen Strait en route to the priority area during spring/early summer break-up and en route to Hudson Strait prior to freeze-up in the fall. Scientific studies assessed here would be planned to cover areas where narwhals are known to occur or are most abundant, and both coastal surveys and those over water (see *Intensity*, above) could overlap with narwhals. It is expected that aerial surveys would overlap with a large proportion of narwhal habitat in the priority area, resulting in a score of 3.
Depth	1	The overlap of sounds produced by an occupied aircraft with water depths used by narwhals would depend on the altitude of the survey (e.g., for cetaceans, typically 305 or 610 m). Received noise levels underwater have been recorded for a few aircraft, including the de Havilland Canada DHC-6 Twin Otter (Richardson et al. 1995a; Patenaude et al. 2002). Only animals at or near the water surface would be exposed. Narwhals spend on average about 31% of their time within 2 m of the water surface (Watt et al. 2015; Doniol-Valcroze et al. 2020) where they could hear sounds of the aircraft. The rest of their time would be spent at depths where the sounds would not be loud enough to disturb the animals. Therefore, depth was scored as 1.
Sensitivity	2 (binned)	Sensitivity = (Acute Change + Chronic Change) X Recovery Factors = (1+1) × 2.5 = 5.0
Acute Change	1	Direct mortality would not be expected to occur because of exposure to sounds produced by a fixed-wing aircraft. Observations by scientists conducting surveys of narwhals and other marine mammals indicate that narwhals are not likely to react if the aircraft altitude is 300 m or higher and they usually do not react at lower altitudes unless they are directly below the aircraft (Patenaude et al. 2002; W. Koski, pers. comm., 2022). Given the lack of species-specific studies on narwhals, studies on closely-related belugas are also referenced here. Belugas exhibit variable responses to aircraft overflights. Some belugas ignored aircraft flying at an altitude of 500 m, while with aircraft at altitudes of 150-200 m, they dove for longer periods and sometimes swam away; feeding belugas appeared to be less prone to disturbance (Kleinenberg et al. 1964). Those in summering areas, including the Mackenzie Estuary, often reacted to aircraft by diving or swimming away (e.g., Fraker and Fraker 1979; Caron and Smith 1990). Belugas in Cook Inlet may be habituated to aircraft, as there are several airports in the area; they did not react to repeated overflights by a fixed-wing aircraft (Rugh et al. 2000). During a spring flight that opportunistically examined the short-term behavioural responses of migrating beluga whales to overflights by a Twin Otter fixed-wing aircraft, a small proportion of belugas were observed to react to the aircraft at altitudes of 60-460 m (Patenaude et al. 2002). Considering observations made during all fixed-wing aircraft altitudes, 3.2% (24 of 760) of beluga singletons or groups reacted overtly, exhibiting behaviours such as diving with tail thrash, changing heading, and twisting to look up at the aircraft; direct overflights generated the most obvious reactions. The proportion of belugas reacting to the Twin Otter at low altitudes (≤182 m) was relatively low at 5.4% (18 of 336); however, the authors acknowledge this is likely an underestimation as observation opportunities were brief (Patenaude et al. 2002). Overall, most (14 of 24) reactions by belugas occurred when the Twin Otter was at altitudes ≤182 m and lateral distances ≤250 m (Patenaude et al. 2002). Patenaude et al. (2002) suggested that the mid-frequency components of Twin Otter sounds from overflights at 150 m altitude should be readily audible to belugas just below the surface but overflights at 300 m might be barely detectable. A greater proportion (38% of 40) reacted to helicopters

Risk Factor	Score	Rationale
		than to fixed-wing aircraft; most reactions (86%) occurred when the helicopter was at altitudes ≤150 m and lateral distances ≤250 m (Patenaude et al. 2002). Seven of 14 beluga groups reacted up to 320 m away when a helicopter was on the ice with its engines running (Patenaude et al. 2002). Considering the results above in relation to aerial survey altitude (i.e., 305 or 610 m) it is not expected that measurable impacts would result. Thus, a score of 1 was assigned.
Chronic Change	1	Overlights of fixed-wing aircraft may result in temporary behavioural responses of narwhals and no mortality is expected. Furthermore, any effects of infrequent noise disturbance from aircraft would diminish quickly after the disturbance. Given that the frequency and duration of aerial surveys would be limited (see *Intensity*, above) and the results of overflight impact studies on odontocetes in relation to survey altitudes (see *Acute Change*, above), there would be no expected effect on population dynamics and a score of 1.
Recovery Factors	2.5	Recovery factors = mean of the factors listed below. Fecundity: 3 (Adult female narwhals have a calf about every 3 years [Garde et al. 2015]). Early life stage mortality: 2 (Few data on first year mortality of narwhal calves are available. Koski and Davis [1994] estimated that 17% of calves died when between 1 and 13 months of age; this is lower than for many other marine mammal species]). Recruitment pattern: 2 (Although annual recruitment is low by some standards, recruitment seems to be consistent among years and because narwhals are long lived [80 years; Garde et al. 2015], a single female can produce a lot of young over her lifetime]). Natural mortality rate: 3 (The data are sparse but the stable population size with the removals by subsistence hunters suggests low mortality in all life stages). Age at maturity: 3 (Age at sexual maturity of females is 6-9 years and older for males [Garde et al. 2015]). Life stages affected: 3 (All life stages are likely to be affected). Population connectivity: 3 (Studies suggest that there is limited interchange among Canadian Arctic narwhal populations [Westdal et al. 2010; Heide-Jørgensen et al. 2013a; Doniol-Valcroze et al. 2020]). Population status: 1 (IUCN classifies narwhals as *least concern* [Lowry et al. 2017]. The last COSEWIC assessment is outdated [from 2004]. Narwhal populations are considered stable [Furgal and Laing 2012; Lowry et al. 2017]).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 1 x 3 = Negligible
Likelihood	2	An interaction has the potential to occur when narwhals occur near aircraft overflights associated with scientific research, although narwhals directly overflown at altitudes above 300 m would not be exposed to high sound levels and are not likely to react based on a study by Patenaude et al. (2002) on belugas, a closely related species, and based on observations of behaviour during past aerial surveys of narwhals. Considering this information, an interaction is unlikely to occur, resulting in a score of 2.
Overall Risk	Low Risk	No additional management actions need to be considered at this time. However, scientific studies involving aircraft should use maximum altitudes that can still achieve study objectives.
Uncertainty		
Exposure	4	Some information exists about narwhal spatial and temporal distribution from the priority area. Survey protocols and the general frequency and timing of aerial surveys are known, though it is possible not every aerial surveyed was captured.

Risk Factor	Score	Rationale
		Since exposure assumptions were based primarily on limited narwhal literature, the uncertainty is high.
Sensitivity	3	Certain aspects of narwhal biology have been reported in other areas of the arctic. The impacts of sounds from aircraft on narwhals have not been systemically studied but information does exist for this species and other odontocetes.
Likelihood	4	Available information, not specific to the priority area or AOI, exists. Since assumptions were based primarily on narwhal observations from other areas and on closely-related belugas, the uncertainty is high.

Risk Statement: If an interaction occurs involving bowhead whales and noise disturbance from aerial research surveys the consequence could result in a negative impact on the bowhead whale population in the Fisher and Evans Straits priority area.

Table 7-10. Bowhead Whale – Scientific Research (Fisher and Evans Straits) – Noise Disturbance.

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 6 = 6 (raw score)
Intensity	1	This interaction investigates noise disturbance from the fixed-wing aircraft and helicopters involved in animal surveys. De Havilland Twin Otters are the likely platform used for surveys and helicopters may also be used. Surveys for walruses, seals, and polar bears are conducted coastally and may expose bowheads to this stressor while they are in bays feeding during summer. Surveys for other marine mammals, including belugas and narwhals, would be conducted over water and may also expose bowheads to this stressor. Polar bear subpopulations are typically surveyed every ten years and the other marine mammal surveys are conducted every five to ten years. Surveys for seals are less frequent. Individual surveys are conducted over the course of about seven to ten days. Survey design for marine mammals excluding walruses follow a parallel transect pattern with transects separated by a few to tens of kilometers, depending on the field of view covered by the imaging equipment and/or surveyors. Transect line surveys are not designed to pass over the same area multiple times. Considering this information, the intensity of aerial surveys is expected to be low resulting in a score of 1.
Temporal	1	Based on scientific studies and current Inuit Qaujimajatuqangit bowheads occur in the Fisher and Evans Straits priority area from April to November but primarily occur there during summer (Idlout 2020; Loewen et al. 2020b). Surveys for polar bears and other marine mammals are likely conducted during summer, while seal surveys are more likely in the spring. Polar bear subpopulations are typically surveyed every ten years and the other marine mammal surveys are conducted every five to ten years. Surveys for seals are less frequent. Individual surveys are conducted over the course of about seven to ten days. Due to the speed of the aircraft individual flyovers last from 30-60 seconds and transect surveys are generally not designed to pass over the same area multiple times. Therefore, there would be very little overlap (<25%) between the activity and when bowheads are present in the priority area, resulting in a score of 1.
Spatial	6	Spatial = Areal x Depth = 3 x 2 = 6
Areal	3	The Fisher and Evans Strait priority area provides important summering habitat for bowhead whales where they are known to feed, calve, and nurse their young (Idlout 2020; Loewen et al. 2020b). Scientific studies assessed here would be planned to cover areas where bowheads are known to occur or are most

Risk Factor	Score	Rationale
		abundant, and coastal surveys and those over water for other species (see *Intensity*, above) could also overlap with bowheads. It is expected that aerial surveys would overlap with a large proportion of bowhead habitat in the priority area, resulting in a score of 3.
Depth	2	The overlap of sounds produced by an aircraft with water depths used by bowheads would depend on the altitude of the survey (e.g., for cetaceans, typically 305 or 610 m). Received noise levels underwater have been recorded for a few aircraft, including the de Havilland Canada DHC-6 Twin Otter (Richardson et al. 1995a; Patenaude et al. 2002). Only animals at or near the water surface would be exposed. Bowhead whales undertake foraging dives (e.g., Fortune et al. 2020) and they spend a considerable amount of time at and near the surface. Therefore, a score of 2 was assigned.
Sensitivity	1 (binned)	Sensitivity = (Acute Change + Chronic Change) X Recovery Factors = (1+1) × 2.3 = 4.6
Acute Change	1	The Fisher and Evans Straits priority area is considered important summering habitat for bowheads where they forage; the nearshore waters of SE Southampton Island in Evans Strait are calving/nursing grounds (see Figure 26 in DFO 2020). Bowhead response to aircraft appears to be variable and may be partially dependent on behavioural state and habitat (Richardson et al. 1995a). Bowhead whales actively feeding, socializing, or mating appear to be less responsive than when resting (Richardson and Malme 1993). However, based on available evidence, most bowheads do not exhibit overt reactions to single straight-line aircraft overflights, even at low altitudes. Some react to single straight-line overflights at altitudes of 150-300 m by diving, turning abruptly, or exhibiting other quick changes in behaviour (see Richardson et al. 1985a, b, 1995b). Richardson et al. (1985b, c) reported that bowhead whales frequently responded to circling aircraft at an altitude of ≤305 m, infrequently at 457 m, and rarely at ≥610 m. During overflights at low altitude, intervals between respirations decreased (Richardson et al. 1985a, b). During low-altitude photogrammetry airplane passes, bowhead whales sometimes dive hastily; however, during the summer feeding period, the same individuals were sighted in the same areas over periods of days or weeks (Koski et al. 1988), indicating little or no displacement from the feeding area. Of 507 bowhead whale groups sighted during overflights by a Twin Otter at altitudes ~145-460 m, only 2.2 % were observed to react overtly to the aircraft (Patenaude et al. 2002). These bowheads were undergoing their spring migration in the Alaskan Beaufort Sea. Reactions consisted of unusually brief surfacings, abrupt dives, and an unusual turn. Most of the reactions were observed when the aircraft approached within a lateral distance of 250 m and at altitude of ~180 m. The proportion of bowheads reacting to the Twin Otter at that altitude was still relatively low at 3.7 % (8 of 218), but the authors acknowledged that reaction frequency was likely underestimated as observation opportunities, especially at low altitudes, were brief. Two of the 11 reacting groups were mother-calf pairs (Patenaude et al. 2002). Bowhead whales in shallow water may be more responsive to Twin Otter overflights than whales in deep water because lateral propagation of aircraft sound is better in shallow water (Richardson and Malme, 1993; Richardson et al. 1995a). In summer, bowheads in water <10 m deep seemed to be more sensitive to aircraft than those in deeper water (Richardson et al. 1985a, b). Prolonged exposure to an aircraft at low altitude (e.g., an aircraft circling at ~300 m), often resulted in dispersal and departure (Richardson et al. 1985a, b). There is no indication that single or occasional overflights cause long-term displacement of whales (Richardson et al. 1995a) and no mortality is expected from this stressor. Considering survey altitudes (e.g., for cetaceans, 305 or 610 m) and the information above, a score of 1 was assigned.

Risk Factor	Score	Rationale
Chronic Change	1	Overflights of fixed-wing aircraft may result in temporary behavioural responses of bowhead whales and no mortality is expected. Furthermore, any effects of infrequent noise disturbance from aircraft would diminish quickly after the disturbance (see Koski et al. 1988). Given that the frequency and duration of aerial surveys would be limited (see *Intensity*, above) and the results of overflight impact studies on bowheads in relation to survey altitudes (see *Acute Change*, above), there would be no expected effect on population dynamics and a score of 1.
Recovery Factors	2.3	Recovery factors = mean of the factors listed below. Fecundity: 3 (Adult female bowheads have 1 calf every 3-4 years [Miller et al. 1992; Koski et al. 1993; Tarpley et al. 2016, 2021]). Early life stage mortality: Unknown; excluded from consideration (There are no data on mortality rates in juvenile bowheads). Recruitment pattern: 1 (Although annual recruitment is low by some standards, bowhead whale pregnancies seem to be determined by the health of the prospective mother to maximize survival of the calf [W. Koski, pers. comm., 2022]. Because bowhead whales live to be about 200 years old, a single female produces a lot of young over her lifetime [Tarpley et al. 2016, 2021]). Natural mortality rate: 3 (The mortality rate of adult bowheads is extremely low, possibly the lowest of any animal. Survival has been estimated as 0.984 [0.948-1.00; Zeh et al. 2002] to 0.996 [0.976-1.00, Givens et al. 2018]). Age at maturity: 3 (Average age at sexual maturity of female bowheads is about 25 years [Koski et al. 1993; George et al. 1999] and appears to have declined in recent years [Tarpley et al. 2021]). Life stages affected: 3 (All life stages may be affected by aircraft overflights.). Population connectivity: 2 (The EC-WG population of bowhead whales occur in the AOI. Until recently, the geographic distributions of the EC-WG and BCB bowhead whale populations were significantly different so that there was little or no overlap between the populations [Zeh et al. 1995]. With the opening of the NW passage resulting from climate change, interchange between these two populations is possible, as suggested by a sighting of two satellite tagged bowhead whales from the two populations in the same general area in the High Arctic [Heide-Jørgensen et al. 2011]). Population status: 1 (IUCN classifies the EC-WG bowhead whale population as *least concern* [Cooke and Reeves 2018]. COSEWIC (2009) classifies bowhead whale as *threatened*; however, that status report is out of date and is currently being reviewed. Recent surveys indicate that the population has increased since commercial overharvesting ended in the early 1900s. They may have increased to the point where this population has reached the carrying capacity of their habitat, based on sightings of skinny whales and apparent natural mortality in Cumberland Sound [Young et al. 2019] and recent cases of apparent natural mortality in other areas [DFO unpublished data]).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 2 x 1 = Negligible
Likelihood	2	An interaction has the potential to occur when bowhead whales occur near aircraft overflights associated with scientific research, although most bowheads not directly overflown or at altitudes above 300 m are not expected to exhibit an overt behavioural response. Considering this information, an interaction is unlikely to occur, resulting in a score of 2.
Overall Risk	Low Risk	No additional management measures need to be considered at this time. However, scientific studies involving aircraft should use maximum altitudes that can still achieve study objectives.
Uncertainty		

Risk Factor	Score	Rationale
Exposure	4	Some information exists about bowhead whale distribution in the priority area. Survey protocols and the general frequency and timing of aerial surveys are known, though it is possible not every aerial surveyed was captured.
Sensitivity	3	Certain aspects of bowhead whale biology have been reported in other areas of the arctic. The impacts of sounds from aircraft including the Twin Otter on bowheads have been documented in other areas. Uncertainty is moderate.
Likelihood	3	Information specific to bowhead whales and this stressor exists, though it is not specific to the priority area or AOI. Uncertainty is moderate.

7.2 Biota Encounters/Handling

Wildlife research often requires marking, tagging, and/or biopsies of animals to monitor movement patterns, identify causes of mortality, monitor impacts from anthropogenic activities, and obtain population size estimates (Walker et al. 2012; Vollset et al. 2020). In an analysis of peer-reviewed articles published from 1980 to 2011, Walker et al. (2012) found that some marine mammal tagging techniques were reported to cause pain and to change swimming and haul-out behaviour, maternal attendance, and duration of foraging trips. However, tagging was typically not found to affect survival rates. With the exception of walruses, it is unclear at present what tagging/biopsies of marine mammals may occur in the future. Walruses are currently being biopsied by community members in Coral Harbour and Naujaat as part of ongoing genetics studies led by DFO. Walruses are sampled on Walrus Island and surrounding areas and the northwestern portion of Southampton Island. This work is anticipated to continue for the next few years (C. Matthews, pers. comm., 2023). Additionally, satellite tagging of walruses has occurred out of Coral Harbour, focused primarily around Walrus Island. Telemetry data will be analysed to understand seasonal habitat use, as well as potential spatial overlaps with shipping routes. As the boundaries of a potential future MPA would extend to the low water mark, this assessment considered interactions between researchers and walruses in the marine environment, which would be most likely to occur from motorboats.

There are several permanent research camps owned and operated by ECCC on Southampton Island for ongoing research projects monitoring the ecology of various bird species and work also occurs on Coats Island. Programs are mainly restricted to terrestrial nesting sites and include observation from concealed locations, banding and/or outfitting individual birds with acoustic or GPS tags, feather and blood sample collection, and collection of eggs. As with the approach for walruses, the assessment on common eiders focussed on sampling and disturbance that occurs in the marine environment. As the distinction between disturbance from noise and from visual cues is difficult to distinguish, this interaction considers both aspects. Common eiders were assessed since there have been several studies that have found highly variable responses among this species to researcher encounters (Table 7-11). As the research programs focused on thick-billed murres on Coats Island or for Thayer’s gulls do not involve travel or sampling by motorboat, these species were not assessed here.

Table 7-11. Scientific Research − Biota Encounters/Handling: ESC Subcomponents and Priority Areas Assessed.

ESC Subcomponent	Priority Area	Assessed by Proxy
Common eider	East Bay	
Walrus	Fisher and Evans Straits	

Risk Statement: If an interaction occurs involving encounters/handling of common eiders for research activities conducted via motorboat the consequence could result in a negative impact on the common eider population in the East Bay priority area.

Table 7-12. Common eider – Scientific Research – Data Collection (East Bay) – Biota Encounters/Handling.

Risk Factor	Score	Rationale
Exposure	1 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 2 = 2 (raw score)
Intensity	1	Seabird research often includes measuring, marking, tagging, and/or biopsies of eggs or individuals to monitor movement patterns, identify causes of mortality, monitor impacts from anthropogenic activities, and obtain population size estimates. Scientific research occurs occasionally at a low density in and near the East Bay priority area, with most sampling occurring on land targeting the common eider colony adjacent to the priority area (Mallory et al. 2019) and limited sampling extending into the marine environment using motorboats, resulting in a score of 1.
Temporal	1	Common eiders are present in the East Bay priority area from mid-June to September. Adult males depart on their moult migration in July (Abraham and Finney 1986). Eggs hatch in July and the flightless females rear their precocial broods in marine and intertidal waters. Groups of females and young are present until late September. Encounters/handling could occur in the nesting colony on land at any time during incubation, hatching, and brood exodus to marine waters. However, disturbance in the marine environment from motorboats would be occasional and short-term, especially considering most handling/encounters would occur on land outside the AOI, resulting in very little overlap with the time period when common eiders are present and a score of 1.
Spatial	2	Spatial = Areal x Depth = 1 x 2 = 2
Areal	1	Eider females are expected to be on nests on Mitvik Island and part of the south shore of East Bay and to abandon the colony with their broods shortly after their eggs hatch. Encounters/handling could occur on land in the nesting colony and occasionally in the intertidal or marine environment. Incubating females are not expected to flush from the nest unless an investigator is within 20 m (Kay and Gilchrist 1998). The long-distance effects of vessel traffic or vessel noise on seabirds are unknown, and there are no established thresholds for behavioural disturbance to seabirds (Halliday et al. 2022). The area of overlap between eiders and encounters/handling in the marine environment during research activities is expected to be restricted to a few locations of the common eider distribution in the priority area, especially considering most sampling occurs on land, resulting in a score of 1.
Depth	2	Common eiders are expected to be incubating eggs or leading their young on foot to water while on land and resting on the water surface or undertaking foraging dives while in the marine environment. As this species commonly forages underwater and encounters would be expected to occur at the water surface, encounters/handling are expected to cover a moderate portion of the depth range of common eiders while in the marine environment, resulting in a score of 2.
Sensitivity	2 (binned)	Sensitivity = (Acute change + Chronic Change) x Recovery Factors = (1 + 1) x 2.6 = 5.2
Acute Change	1	Encounters/handling could have a negative impact on breeding success through increased physiological stress response, temporary nest abandonment causing increased egg predation or egg mortality from exposure to temperature extremes, and nest desertion, and could decrease colony recruitment (Boersma et al. 2002; Boyd et al. 2015; Mallory 2016). Compared to other marine birds, common eiders

Risk Factor	Score	Rationale
		have been described as more sensitive to disturbance from vessels (Garthe and Hüppop 2004; Fliessbach et al. 2019). Human disturbance from boating has been shown to reduce the feeding efficiency of common eiders and can lead to decreased energy stores, with repeated disturbances (>3 per hour) reducing feeding time to almost zero (Merkel et al. 2009). Lost feeding opportunities may force individuals to seek out food sources at less optimal times, potentially resulting in increased energetic costs (Merkel et al. 2009) or energy deficits and an increased chance of predation (Dainko and Phelps 2017). Disturbances due to boating activity has also been linked to increased mortality and population declines in certain species of marine birds (see York 1994 and references therein). These disturbances have been found to increase the incidence of gull predation on velvet scoter *Melanitta fusca* (Mikola et al. 1994) and common eider (Ahlund and Gotmark 1989); in the latter study gull encounters and successful attacks drastically increased after eider crèches (i.e., female with ducklings) were disturbed by boats, and the duration of disturbances increased the closer a vessel passed to a crèche. Gull predation can cause major duckling mortality (Mendenhall and Milne 1985), and Ahlund and Gotmark (1989) identify gull predation as a threat to local eider populations, suggesting that repeated disturbances could have population-level implications. If motorboats are frequenting areas where common eider brood-rearing is occurring, then it is possible that normal eider behaviour could be disrupted, leading to increased rates of predation on ducklings. Predation is most likely to occur in the 21-day post-hatch period when eider ducklings are most vulnerable (Mendenhall and Milne 1985), making this stage of life particularly important to the survival of the population. While behavioural changes in adults (e.g., foraging) may only result in relatively short-term effects, disruptions leading to increased predation on young could contribute in some circumstances to measurable, longer-term negative impacts on the local population. Although the effects above are noted, only a small proportion of the common eider population in the East Bay priority area is expected to be impacted by encounters/handling as part of research activities in the marine environment, in particular considering most sampling occurs on land (Boyd et al. 2015; Mallory 2016). As a result, this stressor is expected to result in an insignificant or undetectable change to the common eider mortality rates against background variability and limited behavioral impacts, resulting in a score of 1.
Chronic Change	1	In some circumstances mortality and behavioural impacts can occur from disturbance due to motorboats (see *Acute Change*, above). However, a small proportion of common eiders would be affected by encounters/handling in the marine environment associated with scientific research in the East Bay priority area as the occurrence of such activities is low. As a result, there would be an insignificant or undetectable change to overall fitness and no impact on population dynamics, resulting in a score of 1.
Recovery Factors	2.6	Recovery factors = mean of the factors listed below. Fecundity: 2 (Three to five eggs laid per year; nesting success 0-40% [Goudie et al. 2020]). Early life stage mortality**:** 3 (90-95% in first year [Goudie et al. 2020]). Recruitment pattern**:** 3 (Probability: 0.17-0.47 [Nicol-Harper et al. 2021]). Natural mortality rate**:** 3 (13% [Goudie et al. 2020]). Age at maturity**:** 2 (≥4 years [Goudie et al. 2020]). Life stages affected**:** 3 (All life stages are expected to be affected).

Risk Factor	Score	Rationale
		Population connectivity**:** 3 (High degree of fine-scale spatial genetic population structuring [Talbot et al. 2015]). Population status**:** 2 (Common eider is listed as *near threatened* by IUCN [BirdLife International 2018a] but is not listed under SARA or COSEWIC. However, the population may be declining due to increased polar bear predation in the East Bay priority area [Loewen et al. 2020b]). Also, avian cholera has the potential to cause mass mortality and significantly impact the East Bay population [Descamps et al. 2012]).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 1 x 2 = Negligible
Likelihood	3	The likelihood of an interaction between common eiders and research activities conducted via motorboat in the marine environment of the East Bay priority area will depend on the individual bird's behavioural state, prior experience with human disturbance, and the incubation stage of the individual's clutch. As most sampling occurs on land, the interaction would involve disturbance from the sampling platform, defined in this scenario as a motorboat; the probability of disturbance would depend on the proximity of the eiders to the boat. An interaction may occur in some but not all circumstances, and a score of 3.
Overall Risk	Low Risk	No additional management measures need to be considered at this time.
Uncertainty		
Exposure	3	There is a moderate amount of scientific information available regarding the abundance and distribution of common eiders in the East Bay priority area. General patterns of research activities in the area are known. Uncertainty is moderate.
Sensitivity	3	There is a moderate amount of scientific information on the sensitivity of common eiders to encounters/handling associated with scientific research, including specifically to the priority area. Uncertainty is moderate.
Likelihood	3	There is a moderate amount of scientific information on the likelihood of an interaction between common eiders and research activity, including specifically to the priority area. Uncertainty is moderate.

Risk Statement: If an interaction occurs involving encounters/handling of walruses for research activities conducted via motorboat the consequence could result in a negative impact on the walrus population in the Fisher and Evans Straits priority area.

Table 7-13. Walrus – Scientific Research (Fisher and Evans Straits) – Biota Encounters/Handling.

Risk Factor	Score	Rationale
Exposure	1 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 2 = 2 (raw score)
Intensity	1	Wildlife research has often required marking, tagging, and/or biopsies of animals to monitor movement patterns, identify causes of mortality, monitor impacts from anthropogenic activities, and obtain population size estimates (Walker et al. 2012; Vollset et al. 2020). DFO operates walrus tagging and biopsy programs on Walrus Island and surrounding areas with participation of local communities that are anticipated to run at least into the foreseeable future. Sampling may be done on the water or on land. Encounters with walruses from researchers in the marine environment would occur occasionally and at a low density in the Fisher and Evans Straits priority area, resulting in a score of 1.
Temporal	1	Based on scientific studies and current Inuit Qaujimajatuqangit walruses occur in the Fisher and Evans Straits priority area year-round (Idlout 2020; Loewen et al.

Risk Factor	Score	Rationale
		2020b). Scientific research involving tagging and biopsies of walruses would be anticipated to only occur over a number of days during the open-water season at haul-out sites or on the water; therefore, there would be very little overlap (<25%) between when walruses are present in priority area and the research activity.
Spatial	1	Spatial = Areal x Depth = 1 x 2 = 2
Areal	1	Walruses are relatively sedentary in summer (Stewart 2008), tending to remain in areas where their food is most abundant and in water less than 80 m deep (Fay 1982; Reeves et al. 2002; Dehn et al. 2007; Lowry 2016a; COSEWIC 2017). The priority area provides walrus foraging habitat, calving areas, and key terrestrial haul-out sites (on Walrus, Bencas, and Coats Islands). Walruses are generally sampled on Walrus Island and the surrounding areas and tagged out of Coral Harbour. This scientific research will occur over a small portion of walrus habitat in the priority area, resulting in a score of 1.
Depth	2	Encounters between scientific investigators in motorboats would be expected to occur at the water surface with walruses both in the water and on land. Therefore, this interaction would occur within a combination of primary and secondary habitats for this species, resulting in a score of 2.
Sensitivity	1 (binned)	Sensitivity = (Acute Change + Chronic Change) X Recovery Factors = (1+1) × 2.1 = 4.2
Acute Change	1	Important walrus haul-out sites, calving, and foraging habitat occur in the Fisher and Evans Straits priority area. In an analysis of peer-reviewed articles published from 1980 to 2011, Walker et al. (2012) found that some marine mammal tagging techniques were reported to cause pain and to change swimming and haul-out behaviour, maternal attendance, and duration of foraging trips. However, tagging was typically not found to affect survival rates. Tagging and biopsies only occur to a portion of the population. There is expected to be undetectable changes to walrus mortality rates and limited behavioural impacts to the walrus population in the priority area, resulting in a score of 1.
Chronic Change	1	As noted above in *Acute Change*, effects on the overall fitness of walrus populations in the priority area from tagging and biopsies are not anticipated, resulting in a score of 1.
Recovery Factors	2.1	Recovery factors = mean of the factors listed below. Fecundity: 3 (Adult female walrus have 1 calf every 3 years [Garlich-Miller and Stewart 1999]). Early life stage mortality: 1 (The data are sparse but the population structure and relatively high proportion of juveniles in the population suggests low mortality in all juvenile stages [Fay et al. 1997]). Recruitment pattern: 1 (Although annual recruitment is low by some standards, recruitment seems to be consistent among years and because walrus are long lived [40 years; Kovacs and Lydersen 2006], a single female produces a lot of young over her lifetime]). Natural mortality rate: 3 (The data are sparse but the population structure and relatively high proportion of juveniles in the population suggests low mortality in all life stages [Fay et al. 1997]). Age at maturity: 3 (Average age at sexual maturity of females is 7 years [Garlich-Miller and Stewart 1999]). Life stages affected: 3 (All life stages may be affected). Population connectivity: 2 (Studies suggest that there is some interchange among Canadian Arctic walrus populations [Stewart 2008; Charette et al. 2020; Loewen et al. 2020b]).

Risk Factor	Score	Rationale
		Population status: 1 (COSEWIC [2017] lists walruses as *special concern* due to threats associated with global warming. The Hudson Bay-Davis Strait stock has increased from a minimum of 3,900 in 1986 to approximately 7,000 and the authors suggest that walruses remain abundant in the Southampton Island area [Hammill et al. 2016a]).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 1 x 1 = Negligible
Likelihood	5	Given that biopsies and tagging are intended to interact with individual walruses a score of 5 was assigned.
Overall Risk	Low Risk	No additional management measures need to be considered at this time.
Uncertainty		
Exposure	2	There is some information about walrus distribution within the priority area, and important haul-out sites are known. The general locations of tagging and biopsy activities are known. Uncertainty is low.
Sensitivity	4	Certain aspects of walrus biology have been reported in other areas of the arctic. Some research has investigated the impacts of biopsies/tagging of walruses and other marine mammals, with some research occurring in the priority area. Uncertainty is high.
Likelihood	1	We know with certainty that an interaction would occur for walruses targeted for a directed tagging/biopsy program.

8.0 Recreation And Tourism – Wildlife Interactions

Recreational and tourism activities that occur within the Southampton Island AOI and are relevant for this assessment include vessel-based wildlife viewing (e.g., whale and bird watching), kayaking, cruises, fishing, hunting, dogsledding, camping, and hiking. Coral Harbour currently has two companies offering tours, including dog-sledding, boating, snowmobiling, walrus and polar bear tours, and marine eco-tours (DFO unpublished[25]). Residents of Coral Harbour have expressed a desire to further develop tourism on Southampton Island, believing that adventure and sightseeing tours would be viable (GN 2012). Stressors and pathways of effects associated with recreational fishing and sport hunting are discussed in Section 9.0, Fisheries and Harvesting; other recreational and tourism activities are considered here.

Three of the 33 vessels with available AIS data from May 2012 to October 2019 in the Southampton Island AOI were passenger ships or pleasure craft (Maerospace 2020). While the volume of tourist cruise ships is currently low in the AOI, it is a growing industry in Canada's Arctic (Johnston et al. 2017). Tourism is a summer-based industry, but as the climate warms and access increases as sea ice disappears, ship-based tourism in Nunavut is expected to increase. Although the majority of ship-based tourists in the Canadian Arctic travel by cruise ship, the fastest growing sector of vessel activity (by km travelled) is the pleasure craft industry, which is expected to continue increasing with decreasing seasonal ice cover and more accessibility to Arctic waters. It should be noted that cruise ships that have operated in the AOI are smaller expedition-type cruise ships that may only carry several hundred people. For example, the only cruise ship identified in the AOI from 2012 to 2019 (Maerospace 2020) was the *Silver Explorer*, with a guest capacity of 144 and crew capacity of 118 (Silversea Cruises Ltd. 2022). Considering that tourism vessels must abide by the approach distances outlined in the *Marine Mammal Regulations* (2018), the potential impacts from vessel movement of cruise ships will be similar to those examined in Section 5.0, Shipping and Vessel Traffic. This section will focus on smaller pleasure craft associated with recreational and tourism activities, particularly motorboats and/or Zodiacs launched from cruise ships. Note that there are currently no helicopter tourism operations in the AOI.

8.1 Noise Disturbance

Vessels specifically used for tourism that are not assessed in Section 5.0, namely motorboats and/or Zodiacs that may closely approach wildlife, are considered here. The assessments in this section include consideration of displacement due to noise disturbance and visual/olfactory cues (where appropriate) as it is difficult to distinguish those pathways when disturbance does occur. As a potential MPA would extend to the low water mark, the assessments focussed on approaches by motorboats and did not consider approaches by individuals on land. The process of habituation may be mentioned where knowledge exists but will not be used as rationale to lower risk scores.

Walrus-viewing boat tours are available from local outfitters in Coral Harbour, with trips to haul-out sites on Walrus and Coats Islands and opportunities for shore visits on Walrus Island (Stewart et al. 2010). Existing literature demonstrates variable effects of walrus ecotourism to date and there is concern among Inuit and scientists that these disturbances could drive herds farther into the pack ice or away from their traditional haul-outs or cause stampedes (Stewart 2002; C. Chenier, pers. comm. 2003; COSEWIC 2017). Øren et al. (2018) studied the effects of tourist interactions on haul-out behaviour and site use by walruses in Svalbard, Norway. Tourists in boats near the haul-out

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[25] DFO. 2024. Southampton Island Area of Interest socio-economic overview report. 45 p. + annexes.

sites did not disturb walrus behaviour significantly at any of the sites, with one exception (Øren et al. 2018), although it has been suggested that walruses are less sensitive to disturbance in Norway as they are not hunted (Higdon et al. 2022). Additionally, walruses are particularly sensitive to mechanical noise caused by ship and aircraft traffic (DFO 2019a) and have been shown to abandon haul-out sites for up to four days as a result of a disturbance (Mansfield and St. Aubin 1991). For these reasons, the interaction with walruses was assessed (Table 8-1). Past studies have generally demonstrated high uncertainty regarding walrus habituation to noise disturbance as habituation may not occur consistently among Pacific and Atlantic walruses, populations, or individuals (Stewart et al. 2012; Oren et al. 2018; DFO 2019a; Higdon et al. 2022). Since walruses in Canada are hunted, they tend to be more sensitive to human presence compared to other areas where they are not (Higdon et al. 2022). Since there is potential for walruses to experience chronic stress whether they were to habituate or not in response to ship noise (Stewart et al. 2012), the possibility of habituation was not incorporated into the risk score calculations.

Polar bears are among the most popular species to view by tourists visiting Canada's Arctic (Maher 2012). As Southampton Island does not currently have the extensive infrastructure to support large numbers of tourists, polar bear viewing within/around the Southampton Island AOI is currently conducted from cruise ships or by local outfitters offering boat tours. With a changing climate and increased interest in developing tourism, there is potential for a future increase in such human-bear interactions within the AOI. For these reasons polar bears were assessed.

There are some tours available that focus on narwhal viewing in the Arctic; however, there is little research on the effects of tourism on narwhals (Huddart and Stott 2020). There are opportunities for tourists to snorkel with narwhals in northern Baffin Island near Pond Inlet, but this is thought to have limited impact due to the small numbers of tourists engaged in this activity each year (Huddart and Stott 2020). Churchill is a popular beluga watching destination where the animals have been habituated to the presence of tour boats, snorkelers, and kayakers; however, there has been no apparent impacts on life processes (Huddart and Stott 2020). There are no known whale watching or snorkelling activities in the AOI. Given the information above, neither narwhals nor belugas were assessed.

There are significant colonies of seabirds found adjacent to the Southampton Island AOI (i.e., on land), and the region is important for several species during migration (Loewen et al. 2020b). Many species of birds are known to nest throughout the coasts and lowland interior parts of Southampton Island and on offshore islands in the spring and summer, including many gull species, terns, guillemots, common eider, Thayer's gull, and many species of waterfowl (Loewen et al. 2020b). Disturbance to seabird colonies can occur when tourists approach too closely, causing birds to leave their nests (Ward et al. 2002). Of most relevance is likely the visual presence of a vessel and the in-air noise (versus the underwater noise) generated by the vessel (and tourists) on breeding birds. Seabirds and their prey species are particularly vulnerable to tourist impacts, including potential effects such as changes in seabird population health and sustainability, ecosystem structure, and abundance (Boersma et al. 2002; Schwemmer et al. 2011; Buxton et al. 2017; Fliessbach et al. 2019). Bird-viewing boat tours are generally not conducted through local outfitters based in Coral Harbour as the distance to noteworthy colonies and cost are both high (DFO 2023a). However, Zodiacs may be launched from visiting cruise ships, likely in Fisher and Evans Straits, in order to more closely approach seabird colonies. An assessment on thick-billed murre was included as significant colonies exist on Coats Island which would be more accessible to cruise ship traffic. Common eider and Thayer's gull were not assessed as their colonies are located along the NE and east coasts of Southampton Island and are not known to draw trips from Cora Harbour-based outfitters (DFO 2023a) or from cruise ship traffic. As a potential MPA would extend to the low water mark, the assessments focussed on approaches by motorboats and did not consider approaches by individuals on land.

Table 8-1. Recreation and Tourism − Noise Disturbance: ESC Subcomponents and Priority Areas Assessed.

ESC Subcomponent	Priority Area	Assessed by Proxy
Thick-billed murre	Fisher and Evans Straits	
Walrus	Fisher and Evans Straits	
Polar bear	Fisher and Evans Straits	

Risk Statement: If an interaction occurs involving thick-billed murre and noise disturbance from motorboats/Zodiacs deployed for recreation and tourism the consequence could result in a negative impact on the thick-billed murre population in the Fisher and Evans Straits priority area.

Table 8-2. Thick-billed murre – Recreation and Tourism (Fisher and Evans Straits) – Noise Disturbance.

Risk Factor	Score	Rationale
Exposure	1 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 1 = 1 (raw score)
Intensity	1	Disturbance due to in-air noise or visual/olfactory disturbances generated by motorboats/Zodiacs and tourists is assessed here. At present there has been a low density of recreation and tourism activity in the Fisher and Evans Straits priority area. Bird-viewing boat tours are operated by local outfitters out of Coral Harbour to Coats Island to view the nesting colonies of thick-billed murres and other colonial seabirds as the distance is large and the cost is prohibitive (DFO 2023a). The only known source of this stressor are Zodiacs deployed from cruise ships in order to facilitate closer approaches (DFO 2023a). The low density of tourist vessels results in a score of 1.
Temporal	1	Thick-billed murres are present in this priority area from mid-May to October (Patterson et al. 2021). Murres would be present at the nesting cliffs on Coats Island from mid-May to through July. Foraging adults capable of flight would be present at sea from June to July and in October, whereas chicks and flightless adults would be present at sea from August to September. Noise and visual/olfactory disturbance from motorboats or Zodiacs could occur near the nesting colonies on Coats Island at any time during egg-laying incubation, hatching, and early chick-rearing, and at sea in the priority area during the marine chick-rearing stage. However, such disturbance would be restricted to a few weeks in the summer months when cruise ships are present and would be short-term, resulting in a score of 1.
Spatial	1	Spatial = Areal x Depth = 1 x 1 = 1
Areal	1	Thick-billed murre distribution in the priority area would be limited to the nesting cliffs on the north coast of Coats Island west of Cape Pembroke and the open water areas of Fisher and Evans Straits (Latour et al. 2008; Mallory et al. 2019; Patterson et al. 2022). The long-distance effects of small boat traffic on seabirds and the responses to vessel noise by Arctic seabirds are unknown, and there are no established thresholds for behavioural disturbance to seabirds (Halliday et al. 2022). However, some research indicates that vessels could cause local displacement of thick-billed murres at sea at a distance of at least 400 m

Risk Factor	Score	Rationale
		(Fliessbach et al. 2019). Disturbance due to small boat traffic would consist primarily of point source disturbances, resulting in a score of 1.
Depth	1	Thick-billed murres typically fly just above the sea but will fly >100 m above the sea with a tail wind (Gaston and Hipfner 2020). This species typically dives to a depth of 7-33 m but can dive as deep as 210 m (Gaston and Hipfner 2020). The closely related common murre (*Uria aalge*) responds underwater to broadband sounds (Anderson Hansen et al. 2020). The location of murre nests on high cliffs and approach by small boat traffic occurring at sea level would result in spatial separation. Encounters with small boat traffic would occur over a small portion of the diving depth range, flying altitude, and nesting habitat of this species, resulting in a score of 1.
Sensitivity	1 (binned)	Sensitivity = (Acute change + Chronic Change) x Recovery Factors = (1 + 1) x 2.4 = 4.8
Acute Change	1	Noise disturbance from boat-based tours could have a negative impact on thick-billed murre breeding success through increased physiological stress response, eggs or chicks falling from the nesting ledge if breeding birds flush (the egg is incubated on the brooding adult's feet), temporary nest abandonment causing increased egg predation or egg mortality from exposure to temperature extremes, and nest desertion, and could decrease colony recruitment (Chardine and Mendenhall 1998; Boersma et al. 2002; Gaston and Hipfner 2020). Noise from tourists could also cause disturbance-related behaviours, as was found in another species of colonially nesting seabirds (Buxton et al. 2017). Non-breeding and breeding off-duty murres show a much stronger response than breeding birds on the nest (Gaston and Hipfner 2020). Murres at sea would be expected to flush or escape dive in response to noise from and perhaps presence of a small vessel. Human disturbance from boating has been shown to reduce the feeding efficiency of other seabirds (i.e., common eiders) and can lead to decreased energy stores, with repeated disturbances (>3 per hour) reducing feeding time to almost zero (Merkel et al. 2009). Lost feeding opportunities may force individuals to seek out food sources at less optimal times, potentially resulting in increased energetic costs (Merkel et al. 2009) or energy deficits and an increased chance of predation (Dainko and Phelps 2017). A small proportion of the thick-billed murre population in the Fisher and Evans Straits priority area could be expected to be impacted with noise or visual disturbance from boat-based tours (Chardine and Mendenhall 1998; Boersma et al. 2002; Latour et al. 2008; Mallory et al. 2019; Gaston and Hipfner 2020; Patterson et al. 2022). As a result, noise disturbance and visual presence of small vessel traffic from tourism would result in an insignificant or undetectable change to the thick-billed murre mortality rates against background variability, resulting in a score of 1.
Chronic Change	1	In some circumstances mortality and behavioural impacts can occur from disturbance due to motorboats/Zodiacs (see *Acute Change*, above). However, a small proportion of thick-billed murres would be affected by noise disturbance and visual cues associated with tourism in the Fisher and Evans Straits priority area. Therefore, considering the low frequency of such activity, this stressor would be unlikely to cause repeated effects or, therefore, chronic change in the thick-billed murre population. As a result, there would be an insignificant or undetectable change to overall fitness and no impact on population dynamics, resulting in a score of 1.
Recovery Factors	2.4	Recovery factors = mean of the factors listed below. Fecundity: 2 (One egg laid per year [Gaston and Hipfner 2020]).

Risk Factor	Score	Rationale
		Early life stage mortality**:** 3 (63-76% before breeding age [Gaston and Hipfner 2020]). Recruitment pattern**:** 3 (Attempted breeding: 3-year olds: 0-2%; 4-year olds: 7-16%; 5-year olds: 0-31% [Noble et al. 1991]). Natural mortality rate**:** 3 (14% [Gaston et al. 1994]). Age at maturity**:** 3 (5.7 years [Gaston and Hipfner 2020]). Life stages affected**:** 3 (All life stages could potentially occur in the priority area [Gaston 2002]). Population connectivity**:** 1 (Very little genetic population structuring [Tigano et al. 2017]). Population status**:** 1 (Thick-billed murre is listed as *least concern* by IUCN [BirdLife International 2018b] and is not listed under SARA or COSEWIC).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 1 x 1 = Negligible
Likelihood	3	An interaction could occur in the Fisher and Evans Straits priority area between thick-billed murres at sea or at a nesting cliff and motorboats/Zodiacs if they approach within 400m. This likelihood will depend on the noise level produced by the boat, the breeding status of the individuals, a boat's angle of approach (towards vs. parallel to the nesting cliff), the behavioural state of individual birds, and each individual's prior experience with human disturbance. An interaction may occur in some but not all circumstances.
Overall Risk	Low Risk	No additional management measures need to be considered at this time. However, boat-based tours should observe minimum set-back distances from birds and active nests and be encouraged not to cause birds to flush, as prescribed by ECCC-CWS.
Uncertainty		
Exposure	3	There is a substantial amount of scientific information available regarding the thick-billed murres nesting colonies in the Fisher and Evans Straits priority area. Cruise ships are known to occasionally visit the priority area, though additional investigation is required to outline activities on a cruise-by-cruise basis. Uncertainty is moderate.
Sensitivity	3	There is a moderate amount of scientific information on the sensitivity of thick-billed murres to noise disturbance associated with vessel traffic (Chardine and Mendenhall 1998; Boersma et al. 2002; Gaston and Hipfner 2020), though none specific to the area.
Likelihood	3	There is a substantial amount of scientific information on the likelihood of an impact of noise disturbance due to vessel traffic on thick-billed murres, with some specific to the smaller vessels investigated here, however, none is specific to the area.

Risk Statement: If an interaction occurs involving walruses and noise disturbance from motorboats/Zodiacs deployed for recreation and tourism the consequence could result in a negative impact on the walrus population in the Fisher and Evans Straits priority area.

Table 8-3. Walrus – Recreation and Tourism (Fisher and Evans Straits) – Noise Disturbance.

Risk Factor	Score	Rationale
Exposure	2 (binned)	Exposure = Intensity x Temporal x Spatial = 1 x 1 x 6 = 6 (raw score)
Intensity	1	Disturbance due to in-air noise or visual/olfactory disturbances generated by motorboats/Zodiacs and tourists is assessed here. At present there has been a low density of recreation and tourism activity in the Fisher and Evans Straits priority area. Walrus-viewing boat tours are occasionally operated by local outfitters out of Coral Harbour to Walrus or Coats Island to view the haul-out sites (DFO 2023a). The more likely source of this stressor are Zodiacs deployed from cruise ships in order to facilitate closer approaches (DFO 2023a). The low density of tourist vessels results in a score of 1.
Temporal	1	Based on scientific studies and current Inuit Qaujimajatuqangit walruses occur in the Fisher and Evans Straits priority area year-round (Idlout 2020; Loewen et al. 2020b). Walrus-viewing tours to Walrus and Coats Islands would be restricted to a few weeks in the summer months when boat-based tours are occurring and/or when cruise ships are present and would be short-term, resulting in a score of 1.
Spatial	6	Spatial = Areal x Depth = 3 x 2 = 6
Areal	2	Walruses are relatively sedentary in summer (Stewart 2008), tending to remain in areas where their food is most abundant and in water less than 80 m deep (Fay 1982; Reeves et al. 2002; Dehn et al. 2007; Lowry 2016a; COSEWIC 2017). The priority area provides walrus foraging habitat, calving areas, and key terrestrial haul-out sites (on Walrus, Bencas, and Coats Islands). Tourism activities assessed here would be planned to occur at key walrus haul-out sites in the priority area. Although tourism activities would occur in a small proportion of the overall Fisher and Evans Straits priority area, it would occur in areas where many walruses are known to concentrate. As such, a score of 2 was assigned.
Depth	3	Walruses typically feed in waters <80 m deep but sometimes feed in waters up to 200 m (Fay 1982; Outridge et al. 2003; COSEWIC 2017). Sounds produced by small boats would be detectable and may elicit a response at all water depths where walrus occur and cause in-air noise that could be heard when hauled out. This results in a score of 3.
Sensitivity	2 (binned)	Sensitivity = (Acute Change + Chronic Change) X Recovery Factors = (2+1) × 2.1 = 6.3
Acute Change	2	Important walrus haul-out sites, calving, and foraging habitat occur in the Fisher and Evans Straits priority area including the haul-out sites where tourism is known to occur. Most studies on walrus response to vessels are for Pacific walrus response to smaller boats. Walruses at a terrestrial haul-out did not appear to be disturbed by boats with an outboard motor when approached at distances >400 m (see Fay 1982). Salter (1979) reported that no walruses were disturbed at a terrestrial haul-out during six approaches by Zodiacs at distances of 1.8-7.7 km. However, noise from outboard motors may be more disturbing than sounds from a diesel engine (Fay et al. 1984). Born et al. (1995) noted that some walruses may react to ships as far as 2 km away. Animals from hunted populations are typically skittish around small boats (see Malme et al. 1989; Born et al. 1995) but Born et al. (1995) noted that some could be approached within 10-20 m when asleep. This was also noted by local experts from Coral Harbour (DFO 2023a). Tourist boats near walrus haul-out sites (with a single exception) in Svalbard did not significantly disturb walrus haul-out behaviour (Øren et al. 2018).

Risk Factor	Score	Rationale
		At Round Island, Alaska, walruses have been observed during disturbances over several years. During 44 potential boat disturbance events (primarily tour boats) in 2008, walruses raised their heads in response to two boats, re-oriented in response to three boats, and dispersed when disturbed by 11 boats; during 28 other events, walruses did not react (Okonek et al. 2008). Similarly, for 43 potential boat disturbances in 2007, walruses had no response during 27 events; head raises occurred on four occasions, and dispersal occurred on 12 occasions (Okonek et al. 2007). If walruses disperse from haul-out sites, young animals can be injured or killed during these evacuations (Fischbach et al. 2009). Walruses have also been documented abandoning haul-out sites after a disturbance for a short period of time (3-4 days; Mansfield and St. Aubin 1991). Although available information suggests that walrus responses to small boats, including tourism boats, in open-water would be minor, walruses at haul-out sites or on sea ice often react to disturbance such as loud sounds or a visual stimulus from a vessel by entering the water (Salter 1979; Brueggeman 1993; Okonek et al. 2007, 2008). Young animals can be injured or killed during these evacuations (Fischbach et al. 2009). Thus, changes to the health or survival of individual walruses are plausible and behavioural impacts are expected if walruses (particularly at haul-out sites) are exposed to sounds and visual cues produced by a motorboat/Zodiac. This results in a score of 2.
Chronic Change	1	Disturbance may cause indirect impacts including interruption of foraging and social interactions (e.g., interference of mother-offspring communication or insufficient nursing of calves) and increased stress and energy expenditure (Born et al. 1995). Additionally, walruses may abandon haul-out sites after repeated exposure that may cause a shift in distribution away from preferred feeding areas (Johnson et al. 1989; Born et al. 1995), which would result in a loss of important habitat and a change in geographic range. However, given the current low level of tourism activity in the priority area, a score of 1 was assigned. To note regarding habituation: Stewart et al. (2012) generally found that evidence of walrus habituation to noise disturbance from vessels and aircraft has not been sufficiently supported. Additionally, observations for walrus haul-out disturbance behaviour from one area may not be transferable to another. For example, since walruses in Canada are hunted, they tend to be more sensitive to human presence compared to other areas where they are not (Higdon et al. 2022). Øren et al. (2018) looked at the effects of tourist visitations on haul-out dynamics and site use by walruses in Svalbard, Norway and found that tourists on land and boats near the haul-out sites did not disturb walrus haul-out behaviour significantly at any of the sites, with a single exception. This perhaps suggests that habituation occurred; however, it has been suggested that this is due to the fact that walruses are not hunted in this area (Higdon et al. 2022). At Round Island, Alaska long-term datasets have suggested that Pacific walruses have not habituated to disturbance from both boats and aircraft as reactions have remained similar over a 20+ year monitoring period (DFO 2019a; Higdon et al. 2022). Habituation may therefore not occur consistently among Pacific and Atlantic walruses, populations, or individuals. Since there is potential for walruses to experience chronic stress whether they were to habituate or not in response to ship noise (Stewart et al. 2012) and since walruses in the Southampton Island AOI may respond differently to sound given that they are hunted for subsistence, the possibility of habituation was not incorporated into the risk score calculations.
Recovery Factors	2.1	Recovery factors = mean of the factors listed below. Fecundity: 3 (Adult female walrus have 1 calf every 3 years [Garlich-Miller and Stewart 1999]).

Risk Factor	Score	Rationale
		Early life stage mortality: 1 (The data are sparse but the population structure and relatively high proportion of juveniles in the population suggests low mortality in all juvenile stages [Fay et al. 1997]). Recruitment pattern: 1 (Although annual recruitment is low by some standards, recruitment seems to be consistent among years and because walrus are long lived [40 years; Kovacs and Lydersen 2006], a single female produces a lot of young over her lifetime]). Natural mortality rate: 3 (The data are sparse but the population structure and relatively high proportion of juveniles in the population suggests low mortality in all life stages [Fay et al. 1997]). Age at maturity: 3 (Average age at sexual maturity of females is 7 years [Garlich-Miller and Stewart 1999]). Life stages affected: 3 (All life stages may be affected). Population connectivity: 2 (Studies suggest that there is some interchange among Canadian Arctic walrus populations [Stewart 2008; Charette et al. 2020; Loewen et al. 2020b]). Population status: 1 (COSEWIC [2017] lists walruses as *special concern* due to threats associated with global warming. The Hudson Bay-Davis Strait stock has increased from a minimum of 3,900 in 1986 to approximately 7,000 and the authors suggest that walruses remain abundant in the Southampton Island area [Hammill et al. 2016a]).
Consequence	2 (binned)	Consequence = Exposure x Sensitivity = 2 x 2 = Low
Likelihood	4	Given the documented responses of walruses to disturbance from vessel noise (see *Acute Change*, above), if a tourism motorboat were to enter the priority area and approach close enough to walruses an interaction would occur in most circumstances. This results in a likelihood score of 4.
Overall Risk	Moderate Risk	Additional management measures should be considered, such as limiting vessel activities during important times of the year for walruses and requiring set-back distances to haul-out sites in the Fisher and Evans Straits priority area.
Uncertainty		
Exposure	4	Cruise ships are known to occasionally visit the priority area, though additional investigation is required to outline activities on a cruise-by-cruise basis. There is some information about walrus distribution within the priority area, and important haul-out sites are known. Uncertainty is considered high.
Sensitivity	3	Certain aspects of walrus biology and their response to transiting boats have been reported in other areas of the arctic. Since assumptions were based primarily on walrus literature from other areas and there is some scientific information available on the topic, the uncertainty is moderate
Likelihood	4	Available information, not specific to the priority area or AOI, indicates that walruses do exhibit measurable behavioural changes to motorboats, but the response can be variable. Since assumptions were based on walrus literature from other areas and there is limited information on tourism activity, the uncertainty is high.

Risk Statement: If an interaction occurs involving polar bears and noise disturbance from motorboats/Zodiacs deployed for recreation and tourism the consequence could result in a negative impact on polar bear populations in the Fisher and Evans Straits priority area.

Table 8-4. Polar Bear – Recreation and Tourism (Fisher and Evans Straits) – Noise Disturbance.

Risk Factor	Score	Rationale
Exposure	1 (binned)	Exposure = Intensity x Temporal x Spatial (Depth x Areal) = 1 x 1 x 2 = 2 (raw score)
Intensity	1	Disturbance due to in-air noise or visual/olfactory disturbances generated by motorboats/Zodiacs and tourists is assessed here. At present there has been a low density of recreation and tourism activity in the Fisher and Evans Straits priority area. Polar bear-viewing boat tours are occasionally operated by local outfitters out of Coral Harbour to the coast east of the community (DFO 2023a). Another likely source of this stressor are Zodiacs deployed from cruise ships in order to facilitate closer approaches to animals (DFO 2023a). The low density of tourist vessels results in a score of 1.
Temporal	1	Polar bears are expected to occur in the Fisher and Evans Strait priority area year-round, although the bears move onto land when the ice breaks up in the summer. No known denning habitat exists in the priority area so females and cubs are less likely to be present in this area during spring and summer. Polar bear-viewing tours would be restricted to a few weeks in the summer months when boat-based tours are occurring and/or when cruise ships are present and would be short-term, resulting in a score of 1.
Spatial	2	Spatial = Areal x Depth = 1 x 2 = 2
Areal	1	Polar bears are likely widely distributed and occur at low densities of 1-11 bears/1,000 km^2 throughout their range (Taylor and Lee 1995; Evans et al. 2003; Aars et al. 2009). Polar bears are frequently found in areas of landfast ice or consolidated pack ice (Stirling et al. 1993); during the summer, they are often found on land (Durner et al. 2009). The area of overlap from tourism-related small boat traffic is expected to be localized, resulting in a score of 1.
Depth	2	Polar bears spend most of their time on the ice surface and not in the water (or in the water but not with their head/ears submerged). Polar bears on the ice or land would still be exposed to in-air sounds and the visual/olfactory cues of vessels. Thus, a score of 2 was assigned.
Sensitivity	1 (binned)	Sensitivity = (Acute change + Chronic Change) x Recovery Factors = (1+1) x 2.4 = 4.8
Acute Change	1	Polar bears typically do not exhibit negative responses to non-icebreaking vessels, although they will occasionally be attracted and investigate anthropogenic activities (Stirling 1988b; Shideler 1993). Responses, if any, would be brief (e.g., Smultea et al. 2016). Polar bears could become habituated to increased occurrence of tourism activities (e.g., Dyck and Baydack 2004). Although there could be increased energetic costs associated with responses (Watts et al. 1991), no mortality is expected from this stressor and no changes in the health of individual bears are expected to occur if bears respond briefly to tourism-associated vessels. Thus, it is expected that there would be insignificant or undetectable changes to polar bear mortality rates against background variability and/or limited behavioural impacts, resulting in a score of 1.
Chronic Change	1	Since individual polar bears will not significantly change their behaviour or distribution when they detect tourism-related small boat traffic, and mortality is not expected (see *Acute Change*, above), insignificant or undetectable changes to overall fitness compared to background variability are expected. Thus, a score of 1 was assigned.
Recovery Factors	2.4	Recovery factors = mean of the factors listed below.

Risk Factor	Score	Rationale
		<u>Fecundity:</u> 3 (Adult female polar bears have an average of 2 [range 1-3] cubs every 3 years [Stirling 1988a]). <u>Early life stage mortality:</u> 2 (Polar bear cubs experience moderate mortality [43%; Taylor et al. 2005; Aars et al. 2006]). <u>Recruitment pattern:</u> 2 (Polar bears have a moderate level of recruitment due to long life span and have an average of two cubs at regular intervals). <u>Natural mortality rate:</u> 3 (Tagging studies from other areas suggest a high level of survival for adult bears [e.g., adult female survival ranges: 0.91-1.00; see Regehr et al. 2015 for review]. Most populations are stable or increasing and have sustainable levels of harvest allowed under regulated quotas). <u>Age at maturity:</u> 3 (Earliest age at sexual maturity of females is 4 years with most females not reproducing until 5 or 6 years of age [Ramsay and Stirling 1988; Stirling 1988a]. Males reach sexual maturity as early as 2 years of age [Richardson et al. 2020]). <u>Life stages affected</u>: 3 (All life stages may be affected). <u>Population connectivity</u>: 2 (Studies suggest that there is little interchange between Canadian Arctic polar bear populations, but there is some exchange within the AOI, including the Fisher and Evans Straits priority area [Paetkau et al. 1999; Sahanatien et al. 2015]). <u>Population status:</u> 1 (IUCN classifies polar bears as *vulnerable* [Wiig et al. 2015], and COSEWIC [2018] classifies them as *special concern* due to threats by global warming. However, aerial surveys of the Foxe Basin area suggest that populations are stable [Stapleton et al. 2016] despite a well-documented decline in cub production and survival in western Hudson Bay [Stirling et al. 1999]).
Consequence	1 (binned)	Consequence = Exposure x Sensitivity = 2 x 1 = Negligible
Likelihood	2	Interactions between tourism-related small boat traffic and polar bears are unlikely because non-denning polar bears are typically not disturbed by the presence of human activities (Stirling 1988b; Shideler 1993). Polar bears in the priority area are not expected to be denning as no known denning sites are present. Thus, a score of 2 was assigned.
Overall Risk	Low Risk	No additional management measures need to be considered at this time.
Uncertainty		
Exposure	4	Cruise ships are known to occasionally visit the priority area, though additional investigation is required to outline activities on a cruise-by-cruise basis. There is some information about polar bear distribution within the priority area. Uncertainty is high.
Sensitivity	2	Although there is very little information from the priority area concerning how polar bears react to tourism-associated vessels, there is substantial information from other anthropogenic activities in other parts of the Arctic. It is unlikely that polar bears in the priority area would react differently. Uncertainty is low.
Likelihood	2	As noted above under sensitivity, polar bears are unlikely to behave differently in the priority area than in other parts of the Arctic where there is substantial information on this and similar pathways of effect.

9.0 Fisheries and Harvesting

Wildlife, including levels of harvesting, in the Nunavut Settlement Area is co-managed by federal and territorial governments, the Nunavut Wildlife Management Board (NWMB), Regional Wildlife Organizations (RWOs), and local Hunters and Trappers Organizations (HTOs). Fisheries are co-managed by DFO, the NWMB, RWOs and HTOs, in accordance with the Nunavut Agreement, the *Fisheries Act* (1985) and its regulations and, in some communities, local hunting bylaws. The NWMB is the main instrument of wildlife management in the Nunavut Settlement Area, but the Minister retains ultimate responsibility for wildlife management and conservation of fish, including marine mammals. In the case of Polar Bears and birds, the Government of Nunavut (GN) and ECCC are part of the co-management regime. Nunavut Tunngavik Inc. is the primary Designated Inuit Organization under the Nunavut Agreement and is responsible for ensuring that obligations and Inuit rights under the Agreement are implemented.

There is a process in place under the Nunavut Agreement for managing levels of harvesting of wildlife populations and the attendant powers and duties rest with the stipulated co-managers. However, there is potential for residual risk (i.e., the risk that remains after management or mitigation measures are considered), and impacts arising from direct biota loss from harvesting of target species have been assessed. Impacts arising from commercial fishing gears have also been assessed. As described earlier, every interaction underwent an initial qualitative level 1 assessment to determine if the interaction was expected to result in measurable impact to ESC subcomponents. Where the level 1 assessment identified possible measurable impact, a qualitative level 2 assessment was conducted.

The current and potential future scope of each fishery within the AOI and, where relevant, within marine habitat in Nunavut as a whole, are described in section 11 of the SI PoE report (Johnson et al. unpublished[26]). Although the magnitudes may differ, particularly at present within the AOI, the four "types" of fisheries/harvesting (i.e., commercial and exploratory fisheries, subsistence harvesting, recreational fishing, and sport hunting; DFO unpublished[27]) that occur in the AOI share the same stressors and impacts to ESCs. Therefore, these assessments examine the combined impacts of all harvesting "types". Additionally, this approach may be more in line with that of the Nunavut Agreement. Stressors and impacts to ESC subcomponents differ by target species and gear type/harvesting method. Therefore, and in contrast to the rest of this document where sections are structured according to sub-activities and their associated stressors, this section will be structured according to "directed harvesting" and gear types.

There is limited baseline information available regarding the populations of marine resources in the AOI, and whether and at what scale they could viably support new fisheries (e.g., harvesting at a commercial scale). In the past, various exploratory fisheries have been conducted in the AOI, including for Greenland halibut *Reinhardtius hippoglossoides*, striped shrimp *Pandalus montagui*, and Iceland scallops *Chlamys islandica*; however, the only species currently harvested on a large scale is Arctic char. Nunavut's offshore groundfish and shrimp fisheries in Baffin Bay and Davis and Hudson Straits are lucrative, and important to the territory's economy. Interest exists in developing new fisheries resources in the AOI area, and in order to inform potential impacts from these

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[26] Johnson et al. 2019. Pathways of effects modelling for the ecological and biological components of the Southampton Island Area of Interest. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/nnn. vi + xx p.

[27] DFO. 2024. Southampton Island Area of Interest socio-economic overview report. 45 p. + annexes.

activities, certain gear types will be included in the risk assessment where the level of fishing is currently minimal or non-existent. Existing commercial fisheries in and adjacent to Nunavut and past exploratory fishing licenses have been used to inform assessments. Based on bathymetry and habitat suitability, it is likely that the area would not support groundfish fisheries (the AOI is shallower than the 800-1,500 m depths in which the territory's offshore commercial groundfish fishery predominantly occurs; DFO 2019b, as well as shallower than the >500 m depths in which the Cumberland Sound inshore groundfish fishery predominantly occurs; DFO 2008a), but might have the ability to support invertebrate fisheries. HTO Board Members from Coral Harbor, Chesterfield Inlet, and Naujaat have expressed interest in benthic invertebrate fisheries (DFO unpublished[28]; DFO 2023a). Meeting participants did not mention turbot (Greenland halibut) or other groundfish, with the exception of Arctic cod, because it is not known what specific fisheries are potentially feasible in the area. The approach was to assess impacts of different gear types that could be used to capture invertebrate species; this does not necessarily imply feasibility of that fishery in the AOI.

Similarly, the extent of a potential future fishery (e.g., number of harvesters, effort) in the SI AOI is difficult to predict. The GN supports the purchase of fishing gear by local harvesters, and for reference, a potential future fishery may manifest similarly to the situation in the new Cumberland Sound small boat Greenland halibut fishery that began in 2011. In this case, the GN was able to outfit eight small boats with longline gear. As fisheries development proceeds in the Southampton Island AOI, fisheries scenarios (e.g., seasons, effort) will become more refined. As such, future risk assessments may be more detailed and precise with regard to the risk to conservation objectives, and they will be used in ongoing management of the area.

9.1 Directed Harvesting

Wildlife, including levels of harvesting, in the Nunavut Settlement Area is co-managed by the federal and territorial governments, the NWMB, RWOs, and local HTOs. Fisheries are co-managed by DFO, the NWMB, RWOs and HTOs, in accordance with the Nunavut Agreement, the *Fisheries Act* (1985) and its regulations and, in some communities, local hunting bylaws. DFO Fishery Officers and local GN Conservation Officers monitor the hunting activities for marine mammals and fish ensuring compliance with applicable regulations (e.g., DFO 2019c). In the case of Polar Bears and birds, the GN and ECCC are part of the co-management regime. The NWMB is the main instrument of wildlife management in the Nunavut Settlement Area, but the Minister retains ultimate authority and responsibility for wildlife management and conservation of fish, including marine mammals. Nunavut Tunngavik Inc. is the primary Designated Inuit Organization under the Nunavut Agreement and is responsible for ensuring that Inuit rights and obligations under the Agreement are implemented.

As harvesting is a central activity for Inuit in the AOI, to be as transparent as possible with this activity detailed level 1 assessments of directed harvesting are included in this report. As the risk results did not reveal an expected measurable impact, none of these interactions proceeded to a level 2 assessment.

9.1.1 Belugas

Risk Statement: If directed harvest of beluga whales occurs, the consequence could result in a negative impact on beluga whale populations in the Southampton Island AOI.

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[28] DFO. 2022. Southampton Island Area of Interest Hunters and Trappers Organizations Fisheries Management meetings Naujaat and Coral Harbour December 2022. Fisheries Management, Marine Conservation Targets. 11 p.

Belugas are hunted for subsistence purposes, usually in the open water by small teams in a couple of boats, from the floe edge, or at ice cracks (NAMMCO 2022b; DFO 2023a). Hunters harpoon the beluga with a detachable head that is tied to a float and shoot the whale with a high-powered rifle when it surfaces, killing the animal (NAMMCO 2022b). Some people harpoon before shooting to reduce loss rates due to belugas sinking, and some people shoot the beluga before harpooning; this varies depending on hunting parties, local customs, and proximity to shore (NAMMCO 2022b; DFO 2023a). Belugas that occur in the Southampton Island AOI are part of the Western Hudson Bay (WHB) population (Loewen 2020b). The WHB belugas have a large annual range and a small portion are believed to summer in parts of the AOI, with the northern border of the AOI around White Island being a main summer aggregation (Loewen 2020b). In 2020, COSEWIC assessed the WHB population as *not at risk* as it is robust, large, and not declining (COSEWIC 2020). The WHB beluga population is estimated to be 54,473 (95% Confidence Interval 44,988-65,957) individuals (Matthews et al. 2017). Although beluga harvesting in Nunavut is co-managed by DFO and the NWMB, the WHB beluga population has no formal management plan in place, and no limit on level of harvesting, as the combined annual removals by communities across its extensive range is considered sustainable (COSEWIC 2020).

Combined harvest by communities adjacent to or near the SI AOI (i.e., Arviat, Whale Cove, Coral Harbour, Kinngait, Chesterfield Inlet, Baker Lake, Rankin Inlet, and Naujaat) was on average 279 belugas per year from 2014 to 2018 (DFO unpublished[29]). The Potential Biological Removal (PBR) is the maximum number of animals that can be removed (not including natural mortality) from a marine mammal stock while allowing it to maintain an optimal population size. PBR levels for all beluga populations in Nunavut have been calculated using the following formula: PBR = N_{min} (the minimum population estimate, the 20th percentile of the log-normal distribution of the estimated population size) x one-half R_{Max} (maximum rate of population increase, which we do not know for beluga; 0.04 is the default for cetaceans and was used in the calculation) x F_R (the recovery factor of between 0.1 and 1.0, which is set at 1 as the population is not known to be depleted) (Wade 1998; DFO 2008b). Using this formula and most recent population estimate for the WHB beluga population (Mathews et al. 2017), the PBR is calculated as 1,003. Considering current data on harvest levels within and outside of the AOI, population estimates, PBR calculations, and input from the communities of Chesterfield Inlet and Coral Harbour (DFO 2023a), residual risk is not expected to result in measurable impact to the WHB beluga population in the AOI and a level 2 assessment was not conducted.

9.1.2 Narwhals

Risk Statement: If directed harvest of narwhals occurs, the consequence could result in a negative impact on narwhal populations in the Southampton Island AOI.

Narwhals are hunted at the floe edge, in ice cracks, and in the open water during summer aggregations, and during spring and fall migration to and from over-wintering areas (DFO 2019c, 2023a). Firearms are used to kill the animal while a harpoon with floats attached is generally used before shooting to catch the animal before sinking (DFO 2019c, 2023a). The narwhal fishery in Nunavut is co-managed by DFO, the NWMB, Regional Wildlife Organizations (RWOs), and HTOs (DFO 2019c). The management is in accordance with the Nunavut Agreement*,* the *Fisheries Act* (1985), and in some communities, local hunting bylaws in place from HTOs. Harvest information for narwhals is collected by HTOs from hunters and shared with DFO annually. A marine mammal tag is

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[29] DFO. 2024. Southampton Island Area of Interest socio-economic overview report. 45 p. + annexes.

needed to hunt for narwhals, with the tag specific to management unit (i.e., narwhal stock) and in some cases season (i.e., summer or migratory); this is important to monitor catches against the Total Allowable Harvest (DFO 2019c). Narwhals that occupy the AOI belong to the Northern Hudson Bay (NHB) population, which is also the management unit. There are no seasonal tags (only tags for the year) in the NHB management unit. Once all the tags for a management unit are used, narwhals are not allowed to be hunted until the next year (DFO 2019c). Another protection measure for narwhals is that calves or an adult with a calf cannot be hunted (DFO 2019c). The NHB narwhal population encompasses the entirety of the AOI, extends south to Arviat, east to Southern Baffin Island, and north partially into Foxe Basin (DFO 2019c).

The NHB population was previously estimated to be 12,485 animals, with a PBR of 201, and a total allowable landed catch (TALC) recommendation of 157 animals, with 10 of those being designated for the Nunavik Marine Region Wildlife Board (Asselin et al. 2012; DFO 2019c). (The TALC recommendation derives from the PBR level adjusted to account for hunting losses.) The Total Allowable Harvest (TAH) established by the NWMB is the same as the TALC recommendation. However, new survey data suggest a NHB narwhal population of 19,232 (95% Confidence Interval = 11,257-32,856) animals, indicating current PBR and TALC are less than they would be if based on updated population estimates (Watt et. al 2020). From 2014 to 2018, an average of 79 narwhals were harvested per year by Coral Harbour, Kinngait, Chesterfield Inlet, Baker Lake, Rankin Inlet, and Naujaat (DFO unpublished[30]). The community of Coral Harbour has harvested their entire allocation of the Total Allowable Harvest in recent years while the community of Chesterfield Inlet has not (DFO 2023a). Considering current data on allowable and reported harvest levels, PBR and TALC calculations, population estimates, and input from the communities of Coral Harbour and Chesterfield Inlet (DFO 2023a), residual risk is not expected to result in measurable impact to the narwhal population in the AOI and a level 2 assessment was not conducted.

9.1.3 Bowhead Whales

Risk Statement: If directed harvest of bowhead whales occurs, the consequence could result in a negative impact on bowhead whale populations in the Southampton Island AOI.

Bowhead whales are hunted by Inuit for subsistence, usually by a large team of people in multiple boats organized by the community (DFO 2023a). To capture the whale, harpoons with floats attached are impaled in the whale so diving becomes difficult; explosive ammunition is used alongside high-powered rifles to kill the whale, though a harpoon may also be used (DFO 2023a). Once the whale is killed, it is dragged through the water to ice or land where it is prepared to bring back to the community. Bowhead populations were severely depleted from commercial whaling in the early 1900s, but have been increasing in recent years (COSEWIC 2009). A ban on hunting bowheads was in place until 1996 when a limited subsistence hunt was allowed to resume (DFO 2015c). Current population estimates suggest the EC-WG population (distribution encompasses the Southampton Island AOI and most of Nunavut, as well as West Greenland) is 7,660 individuals (95% Highest Density Interval 4,500-11,100; DFO 2015c). This estimate means the population can support a maximum human-induced mortality of 52 individuals annually across its range (i.e., PBR; DFO 2015c). Nunavut has an annual Total Allowable Harvest of five bowheads per year, Nunavik has an annual Total Allowable Take of two bowheads per year, and Greenland has an annual quota of two bowheads per year from the EC-WG population (DFO 2015c; NAMMCO 2020a). This totals

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[30] DFO. 2024. Southampton Island Area of Interest socio-economic overview report. 45 p. + annexes.

nine bowhead whales captured at maximum per year, allowing a buffer of 43 bowhead whales for other human induced mortality (e.g., entanglement in fishing gear or a vessel strike). COSEWIC has assessed the EC-WG population as *special concern*, but the population is not listed under the *Species at Risk Act* (COSEWIC 2009). The Southampton Island AOI is mainly a migratory pathway for bowheads, which winter outside of the area, though summer foraging and calving is known to occur off the southeast coast of Southampton Island and summer foraging is known in Frozen Strait (Loewen 2020b). From 2014 to 2018, Naujaat harvested two bowheads and Coral Harbour harvested one (DFO unpublished[31]). This totals three bowheads over five years, less than one per year on average. Considering current data on allowable and actual harvest levels within and outside of the AOI, PBR calculations, and input from the communities of Chesterfield Inlet and Coral Harbour (DFO 2023a), residual risk is not expected to result in measurable impact to the bowhead whale population in the AOI and a level 2 assessment was not conducted.

9.1.4 Atlantic Walruses

Risk Statement: If directed harvest of walruses occurs, the consequence could result in a negative impact on walrus populations in the Southampton Island AOI.

Directed harvesting (hunting) of walruses in Nunavut occurs primarily for subsistence purposes by Inuit enrolled under the Nunavut Agreement ("beneficiaries"; DFO 2018a). However, a non-beneficiary may be authorized to harvest a walrus with a Marine Mammal Fishing License. Walruses are hunted year-round using a combination of modern and traditional equipment, such as snowmobiles, boats, rifles, harpoons, and floats (DFO 2018a). Walruses are usually hunted from boats when they are on ice floes or swimming in open water. If on ice, most walruses are shot then collected; if in the water, they are struck first with harpoons with floats attached and then shot as they are prone to sinking (DFO 2023a).

In addition to the governance structure outlined above, the Walrus Working Group developed the Integrated Fisheries Management Plan for Atlantic Walrus in 2017 and continue to work together on the management of walrus populations laid out in the plan (DFO 2018a).

The SI AOI supports walruses from the Hudson Bay-Davis Strait (HB-DS) Management Unit which is shared with Nunavik and Greenland. The distribution of this stock includes Southeast Baffin Island, Davis Strait, Western Greenland, Hudson Strait, Foxe Channel, and Northern Hudson Bay. There are 7,100 (95% Confidence Limit 2,500-20,400) individuals in the Hudson Bay-Hudson Strait component of the HB-DS stock, which excludes the area around Southeast Baffin Island-Davis Strait (Hammill et al. 2016a). Within the vicinity of the AOI, a community quota of 60 walruses per annum is in place for the community of Coral Harbour, and an individual quota of 4 walruses per Inuk per year is in place for Chesterfield Inlet, Kinngait, Rankin Inlet, and Naujaat (DFO 2018a; NWMB 2022). From 2014 to 2018, an average of 42 walruses were reported harvested per year by these communities, and an average of eight walruses harvested annually through the sport hunt (DFO unpublished[32]). The current average annual harvest of 50 walruses by these communities is less than the calculated potential biological removal (PBR) of 90-180 animals for the Hudson Bay-Hudson Strait component (Hammill et al. 2016a,b). Considering current data on allowable and reported harvest levels, PBR calculations, and input from the communities of Coral Harbour and Chesterfield Inlet (DFO 2023a), residual risk is not expected to result in measurable impact to the walrus population in the AOI and a level 2 assessment was not conducted.

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[31] DFO. 2024. Southampton Island Area of Interest socio-economic overview report. 45 p. + annexes.

9.1.5 Seals

Harvest data for all seal species in the AOI is hard to find and no recent data exist. However, total seal harvests (not indicating species) from 1996-2001 do exist for communities in the vicinity of the AOI (i.e., Coral Harbour, Chesterfield Inlet, Baker Lake, Kinngait, Naujaat, and Rankin Inlet; Priest and Usher 2004). The total average annual number of seals harvested between 1996-2001 from these communities is 2,704, with most of that number likely being ringed seals (Priest and Usher 2004). In 2021, the Government of Canada put out a news release supporting the sealing industry in Nunavut, citing room for growth and the benefit to Nunavummiut, investing $3.2 million dollars on multiple projects (GoC 2021a). Inuit Qaujimajatuqangit indicates that seal populations are more vulnerable now due to increased predation (e.g., from polar bears, foxes, and wolves) and climate change (Idlout 2020; COSEWIC 2019). Ringed and bearded seals can be found in the AOI year-round, while harp seals are migratory and arrive in the summer when ice retreats (Idlout 2020; Loewen 2020b).

Ringed Seals

Risk Statement: If directed harvest of ringed seals occurs, the consequence could result in a negative impact on ringed seal populations in the Southampton Island AOI.

Ringed seals are hunted throughout Nunavut. Ringed seals are generally caught using a rifle, and a harpoon or nitsik (a stick with a curved hook on the end) to retrieve the animal from the water or breathing hole (DFO 2023a). There is no limit on level of harvesting for ringed seals anywhere in Canada, including Nunavut. COSEWIC has assessed ringed seals as *special concern*, citing the threat to the species due to climate change, mainly as a result of the ongoing changes to sea ice and snow cover (COSEWIC 2019). This designation mainly considered potential impacts from climate change-induced loss of habitat rather than changes in abundance estimates, and the global population has been coarsely estimated between 2-5 million individuals, though estimates are dated, and the global abundance trend is unknown (Laidre et al. 2015; COSEWIC 2019; NAMMCO 2021). International programs under the Arctic Council have explicitly requested that all Arctic countries begin monitoring programs on ringed seal population structure and abundance (NAMMCO 2021). It was estimated that the population of ringed seals in the Hudson Bay and James Bay area in 1974 was 516,000 (Smith 1975), while only the western portion of Hudson Bay was estimated to host 280,000 individuals in 1995 (Lunn et al. 1997). NAMMCO (2021) notes that ringed seal harvests have been conducted continuously in Canada for hundreds or thousands of years with little evidence of overexploitation and that declines due to overharvesting are not known in Canada, while cautioning that more information was needed to assess population trends. The most recent COSEWIC (2019) assessment does not identify harvest as a potential threat to the population, noting that polar bear predation is estimated to be an order of magnitude larger than human harvest. Young and authors (2015) suggest western Hudson Bay (i.e., from Churchill to Arviat) ringed seal density varies from year to year following a decadal cycle and did not decline significantly from 1995-2013. The abnormally low density estimates in 2013 were attributed to fluctuations and overall decline in sea ice and availability of quality prey (Ferguson et al. 2017), with neither study suggesting harvesting levels as a potential contributing factor. Local experts from Chesterfield Inlet indicated that harvesting has decreased in recent years as there is less demand in their community for the meat, while local experts from Coral Harbour indicated that ringed seal harvest levels remain consistent; representatives from both communities indicated no concern about current harvest levels impacting the populations in the area (DFO 2023a). Considering data on abundance, known discussions of external threats, and input from the communities of Chesterfield Inlet and Coral

Harbour (DFO 2023a), residual risk from harvesting is not expected to result in a measurable impact on the ringed seal population in the AOI. Therefore, a level 2 assessment was not conducted.

Bearded Seals

Risk Statement: If directed harvest of bearded seals occurs, the consequence could result in a negative impact on bearded seal populations in the Southampton Island AOI.

Bearded seals are hunted for subsistence in the same way as ringed seals described above, though they are generally harpooned before being shot to avoid losing them in the water, as they are the largest species of seal in the Arctic (NAMMCO 2020b; DFO 2023a). COSEWIC assessed bearded seals in Canada as *data deficient* in 2007, with no update since that time (GoC 2021b). It is estimated that there are between 500,000 to 1 million bearded seals across the circumpolar Arctic, though current data are limited (NAMMCO 2020b). Bearded seals were harvested in low numbers in the AOI from 1996-2001, with 76 bearded seals being captured annually in Coral Harbour, 14 annually in Naujaat, and 5 annually in Chesterfield Inlet (Priest and Usher 2004). One bearded seal was recorded as captured in Baker Lake between 1996 and 2001 (Priest and Usher 2004). More recent information indicates that bearded seals are popular targets for harvesting by the community of Coral Harbour and are occasionally targeted by the community of Chesterfield Inlet, and that there are no concerns about abundance (DFO 2023a). Considering available data on harvest levels, population estimates and species distribution, and input from the communities of Chesterfield Inlet and Coral Harbour (DFO 2023a), residual risk from harvesting is not expected to result in measurable impact to the bearded seal population in the AOI and a level 2 assessment was not conducted.

Harp Seals

Risk Statement: If directed harvest of harp seals occurs, the consequence could result in a negative impact on harp seal populations in the Southampton Island AOI.

Harp seals are hunted throughout Nunavut in the same manner as other seals described above. However, they are not hunted as frequently as ringed or bearded seals (DFO 2023a), especially as harp seals are migratory, seasonal visitors to Nunavut waters including the SI AOI (Loewen 2020b). Instead, harp seals are a more popular commercial species that is harvested for their pelt in Canada’s Atlantic provinces (DFO 2011b). The population of harp seals in Canada is estimated at 7.4 million individuals and is thought to be stable or increasing (Hammill et al. 2014). Harp seals are not listed under the SARA and have not been assessed by COSEWIC (Loewen 2020b). Harvest data collected from Priest and Usher (2004) indicates that the annual five-year mean (1996-2001) of harp seals harvested from communities in the vicinity of the AOI (i.e., Chesterfield Inlet, Coral Harbour, and Naujaat,) was 24 animals per annum. Baker Lake reported no harp seals harvested during this time, and Rankin Inlet had no specified amount for harp seals (Priest and Usher 2004). More recently, it has been corroborated that harp seals are only rarely harvested by the communities of Chesterfield Inlet and Coral Harbour and they are rarely seen around the community of Coral Harbour where they were in the past (DFO 2023a). In Atlantic Canada, the commercial harvest of harp seals is managed by DFO, with harvest levels monitored daily, though no limit on level of harvesting is set as catches have been declining in recent years (DFO Fisheries and Resource Management, Internal Correspondence, 2023). The last catch limit for harp seals in Atlantic Canada was set in 2016 at 400,000 individuals. Considering the most recent data on population size, harvesting numbers, and decreasing commercial harvests elsewhere, residual risk from harvesting is not expected to result in a measurable impact to the harp seal population in the AOI and a level 2 assessment was not conducted.

9.1.6 Arctic Char

Risk Statement: If directed harvest of Arctic char occurs, the consequence could result in a negative impact on Arctic char populations in the Southampton Island AOI.

Arctic char in the AOI are harvested commercially, recreationally, and for personal use (subsistence harvest by Nunavut Inuit or domestic fishing by non-Inuit residents). Distribution of fishing effort, from shore, boat, and through the ice, is expected to be patchy as people have their preferred fishing spots. Harvesting methods (e.g., fishing rod, gill nets, and traditional methods such as the kakivak) vary according to season and personal preference (DFO 2023a). The *Northwest Territories Fishery Regulations* (2020) regulate gillnet mesh size (5.5 inches) for commercial use to reduce bycatch of smaller char. Nets in the ocean are generally set at low tide and retrieved at the following low tide (DFO 2023a). For personal catch, fishing with rod and reel has become more popular in recent years (DFO 2023a). Domestic and sport (or recreational) fishing of char by non-Inuit requires a license to catch fish, and individual daily catch and possession limits are in place for recreational fishing (GN 2021). Sport fishing licenses allow only hook and line fishing, and snagging is not allowed (i.e., the fish must bite your hook). In the portion of the AOI that overlaps the NSA, Inuit can capture char using any method, and there is no limit on the level of harvesting. Harvesting is widespread and important to Inuit.

An Integrated Fisheries Management Plan exists for the Cambridge Bay commercial char fishery (DFO 2014a), but none has been released for the Kivalliq Region. The total commercial quota from different waterbodies near the SI AOI is 73,100 kg, though much of that is not actively used (DFO unpublished[32]). There is minor commercial fishing recorded in Cleveland River and in the Coral Harbour area (DFO unpublished data). For the period of the Nunavut Wildlife Harvest Study (June 1996 to May 2001), the residents of Chesterfield Inlet harvested on average around 2,500 to 3,400 Arctic char annually for subsistence purposes from various waterbodies in the area (the latter estimate excludes two years for which community feedback indicated that estimates seemed low; Priest and Usher 2004). For the same period, the residents of Coral Harbour harvested on average around 6,700 Arctic char annually for subsistence purposes from various waterbodies in the area (community feedback indicated that estimates looked fairly accurate; Priest and Usher 2004). Perceived community use of Arctic char, based on a questionnaire completed in 2022 by five harvesters from Coral Harbour, suggests that the community catches either about the same number of Arctic char as a generation (20 years) ago or a greater number of Arctic char (DFO unpublished[33]). Much of the community of Chesterfield Inlet's char harvesting takes place in the summertime around Fish Bay (DFO 2023a). The community of Coral Harbour catches char year-round. Important harvesting areas include the Duke of York Bay and connected lakes and rivers, and around the community (DFO 2023a). Arctic char primarily occur in marine waters during summer (June to August), generally within 1,500 m from shore (Moore et al. 2016), though young char may stay in freshwater during the summer months to feed. Arctic char that use the SI AOI in the summer overwinter in many different freshwater lakes (Loewen et al. 2020b), and although not studied in the AOI, evidence from populations in the Kitikmeot and Qikiqtani Regions of Nunavut has shown that char may not always overwinter in the same lake (Moore et al. 2013; Gilbert et al. 2016). Char from different rivers and stocks mix in fresh and marine waterbodies, including some char that may enter the AOI from other waterbodies farther south on the western Hudson Bay coastline, which makes

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[32] DFO. 2024. Southampton Island Area of Interest socio-economic overview report. 45 p. + annexes.

[33] DFO. 2022. Southampton Island AOI public consultation findings – Coral Harbour. 11 p. + annexes.

stock assessments more difficult. There are no full or current stock assessments on Arctic char in the SI AOI (DFO 2020a). Little is known about Arctic char in the AOI, including population size estimates, population dynamics, life histories, marine and freshwater habitat use, diversity, and food web ecology (Loewen et al. 2020a, b; Idlout 2020).

It's possible that there is measurable impact to Arctic char stocks in the AOI from directed harvesting of this species. However, given knowledge gaps for Arctic char, it was not possible to conduct a science-based level 2 assessment (Dempson et al. 2008; Harwood et al. 2013; DFO 2014a; Harris et al. 2022). A particular knowledge gap is the sensitivity of AOI stocks to harvesting pressure, which may be quite different among Arctic char stocks (Dempson et al. 2008). The char population in the AOI is not homogeneous, with numerous stocks originating from numerous rivers. Moreover, there is no information about any of the Kivalliq Region stocks on which to base approximations for the other stocks.

The best available information regarding Arctic char directed harvesting is local knowledge. Local experts believed levels of harvesting of char in the AOI to be sustainable, and stated that the Inuit practice of taking only what you need is still followed (DFO 2023a). They also noted that the abundance of fish at different locations fluctuates from year to year, making it difficult to comment on an abundance trend (e.g., stable, decreasing or increasing) (DFO 2023a). Having fewer waterbodies at which harvesting pressure is more concentrated was put forward as an attribute that might increase risk to char from directed harvesting, but this is not the situation in the AOI (DFO 2023a).

Data from the Sylvia Grinnell River near Iqaluit, Nunavut suggest that persistent harvesting has decreased the mean length and age of Arctic char (Gallagher and Dick 2010), and a similar effect for other stocks would be expected if harvesting levels were unsustainable. However, generally speaking for Arctic char distributed across the Canadian Arctic Ocean, biological data collected from fisheries indicate a wide range of sizes and ages are present, with no loss of older age classes, which suggests current levels of harvesting are sustainable (DFO 2014b). Local experts from Chesterfield Inlet reported that Arctic char have been getting bigger over the years; local experts from Coral Harbour did not report noticing a change in size (DFO 2023a).

Based on local knowledge, there is low risk to Arctic char populations in the SI AOI from directed harvesting.

Lack of population assessments for anadromous Arctic char and the overall understanding of their marine habitat use is a substantial gap in relevant knowledge for the SI AOI (DFO 2020a, b; Loewen et al. 2020b). Additional concerted study and analysis to develop this baseline knowledge of Arctic char ecology, population estimates and dynamics in the AOI is recommended to inform a future, more detailed and precise risk assessment of Arctic char directed harvesting.

9.1.7 Forage Fish

Risk Statement: If directed harvest of forage fish occurs, the consequence could result in a negative impact on forage fish populations in the Southampton Island AOI.

There are many forage fish in the SI AOI; for a complete list of marine fishes see Loewen et al. (2020a). Some of the more ecologically important fish include Arctic cod, capelin, and sand lance (Loewen et al. 2020b). No commercial fisheries exist for any forage fish in the AOI. Arctic cod is harvested for subsistence use by some communities (e.g., Naujaat, Coral Harbour), while others (e.g., Chesterfield Inlet) may keep some if caught as bycatch during other fishing activities (Priest and Usher 2004; GN 2011, 2012). Arctic cod are often targeted during annual fishing derbies held in the spring in communities adjacent to the AOI, though the total number of fish caught is not expected to result in measurable impact to the population (DFO 2023a). Although capelin are harvested for consumption in other Canadian coastal communities (e.g., Newfoundland, Beaufort Sea), it is reported that they are not harvested in the AOI (DFO 2023a). Additionally, recent information suggests that directed harvesting for sand lance is not known (DFO 2023a). Though there are no data to reflect stock size or population of any forage fish in the AOI, most are not actively pursued. Considering the low level of directed harvest on forage fishes in the AOI, residual risk is not expected to result in a measurable impact to forage fish populations and a level 2 assessment was not conducted.

9.1.8 Kelps Beds and other Macroalgae

Risk Statement: If directed harvest of kelp/other macroalgae occurs, the consequence could result in a negative impact on the kelp beds/other macroalgae habitat in the Southampton Island AOI.

There are four main kelp species in the SI AOI, *Agarum clathratum*, *Saccharina latissima*, *Alaria esculenta*, and *Laminaria solidungula*. (Filbee-Dexter et al. 2022). Some of these species are edible: *A. esculenta* is traditionally harvested by Inuit communities around Hudson Bay and *S. latissima* is a popular commercial species globally (Wein et al. 1996; Rapinski et al. 2018). No commercial harvest of kelp occurs in the AOI and although some harvesting occurs by the community of Coral Harbour it mainly involves kelp that has washed ashore and is thus already detached from its holdfast (GN 2012; DFO 2023a). Kelp ecosystems in the AOI are large and it has been suggested that their distribution may expand with climate change (Goldsmit et al. 2021b; Assis et al. 2022; Filbee-Dexter et al. 2022). With extensive kelp beds in the AOI, and little to no directed harvesting of intact kelp beds or other macroalgae, residual risk is not expected to result in a measurable impact to kelp beds/other macroalgae habitat and a level 2 risk assessment was not conducted.

9.1.9 Benthic Invertebrates

Risk Statement: If directed harvest of benthic invertebrates occurs, the consequence could result in a negative impact on benthic invertebrate populations in the Southampton Island AOI.

There is personal harvesting of some benthic invertebrates (e.g., clams, mussels, scallops, sea cucumbers, urchins) in Nunavut (Priest and Usher 2004; GN 2010, 2012). Typically, clams and mussels are harvested during low tides in the summer months, when it is possible to dig up clams and access mussels (Idlout 2020). There are no data on any invertebrate harvesting for Chesterfield Inlet from the Nunavut Wildlife Harvest Study, though the Nunavut Coastal Resource Inventory suggests there is some harvesting of mussels, clams, and scallops (Priest and Usher 2004; GN 2010), and there was an exploratory scallop fishery from 1994-1998 in the vicinity of the community. In Coral Harbour, an average of 1,475 mussels were harvested annually between 1996-2001 (Priest and Usher 2004). The Nunavut Resource Coastal Inventory for Coral Harbour suggests people also harvest clams (GN 2010), though more recent information suggests they are not harvested in the same abundance now as 20 years ago (DFO 2023a). Little is known about population size or health of benthic invertebrate species. Though an assessment of epifaunal communities throughout Hudson Bay documented high diversity and biomass at stations associated with mixed substrate or located near polynyas within or adjacent to the southern portion of the AOI (Pierrejean et al. 2020), limited studies have gathered data on biomass or distribution throughout the AOI (Loewen et al. 2020b; Misiuk and Aitken 2020). Considering the limited personal harvest of benthic invertebrates in the AOI, residual risk is not expected to result in a measurable impact to benthic invertebrate populations in the AOI and a level 2 risk assessment was not conducted.

9.1.10 Thick-billed Murres

Risk Statement: If directed harvest of thick-billed murres occurs, the consequence could result in a negative impact on thick-billed murre populations in the Southampton Island AOI.

It is estimated that thick-billed murres are the most abundant marine bird species in the Canadian Arctic with 30,000 nesting pairs on Coats Island alone (Gaston et al. 2012). Collection of thick-billed murre eggs would occur on land, outside of the potential boundary of an MPA, and is therefore not being considered in this assessment. Even so, the nesting sites located on steep cliffs make egg harvest dangerous and it is not expected to occur (DFO 2023a). In Newfoundland and Labrador, people hunt murres, and there is a limit of 20 murre per person per day (ECCC 2022a). Recent information indicates that thick-billed murres are not actively targeted in the SI AOI, and if harvest does occur, it is likely in a small quantity (DFO 2023a). Considering thick-billed murre abundance and the low level of directed harvest on thick-billed murres in the AOI, residual risk from directed harvesting is not expected to result in a measurable impact to the thick-billed murre population in the AOI and a level 2 assessment was not conducted.

9.1.11 Common Eiders

Risk Statement: If directed harvest of common eiders occurs, the consequence could result in a negative impact on common eider populations in the Southampton Island AOI.

The largest colony of common eiders in Nunavut occurs in East Bay, with approximately 3,500 breeding pairs, and possibly more along the northern coast of SI (Loewen 2020b). The collection of eider eggs and down from nests occurs on land, outside of the potential boundary of an MPA, and is therefore not being considered in this assessment. Common eiders are harvested in parts of Atlantic Canada, but due to concerns of a declining population in the region the CWS has asked hunters to voluntarily reduce their catch (ECCC 2022b). In Nunavut, per the *Migratory Birds Regulations* (2022), the daily bag limit for all ducks combined is 25. Specifically for the SI AOI, recent information indicates that common eiders are not harvested often, with only a small handful of hunters catching a few in the year (DFO 2023a). An outbreak of avian cholera over the last decade halted eider harvest though some individuals have begun to harvest in the last couple of years (DFO 2023a). Henri (2007) documented that residents reported some hunters have switched to hunting Canada geese, decreasing the number of eiders that are being harvested. It was estimated at the time of that study that Coral Harbour harvested approximately 70-80 eiders annually (Henri 2007). Considering data on population size and harvest numbers, and input from the communities of Chesterfield Inlet and Coral Harbour (DFO 2023a), residual risk is not expected to result in a measurable impact to the common eider population in the AOI and a level 2 assessment was not conducted.

9.2 Main Gear Types of Interest

As the risk assessment approach is meant to assess impacts from potential future fisheries in addition to the existing Arctic char fishery, it would be impractical to assess every possible gear type. Therefore, assessments will focus on gear types that may be plausible in the AOI and that are known to have a greater environmental impact, including trawl, dredge, nearshore and bottom set gillnets and trap/pot. Hook and line fisheries (including angling and jigging), the use of a fishing weir, and harvesting via SCUBA are not expected to result in a measurable impact and will not be assessed; however, fuller rationales for not assessing these gears are provided below.

Because gear types are associated with potential future fisheries, they do not have well-defined scenarios like the other activities considered in this ERA, Moreover, limited baseline information is available regarding the populations of marine resources in the AOI and whether and at what scale they could viably support new fisheries. Due this lack of information, the fishing gear assessments were approached as qualitative level 2 assessments.

9.2.1 Mobile Bottom-Contact Gears – Bottom Trawls and Dredges

Various types and configurations of mobile bottom contact fishing gear exist, including beam trawls, bottom otter trawls, dredges, and mid-water trawls (Fuller et al. 2008; DFO 2010). As impacts from beam, bottom otter, and other configurations of bottom contact trawls would be similar, impacts from all trawl gear will be inferred by assessment of interactions with bottom otter trawls. Dredges are also plausible in the AOI, and interactions with these will also be assessed. Bottom trawling involves pulling large nets along the seafloor. The net would be held open by either metal doors on either side or a beam, targeting species that live on or close to the benthic substrate, such as groundfish and shrimp (Fuller et al. 2008). Though commercial-scale equipment can be >10 m across for trawls and >3 m for dredges, smaller-scale equipment (e.g., 1-2 m across) could be deployed from boats that are already present in the communities (i.e., small boats from 20-30 feet (6-9 m) in length), as is currently occurring in some communities in Nunavut (e.g., Sanikiluaq and Pangnirtung). Bottom trawling for Greenland halibut occurs in Nunavut's adjacent offshore waters, in Davis Strait and Baffin Bay, mainly using bottom otter trawls and occasionally beam trawls. Shrimp are primarily harvested using bottom trawls (DFO 2018b). Trawling for northern shrimp *Pandalus borealis* and striped shrimp occurs in Davis and Hudson Straits. Dredging gear targets species that live in the substrate, particularly shellfish and echinoderms, and involves dragging metal baskets designed to penetrate the seafloor (Fuller et al. 2008; DFO 2010). Exploratory licenses were issued for two areas within the AOI to harvest scallops using Digby dredges in the mid 1990s. Trawl (e.g., for shrimp) and dredge (e.g., for scallops) fisheries would both operate in the AOI during the open water season (likely spanning at maximum four months from July to October), and assessments for these gear types will be based on this assumption. A separate set of assessments will examine each of these two gear types.

9.2.1.1 Mobile bottom-contact gears: bycatch

Non-target fish and invertebrate bycatch occurs in all fisheries, with its prevalence contingent on gear type, season, and other factors (Fuller et al. 2008; DFO 2010). In Canada's northern shrimp fishery, shrimp trawl bycatch included dozens of fish and invertebrate species and accounted for greater than 18% of the total catch prior to introduction of the Nordmore grate, which reduced bycatch to less than 5% of total catch in all areas (Siferd 2010; DFO 2019d). Those ESC subcomponents that occur on or close to the bottom substrate would be at greatest risk of exposure, and Arctic cod, other forage fish, and benthic invertebrates were assessed for bottom otter trawl bycatch (Table 9-1). Marine mammals and seabirds were not assessed as none of the marine mammal or seabird ESC subcomponents are listed in 12 years (2010-2022) of trawl fishery bycatch data from NAFO Subarea 0 (divisions 0A and 0B), encompassing Baffin Bay and Davis Strait in Canada's Exclusive Economic Zone (DFO unpublished data). Though likely at lower rates than in trawls, benthic fish are also caught as bycatch in dredges (Craven et al. 2013), and Arctic cod bycatch was assessed (Table 9-2), covering forage fish by proxy. No marine mammal or seabird bycatch was recorded over 13 years in a dredge fishery in Ireland (Craven et al. 2013) and neither were assessed for the Digby dredge assessments. Benthic invertebrate bycatch is known in dredge fisheries and was assessed.

Table 9-1. Bottom otter trawl – bycatch: ESC subcomponents assessed.

ESC Subcomponent	Priority Area	Assessed by Proxy
Arctic cod	Not restricted to a priority area	
Other forage fish	Not restricted to a priority area	
Benthic invertebrates	Not restricted to a priority area	

Arctic cod – bottom otter trawl fishery – bycatch

Risk Statement: If Arctic cod bycatch occurs due to a fishery using bottom otter trawl, the consequence could result in a negative impact to Arctic cod populations in the SI AOI.

Arctic cod are expected to be present in the AOI year-round. A ubiquitous species, they can occupy coastal and offshore waters in areas with and without sea ice and are expected to be widespread throughout the Arctic Ocean (Coad and Reist 2018). Based on Loewen et al. (2020a), most records for Arctic cod within the AOI are for Evans Strait though Loewen et al. (2020b) also noted the occurrence of Arctic cod around small islands in Fisher Strait. A fishery using a bottom otter trawl, for example targeting shrimp, would likely occur during the open water period, between July to October in the AOI (Loewen et al. 2020b). A bottom trawl fishery for shrimp would likely occur where shrimp are abundant. Though systematic exploration for these locations within the SI AOI has not occurred, both striped and northern shrimp occur in water depths between 150-600 m, with the former preferring a hard bottom, and the latter preferring a soft and muddy substrate (DFO 2018b). Based on bathymetry and substrate type, up to 13% of the AOI is considered a suitable habitat likely to support shrimp and may be targeted during trawling (DFO unpublished data). Arctic cod are benthopelagic, occurring at different water depths based on factors such as life history stage (Geoffroy et al. 2016), seasonal diet (Majewski et al. 2016), and light regime (Benoit et al. 2010). Arctic cod are more likely to be found at greater depths during the open water period to avoid predation from seals and other marine mammals (Coad and Reist 2018). Bottom trawling involves pulling large nets along the seafloor held open by metal doors on either side, targeting species that live on or close to the benthic substrate, such as groundfish and shrimp (Fuller et al. 2008). The minimum mesh size in bottom otter trawl shrimp fisheries in Canada is 40 mm (DFO 2018b). Intensity of this stressor (bycatch) would depend on the scenario of a potential future fishery (e.g., scale of the fishery).

Bycatch data from shrimp trawling in the Hudson Strait (Nunavut/Nunavik West and East management areas) indicate a substantial amount of Arctic cod bycatch from 2010-2022, with bycatch levels between 220-67,018 kg in a given year, with no bycatch recorded in some years (DFO unpublished data). Removal of 400-2,300 kg of Arctic cod *per tow* has been recorded in the shrimp trawl fishery in Shrimp Fishing Areas 1, 2, and 3 in Baffin Bay and Davis Strait (Walkusz et al. 2020).

The SI AOI is considered a ‘frontier area’ (DFO 2006), as there is little to no history of use of mobile bottom contact gear in the area. This makes it difficult to compare to other areas where the impacts of bottom trawls have been studied, as many of these have already been impacted by fishing gear for decades (DFO 2006); however, it is assumed that any impacts demonstrated in areas with a long history of mobile bottom contact fishing would be at least equally manifested in a frontier area. Additionally, many authors have concurred that coastal benthic recovery processes should be much slower in the Arctic than in temperate waters (Dunton et al. 1982; Conlan 2005; Keck et al. 2020), though as an R-selected species Arctic cod reflect characteristics that generally support quicker recovery (Coad and Reist 2018). However, the cumulative effects of warming temperature on sea ice are expected to have a significant impact on Arctic cod during their early life history stages (Florko et al. 2021).

Fish captured in a shrimp bottom trawl fishery may be tossed back to sea as bycatch. Even though many of these are typically released alive, internal and external injuries suffered as a result of the catching process (Neilson et al. 1989; Rummer and Bennett 2005; Nichol and Chilton 2006) can reduce swimming speeds and vigilance making them more susceptible to predation (Ryer et al. 2004). Direct mortality may also occur depending on multiple factors, including deck time and fishing gear, with trawl-caught fish demonstrating higher mortality rates than hook-captured fish (Benoît et al. 2010). Indeed, survival of released Arctic cod is expected to be low in the shrimp trawl fishery in the eastern Canadian Arctic due to the length of the tow (i.e., 2-3 hours; DFO 2020). Arctic cod populations are large throughout the Arctic, with aggregations outside the AOI (i.e., Lancaster Sound, Cornwallis Island) numbering up to 900 million individuals, and Arctic cod reflect characteristics that generally support quicker recovery (Coad and Reist 2018). However, the cumulative effects of warming temperature on sea ice are expected to have a significant impact on Arctic cod during their early life history stages (Florko et al. 2021).

While Arctic cod are abundant in the Canadian Arctic (Coad and Reist 2018), due to potential high levels of bycatch and negative impacts associated with capture, there is moderate risk to Arctic cod populations in the SI AOI from bottom otter trawl bycatch, and a potential future fishery should consider management measures appropriate to the scenario of that fishery.

Uncertainty
There is moderate uncertainty with this assessment. Arctic cod are known to be caught as bycatch in a bottom trawl shrimp fishery near the AOI (i.e., Nunavut/Nunavik West and East management areas), and some information exists outside the AOI regarding preferred cod habitat, feeding areas, and population sizes. However, Arctic cod population estimates specific to the AOI do not exist and the impacts of climate change on populations is difficult to predict. As well, the intensity of this stressor (e.g., number of harvesters, effort) is unknown and would depend on the scenario of a potential future fishery. The areas within the AOI in which a trawl fishery might operate are uncertain.

Other forage fish – bottom otter trawl fishery – bycatch

Risk Statement: If forage fish bycatch occurs due to a fishery using bottom otter trawl, the consequence could result in a negative impact to forage fish populations in the SI AOI.

Many forage fish are thought to reside in the AOI year-round (e.g., capelin, sculpin), while some (e.g., herring) may travel into the AOI in summer to feed (Coad and Reist 2018; Loewen et al. 2020b). A fishery using a bottom otter trawl, for example targeting shrimp, would likely occur during the open water period, between July to October in the AOI (Loewen et al. 2020b). Forage fish are expected to occur throughout the AOI, with benthic forage fish inhabiting many different benthic habitats. A bottom trawl fishery for shrimp would likely occur where shrimp are abundant. Though systematic exploration for these locations within the SI AOI has not occurred, both striped and northern shrimp occur in water depths between 150-600 m, with the former preferring a hard bottom, and the latter preferring a soft and muddy substrate (DFO 2018b). Based on bathymetry and substrate type, up to 13% of the AOI is suitable habitat likely to support shrimp and may be targeted during trawling (DFO unpublished data). Bottom trawling involves pulling large nets along the seafloor held open by metal doors on either side, targeting species that live on or close to the benthic substrate, such as groundfish and shrimp (Fuller et al. 2008). The minimum mesh size in bottom otter trawl shrimp fisheries in Canada is 40 mm (DFO 2018b). A bottom otter trawl is more likely to catch benthic forage fish, but there is a possibility that pelagic or benthopelagic forage fish in the AOI may be captured by a bottom otter trawl. Intensity of this stressor (bycatch) would depend on the scenario of a potential future fishery (e.g., scale of the fishery).

Though no trawl fishing currently exists in the AOI, some forage fish are caught in trawl fisheries that exist elsewhere in the eastern Canadian Arctic as represented in bycatch data from 2010-2022. Capelin are recorded as bycatch in the Davis Strait East and West management areas and in Shrimp Fishing Area 1, with 2-30 kg of capelin recorded as bycatch in a given year in one management area, and no bycatch recorded in some years (DFO unpublished data). Sculpin are recorded as bycatch in the trawl fishery in the Nunavut/Nunavik West management area, Shrimp Fishing Area 1, and the Davis Strait East and West management areas, with bycatch ranging from at 10-550 kg of sculpin in a given year. The only sand lance bycatch recorded was 2 kg in 2017. Overall, there is a low abundance of forage fish bycatch in Arctic bottom trawl fisheries (DFO unpublished data). Forage fish community investigations are limited in the AOI (Loewen et al. 2020b) and population estimates for any of the species mentioned above are not known.

The SI AOI is considered a ‘frontier area’ (DFO 2006), as there is little to no history of use of mobile bottom contact gear in the area. This makes it difficult to compare to other areas where the impacts of bottom trawls have been studied, as many of these have already been impacted by fishing gear for decades (DFO 2006); however, it is assumed that any impacts demonstrated in areas with a long history of mobile bottom contact fishing would be at least equally manifested in a frontier area. Additionally, many authors have concurred that coastal benthic recovery processes should be much slower in the Arctic than in temperate waters (Dunton et al. 1982; Conlan 2005; Keck et al. 2020), though with high fecundity, short generation times, and low age at maturity, forage fish populations reflect characteristics that generally support quicker recovery (Scott and Scott 1988; Coad and Reist 2018).

Fish captured in a shrimp bottom trawl fishery may be tossed back to sea as bycatch. Even though many of these are typically released alive, internal and external injuries suffered as a result of the catching process (Neilson et al. 1989; Rummer and Bennett 2005; Nichol and Chilton 2006) can reduce swimming speeds and vigilance making them more susceptible to predation (Ryer et al. 2004). Direct mortality may also occur depending on multiple factors, including deck time and fishing gear, with trawl-caught fish demonstrating higher mortality rates than hook-captured fish (Benoît et al. 2010).

Considering low levels of bycatch in other Arctic trawl fisheries, and low areal overlap between forage fish habitat and the hypothesized target species with only an estimated 13% of the AOI being a likely suitable habitat for shrimp, the risk to forage fish in the SI AOI from bycatch in an otter trawl fishery is low. No additional management measures need to be considered at this time.

Uncertainty

There is high uncertainty in this assessment. It is known that forage fish (including capelin, sand lance, and sculpin) inhabit the AOI, and these species are represented in bycatch data from a bottom trawl fishery in the eastern Canadian Arctic outside the AOI. However, there is a lack of information on the basic biology of forage fish (e.g., distribution, migratory patterns, population sizes) in the SI AOI. As well, the intensity of this stressor (e.g., number of harvesters, effort) is unknown and would depend on the scenario of a potential future fishery. The areas within the AOI in which a trawl fishery might operate are uncertain.

Benthic invertebrates – bottom otter trawl fishery – bycatch

Risk Statement: If benthic invertebrate bycatch occurs due to a fishery using bottom otter trawl, the consequence could result in a negative impact to benthic invertebrate populations in the SI AOI.

The AOI is known to support a number of benthic invertebrates, including amphipods, polychaetes, gastropods, echinoderms, and bivalves (GN 2011, 2012; Loewen et al. 2020a, b; Misiuk and Aitken 2020), which are expected to occur in the AOI year-round. A fishery using a bottom otter trawl, for example targeting shrimp, would likely occur during the open water period, between July to October in the AOI (Loewen et al. 2020b). Benthic invertebrates are located in the lower water column, on and in the benthic substrate, throughout the AOI (Loewen et al. 2020a, b). A bottom trawl fishery for shrimp would likely occur where shrimp are abundant. Though systematic exploration for these locations within the SI AOI has not occurred, both striped and northern shrimp occur in water depths between 150-600 m, with the former preferring a hard bottom, and the latter preferring a soft and muddy substrate (DFO 2018b). Based on bathymetry and substrate type, up to 13% of the AOI is suitable habitat likely to support shrimp and may be targeted during trawling (DFO unpublished data). Bottom trawling involves pulling large nets along the seafloor held open by metal doors on either side, targeting species that live on or close to the benthic substrate, such as shrimp (Fuller et al. 2008). The minimum mesh size in bottom otter trawl shrimp fisheries in Canada is 40 mm (DFO 2018b). Intensity of this stressor would depend on the scenario of a potential future fishery (e.g., scale of fishery).

Though a bottom otter trawl does not penetrate as deeply into the substrate as a dredge, they are towed over the substrate and capture any organism that is too large to pass through the nets (National Academy of Sciences 2002). Trawl fisheries for shrimp exist in Nunavut, occurring in the Nunavut/Nunavik East and West (Hudson Strait) and Davis Strait East and West management areas. The only recorded invertebrate bycatch data from these management areas from 2010-2022 is 2 and 6 kg of squids in 2017 and 2021 respectively (DFO unpublished data). However, this does not conclusively indicate a lack of bycatch in this fishery as invertebrate bycatch is thought to be underreported.

The SI AOI is considered a ‘frontier area’ (DFO 2006), as there is little to no history of use of mobile bottom contact gear in the area. This makes it difficult to compare to other areas where the impacts of bottom trawls have been studied, as many of these have already been impacted by fishing gear for decades (DFO 2006); however, it is assumed that any impacts demonstrated in areas with a long history of mobile bottom contact fishing would be at least equally manifested in a frontier area. Many authors have concurred that coastal benthic recovery processes should be much slower in the Arctic than in temperate waters (Dunton et al. 1982; Conlan 2005; Keck et al. 2020), though with high fecundity, short generation times, and low age at maturity, some benthic invertebrate species reflect characteristics that generally support quicker population recovery. Other benthic invertebrates, such as corals and sponges, are known to recover slowly (Girard et al. 2018; Montagna and Girard 2020).

Mobile bottom contact gears cause bottom disturbances, including reducing habitat complexity (Rice 2006; Kenchington et al 2007), decreasing the level of organic material in the surface layer (Watling et al. 2001; Tiano et al. 2019; Morys et al. 2021), and creating turbid environments (Churchill 1989), which can harm photosynthetic and filter feeding species (Bell et al 2015; Krause-Jensen et al.

2021). Though species dependent, damage sustained during trawl gear retrieval can particularly affect survival in crustaceans and echinoderms even when released alive (Bergmann et al. 2001). As certain echinoderms (i.e., sea stars) have been suggested as high trophic-level keystone organisms important for nutrient cycling in the AOI (Amiraux et al. 2022), high removals of these species may affect food web dynamics.

Considering bottom otter trawls are known to alter and damage benthic habitats and communities (Kaiser et al. 2001; McConnaughey et al. 2020), and particularly negatively impact long-lived benthic species (DFO 2006), which are present in the AOI (e.g., corals and sponges; Loewen et al. 2020a; Misiuk and Aitken 2020), there is moderate risk to benthic invertebrates where a shrimp trawl fishery would occur. A potential future fishery should consider management measures appropriate to the scenario of that fishery.

Uncertainty

There is high uncertainty in this assessment. It is known that benthic invertebrates inhabit the AOI, and the impacts from mobile bottom contact gear including trawls in other areas where it is used are known. However, there is a lack of information on the basic biology of these species (e.g., distribution, migratory patterns, population sizes) in the SI AOI, no current fishery exists on which to base an assessment scenario, and though thought to be an under representation, benthic invertebrates are not commonly represented in bycatch data from other similar fisheries outside the AOI. The intensity of this stressor (e.g., number of harvesters, effort) is unknown and would depend on the scenario of a potential future fishery. The areas within the AOI in which a trawl fishery might operate are uncertain.

Table 9-2. Digby dredge – bycatch: ESC subcomponents assessed.

ESC Subcomponent	Priority Area	Assessed by Proxy
Arctic cod	Not restricted to a priority area	Other forage fish
Benthic invertebrates	Not restricted to a priority area	

Arctic cod – Digby dredge fishery – bycatch

Risk Statement: If Arctic cod bycatch occurs due to a fishery using Digby dredge, the consequence could result in a negative impact to Arctic cod populations in the SI AOI.

Arctic cod are expected to be present in the AOI year-round. A ubiquitous species, they can occupy coastal and offshore waters in areas with and without sea ice and are expected to be widespread throughout the Arctic Ocean (Coad and Reist 2018). Based on Loewen et al. (2020a), most records for Arctic cod within the AOI are for Evans Strait though Loewen et al. (2020b) also noted the occurrence of Arctic cod around small islands in Fisher Strait. A fishery using Digby dredges, for example targeting scallops, would likely occur during the open water period, between July to October in the AOI (Loewen et al. 2020b). A Digby dredge fishery for scallop would likely occur where scallops are abundant. Though systematic exploration for these locations within the SI AOI has not occurred, in general the preferred depth and substrate composition for scallops is known. Iceland scallops occur in water depths between 50-200 m, and a variety of substrate compositions including sand, gravel, shell fragments, and stones (DFO 2019e; Misiuk and Aitken 2020). Based on these considerations, up to 61% of the AOI is suitable habitat likely to contain Iceland scallops (DFO unpublished data). Arctic cod are benthopelagic, occurring at different water depths based on factors such as life history stage (Geoffroy et al. 2016), seasonal diet (Majewski et al. 2016), and light regime (Benoit et al. 2010). This species is more likely to be found at greater depths during the open water period to avoid predation from seals and other marine mammals (Coad and Reist 2018). A Digby dredge is pulled along the benthic substrate, while its teeth dig up to 10 cm into the seafloor (National Academy of Sciences 2002). Intensity of this stressor (bycatch) would depend on the scenario of a potential future fishery (e.g., scale of the fishery).

Experience from an exploratory Digby dredge fishery around Chesterfield Inlet in the 1990s suggests that Arctic cod bycatch in dredge gear is low (DFO unpublished data). Bycatch data from the shrimp bottom trawl fishery in the Nunavut/Nunavik West and East management areas indicates that this fishery has captured a substantial amount of Arctic cod bycatch from 2010-2022, ranging from 220-67,018 kg in a given year, with no bycatch recorded in some years (DFO unpublished data). While studies have suggested that finfish bycatch in dredge fisheries is less than that in trawl fisheries (Craven et al. 2013), finfish bycatch does occur.

Many finfish captured in dredges are tossed back as bycatch. Even though many of these are typically released alive, internal and external injuries suffered as a result of the catching process (Neilson et al. 1989; Rummer and Bennett 2005; Nichol and Chilton 2006) can reduce swimming speeds and vigilance making them more susceptible to predation (Ryer et al. 2004). Dredges are usually pulled relatively slowly (1-3 m/s) along the seafloor (National Academy of Sciences 2002; Craven et al. 2013), and it is suggested that adult finfish may be able to avoid capture (DFO unpublished data; Craven et al. 2013). Arctic cod populations are large throughout the Arctic, with aggregations outside the AOI (i.e., Lancaster Sound, Cornwallis Island) numbering up to 900 million individuals (Coad and Reist 2018). However, the cumulative effects of warming temperature on sea ice are expected to have a significant impact on Arctic cod during their early life history stages (Florko et al. 2021).

The SI AOI is considered a 'frontier area' (DFO 2006), as there is little to no history of use of mobile bottom contact gear in the area. This makes it difficult to compare to other areas where the impacts of dredges have been studied, as many of these have already been impacted by fishing gear for decades (DFO 2006); however, it is assumed that any impacts demonstrated in areas with a long history of mobile bottom contact fishing would be at least equally manifested in a frontier area. Many authors have concurred that coastal benthic recovery processes should be much slower in the Arctic than in temperate waters (Dunton et al. 1982; Conlan 2005; Keck et al. 2020), though as an R-selected species Arctic cod reflect characteristics that generally support quicker recovery (Coad and Reist 2018). However, the cumulative effects of warming temperature on sea ice are expected to have a significant impact on Arctic cod during their early life history stages (Florko et al. 2021).

Though Arctic cod bycatch in dredge fisheries does occur and capture can result in negative impacts to the individual, Arctic cod are abundant in the Canadian Arctic (Coad and Reist 2018) and dredge bycatch rates for this species (DFO unpublished data) or Gadids in general (Craven et al. 2013) are not expected to be high. Therefore, there is a low risk to Arctic cod populations in the SI AOI from Digby dredge bycatch. No additional management measures need to be considered at this time.

Uncertainty

There is high uncertainty in this assessment. Arctic cod have been studied in the Arctic, and some information exists outside the AOI regarding preferred cod habitat, feeding areas, and population sizes. However, Arctic cod population estimates specific to the AOI do not exist and the impacts of climate change on populations is difficult to predict. Some information exists on finfish bycatch rates in dredge fisheries outside the AOI. Information exists from an exploratory Digby dredge fishery around Chesterfield Inlet in the 1990s, but no quantitative dredging bycatch data exist specific to the Arctic. Intensity of this stressor (e.g., number of harvesters, effort) is unknown and would depend on the scenario of a potential future fishery. The areas within the AOI in which a dredge fishery might operate are uncertain.

Benthic invertebrates – Digby dredge fishery – bycatch

Risk Statement: If benthic invertebrate bycatch occurs due to a fishery using Digby dredge, the consequence could result in a negative impact to benthic invertebrate populations in the SI AOI.

The AOI is known to support a number of benthic invertebrates, including polychaetes, gastropods, echinoderms, corals, sponges, and bivalves (GN 2011, 2012; Loewen et al. 2020a, b; Misiuk and Aitken 2020), which are expected to occur in the AOI year-round. A fishery using Digby dredges, for example targeting scallops, would likely occur during the open water period, from July to October in the AOI (Loewen et al. 2020b). Benthic invertebrates are located in the lower water column, on and in the benthic substrate, throughout the AOI. A Digby dredge fishery for scallop would likely occur where scallops are abundant. Though systematic exploration for these locations within the SI AOI has not occurred, in general the preferred depth and substrate composition for scallops is known. Iceland scallops occur in water depths between 50-200 m, and a variety of substrate compositions including sand, gravel, shell fragments, and stones (DFO 2019e; Misiuk and Aitken 2020). Based on these considerations, up to 61% of the AOI is suitable habitat likely to contain Iceland scallops (DFO unpublished data). Considering a Digby dredge is designed to target Iceland scallops (a benthic invertebrate), it is likely to interact consistently with other benthic species as well. Intensity of this stressor (bycatch) would depend on the scenario of a potential future fishery (e.g., scale of the fishery).

The SI AOI is considered a ‘frontier area’ (DFO 2006), as there is little to no history of use of mobile bottom contact gear in the area. This makes it difficult to compare to other areas where the impacts of dredges have been studied, as many of these have already been impacted by fishing gear (DFO 2006); however, it is assumed that any impacts demonstrated in areas with a long history of mobile bottom contact fishing would be at least equally manifested in a frontier area. Many authors have concurred that coastal benthic recovery processes should be much slower in the Arctic than in temperate waters (Dunton et al. 1982; Conlan 2005; Keck et al. 2020), though with high fecundity, short generation times, and low age at maturity, some benthic invertebrate populations reflect characteristics that generally support quicker recovery. Other benthic invertebrates, such as corals and sponges, are known to recover slowly (Girard et al. 2018; Montagna and Girard 2020).

Scallop dredges are designed with 10 cm-long teeth that dig into the substrate (National Academy of Sciences 2002). Penetration depth is positively correlated with benthic organism removal and a meta-analysis calculated that a median of 20% of organisms were removed per trawl pass (Hiddink et al. 2017). Mussels and clams, both present in the AOI, are common discards/bycatch in scallop dredges from other regions (Gavaris et al. 2010), and can be crushed and damaged from the gear during dredging or gear hauling (DuPaul et al. 1995: Jenkins et al. 2001). This has been shown to increase bivalve vulnerability to predation if they are not already dead when released (Jenkins and Brand 2001). Though species dependent, damage sustained during mobile bottom contact gear retrieval can particularly affect survival in crustaceans and echinoderms even when released alive (Bergmann et al. 2001). As certain echinoderm seastars have been suggested as high trophic-level keystone organisms important for nutrient cycling in the AOI (Amiraux et al. 2022), high removals of these species may affect food web dynamics. Dredging alters the benthic habitat and community and can reduce biodiversity (Kaiser et al. 2001; Løkkeborg 2005 and references therein; DFO 2006,2008; McConnaughey et al. 2020) particularly if habitat forming organisms (e.g., corals and sponges) are present, though effects are less persistent in soft bottom substrates (Løkkeborg 2005; DFO 2006). It is suggested that impacts to the benthic environment can manifest negatively in higher trophic level marine mammals (Amiraux et al. 2022).

Considering the bycatch rates and impacts on benthic invertebrate survivability even when released alive, and the large estimated area of likely scallop habitat (up to 61% of the AOI), as well as the known impacts from dredge gear on benthic communities, there is moderately-high risk to benthic invertebrate populations in the SI AOI from a Digby dredge fishery. A potential future fishery should consider management measures appropriate to the scenario of that fishery.

Uncertainty

There is high uncertainty in this assessment. It is known that benthic invertebrates inhabit the AOI, and the impacts from mobile bottom contact gear including dredges in other areas where it is used are well studied. However, there is a lack of information on the basic biology of these species (e.g., distribution, migratory patterns, population sizes) in the SI AOI, no current fishery exists on which to base an assessment scenario, and bycatch data from other regionally-relevant fisheries do not exist (i.e., in Nunavut or the Arctic). The intensity of this stressor (e.g., number of harvesters, effort) is unknown and would depend on the scenario of a potential future fishery. The areas within the AOI in which a dredge fishery might operate are uncertain.

9.2.1.2 Mobile bottom-contact gears: habitat alteration

Effects on habitats from mobile bottom contact fishing gears include direct alteration, disturbance, and destruction, the extent of which can vary depending on gear type, habitat type, and fishery intensity and timing (Jennings and Kaiser 1998; Kaiser et al. 2001; DFO 2006, 2010). Complex habitats such as reefs, seagrass beds, kelp forests, and those that are naturally stable (e.g., deep-water mud) are the most vulnerable to mobile bottom contact fishing, while coastal areas with loose sediments are the least affected (Kaiser et al. 2001; Rice 2006). In addition, the more complex the habitat, the longer the recovery time following impacts from a fishery (Kaiser et al. 2001). Mobile bottom-contact gears can damage or reduce complex habitats and structure-forming biota, with the greatest impacts on low energy sites (e.g., deep-water; DFO 2006). Among such gears, bottom trawls and dredges are considered to be the most damaging to benthic habitats and ecosystems (Fuller et al. 2008; DFO 2006, 2010). Although not as potentially destructive as bottom trawls and dredges, other gear types can also affect benthic habitat. For instance, mid-water trawls are designed to avoid contacting benthic habitat, but parts of the gear may occasionally cause damage to some biogenic structures and cause sediment resuspension.

Bottom trawling also has the capability to reduce the productivity of benthic communities. Jennings et al. (2001) found a 75% reduction in total infaunal production when comparing undisturbed areas and heavily trawled locations. Collie et al. (1997) looked at trawled and undisturbed sites on gravel/pavement substrate on northern Georges Bank off the northeast coast of the United States and found that undisturbed sites had higher biomass, species richness, and diversity than disturbed sites and were dominated by bushy epifaunal organisms (i.e., bryozoans, hydroids, polychaete tubes) that provided complex habitat for several other epibenthic organisms. The mechanisms by which active benthic fishing gear can impact habitat include scraping/ploughing, increased sedimentation, destruction of complex benthic structures (e.g., rocky reefs) leading to homogenization of habitat, and scattering and mortality of non-target species that alter ecosystem dynamics (Collie et al. 1997). These effects can be long-term depending on the community/habitat being fished. Long-term fisheries monitoring shows strong evidence of permanent impacts in both high and low energy environments from removal of major physical habitat features (Rice 2006). Similarly, there is strong evidence of impacts lasting years to decades from the reduction in biogenic habitat particularly on low energy environments (Rice 2006). Removal or alteration of complex habitats and structure-forming organisms decreases available shelter for other invertebrates and juvenile fish, changes benthic community composition and increases abundance and biomass of scavengers (Kaiser et al. 2001).

Although it is acknowledged that habitat integrity is important for all ESC subcomponents it is expected that greater impacts will accrue to those that interact directly with the substrate, through foraging (e.g., Arctic cod, walruses, bearded seals) or as habitat (e.g., benthic invertebrates), and these subcomponents were the focus of this section. Kelp beds/other macroalgae was not assessed as it is not expected that trawling or dredging would occur in water shallow enough to host substantial macroalgal communities or target areas with macroalgal growth. Generally, kelp forests are also avoided in dredge fisheries as it fills and tangles the gear. Walruses and bearded seals forage in similar benthic habitats and have similar diets, so walrus was assessed with bearded seal assessed by proxy (Table 9-3). As dredges interact with the substrate to a greater degree than bottom trawls and the impacts are expected to be similar between the two types of gear, the habitat alteration stressor will be examined through dredge gear.

Table 9-3. Digby dredge – habitat alteration: ESC subcomponents assessed.

ESC Subcomponent	Priority Area	Assessed by Proxy
Arctic cod	Not restricted to a priority area	
Walrus	Not restricted to a priority area	Bearded seal
Benthic invertebrates	Not restricted to a priority area	

Arctic cod – Digby dredge fishery – habitat alteration/removal

Risk Statement: If a fishery using Digby dredge gear interacts with Arctic cod habitat, the consequence could result in a negative impact on the ecosystem function of Arctic cod habitat in the SI AOI.

Arctic cod are expected to be present in the AOI year-round. A ubiquitous species, they can occupy coastal and offshore waters in areas with and without sea ice and are expected to be widespread throughout the Arctic Ocean (Coad and Reist 2018). Based on Loewen et al. (2020a), most records for Arctic cod within the AOI are for Evans Strait though Loewen et al. (2020b) also noted the occurrence of Arctic cod around small islands in Fisher Strait. A fishery using Digby dredges, for example targeting scallops, would likely occur during the open water period, from July to October in the AOI (Loewen et al. 2020b). Arctic cod are benthopelagic, occurring throughout the water column based on factors such as life history stage (Geoffroy et al. 2016), seasonal diet (Majewski et al. 2016), and light regime (Benoit et al. 2010). A Digby dredge fishery for scallop would likely occur where scallops are abundant. Though systematic exploration for these locations within the SI AOI has not occurred, in general the preferred depth and substrate composition for scallops is known. Iceland scallops occur in water depths between 50-200 m, and a variety of substrate compositions including sand, gravel, shell fragments, and stones (DFO 2019e; Misiuk and Aitken 2020). Based on these considerations, up to 61% of the AOI is suitable habitat likely to contain Iceland scallops and therefore may be targeted during dredging (DFO unpublished data). Certain habitat occupied by Arctic cod would not be impacted by an open water dredge fishery, such as spawning or feeding habitat located under sea ice (Coad and Reist 2018; Huserbråten et al. 2019). Dredges are designed with teeth that may dig up to 10 cm into benthic substrate (National Academy of Sciences 2002) and would interact with this habitat. Intensity of this stressor (habitat alteration) would depend on the scenario of a potential future fishery (e.g., scale of the fishery).

The SI AOI is considered a 'frontier area' (DFO 2006), as there is little to no history of use of mobile bottom contact gear in the area. This makes it difficult to compare to other areas where the impacts of dredges have been studied, as many of these have already been impacted by fishing gear for decades (DFO 2006); however, it is assumed that any impacts demonstrated in areas with a long history of mobile bottom contact fishing would be at least equally manifested in a frontier area. Many authors have concurred that coastal benthic recovery processes should be much slower in the Arctic than in temperate waters (Dunton et al. 1982; Conlan 2005; Keck et al. 2020).

During the open water period, cod are known to feed on small benthic crustaceans (Coad and Reist 2018), which are not expected to be captured in a dredge fishery given mesh size. However, crustaceans may be crushed or removed from the benthic substrate when exposed to a dredge (Norderhaug et al. 2020). More broadly, dredging alters the benthic habitat and community and can reduce biodiversity (Kaiser et al. 2001; Løkkeborg 2005 and references therein; DFO 2006,2008; McConnaughey et al. 2020) particularly if habitat forming organisms (e.g., corals and sponges) are present, and alter food web dynamics manifesting through to higher trophic levels (Hiddink et al. 2016; Amiraux et al. 2022). Effects depend on substrate type: generally, initial impacts are greater in sand or mud bottom substrate than hard bottom, though effects are not as persistent in sand or mud, and it has been suggested that organism removal is greatest over gravel substrate (Løkkeborg 2005; DFO 2006; Hiddink et al. 2017); the AOI contains large areas of soft bottom or mixed substrate (DFO unpublished data). It should be noted, however, that impacts are greatest from the first few fishing events and therefore frontier areas are at higher risk (DFO 2006). If dredging impacts distribution or abundance of common Arctic cod prey species it may affect cod distribution or foraging efficiency (DFO 2006; Johnson et al. 2015).

Though changes in benthic community structure and habitat may negatively impact Arctic cod prey availability or distribution, Arctic cod are not entirely dependent on the benthic environment as they forage in and inhabit the entire water column (Coad and Reist 2018). Considering the reliance of Arctic cod on sea ice for spawning and winter foraging, the overall risk to Arctic cod habitat from a Digby dredge scallop fishery is considered low. Additional management measures aimed at mitigating impacts to Arctic cod habitat may not be necessary in a potential future dredge fishery.

Uncertainty

There is high uncertainty in this assessment. Arctic cod have been studied in the Arctic, and some information exists outside the AOI regarding preferred cod habitat, feeding areas, and population sizes. However, Arctic cod population estimates specific to the AOI do not exist and the particular reliance of cod on benthic invertebrates that might be susceptible to dredging is not well studied. Additionally, the impacts of climate change on Arctic cod habitat use distribution is difficult to predict. The impacts of dredging to benthic communities and habitat are well studied in non-Arctic regions. Intensity of this stressor (e.g., number of harvesters, effort) is unknown and would depend on the scenario of a potential future fishery. The areas within the AOI in which a dredge fishery might operate are uncertain.

Walruses – Digby dredge fishery – habitat alteration/removal

Risk Statement: If a fishery using Digby dredge gear interacts with walrus habitat, the consequence could result in a negative impact on the ecosystem function of walrus habitat in the SI AOI.

Based on scientific studies and Inuit Qaujimajatuqangit, walruses occur in the AOI year-round and primarily forage on benthic mollusks and other invertebrates (Dietz et al. 2013; Idlout 2020; Loewen et al. 2020b); therefore, walrus habitat exists in the AOI year-round as well. Walruses are relatively sedentary in the summer (Stewart 2008), tending to remain in areas where their food is most abundant and in water less than 80 m deep (Fay 1982; Reeves et al. 2002; Dehn et al. 2007; Lowry 2016a; COSEWIC 2017). The AOI provides walrus foraging habitat, calving areas, and key terrestrial haul-out sites (on Walrus, Bencas, and Coats islands). A fishery using Digby dredges, for example targeting scallops, would likely occur during the open water period, from July to October in the AOI (Loewen et al. 2020b). A Digby dredge fishery for scallop would likely occur where scallops are abundant. Though systematic exploration for these locations within the SI AOI has not occurred, in general the preferred depth and substrate composition for scallops is known. Iceland scallops occur in water depths between 50-200 m, and a variety of substrate compositions including sand, gravel, shell fragments, and stones (DFO 2019e; Misiuk and Aitken 2020). Based on these considerations, up to 61% of the AOI is suitable habitat likely to contain Iceland scallops and therefore may be targeted during dredging (DFO unpublished data). Dredges are designed with teeth that may dig up to 10 cm into benthic substrate (National Academy of Sciences 2002) and would interact with this habitat. Intensity of this stressor (habitat alteration) would depend on the scenario of a potential future fishery (e.g., scale of the fishery).

The SI AOI is considered a ‘frontier area’ (DFO 2006), as there is little to no history of use of mobile bottom contact gear in the area. This makes it difficult to compare to other areas where the impacts of dredges have been studied, as many of these have already been impacted by fishing gear for decades (DFO 2006); however, it is assumed that any impacts demonstrated in areas with a long history of mobile bottom contact fishing would be at least equally reflected in a frontier area. Many authors have concurred that coastal benthic recovery processes should be much slower in the Arctic than in temperate waters (Dunton et al. 1982; Conlan 2005; Keck et al. 2020), and with low fecundity and high age at maturity, walruses display characteristics that generally reflect slower recovery from disturbance.

The seafloor is an important foraging habitat for walruses as they primarily feed on benthic mollusks and other invertebrates (Outridge et al. 2003; Dietz et al. 2013). Dredging alters the benthic habitat and community and can reduce biodiversity (Kaiser et al. 2001; Løkkeborg 2005 and references therein; DFO 2006,2008; McConnaughey et al. 2020) particularly if habitat forming organisms (e.g., corals and sponges) are present, and alter food web dynamics manifesting through to higher trophic levels (Hiddink et al. 2016; Amiraux et al. 2022). Effects depend on substrate type: initial impacts are greater in sand or mud bottom substrate than hard bottom, though effects are not as persistent, and it has been suggested that organism removal is greatest over gravel substrate (Løkkeborg 2005; DFO 2006; Hiddink et al. 2017); the AOI contains large areas of soft bottom or mixed substrate (DFO unpublished data). It should be noted, however, that impacts are greatest from the first few fishing events and therefore frontier areas are at higher risk (DFO 2006). If dredging impacts distribution or abundance of common walrus prey species, it may affect walrus distribution or foraging efficiency (DFO 2006; Amiraux et al. 2022). Additionally, considering that walruses frequently consume scallops (DFO 2023a), a fishery targeting scallops would negatively affect prey biomass, which can negatively affect predator condition and decrease foraging efficiency (Johnson et al. 2015; Hiddink et al. 2016). Dredges can also decrease the abundance of long-lived species such as Iceland scallop, which frequently live for 25+ years (DFO 2019e; DFO 2006). Walrus likely select and stay at a haul-out location due in part to its proximity to ideal foraging locations (Fischbach et al. 2016). Therefore, if preferential prey is reduced or lost through any of the mechanisms discussed above, it may alter walrus foraging efficiency and distribution, possibly causing haul-out abandonment.

While walrus terrestrial and ice habitat will not be affected by an open water scallop dredge fishery, there are known implications to benthic communities from dredging. Considering the importance of benthic foraging opportunities to walrus haul-out locations and the potential for haul-out abandonment, there is a moderately-high risk to walrus habitat from a Digby dredge. A potential future fishery should consider management measures appropriate to the scenario of that fishery.

Uncertainty

The uncertainty in this assessment is moderate. Basic life history of walruses, including diet, distribution, haul-out sites, and foraging behaviour, have been studied, including investigation particular to the AOI. The impacts of dredging to benthic communities and habitats are well studied in non-Arctic regions, though less so regarding the effects to higher-trophic level organisms foraging on benthic communities. Intensity of this stressor (e.g., number of harvesters, effort) is unknown and would depend on the scenario of a potential future fishery. The areas within the AOI in which a dredge fishery might operate are uncertain.

Benthic invertebrates – Digby dredge fishery – habitat alteration/removal

Risk Statement: If a fishery using Digby dredge gear interacts with benthic invertebrate habitat, the consequence could result in a negative impact on the ecosystem function of benthic invertebrate habitat in the SI AOI.

The AOI is known to support a number of benthic invertebrates, including polychaetes, gastropods, echinoderms, corals, sponges, and bivalves (GN 2011, 2012; Loewen et al. 2020a, b; Misiuk and Aitken 2020), which are expected to occur in the AOI year-round. A fishery using Digby dredges, for example targeting scallops, would likely occur during the open water period, from July to October in the AOI (Loewen et al. 2020b). Benthic invertebrates are located in the lower water column, on and in the benthic substrate, throughout the AOI. A Digby dredge fishery for scallop would likely occur where scallops are abundant. Though systematic exploration for these locations within the SI AOI has not occurred, in general the preferred depth and substrate composition for scallops is known. Iceland scallops occur in water depths between 50-200 m, and a variety of substrate compositions including sand, gravel, shell fragments, and stones (DFO 2019e; Misiuk and Aitken 2020). Based on these considerations, up to 61% of the AOI is suitable habitat likely to contain Iceland scallops and therefore may be targeted during dredging (DFO unpublished data). Considering a Digby dredge is designed to target Iceland scallops (a benthic invertebrate), it is likely to interact consistently with other benthic species as well. Intensity of this stressor (habitat alteration) would depend on the scenario of a potential future fishery (e.g., scale of the fishery).

The SI AOI is considered a 'frontier area' (DFO 2006), as there is little to no history of use of mobile bottom contact gear in the area. This makes it difficult to compare to other areas where the impacts of dredges have been studied, as many of these have already been impacted by fishing gear (DFO 2006); however, it is assumed that any impacts demonstrated in areas with a long history of mobile contact fishing would be at least equally manifested in a frontier area. Many authors have concurred that coastal benthic recovery processes should be much slower in the Arctic than in temperate waters (Dunton et al. 1982; Conlan 2005; Keck et al. 2020), though with high fecundity, short generation times, and low age at maturity, some benthic invertebrate populations reflect characteristics that generally support quicker recovery. Other benthic invertebrates, such as corals and sponges, are known to recover slowly (Girard et al. 2018; Montagna and Girard 2020).

Scallop dredges are designed with 10 cm-long teeth that dig into the substrate (National Academy of Sciences 2002) with penetration depth positively correlated with benthic organism removal (Hiddink et al. 2017). Dredging causes bottom disturbances, including reducing habitat complexity (Rice 2006; Kenchington et al. 2007), decreasing the level of organic material in the surface layer (Watling et al. 2001; Tiano et al. 2019; Morys et al. 2021), and creating turbid environments (Churchill 1989), which can harm photosynthetic and filter feeding species (Bell et al. 2015; Krause-Jensen et al. 2021). Dredging alters the benthic habitat and community and can reduce biodiversity (Kaiser et al. 2001; Løkkeborg 2005 and references therein; DFO 2006,2008; McConnaughey et al. 2020) particularly if habitat forming organisms (e.g., corals and sponges) are present, and alter food web dynamics manifesting through to higher trophic levels (Hiddink et al. 2016; Amiraux et al. 2022). Effects depend on substrate type: initial impacts are greater in sand or mud bottom substrate than hard bottom, though effects are not as persistent, and it has been suggested that organism removal is greatest over gravel substrate (Løkkeborg 2005; DFO 2006; Hiddink et al. 2017); the AOI contains large areas of soft bottom or mixed substrate (DFO unpublished data). It should be noted, however, that impacts are greatest from the first few fishing events and therefore frontier areas are at higher risk (DFO 2006).

Considering the known negative impacts on benthic habitat function and communities, the large estimated area of likely scallop habitat (up to 61% of the AOI), and initially greater impacts in soft bottom and gravel substrate, there is a moderately-high risk to benthic invertebrate habitat in the SI AOI from a dredge fishery. A potential future fishery should consider management measures appropriate to the scenario of that fishery.

Uncertainty

There is moderate uncertainty in this assessment. It is known that benthic invertebrates inhabit the AOI, and the impacts from mobile bottom contact gear including dredges in other areas where it is used are well studied. However, there is a lack of information on the basic biology of these species (e.g., distribution, migratory patterns, population sizes) in the SI AOI and bycatch data from other regionally-relevant fisheries do not exist (i.e., in Nunavut or the Arctic). The intensity of this stressor (e.g., number of harvesters, effort) is unknown and would depend on the scenario of a potential future fishery. The areas within the AOI in which a dredge fishery might operate are uncertain.

9.2.2 Gillnets – Nearshore and Bottom Set

Gillnets are used to target culturally and economically important species, such as Arctic char, in the nearshore environment, and Greenland halibut in deeper offshore waters. Fishing by gillnet involves deploying a vertically hanging net in the water column targeting species that regularly move along a particular path (Fuller et al. 2008; DFO 2010). Where gillnets are set on the benthic substrate they are generally anchored in place by weights and held vertical by lines attached to floating buoys or a float line. The gillnets used in nearshore and offshore environments differ in their specifications (described in more detail in the following sections), based on the preferred habitat of their target species. Therefore, nearshore and bottom set gillnet bycatch will be assessed separately. Bycatch is common in offshore bottom gillnet fisheries, much of which is discarded dead or in damaged condition (DFO 2010). As organisms are caught in gillnets by entanglement and not through baited hooks it will be difficult to differentiate between the two pathways and one set of assessments will cover both entanglement and bycatch.

9.2.2.1 Gillnets – nearshore: bycatch

For the purposes of this assessment, the season for Arctic char gillnet fishing is defined as the open water season when the char have migrated to the ocean habitat to feed, and before they migrate back upstream. Inuit Qaujimajatuqangit has indicated this would occur over approximately four months, from July to October (Idlout 2020). Gillnets approximately 6-12 feet (1.8-3.5 m) high and 150 (45.7 m) feet long are used by individuals to harvest Arctic Char nearshore (DFO 2023a), much smaller than the offshore bottom-set gillnets. Though the number of harvesters and sets is not well described, with community populations of around 1000 and 400 in Coral Harbour and Chesterfield Inlet, respectively, this activity is expected to be pursued in the coastal marine environment by dozens of local harvesters from each community due to desirability of char, accessibility from shore, and relatively low cost of gear. However, gear type is dependent on season and personal preference, and not all individuals that fish for char in the marine environment use gillnets; many individuals prefer to fish using a rod and reel instead of a net (DFO 2023a). Spatially, Arctic char gillnets are generally set extending from shore at a variety of locations along the coast and would likely not be present in areas greater than 100 m from the coast. Though bycatch rates in nearshore marine Arctic char gillnets are not well known, there is potential for forage fish and Arctic cod to be occasionally captured, and Arctic cod was assessed (Table 9-4). Other forage fishes were not assessed (e.g., capelin, sand lance, and sculpin), as these species are not frequently captured in gillnets used to target Arctic char (DFO 2023a). Additionally, Arctic char gillnets are designed to capture char, which attain a larger size than the aforementioned forage fish; a standard mess size of 5.5” (mandatory minimum mesh size in the commercial Arctic char fishery as described in the *Northwest Territories Fishery Regulations* (2020) and common in the subsistence fishery) is generally too large to capture these other forage fish in most cases. Bycatch of Arctic char will not be assessed. Bycatch is dependent on gillnet mesh size and standard sizes allow for the smallest individuals to avoid capture. Additionally, it is believed all captured char are kept; some prefer the taste of smaller char, and others will feed smaller or less preferred char to their dogs (DFO 2023a). Directed harvest of Arctic char is covered elsewhere in the assessment. Common eiders, and other diving seabirds, are susceptible to being incidentally caught in gillnets (Regular et al. 2013; Hedd et al. 2015) and they have been assessed, acting as a proxy assessment for other seabirds. Marine mammals are not often entangled in Arctic char gillnets in the AOI (DFO 2023a) and none of these species will be assessed. Gear components from gillnet fisheries can also impact habitat, including the crushing of benthic organisms and sediment resuspension during deployment or retrieval (DFO 2010). Due to the small footprint of the Arctic char gillnets, habitat alteration is not expected to result in measurable impact to any ESC subcomponent and will not be assessed. Although Arctic char gillnets can be fished under the ice, this would occur in freshwater (i.e., lakes, deep pools in rivers), and not in the marine environment (i.e., ocean, estuaries), as sea-run char generally overwinter in freshwater, and because a strong current would preclude the use of nets under the ice in marine waters.

Table 9-4. Arctic char gillnet – bycatch: ESC subcomponents assessed

ESC Subcomponent	Priority Area	Assessed by Proxy
Arctic cod	Not restricted to a priority area	
Common eider	Not restricted to a priority area	Other seabirds

Arctic cod – Arctic char gillnet – bycatch

Risk Statement: If Arctic cod bycatch occurs due to the Arctic char gillnet fishery, the consequence could result in a negative impact to Arctic cod populations in the SI AOI.

Arctic cod are expected to be present in the AOI year-round. A ubiquitous species, they can occupy coastal and offshore waters in areas with and without sea ice and are expected to be widespread throughout the Arctic Ocean (Coad and Reist 2018). Based on Loewen et al. (2020a), most records for Arctic cod within the AOI are for Evans Strait though Loewen et al. (2020b) also noted the occurrence of Arctic cod around small islands in Fisher Strait. The Arctic char gillnet fishery in the AOI occurs during the approximate 4 months of open water, from July to October in the AOI (Loewen et al. 2020b; DFO 2023a). Arctic char gillnets are generally set extending from shore at a variety of locations along the coast and would likely not be present in areas greater than 100 m from shore. Arctic cod are benthopelagic, and occur at many depths throughout the water column, based on factors like life history stage (Geoffroy et al. 2016), seasonal diet (Majewski et al. 2016), and light regime (Benoit et al. 2010); this species has been captured in coastal gillnets in Kinngait (D. McNicholl, pers. comm., 2023) and also at depths up to 550 m (Coad and Reist 2018). Indeed, Arctic cod are more likely to be found at greater depths during the open water period to avoid predation from seals and other marine mammals (Coad and Reist 2018). Although there is some spatial overlap, cod occupy a variety of habitats beyond that fished with Arctic char gillnets. Intensity of this stressor (bycatch) would depend on the scenario of the fishery (e.g., scale of the fishery).

Arctic char gillnets are designed to capture larger char and use a 3.5-5.5 inch mesh size (5.5 inch mesh size is the mandatory minimum mesh size in the commercial Arctic char fishery as described in the *Northwest Territories Fishery Regulations* (2020) and common in the subsistence fishery). Arctic char are typically between 30-60 cm in total length and can attain a maximum total length of 100 cm (Coad and Reist 2018). Arctic cod can attain a maximum total length of 45 cm but are usually no longer than 25 cm (Coad and Reist 2018). It can be assumed that Arctic cod are generally too small to be caught in Arctic char gillnets, and indeed, Arctic cod are not commonly caught as bycatch in Arctic char gillnets in the AOI (DFO 2023a). It is suggested that Greenland cod are the more commonly captured gadid species in Arctic char gillnets in the nearshore environment (D. McNicholl, pers. comm., 2023). Char are an important subsistence and commercial species and a variety of methods are used to catch them, based on season and personal preference (DFO 2023a); therefore, although Arctic char fishing is common, gillnets are only one of multiple methods (e.g., angling, under-ice jigging) used in their capture and the gillnet fishing intensity is not known to be significant. While Arctic cod populations are unknown in the AOI, populations outside of the AOI are considered large (i.e., Lancaster Sound and Cornwallis Island) with an estimated 900 million individuals, and as an R-selected species Arctic cod reflect characteristics that generally support quicker population recovery after disturbance (Coad and Reist 2018). However, the cumulative effects of warming temperature on sea ice are expected to have a significant impact on Arctic cod during their early life history stages (Florko et al. 2021).

Although Arctic cod are known to inhabit nearshore areas where Arctic char gillnets are set, nearshore areas are one of many inhabited by Arctic cod. Gillnets are only deployed in the summer months and are one of multiple methods used to capture char in summer, and gillnets are designed to target larger fish. Therefore, the risk to Arctic cod in the AOI from bycatch in an Arctic char gillnet fishery is low and no additional management measures need to be considered at this time.

Uncertainty

There is high uncertainty in this assessment. Arctic cod have been studied in the Arctic, and some information exists outside the AOI regarding preferred cod habitat, feeding areas, and population sizes. However, Arctic cod population estimates specific to the AOI do not exist and the impacts of climate change on populations is difficult to predict. Information exists on the dimensions of gillnets used in the Arctic char commercial and subsistence gillnet fisheries, and where gillnets are likely to be set. Arctic char harvesting using gillnets does occur in the AOI, though no targeted scientific studies on Arctic cod and Greenland cod bycatch exist introducing uncertainty regarding which species is more commonly caught in char gillnets. Bycatch information exists from local fish harvesters. Limited logbook data specific to the Kivalliq Region or the AOI exist to inform this assessment, including fishing effort and bycatch data.

Common eider – Arctic char gillnet – bycatch

Risk Statement: If common eider bycatch occurs due to the Arctic char gillnet fishery, the consequence could result in a negative impact to common eider populations in the SI AOI.

Common eiders are present in the AOI from mid-June to September. Adult males depart on their moult migration in July (Abraham and Finney 1986). Eggs hatch in July and the flightless females rear their precocial broods in marine and intertidal waters. Females and young are present until late-September (Abraham and Finney 1986). East Bay hosts the largest known common eider colony in the Canadian Arctic and they also inhabit the coastal areas in the northern portion of the AOI (Mallory et al. 2019). Common eiders are generally present in waters <20 m deep, as this is where they forage for benthic invertebrates (Goudie et al. 2020). The Arctic char gillnet fishery in the AOI occurs during the approximate 4 months of open water, from July to October in the AOI (Loewen et al. 2020b; DFO 2023a). Arctic char gillnets are generally set extending from shore at a variety of locations along the coast and would likely not be present in areas greater than 100 m from shore. Though people from Coral Harbour fish for Arctic char along the north coast of SI (DFO 2023a), due to distance from the community and a lack of well-travelled access routes, it is not expected that the area in the vicinity of the East Bay common eider colony is commonly targeted. Intensity of this stressor (bycatch) would depend on the scenario of the fishery (e.g., scale of the fishery).

Seabird bycatch is a global concern and mortality of birds caught in a gillnet is likely (Žydelis et al. 2009). Common eider bycatch in nearshore gillnets has been observed in Greenland and while rates were much lower outside of spring, bycatch in March and April accounted for the majority of caught eiders (Merkel 2004). Hedd et al. (2015) indicate that gillnets near breeding colonies during breeding season are more likely to lead to bycatch. Davoren (2007) suggests that substantial mortality can occur at localized scales where seabird foraging behaviour increases the chance of an interaction with the gillnet (i.e., where seabirds prey on the gillnet's target species), however where prey overlap does not occur (e.g., eiders are not known to target Arctic char) seabirds are likely less susceptible. Common eiders rely on survival over recruitment, making the population much more sensitive to adult survival rates than breeding success and youth survival, and common eiders display characteristics that generally result in slower recovery from disturbance (Merkel 2004; Goudie et al. 2020). Generally, locations targeted by Arctic char gillnets in the marine environment and habitat commonly occupied by common eiders largely overlap, although it is not expected that much gillnet fishing occurs in East Bay due to inaccessibility from Coral Harbour. Along the north coast of Southampton Island, much of the targeted marine harvest of Arctic char occurs in Duke of York Bay (DFO 2023a).

Although common eider habitat and locations to set Arctic char gillnets generally overlap, it is not expected that much overlap currently occurs in close proximity to the common eider breeding colony at East Bay due to access logistics from Coral Harbour. However, coastal gillnets are a known source of mortality for common eiders with high mortality rates for those caught. Therefore, the risk to common eiders in the Southampton Island AOI is moderate and additional management measures may need to be considered.

Uncertainty

There is moderate uncertainty in this assessment. Common eider habitat preferences and seasonal occupation are known, and there is knowledge specific to the East Bay breeding colony. The risk from coastal gillnets on seabirds has been studied in other regions, including the Arctic, though it has not been studied in relation to char gillnets or in the AOI specifically. Limited logbook data specific to the Kivalliq Region or the AOI exist to inform this assessment, including fishing effort and bycatch data.

9.2.2.2 Gillnets – offshore: bycatch/entanglement

Bottom set gillnets have been the dominant fixed gear used to harvest Greenland halibut offshore in NAFO Subarea 0 since 2004 (DFO 2019b) and similar dimensions of gillnet have been used in an exploratory Porcupine Crab fishery in Subarea 0 (Grant et al. 2017). Bottom gillnets (e.g., targeting porcupine crab) would be deployed from vessels and only during the approximately four months of the open water season which occurs from July to October in the AOI (Loewen et al. 2020b). Porcupine crab have been of interest in commercial application for a number of years (Grant et al. 2017), as they are one of the species most significantly captured as bycatch in the Subarea 0 groundfish gillnet fishery, though no commercial fishery exists for this crustacean (GNL n.d). They are generally found offshore in depths greater than 800 m, but they can live in waters as shallow as 100 m (GNL n.d.; DFO 2016). While porcupine crab have not been recorded in the AOI (Loewen et al. 2020a), deep-water sampling in the AOI has been limited and they may be present. Greenland halibut gillnets are typically 90 m in length with a mesh size of 153-190 mm and can be set in "gangs" of up to 500 individual nets strung together (Treble and Stewart 2010; DFO 2023b). Individual bottom gillnets can be deployed from boats that are already present in the communities (i.e., small boats from 20-30 feet (6-9 m) in length), though some specialized equipment (i.e., hydraulic winches and gillnets) would need to be purchased (FAO 1980). While it is unknown what mesh size requirements may be implemented in a future bottom gillnet fishery, the Conservation Harvesting Plans for NAFO Subarea 0 (divisions 0A and 0B), encompassing Baffin Bay and Davis Strait in Canada's Exclusive Economic Zone, requires a minimum mesh size of 153 mm (6.0") in depths less than 730 m. Depths less than 730 m would encompass the entire SI AOI, so we have assumed this mesh size here. Gillnets are set directly on the benthic substrate and may inadvertently capture forage fish, Arctic cod, and benthic invertebrates; benthic invertebrates and Arctic cod (covering forage fish by proxy) were assessed (Table 9-5). Gillnets can injure and/or kill a variety of marine mammals and seabirds via entanglement as well (DFO 2010), including during deployment or retrieval of the nets. Thick-billed murre were assessed for this gear type, acting as a proxy for other seabirds. Narwhals (covering belugas by proxy), bearded seals (covering walruses by proxy), and bowhead whales were also assessed. Narwhals were chosen for assessment because Watt et al. (2013) documented a heavier reliance on benthic prey for narwhal occurring in the AOI whereas belugas are known to feed in river mouths and on more pelagic prey (Idlout 2020; Loewen et al. 2020b); deep foraging dives are expected to result in greater exposure of narwhals to bottom gillnets. Bearded seals acted as a proxy for walruses as bearded seals often forage at greater depths (up to 500 m), increasing their exposure to a bottom gillnet (NOAA 2022a). Walruses may forage in depths up to 200 m but most commonly <80 m (Fay 1982; Outridge et al. 2003). Additionally, Reeves et al. (2013) report that walrus entanglement in gillnet fisheries was not known from 1990-2011; bearded seal entanglement was known, though not in high numbers compared with other marine mammals studied.

Gear components from gillnet fisheries can also impact habitat, including the crushing of benthic organisms and sediment resuspension during deployment or retrieval (DFO 2010). Macroalgae is unlikely to grow at the depths (100 m and deeper; Castro de la Guardia et al. 2023; Filbee-Dexter et al. 2023) these nets would be deployed and was not assessed. Though a certain level of impact to the benthic environment is possible (DFO 2010), impacts to the benthic substrate are not expected to manifest in measurable indirect impacts to other ESC subcomponents. See the assessments on habitat alteration from Digby dredge (Section 9.2.1.2) for possible habitat impacts from that fishing gear.

Table 9-5. Bottom gillnet – bycatch/entanglement: ESC Subcomponents assessed.

ESC Subcomponent	Priority Area	Assessed by Proxy
Thick-billed murre	Not restricted to a priority area	Other seabirds
Arctic cod	Not restricted to a priority area	Other forage fish
Benthic invertebrates	Not restricted to a priority area	
Narwhal	Not restricted to a priority area	Beluga
Bowhead whale	Not restricted to a priority area	
Bearded seal	Not restricted to a priority area	Walrus

Thick-billed murre – Bottom gillnet – bycatch/entanglement

Risk Statement: If thick-billed murre bycatch/entanglement occurs due to a bottom gillnet fishery, the consequence could result in a negative impact to thick-billed murre populations in the SI AOI.

Thick-billed murres are present in the AOI from mid-May to October (Patterson et al. 2021). Murres would be present at the nesting cliffs on Coats Island from mid-May through July. Foraging adults capable of flight would be present at sea in Fisher and Evans straits from June to July and in October, whereas chicks and flightless adults would be present in marine waters from August to September (Latour et al. 2008; Mallory et al. 2019; Patterson et al. 2022). A bottom gillnet fishery, for example targeting porcupine crab (Grant et al. 2017), would occur during the approximate four-month open water season from July to October in the AOI (Loewen et al. 2020b). A bottom gillnet fishery for porcupine crab would likely occur where this species is abundant. Though systematic exploration for these locations within the SI AOI has not occurred, the species is more likely to occur towards the northeast part of the AOI boundary, where porcupine crab water depth and substrate type preferences overlap (>300 m and soft/muddy, respectively; DFO 2016), accounting for 1% of total AOI area (DFO unpublished data). It is not likely that such a fishery would occur in Fisher and Evans straits, as much of that area is shallower than the preferred depth preference of porcupine crabs (DFO 2016). Thick-billed murre are not known to regularly use the northeast part of the AOI, as their only known nesting location within the AOI boundary is on Coats Island (Gaston and Hipfner 2020). Thick-billed murre typically dive to depths between 7-33 m to forage, but they have been recorded diving as deep as 210 m (Gaston and Hipfner 2020). Even if a gillnet is set in waters in which thick-billed murres commonly forage, the potential overlap between typical dive depths and the bottom set net is minimal. However, seabirds can also become entangled during gear retrieval which occurs at the water’s surface and can result in mortality (DFO 2010). Intensity of this stressor (bycatch) would depend on the scenario of a potential future fishery (e.g., scale of the fishery).

Seabird bycatch is a global concern and mortality of birds caught in a gillnet is likely, with thick-billed murres identified as a species of particular concern (Žydelis et al. 2009, 2013). If thick-billed murre bycatch/entanglement occurs in a gillnet, likely the bird would drown before it is found in the net (DFO 2010). Seabird bycatch data from eastern Canadian waters (i.e., Gulf of St. Lawrence, Maritimes, Newfoundland and Labrador, and Arctic regions investigating gillnet, pelagic and demersal longline, and purse seine gears) demonstrated that the NAFO Subarea 0 Greenland halibut gillnet fishery demonstrated the highest rates of bird bycatch in the study, composed mainly of Northern Fulmars *Fulmarus glacialis* (Hedd et al. 2015). Laist (1997) also identifies that lost fishing gear can have similar impacts to actively fished gear. It is estimated that thick-billed murres are the most abundant marine bird species in the Canadian Arctic with 30,000 nesting pairs on Coats Island alone (Gaston et al. 2012). However, with low fecundity and high age at maturity thick-billed murres display characteristics that generally reflect slower population recovery after disturbance (Gaston and Hipfner 2020), and although Canadian Arctic populations of this species are considered to be stable (Gaston et al. 2012) declining trends are seen in other Arctic populations (Merkel et al. 2014).

Considering the minimal overlap between thick-billed murre foraging areas in the AOI and the estimated locations gillnets may be used (due to depth preference of porcupine crab vis a vis the depth of the AOI), as well as the abundance of thick-billed murres, the overall risk to this species in the SI AOI is low and additional management measures aimed at mitigating impacts to thick-billed murres due to bycatch may not be necessary in a potential future gillnet fishery. However, considering the known susceptibility of this species to this stressor the risk would increase should a bottom gillnet fishery become feasible within foraging distance of their breeding colonies.

Uncertainty

There is moderate uncertainty in this assessment. Analysis of thick-billed murre bycatch data exists from a bottom gillnet fishery targeting groundfish near the AOI (i.e., NAFO Subarea 0) and knowledge exists on thick-billed murre distribution, foraging habits, population health, and habitat preference within the AOI. It should be noted that other thick-billed murre populations that are monitored globally are declining and that Canadian Arctic colonies have not been surveyed in over 20 years. The susceptibility of this species to bycatch in bottom gillnets has been studied in other regions. However, the intensity of this stressor (e.g., number of harvesters, effort) is unknown and would depend on the scenario of a potential future fishery. The areas within the AOI in which a bottom gillnet fishery might operate are uncertain.

Arctic cod – Bottom gillnet – bycatch

Risk Statement: If Arctic cod bycatch occurs due to a bottom gillnet fishery, the consequence could result in a negative impact to Arctic cod populations in the SI AOI.

Arctic cod are expected to be present in the AOI year-round. A ubiquitous species, they can occupy coastal and offshore waters in areas with and without sea ice and are expected to be widespread throughout the Arctic Ocean (Coad and Reist 2018). Based on Loewen et al. (2020a), most records for Arctic cod within the AOI are for Evans Strait though Loewen et al. (2020b) also noted the occurrence of Arctic cod around small islands in Fisher Strait. A bottom gillnet fishery, for example targeting porcupine crab (Grant et al. 2017), would occur during the approximate four-month open water season from July to October in the AOI (Loewen et al. 2020b), and would likely occur where this species is abundant. Though systematic exploration for these locations within the SI AOI has not occurred, the species is more likely to occur towards the northeast part of the AOI boundary, where porcupine crab water depth and substrate type preferences overlap (>300 m and soft/muddy, respectively; DFO 2016), accounting for 1% of total AOI area (DFO unpublished data). Arctic cod are benthopelagic, and occur at many depths throughout the water column, based on factors like life history stage (Geoffroy et al. 2016), seasonal diet (Majewski et al. 2016), and light regime (Benoit et al. 2010); this species has been captured in coastal gillnets in Kinngait (D. McNicholl, pers. comm., 2023) and also at depths up to 550 m (Coad and Reist 2018). Arctic cod are more likely to be found at greater depths during the open water period to avoid predation from seals and other marine mammals (Coad and Reist 2018). Although there is some spatial overlap, this species occupies a variety of habitats beyond that fished with a bottom gillnet. Intensity of this stressor (bycatch) would depend on the scenario of a potential future fishery (e.g., scale of the fishery).

Bycatch data spanning 2010-2022 from an offshore gillnet fishery in NAFO Subarea 0 (divisions 0A and 0B), the nearest gillnet fishery to the SI AOI, showed low amounts of Arctic cod bycatch while directing for groundfish, ranging from 55-1,496 kg of Arctic cod in a given year, with no bycatch recorded in some years (DFO unpublished data). These bycatch data do not contain any information regarding condition of any cod (e.g., dead or alive, damaged, etc.). While little is known about impacts to Arctic cod populations from bycatch, Walkusz et al. (2020) suggested the cod populations in the eastern Canadian Arctic are not greatly impacted by high removal in the shrimp fisheries in Shrimp Fishing Areas 1, 2, and 3 where 400-2,300 kg of cod per tow has been recorded. This amount *per tow* is more than the maximum *yearly* recorded amount in the NAFO Subarea 0 bottom gillnet groundfish fishery, and would suggest that a potential future gillnet fishery with Arctic cod bycatch levels similar to those found in the Subarea 0 gillnet fishery would not be cause for concern. Moreover, the scale of the Subarea 0 commercial groundfish gillnet fishery is much larger than expected for a potential future gillnet fishery in the SI AOI. Even though some bycatch is released alive, internal and external injuries suffered as a result of the catching process (Neilson et al. 1989; Rummer and Bennett 2005; Nichol and Chilton 2006) can reduce swimming speeds and vigilance making individuals more susceptible to predation (Ryer et al. 2004). Direct mortality of bycaught fish is common and depends on multiple factors, including deck time and fishing gear, with gillnet-caught fish demonstrating higher mortality rates than hook-caught fish (Benoît et al. 2010; Treble and Stewart 2010). Arctic cod populations are large, with certain populations outside of the AOI (i.e., Lancaster Sound, Cornwallis Island) numbering up to 900 million individuals, and as an R-selected species Arctic cod reflect characteristics that generally support quicker population recovery after disturbance (Coad and Reist 2018). However, the cumulative effects of warming temperature on sea ice are expected to have a significant impact on Arctic cod during their early life history stages (Florko et al. 2021).

Considering the small amount of estimated area that may support a potential gillnet fishery in the AOI, and the minimal overlap between Arctic cod habitat and depths at which a bottom gillnet would be deployed, the overall risk to Arctic cod populations in the SI AOI from bycatch in a bottom gillnet fishery is considered low. No additional management measures need to be considered at this time.

Uncertainty

There is moderate uncertainty in this assessment. Arctic cod bycatch data from a bottom gillnet groundfish fishery outside the AOI exists (i.e., NAFO Subarea 0). Arctic cod have been studied in the Arctic, and some information exists outside the AOI regarding preferred cod habitat, feeding areas, and population sizes. However, Arctic cod population estimates specific to the AOI do not exist and the impacts of climate change on populations is difficult to predict. The intensity of the bycatch stressor (e.g., number of harvesters, effort) is unknown and would depend on the scenario of a potential future fishery. The areas within the AOI in which a bottom gillnet fishery might operate are uncertain.

Benthic invertebrates – Bottom gillnet – bycatch

Risk Statement: If benthic invertebrate bycatch occurs due to a bottom gillnet fishery, the consequence could result in a negative impact to benthic invertebrate populations in the SI AOI.

The AOI is known to support a number of benthic invertebrates, including polychaetes, gastropods, echinoderms, corals, sponges, and bivalves (GN 2011, 2012; Loewen et al. 2020a, b; Misiuk and Aitken 2020), which are expected to occur in the AOI year-round. A bottom gillnet fishery, for example targeting porcupine crab (Grant et al. 2017), would occur during the approximate four-month open water season from July to October in the AOI (Loewen et al. 2020b). Benthic invertebrates are located in the lower water column, on and in the benthic substrate, throughout the AOI (Loewen et al. 2020a, b). A bottom gillnet fishery, for example targeting porcupine crab, would likely occur where this species is abundant. Though systematic exploration for these locations within the SI AOI has not occurred, the species is more likely to occur towards the northeast part of the AOI boundary, where porcupine crab water depth and substrate type preferences overlap (>300 m and soft/muddy, respectively; DFO 2016), accounting for an estimated 1% of total AOI area (DFO unpublished data). Intensity of this stressor (habitat alteration) would depend on the scenario of a potential future fishery (e.g., scale of the fishery).

Bycatch data from the offshore gillnet fishery directing for groundfish in NAFO Subarea 0 (divisions 0A and 0B) between the years of 2010-2022 indicate shrimp (both northern and striped) and multiple species of crabs (stone, king, porcupine, and unspecified) as bycatch (DFO unpublished data). Porcupine crab is one of the most significant bycatch species in the Subarea 0 gillnet fishery, with bycatch ranging from 24-3,283 kg captured in a given year, with no bycatch recorded in some years (DFO unpublished data), and crustaceans are often caught as bycatch in other gillnet fisheries (Reddin et al. 2002). The NAFO Subarea 0 data do not contain any information regarding condition of the species captured and it is thought that recorded benthic invertebrate bycatch is not a comprehensive list of those actually caught. More sessile benthic invertebrates would likely be captured only when the net is dragged along the seafloor during retrieval (Dias et al. 2020). Though species dependent, damage sustained during trawl gear retrieval can particularly affect survival in crustaceans and echinoderms even when released alive (Bergmann et al. 2001). As certain echinoderm seastars have been suggested as high trophic-level keystone organisms important for nutrient cycling in the AOI (Amiraux et al. 2022), high removals of these species may affect food web dynamics. Gillnet fisheries in Europe have recorded cold water corals as bycatch, and this would kill the coral and remove its function as biogenic habitat (Dias et al. 2020). Many authors have concurred that coastal benthic recovery processes should be much slower in the Arctic than in temperate waters (Dunton et al. 1982; Conlan 2005; Keck et al. 2020), though with high fecundity, short generation times, and low age at maturity, some benthic invertebrate populations reflect characteristics that generally support quicker recovery. Other benthic invertebrates, such as corals and sponges, are known to recover slowly (Girard et al. 2018; Montagna and Girard 2020).

Considering the bycatch observed in data from the Subarea 0 groundfish gillnet fishery, as well as high bycatch amounts of crab species in other gillnet fisheries in Atlantic Canada (Reddin et al. 2002), as well as the destructive impacts to certain less-mobile invertebrates where bycatch occurs (Dias et al. 2020), the overall risk to benthic invertebrate populations in the SI AOI is considered moderate. A potential future bottom gillnet fishery should consider management measures appropriate to the scenario of that fishery, particularly for species whose habitat is restricted to deeper AOI waters.

Uncertainty

There is high uncertainty in this assessment. It is known that benthic invertebrates inhabit the AOI, and some bycatch data from other regionally-relevant gillnet fisheries do exist. However, benthic invertebrate bycatch data is not thought to be a comprehensive list of those species caught. Moreover, there is a lack of information on the basic biology of these species (e.g., distribution, migratory patterns, population sizes) in the AOI. The intensity of the bycatch stressor (e.g., number of harvesters, effort) is unknown and would depend on the scenario of a potential future fishery. The areas within the AOI in which a bottom gillnet fishery might operate are uncertain.

Narwhals – Bottom gillnet – bycatch/entanglement

Risk Statement: If narwhal bycatch/entanglement occurs due to a bottom gillnet fishery, the consequence could result in a negative impact to narwhal populations in the SI AOI.

Narwhals migrate into the AOI in June and July, and back out in August and September (Westdal et al. 2010). A bottom gillnet fishery, for example targeting porcupine crab (Grant et al. 2017), would occur during the approximate four-month open water season from July to October in the AOI (Loewen et al. 2020b). Narwhals' preferred habitat includes leads in landfast ice or pack ice (Koski and Davis 1994; Kovacs et al. 2011), and Repulse Bay and nearby waters provide important summering habitat for narwhals, where they are known to feed and calve (Idlout 2020; Loewen et al. 2020b). Narwhals migrate through Frozen Strait enroute to Repulse Bay during spring/early summer ice break-up and enroute to Hudson Strait prior to freeze-up in the fall. A bottom gillnet fishery for porcupine crab would likely occur where this species is abundant. Though systematic exploration for these locations within the SI AOI has not occurred, the species is more likely to occur towards the northeast part of the AOI boundary, where porcupine crab water depth and substrate type preferences overlap (>300 m and soft/muddy, respectively; DFO 2016), accounting for an estimated 1% of total AOI area (DFO unpublished data). Narwhal typically forage in depths <500 m (Heide-Jørgensen and Dietz 1995; Laidre et al. 2003). Bottom gillnets are set on the seafloor, and porcupine crab occur in waters >300 m but can be found in waters as shallow as 100 m (DFO 2016: GNL n.d.). Much of the SI AOI is <100 m in depth (see Figure 2-3), but any areas deeper than this could be inhabited by porcupine crab and thus have potential for deployment of bottom gillnets. Intensity of this stressor (bycatch/entanglement) would depend on the scenario of a potential future fishery (e.g., scale of the fishery).

Mortality of an entangled cetacean is dependent on the length of time it has been trapped and how long it can take to become free, though mortality is possible especially when entangled in heavy gear such as a gillnet (Laist 1997). An evaluation of the potential impacts of an inshore gillnet Greenland halibut fishery highlighted the risk to narwhals from this gear and narwhal entanglement has been noted in NAFO Division 0A (Baffin Bay) and other offshore gillnet fisheries in Canada (DFO 2010; Treble and Stewart 2010). Cetaceans can become chronically entangled if they do not drown immediately, which often leads eventually to mortality (Laist 1997). Even when not lethal, research has demonstrated that entanglement elicits an increased stress response in narwhals (low heart rate paired with high stroke/swimming rate) for up to 45-90 minutes post-entanglement before returning to normal levels (Williams et al. 2017). In addition to risks of entanglement while fishing, in their consideration of inshore areas along the eastern Baffin Island coast, Treble and Stewart (2010) identify high risk of losing bottom gillnets, which will continue to cause marine mammal mortality.

They cite severe ice conditions encountered throughout the year, strong currents, and rough bottom as increasing the likelihood of losing gear that will continue to fish or present an underwater hazard (Treble and Stewart 2010). Narwhals have low fecundity and generally display characteristics that limit the ability of the population to recover quickly from disturbance (Garde et al. 2015; Lowry et al. 2017).

Considering the noted risk to narwhals associated with bottom gillnets, and the overlap between the estimated area that may support a potential gillnet fishery and the known seasonal foraging and migratory habitat of narwhals in the AOI, the overall risk to narwhal populations in the SI AOI is considered moderate. A potential future fishery should consider management measures appropriate to the scenario of that fishery.

Uncertainty

There is high uncertainty with this assessment. Although entanglement has been identified as a risk to narwhals in multiple reports little direct study has occurred to quantify impacts or likelihood. Information on narwhal distribution and populations are known, including information specific to the AOI. The intensity of the entanglement stressor (e.g., number of harvesters, effort) is unknown and would depend on the scenario of a potential future fishery. The areas within the AOI in which a bottom gillnet fishery might operate are uncertain.

Bowhead whales – Bottom gillnet – bycatch/entanglement

Risk Statement: If bowhead whale bycatch/entanglement occurs due to a bottom gillnet fishery, the consequence could result in a negative impact to bowhead populations in the SI AOI.

Bowhead whales may occur in the AOI from April to November, though primarily occur during the summer months (Idlout 2020; Loewen et al. 2020b). A bottom gillnet fishery, for example targeting porcupine crab (Grant et al. 2017), would occur during the approximate four-month open water season from July to October in the AOI (Loewen et al. 2020b). Bowhead migratory pathways occur throughout the AOI. Additionally, summer foraging is known to occur in Frozen Strait, and Evans Strait is a summer calving and nursery area for bowheads (Idlout 2020; Loewen et al. 2020b). A bottom gillnet fishery for porcupine crab would likely occur where this species is abundant. Though systematic exploration for these locations within the SI AOI has not occurred, the species is more likely to occur towards the northeast part of the AOI boundary, where porcupine crab water depth and substrate type preferences overlap (>300 m and soft/muddy, respectively; DFO 2016), accounting for an estimated 1% of total AOI area (DFO unpublished data). Though bowhead whales spend a considerable amount of time at or near the surface of the water, bowhead whales in the eastern Canadian Arctic routinely conduct foraging dives >100 m with maximum depths exceeding 650 m (Fortune et al. 2020). Bowhead foraging depth is seasonally variable, with shallower dives ≤50 m from spring to mid-summer, and deeper dives ≥150 m in the fall and winter (Fortune et al. 2020). Much of the SI AOI is <100 m in depth (see Figure 2-3), but any areas deeper than this could be inhabited by porcupine crab and thus have potential for deployment of bottom gillnets. Intensity of this stressor (bycatch/entanglement) would depend on the scenario of a potential future fishery (e.g., scale of the fishery).

While little information is available regarding bowhead whale entanglement in the Canadian Arctic, there is some information from Alaskan waters, and relevant data from North Atlantic right whales and other baleen whales. Bowheads and North Atlantic right whales are closely related and share many similar morphological and behavioural features, making them a valid proxy species when comparing impacts of vessel strikes, entanglement, and other stressors (Reeves et al. 2012). While entanglement is often not immediately fatal (unless trapped underwater to drown), bowheads may remain entangled for years, carrying lengths of rope, netting, or buoys (Reeves et al. 2012). Circumstances like these often lead to chronic debilitation, stress, and death (Cassoff et al. 2011; Moore and van der Hoop 2012). Subsistence hunters in Alaska reported that approximately 10% of the bowhead whales they have captured show evidence of entanglement (Reeves et al. 2012). Fishing gear entanglement is a known source of injury, stress and mortality for baleen whales (Cassoff et al. 2011; Robbins et al. 2015), entanglement in gillnets is known to have occurred to bowhead whales in Nunavut (Treble and Stewart 2010), and it is a leading cause of mortality in similar species such as the North Atlantic right whale (Knowlton et al. 2012). In addition to risks of entanglement with active fishing gear, Treble and Stewart (2010) identify high risk of losing bottom gillnets, which will continue to cause marine mammal mortality. Bowheads have low fecundity and high age at maturity and generally display characteristics that limit the ability of the population to recover quickly from disturbance (Tarpley et al. 2021).

Bowhead whale behaviour increases the likelihood of entanglement in fixed (non-mobile) fishing gear (Knowlton et al. 2012; Robbins et al. 2015), and negative effects from gear entanglement have already been seen in other bowhead populations (Reeves et al. 2012). Additionally, bowhead whales forage, calve, and migrate through the AOI during the expected fishing season, passing through the area where a bottom gillnet fishery would be expected to occur. Therefore, entanglement from a bottom gillnet fishery poses a moderately-high risk to the bowhead population in the SI AOI. A potential future fishery should consider management measures appropriate to the scenario of that fishery.

Uncertainty

There is moderate uncertainty in this assessment. Bowhead whale entanglement data in fixed gear fisheries from other Arctic areas exist (i.e., Alaska) and entanglement is a known source of mortality in large baleen whales in all regions where it has been studied. There is a moderate amount of information on bowhead whale distribution, behaviour, and habitat preference in the AOI. The intensity of the entanglement stressor (e.g., number of harvesters, effort) is unknown and would depend on the scenario of a potential future fishery. The areas within the AOI in which a bottom gillnet fishery might operate are uncertain.

Bearded seals – Bottom gillnet – bycatch/entanglement

Risk Statement: If bearded seal bycatch/entanglement occurs due to a bottom gillnet fishery, the consequence could result in a negative impact to bearded seal populations in the SI AOI.

Bearded seals are thought to occur in the AOI year-round (Idlout 2020; Loewen et al. 2020b). A bottom gillnet fishery, for example targeting porcupine crab (Grant et al. 2017), would occur during the approximate four-month open water season from July to October in the AOI (Loewen et al. 2020b). Bearded seals are expected to be widely distributed throughout the AOI in low densities (Loewen et al. 2020b). Typically, bearded seals dive to depths of <100 m while foraging, demonstrating a preference for shallower waters due to easier access to prey, but they have the ability to dive down to 500 m (Mansfield 1963; NOAA 2022a). A bottom gillnet fishery for porcupine crab would likely occur where this species is abundant. Though systematic exploration for these locations within the SI AOI has not occurred, the species is more likely to occur towards the northeast part of the AOI boundary, where porcupine crab water depth and substrate type preferences overlap (>300 m and soft/muddy, respectively; DFO 2016), accounting for an estimated

1% of total AOI area (DFO unpublished data). Intensity of this stressor (bycatch/entanglement) would depend on the scenario of a potential future fishery (e.g., scale of the fishery).

Although other seals and diving marine mammals experience negative repercussions from gillnet entanglement, including mortality (e.g., Knowlton et al. 2012; Reeves et al. 2013; Williams et al. 2017), little literature exists specific to bearded seals. Generally, based on information for other seals, if a bearded seal is entangled in a bottom gillnet it will likely drown, or may experience wounds and/or a stress response if it is able to escape (Laist 1997; Reeves et al. 2013). Treble and Stewart (2010) identify a risk of bearded seal entanglement from a potential inshore Greenland halibut gillnet fishery. Bycatch/entanglement in fishing gear is not a main management concern for bearded seals as they prefer shallower inshore waters in many places and mortality is not expected to be high (NAMMCO 2020). Reeves et al. (2013) estimated that 16 bearded seals died due to gillnet entanglement from 1990-2010, far few than the 100s to 1,000s estimated for other seal species.

Considering bearded seals have a wide and scattered distribution throughout the AOI, a preference for foraging in shallow water and thus low expected overlap in water depths that a bottom gillnet would be used, the overall risk to bearded seal populations in the SI AOI from this stressor is considered low and no additional management measures need to be considered at this time.

Uncertainty

There is high uncertainty in this assessment. Little information exists specific to bearded seals, including population estimates and seasonal foraging depths, with little information specific to the AOI. Though some information exists for seal bycatch in gillnets, little documentation exists specific to bearded seals. The intensity of this stressor (e.g., number of harvesters, effort) is unknown and would depend on the scenario of a potential future fishery. The areas within the AOI in which a bottom gillnet fishery might operate are uncertain.

9.2.3 Traps and Pots

Trap and pot fisheries can take a multitude of forms and target a variety of species, but generally involve a structure kept in place on the benthic substrate for a period of time in order to attract the target species (Fuller et al. 2008; DFO 2010). Although some nuanced differences exist in the deployment and structure between traps and pots, these are not expected to manifest in differences for the purposes of the risk assessment and the terms will be used interchangeably. Though ropeless gear that would eliminate buoy lines is being developed, the majority of trap gear is connected to a buoy on the water's surface by rope that remains in place until the trap is collected (Fuller et al. 2008). Trap fisheries are not currently used on a commercial scale in Nunavut, though there have been various small scale and exploratory fisheries throughout the Canadian Arctic. Commercial trap fisheries do exist in other parts of North America; for example, northern shrimp are fished using traps in Maine and Nova Scotia, and snow crab pots are used extensively in the Gulf of St. Lawrence (DFO 2021b). Snow crab and shrimp trap fisheries are plausible, as these species are known to occur in the AOI (Loewen et al. 2020a). These fisheries could plausibly occur throughout much of the year, as they could occur during the open water season and through the ice once freeze-up has occurred. There will however be a couple of months during the shoulder seasons (e.g., July and November) when the ice is forming or going out and there will be too much ice to safely boat/set gear in open water but not a sufficiently stable ice platform for through-ice fishing. For the purposes of this assessment, a trap fishery is assumed to operate during the summer (i.e., open water) months only as it is anticipated that a summer fishery would have greater intensity through ease of deployment (easier to deploy more traps and continue doing so for longer).

9.2.3.1 Traps/pots – bycatch/entanglement

Though fairly limited compared to trawls and gillnets (DFO 2010), bycatch of benthic fish and invertebrates is known to occur in trap fisheries (Moffett et al. 2012), and Arctic cod and benthic invertebrates were assessed (Table 9-6). Marine mammals and seabirds are not likely to be caught in traps and were not assessed: there were no recorded instances of mammal or seabird bycatch in the northern shrimp trap fishery in Maine over a two-year period, in the lobster and snow crab trap fisheries in the United Kingdom over a four year period, and no mention of either marine mammals or seabirds as bycatch in the Scotian Shelf snow crab trap fishery (DFO 2020c; Hubley et al. 2018; Moore et al. 2023). Entanglement of marine mammals is known, however, in the buoy lines of trap fisheries (Dayton et al. 1995; DFO 2010; Knowlton et al. 2012; Moore and van der Hoop 2012), for example for North Atlantic right whales in the snow crab pot fishery in the Gulf of St. Lawrence and along the Atlantic coast (e.g., Cole et al. 2021). Bowhead whales are closely related to North Atlantic right whales and share many similar morphological and behavioral features that increase the likelihood of entanglement in fishing gear (Reeves et al. 2012); therefore, they were assessed. It is suggested that belugas are not susceptible to entanglement in buoy lines due to their agility in water and ability to swim backwards, as well as their echolocation abilities (NAMMCO 2018; COSEWIC 2020). Furthermore, although the Gulf of St. Lawrence snow crab fishery uses pots with buoy lines and entanglement is frequently discussed in relation to the North Atlantic right whale, beluga entanglement in all fishing gears (i.e., not only buoy lines) accounted for only 1% of recorded beluga deaths from 1983 to 2012 (Lair et al. 2014). Although noted, this threat is not discussed in the COSEWIC report on the Gulf of St. Lawrence population (COSEWIC 2014). It is expected that the closely related narwhal is similarly negligibly affected by this stressor (NAMMCO 2018); therefore, neither was assessed. Pinnipeds are not known to have been entangled in buoy lines (Dayton et al. 1995; DFO 2010) and were not assessed.

Table 9-6.Trap/pot fishery – bycatch/entanglement: ESC Subcomponents assessed.

ESC Subcomponent	Priority Area	Assessed by Proxy
Arctic cod	Not restricted to a priority area	
Benthic invertebrates	Not restricted to a priority area	
Bowhead whales	Not restricted to a priority area	

Arctic cod – Traps/pots – bycatch

Risk Statement: If Arctic cod bycatch occurs due to a trap fishery, the consequence could result in a negative impact to Arctic cod populations in the Southampton Island AOI.

Arctic cod are expected to be present in the AOI year-round. A ubiquitous species, they can occupy coastal and offshore waters in areas with and without sea ice and are expected to be widespread throughout the Arctic Ocean (Coad and Reist 2018). Based on Loewen et al. (2020a), most records for Arctic cod within the AOI are for Evans Strait though Loewen et al. (2020b) also noted the occurrence of Arctic cod around small islands in Fisher Strait. A trap fishery, for example targeting shrimp, would likely occur during the open water period (see introductory text for this section), between July to October in the AOI (Loewen et al. 2020b). A trap fishery for shrimp would likely occur where shrimp are abundant. Though systematic exploration for these locations within the Southampton Island AOI has not occurred, both striped and northern shrimp occur in water depths between 150-600 m, with the former preferring a hard bottom, and the latter preferring a soft and muddy substrate (DFO 2018b). Based on bathymetry and substrate type, an estimated 13% of the AOI is suitable habitat likely to support shrimp (DFO unpublished data). Arctic cod are benthopelagic, occurring at different water depths based on factors such as life history stage (Geoffroy et al. 2016), seasonal diet (Majewski et al. 2016), and light regime (Benoit et al. 2010); this species has been captured in coastal gillnets in Kinngait (D. McNicholl, pers. comm., 2023) and also at depths up to 550 m (Coad and Reist 2018). Arctic cod are more likely to be found at greater depths during the open water period to avoid predation from seals and other marine mammals (Coad and Reist 2018). A trap fishery would occur on the seafloor. Intensity of this stressor (bycatch) would depend on the scenario of a potential future fishery (e.g., scale of the fishery).

Relevant bycatch data are limited. Moffett et al. (2012) investigated the northern shrimp trap fishery in the Gulf of Maine over 2010 and 2011, which displayed bycatch rates of 1.21% and 1.11% respectively. Various species of crabs composed the majority of bycatch by weight and pelagic finfish made up 0.3% bycatch by weight. Trap gears are known to generally produce much lower rates of bycatch than mobile bottom contact gears (Moffett et al. 2012; Savoca et al. 2020; Moore et al. 2023). When caught, it is suggested that most finfish have high rates of survival when discarded from traps due to less destructive capture and hauling methods, though survival is reduced when hauled from greater depth and is dependent on responsible handling procedures (DFO 2010; Moore et al. 2023). Though no investigations have directly studied Arctic cod, Atlantic cod *Gadus morhua* survivability in lobster pot bycatch is suggested to be high given proper handling procedures (Boenish 2018). Many authors have concurred that coastal benthic recovery processes should be much slower in the Arctic than in temperate waters (Dunton et al. 1982; Conlan 2005; Keck et al. 2020). Arctic cod populations are large throughout the Arctic, with aggregations outside the AOI (i.e., Lancaster Sound, Cornwallis Island) numbering up to 900 million individuals, and as an R-selected species Arctic cod reflect characteristics that generally support quicker recovery (Coad and Reist 2018). However, the cumulative effects of warming temperature on sea ice are expected to have a significant impact on Arctic cod during their early life history stages (Florko et al. 2021).

Considering the small amount of estimated area that may support a potential trap fishery in the AOI compared with the widespread distribution of Arctic cod, low finfish bycatch rates in trap fisheries particularly for non-benthic finfish, expected higher survivability of finfish if discarded, and large Arctic cod populations in the Canadian Arctic, the overall risk to Arctic cod populations in the AOI from a trap fishery bycatch is considered low. No additional management measures need to be considered at this time.

Uncertainty

There is high uncertainty in this assessment. Arctic cod have been studied in the Arctic, and some information exists outside the AOI regarding preferred cod habitat, feeding areas, and population sizes. However, Arctic cod population estimates specific to the AOI do not exist and the impacts of climate change on populations is difficult to predict. There is a lack of scientific information pertaining to bycatch in relevant trap fisheries and no known information pertaining to Arctic cod. There are no trap fisheries in or near the AOI, and therefore no available bycatch data. The intensity of this bycatch stressor (e.g., number of harvesters, effort) is unknown and would depend on the scenario of a potential future fishery. The areas within the AOI in which a trap fishery might operate are uncertain.

Benthic invertebrates – Traps/pots – bycatch

Risk Statement: If benthic invertebrate bycatch occurs due to a pot/trap fishery, the consequence could result in a negative impact to benthic invertebrate populations in the Southampton Island AOI.

The AOI is known to support a number of benthic invertebrates, including polychaetes, gastropods, echinoderms, corals, sponges, and bivalves (GN 2011, 2012; Loewen et al. 2020a, b; Misiuk and Aitken 2020), which are expected to occur in the AOI year-round. A trap fishery, for example targeting shrimp, would likely occur during the open water period (see introductory text for this section), between July to October in the AOI (Loewen et al. 2020b). A trap fishery for shrimp would likely occur where shrimp are abundant. Though systematic exploration for these locations within the Southampton Island AOI has not occurred, both striped and northern shrimp occur in water depths between 150-600 m, with the former preferring a hard bottom, and the latter preferring a soft and muddy substrate (DFO 2018b). Based on bathymetry and substrate type, an estimated 13% of the AOI is suitable habitat likely to support shrimp (DFO unpublished data). Benthic invertebrates are located in the lower water column, on and in the benthic substrate, throughout the AOI (Loewen et al. 2020a, b). A trap fishery would occur on the seafloor. Intensity of this stressor (bycatch) would depend on the scenario of a potential future fishery (e.g., scale of the fishery).

Relevant bycatch data are limited. Moffett et al. (2012) investigated the northern shrimp trap fishery in the Gulf of Maine over 2010 and 2011, which exhibited bycatch rates of 1.21% and 1.11% respectively. Various species of crabs and other invertebrates composed the majority of bycatch. Trap gears are known to generally produce much lower rates of bycatch than mobile bottom contact gears (Moffett et al. 2012; Savoca et al. 2020; Moore et al. 2023). When caught, it is suggested that most invertebrates have high rates of survival when discarded from traps due to less destructive capture and hauling methods if responsible handling procedures are followed (DFO 2010; Moore et al. 2023). Many authors have concurred that coastal benthic recovery processes should be much slower in the Arctic than in temperate waters (Dunton et al. 1982; Conlan 2005; Keck et al. 2020), though with high fecundity, short generation times, and low age at maturity, many benthic invertebrate populations reflect characteristics that generally support quicker recovery. Other benthic invertebrates, such as sessile corals and sponges, which are not expected as bycatch in a trap fishery, are known to recover slowly (Girard et al. 2018; Montagna and Girard 2020).

Though benthic invertebrates are known to compose the majority of bycatch in trap fisheries, overall bycatch using these gears is expected to be low, survivability of discarded species is expected to be high, known sensitive and slowly-recovering benthic invertebrate species such as corals and sponges are not expected to occur as bycatch, and the amount of estimated area that may support a potential trap fishery in the AOI is low compared with the widespread distribution of benthic invertebrates. Therefore, overall risk to benthic invertebrate populations in the AOI from bycatch in a trap fishery is low. No additional management measures need to be considered at this time.

Uncertainty

There is high uncertainty in this assessment. It is known that benthic invertebrates inhabit the AOI though there is a lack of information on the basic biology of these species (e.g., distribution, migratory patterns, population sizes). As there are no trap fisheries in or near the AOI, no bycatch data are available from these. There is also a lack of scientific information pertaining to bycatch in relevant trap fisheries. The intensity of the bycatch stressor (e.g., number of harvesters, effort) is unknown and would depend on the scenario of a potential future fishery. The areas within the AOI in which a trap fishery might operate are uncertain.

Bowhead whale – Traps/pots – entanglement

Risk Statement: If bowhead whale entanglement occurs due to a pot/trap fishery, the consequence could result in a negative impact to bowhead whale populations in the Southampton Island AOI.

Bowhead whales occur in the AOI from April to November, though primarily occur during the summer months (Idlout 2020; Loewen et al. 2020b). A trap fishery, for example targeting shrimp, would likely occur during the open water period (see introductory text for this section), between July to October in the AOI (Loewen et al. 2020b). Bowhead migratory pathways occur throughout the AOI. Additionally, summer foraging is known to occur in Frozen Strait, and Evans Strait is a summer calving and nursery area for bowheads (Idlout 2020; Loewen et al. 2020b). A trap fishery for shrimp would likely occur where shrimp are abundant. Though systematic exploration for these locations within the Southampton Island AOI has not occurred, both striped and northern shrimp occur in water depths between 150-600 m, with the former preferring a hard bottom, and the latter preferring a soft and muddy substrate (DFO 2018b). Based on bathymetry and substrate type, an estimated 13% of the AOI is suitable habitat likely to support shrimp (DFO unpublished data). Though bowhead whales spend a considerable amount of time at or near the surface of the water, bowheads in the eastern Canadian Arctic routinely conduct foraging dives >100 m with maximum depths exceeding 650 m (Fortune et al. 2020). Bowhead foraging depth is seasonally variable, with shallower dives ≤50 m from spring to mid-summer, and deeper dives ≥150 m in the fall and winter (Fortune et al. 2020). A trap fishery will occur on the seafloor and the buoy lines trail through the water column to the surface. Ropes may also connect a line of traps and trail on and along the benthic substrate (Fuller et al. 2008), exposing animals that dive to the seafloor. Intensity of this stressor (entanglement) would depend on the scenario of a potential future fishery (e.g., scale of the fishery).

Although little information is available regarding bowhead whale entanglement in the Canadian Arctic, there is some information from Alaskan waters, and relevant data from North Atlantic right whales and other baleen whales. Bowhead whales and North Atlantic right whales are closely related and share many similar morphological and behavioural features, making them a valid proxy species when comparing impacts of vessel strikes, entanglement, and other stressors (Reeves et al. 2012). While entanglement is often not immediately fatal (unless trapped underwater to drown), bowheads may remain entangled for years, carrying lengths of rope, netting, or buoys (Reeves et al. 2012). Circumstances like these often lead to chronic debilitation, stress, and death (Cassoff et al. 2011; Moore and van der Hoop 2012). Subsistence hunters in Alaska reported that approximately 10% of the bowheads they have captured show evidence of entanglement (Reeves et al. 2012). Fishing gear entanglement in trap gear is a known source of injury, stress and mortality for baleen whales (Cassoff et al. 2011; Robbins et al. 2015) and it is a leading cause of mortality in similar species such as the North Atlantic right whale (Knowlton et al. 2012). In addition to risks of entanglement with active fishing gear, lost gear can cause bowhead entanglement in areas and time in which a fishery does not occur (Citta et al. 2013), which may cause mortality (Laist 1997). Bowhead whales have low fecundity and high age at maturity and generally display characteristics that limit the ability of the population to recover quickly from disturbance (Tarpley et al. 2021).

Bowhead whale behaviour increases the likelihood of entanglement in fixed (non-mobile) fishing gear (Knowlton et al. 2012; Robbins et al. 2015) and negative effects have already been seen in other bowhead populations from gear entanglement (Reeves et al. 2012). Additionally, bowhead whales forage, calve, and migrate through the AOI during the expected fishing season, including in Evans Strait and the eastern edge of the AOI, both estimated areas of likely shrimp habitat. Therefore, entanglement from a trap fishery poses a moderately-high risk to the bowhead population in the Southampton Island AOI. A potential future fishery should consider management measures appropriate to the scenario of that fishery.

Uncertainty

There is moderate uncertainty in this assessment. Bowhead whale entanglement data in fixed gear fisheries from other Arctic areas exist (i.e., Alaska) and entanglement is a known source of mortality in large baleen whales in all regions where it has been studied. There is a moderate amount of information on bowhead distribution, behaviour, and habitat preference in the AOI. The intensity of the entanglement stressor (e.g., number of harvesters, effort) is unknown and would depend on the scenario of a potential future fishery. The areas within the AOI in which a trap fishery would operate are uncertain.

9.2.3.2 Traps/pots – habitat alteration

Trap fisheries can crush or entangle biogenic structures, particularly during retrieval, with potential impacts dependent on type, size, and set duration of traps and the type of habitat being fished (Fuller at al. 2008; DFO 2010). They can also resuspend sediment in the water column during deployment and retrieval. Traps rest on the seafloor, but these are restricted in space and likely would only impact certain ESC subcomponents like kelp beds/other macroalgae; therefore, this ESC subcomponent was assessed (Table 9-7). It is not expected that the disturbance to the seafloor from a trap fishery would result in measurable impacts to foraging marine mammals or seabirds due to the low spatial area of substrate impacted.

Table 9-7.Trap/pot fishery – habitat alteration: ESC Subcomponents assessed.

ESC Subcomponent	Priority Area	Assessed by Proxy
Kelp beds and other macroalgae	Not restricted to a priority area	

Kelp beds/other macroalgae – Traps/pots – habitat alteration

Risk Statement: If a fishery using trap/pot gear causes habitat alteration to kelp beds/other macroalgae, the consequence could result in impacts to the ecosystem function of kelp beds/other macroalgae in the Southampton Island AOI.

Kelp beds/other macroalgae are present in the AOI year-round, though photosynthetic activity, important in advance of the growth phase which largely occurs under ice (Chapman and Lindley 1980), is restricted to the ice-free season. A trap fishery, for example targeting shrimp, would likely occur during the open water period (see introductory text for this section), between July to October in the AOI (Loewen et al. 2020b). Macroalgae typically occurs in water depths between 5-50 m in the AOI, with higher densities at 10 and 15 m compared with 5 m (Krause-Jensen et al. 2012; Filbee-Dexter et al. 2022). A trap fishery for shrimp would likely occur where shrimp are abundant. Though systematic exploration for these locations within the Southampton Island AOI has not occurred, both striped and northern shrimp occur water depths between 150-600 m, with the former preferring a hard bottom, and the latter preferring a soft and muddy substrate (DFO 2018b). Based on bathymetry and substrate type, an estimated 13% of the AOI is suitable habitat likely to support shrimp (DFO unpublished data). Kelp beds/other macroalgae grow on and in the benthic substrate. A trap fishery would occur on the seafloor. Intensity of this stressor (habitat alteration) would depend on the scenario of a potential future fishery (e.g., scale of the fishery).

Physical impacts on the benthic environment may occur from pot gears by: crushing during deployment (Eno et al. 2001); abrasion due to movement of deployed pots by tides and currents (Jones et al. 2000; Lewis et al. 2009); and damage of substrate during pot retrieval when gear may be dragged (Eno et al. 2001; Coleman et al. 2013). The potential impacts associated with pot/trap gear depend on a variety of factors including size, weight and trap material, substrate, ocean conditions, soak time, string configuration, and retrieval method (DFO 2010). Traps deployed as singles are expected to cause less impact than strings of multiple connected pots as there will be less dragging of gear along the substrate during the hauling process. Most kelp species are found in high energy ocean areas and possess adaptations to prevent being torn-free (Feder et al. 1974). Deployment and retrieval of fishing pots can cause fronds and stipes to break and has the potential to periodically dislodge holdfasts from the substrate (CEQA 2001). Although individual kelp sporophytes have high growth rates compared to other animals (Mann 1973), it can take a kelp bed months to a year to recover from localized disturbances in non-Arctic environments (Johnson and Mann 1988; Scheibling and Gagnon 2009; O’Brien and Scheibling 2018), and many authors have concurred that coastal benthic recovery processes should be much slower in the Arctic than in temperate waters (Dunton et al. 1982; Conlan 2005; Keck et al. 2020). While some damage may occur to dense areas of kelp if the area is subject to frequent trap hauls, impacts are predicted to be either undetectable beyond natural disturbance levels (Feder et al. 1974) or minor and of short duration (NOAA 2010).

Based on the depth preferences of shrimp and kelp beds, which generally do not overlap, it is expected that pot deployment in kelp would not be common. Considering this along with the limited effects when pots are deployed in kelp beds, the overall risk to kelp beds/other macroalgae from habitat alteration due to a pot fishery is considered low. No additional management measures need to be considered at this time.

Uncertainty

There is moderate uncertainty in this assessment. The effects of pot deployment in kelp beds have been studied in other regions in Canada and there is information on kelp bed recovery including investigation in the Arctic. Information exists on kelp distribution in the AOI. The intensity of the habitat alteration stressor (e.g., number of harvesters, effort) is unknown and would depend on the scenario of a potential future fishery. The areas within the AOI in which a trap fishery might operate are uncertain.

9.2.4 Bottom Longline Fishing

Bottom longline fishing occurs either in open water or through ice, typically using hundreds to thousands of baited hooks on a single main line that can be kilometers long, and targets groundfish species. In Nunavut, the most commonly fished species using this type of gear is Greenland halibut. In open water fishing from a vessel, bottom longlines are held in place by a series of anchors on the seafloor and are marked by lines attached to buoys at the surface (Fuller et al. 2008). Since 2004, bottom longline has not been the dominant fixed gear type for offshore harvesting of Greenland halibut in NAFO Subarea 0. However, it has been and still is the dominant gear type for inshore harvesting of this species by Nunavummiut, which occurs through the ice in Cumberland Sound and the inshore area of Baffin Island’s east coast during the season when an ice platform is present. Exploratory longline licenses were issued for cod and Greenland halibut in the AOI in the early 1990s. Other species that could be fished by bottom longline include species in the Anarhichadidae (wolffish species), Cyclopteridae (lumpfish, *Cyclopterus lumpus*), Myxinidae (Atlantic hagfish, *Myxine glutinosa*), and Pleuronectidae (American plaice, *Hippoglossoides platessoides*) families (Coad and Reist 2018; Loewen et al. 2020a). There is a lack of definitive information about fish species presence and distribution in the Hudson Bay Complex generally (Loewen et al. 2020b), though the limited records available indicate that members of these families do not occur in the SI AOI (Loewen et al. 2020b). Based on bathymetry and habitat suitability, it is likely that the area would not support groundfish fisheries (Stewart and Howland 2009) as the AOI is shallower than the 800-1,500 m depths in which the territory’s offshore commercial groundfish fishery predominantly occurs (DFO

2019b), as well as shallower than the >500 m depths in which the Cumberland Sound inshore groundfish fishery predominantly occurs (DFO 2008a). Therefore, based on available information, a fishery using this gear type is not plausible within the AOI and will not be assessed. If conditions and population densities change or are reassessed in the future this gear type may be revisited.

9.2.5 Other Fishing Methods

Other methods of fishing in addition to those discussed in more detail above include angling, jigging, weirs, and SCUBA diving. Angling and jigging are likely relatively common recreational fishing activities in the AOI as in other areas, whereas fishing conducted by SCUBA diving is likely less common. Nonetheless, given their selectivity and small spatial footprints the impacts from the habitat alteration and bycatch stressors using any of these methods are expected to be negligible in the AOI, and assessments will not be conducted. Weirs are predominantly used to target Arctic Char and occur in the freshwater environment (i.e., rivers). As such, a risk assessment will not be conducted for this method.

9.3 Lost Gear

The inadvertent capture of biota in fishing gear, via bycatch or entanglement, is expected to manifest similarly in lost gear as in active, the difference between the two being the long-term and unmonitored presence of lost gear (Laist 1997). The amount and distribution of lost harvesting gear (or “ghost gear”) in the AOI is unknown though expected to be minimal at present considering the very limited history of open water commercial fishing. Lost gear is expected to be able to cause impacts to biota until it is removed from the environment or degrades sufficiently (Dayton et al. 1995; Treble and Stewart 2010). Despite differences in the temporal component of risk between active versus lost gear, the risks posed by lost gear depend on how much gear is lost in the AOI, and how it is distributed spatially following its loss. Gear loss may reasonably be expected to occur a certain percentage of the time in the AOI, as in any area where fishing gear is deployed. Management instruments (e.g., fishing regulations, license conditions, harvesting plans) may help to prevent lost gear or mitigate its impacts. The lack of information generally precludes individual assessment of the residual risk of lost gear in the AOI beyond what is mitigated by existing management instruments; however, it has been included in the assessments above where appropriate.

10.0 Summary and Next Steps

The Southampton Island AOI supports several species of marine mammals and seabirds, marine and anadromous fishes, and important kelp bed and polynya habitat. The area also supports culturally significant activities, including harvesting, for the communities in its vicinity. This Ecological Risk Assessment provides information about the potential risk that human activities can pose to the Southampton Island AOI's important ecological features (i.e., ecologically significant subcomponents). It is important to note that an assessment of the socio-economic impacts of these stressors is not within the scope of this document.

The Ecological Risk Assessment follows the Ecological Risk Assessment Framework developed by DFO Arctic region, which provides a consistent approach for calculating risk of impact to Arctic species and habitats. The risk assessment was developed in consideration of a draft Pathways of Effects report (Johnson et al. unpublished[34]) that outlined all potential pathways through which human activities could affect the study area, and a scoping process that set temporal and spatial boundaries. Every interaction identified in the PoE report (Johnson et al. unpublished[34]) underwent an initial qualitative level 1 assessment to determine if the interaction was expected to result in measurable impact to the ESC subcomponent. Where an interaction was expected to potentially result in measurable impact, a more detailed semi-quantitative or qualitative level 2 assessment was undertaken. Qualitative level 2 assessments considered the same factors as the semi-quantitative level 2 assessments and only a final risk score was provided for each interaction. Risk scores were assessed by investigating the consequence and likelihood of interactions between activities (and their associated stressors) and ESC subcomponents. The final output of each assessment included an overall risk score of low, moderate, moderately-high, or high. Assessments were conducted on the residual risk that remains after existing and effective management measures are considered; i.e., existing and effective management measures, such as zoning, may contribute to a lower risk score. Given the hundreds of potential interactions, proxy assessments were used where appropriate for efficiency (e.g., in some assessments Arctic cod acted as proxy for other forage fish). The report underwent a Canadian Science Advisory Secretariat peer-review process in November 2022 and a review workshop with local experts from Chesterfield Inlet and Coral Harbour was held in March 2023.

Five primary activities and their associated stressors were assessed in relation to ESCs: shipping and vessel traffic, submarine cables, scientific research, recreation and tourism, and fisheries and harvesting. The ESCs (i.e., important species and habitats) included in the ERA were: kelp beds and other macroalgae, benthic invertebrates, Arctic char, Arctic cod and other forage fish, ringed and bearded seals, walruses, belugas, narwhals, bowhead whales, and sea ice and polynya habitat.

The potential impacts from submarine cable installation to sessile benthic invertebrates resulted in the only interaction scored as high risk (Table 10-1). Noise disturbance from large moving vessels resulted in moderately-high risk scores for walruses and cetaceans (i.e., narwhals, belugas, and bowhead whales) in the area, whereas vessel strikes from large vessels resulted in a low risk score for bowheads and eiders. Vessels at rest generally resulted in low risk scores across all stressors, including risk from noise disturbance to most marine mammals and risk from disturbance from artificial light to Arctic cod and Arctic char. However, the risk from fouling NIS from vessels at rest

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[34] Johnson et al. 2019. Pathways of effects modelling for the ecological and biological components of the Southampton Island Area of Interest. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/nnn. vi + xx p.

was scored as moderately-high to benthic invertebrates and kelp beds/other macroalgae. The risk from noise disturbance from acoustic surveys associated with submarine cable installation was moderately-high for narwhals, and was scored as low for all other subcomponents. The risk from noise and visual disturbance from small motorized vessels (i.e., motorboats and Zodiacs) to polar bears and thick-billed murres was assessed as low, and as moderate for walruses.

Limited information exists regarding the potential of new fisheries (e.g., commercial fisheries) in the Southampton Island AOI and therefore qualitative (rather than semi-quantitative) assessments were conducted on fishing gears that might foreseeably be used in the area in future, including bottom otter trawls, Digby dredges, bottom-set gillnets, nearshore Arctic char gillnets, and traps/pots. Habitat alteration from Digby dredge gear resulted in moderately-high risk scores to benthic invertebrates and walruses, while bycatch from the same gear resulted in a moderately-high risk to benthic invertebrates. The risk from trap/pot gear to Arctic cod and benthic invertebrates due to bycatch was low, while traps/pots resulted in a moderately-high risk to bowhead whales due to entanglement. The risk of bycatch/entanglement in bottom-set gillnets varied among ESC subcomponents. Overall, potential future fisheries in the AOI should consider management measures appropriate to the scenario of that fishery (location, intensity, etc.). Detailed level 1 assessments of the directed harvest (including subsistence, commercial, recreational, and sport hunting) of all species included in the assessment revealed no expected measurable impact , though DFO lacked sufficient scientific information to assess the risk of directed harvest to Arctic char. The risk to Arctic char from directed harvest was discussed at the workshop with local experts and participants agreed that the risk from this activity was low.

Several challenges arose and were addressed while undertaking this assessment. The many activities, stressors, and ESC subcomponents involved in the Ecological Risk Assessment created a challenge in applying each factor in the risk equation consistently among the dozens of interactions. This was addressed through thorough, iterative review and comparison of each factor score with other interactions to ensure appropriate relativity. Uncertainty was generally high across assessments due to a lack of research focused on Arctic ecosystems both generally and within the AOI, particularly with regard to investigations of the biological impacts of stressors. Uncertainties were acknowledged for each interaction and following the precautionary principle, a lack of certainty was not used as a reason to postpone or fail to take action to preserve the marine environment (i.e., this ecological risk assessment is a requirement of the MPA establishment process and the best available knowledge was used). Given the difference in annual AOI occupancy between resident and migratory species, there is recognition among practitioners that the application of the temporal factor is biased to offer more precautionary scoring towards either migratory or resident species depending on the approach taken. During development of the assessment framework in collaboration with DFO Science and Fisheries Management colleagues (see Section 2.2), it was recommended that a more precautionary approach towards migratory species be adopted, and this approach was applied consistently throughout the assessment (see Section 4.2). Additional investigation of this consideration is warranted, especially with regard to the Arctic, given its extreme seasonality.

That the AOI encompasses a large area (i.e., 93,087 km^2) and different parts of the AOI exhibit different ecologies challenged practitioners to think through application of the risk framework. First, the large size of the AOI and the low absolute density of human activities may have resulted in a diluted risk level if the risk was evaluated against the entire population of an individual ESC that occurs within the AOI boundaries. Moreover, ESC subcomponents (e.g., Arctic char, beluga) use multiple areas within the AOI in different seasons and for different purposes, resulting in challenges when determining a single risk score for the entire area across life history stages or behaviours. These challenges were addressed by investigating risk to the ESC population that occurred in "priority areas" (i.e., smaller zones within the AOI; identified in DFO 2020a). The dilution of risk was mitigated because the same low absolute density of human activity was investigated on a smaller population of assessment (i.e., within a priority area instead of the entire AOI) and thus some measurable level of risk was apparent (for context, the Southampton Island AOI's individual priority areas are larger than many other MPAs in Canada). As well, the approach to focus on one life history stage enabled the assessment to include more specific details about that life history stage, avoiding the ambiguity of an assessment covering an "average" life history stage. A precautionary approach was applied by selecting the priority area for assessment with the greatest exposure or highest sensitivity of the ESC due to their behaviour in the area, thereby offering a conservative estimate of risk when qualitatively applying the result to other priority areas.

Finally, it should be noted that the risk assessment framework was based on expertise present within DFO, which is rooted in western science. Though Inuit Qaujimajatuqangit was included where available (e.g., in sensitivity rationales) and a novel process was added in order to make the review more accessible to local experts (see Section 2.2), it is recognized that the framework employed is not necessarily intuitive to Inuit ways of knowing. Practitioners should continue to further explore a framework and/or process that is more inclusive to Inuit ways of knowing.

Risk assessment results will be used to inform discussions around potential MPA design options including the boundary, seasonally and spatially applied mitigation measures, and allowed activities (i.e., those exempted from the general prohibition).

Table 10-1. Summary of overall risk scores to Ecologically Significant Subcomponents (ESC) by activity and stressor for the Southampton Island AOI ecological risk assessment.

Esc	Activity	Stressor	Overall Risk
Benthic invertebrates (corals and sponges)	Submarine cables	Habitat alteration/removal	High
Arctic char	Vessel discharge (ballast water)	Pathogens/NIS	Moderately-High
Walrus	Vessel underway	Noise disturbance	Moderately-High
Narwhal	Vessel underway	Noise disturbance	Moderately-High
Beluga	Vessel underway	Noise disturbance	Moderately-High
Bowhead whale	Vessel underway	Noise disturbance	Moderately-High
Arctic char	Vessel underway	Noise and vibration disturbance	Moderately-High
Beluga	Icebreaking	Noise disturbance	Moderately-High
Narwhal	Icebreaking	Noise disturbance	Moderately-High
Bowhead whale	Icebreaking	Noise disturbance	Moderately-High
Narwhal	Vessel discharge (ballast water)	Pathogens/NIS	Moderately-High
Bearded seal	Vessel discharge (ballast water)	Pathogens/NIS	Moderately-High
Beluga	Vessel discharge	Petroleum product (large accidental)	Moderately-High

Esc	Activity	Stressor	Overall Risk
Narwhal	Vessel discharge	Petroleum product (large accidental)	Moderately-High
Bowhead whale	Vessel discharge	Petroleum product (large accidental)	Moderately-High
Walrus	Vessel discharge	Petroleum product (large accidental)	Moderately-High
Bearded seal	Vessel discharge	Petroleum product (large accidental)	Moderately-High
Ringed seal	Vessel discharge	Petroleum product (large accidental)	Moderately-High
Benthic invertebrates	Vessel discharge	Petroleum product (large accidental)	Moderately-High
Kelp beds and other macroalgae	Vessel discharge	Petroleum product (large accidental)	Moderately-High
Arctic char	Vessel discharge	Petroleum product (large accidental)	Moderately-High
Arctic cod	Vessel discharge	Petroleum product (large accidental)	Moderately-High
Polar bear	Vessel discharge	Petroleum product (large accidental)	Moderately-High
Polynya habitat	Vessel discharge	Petroleum product (large accidental)	Moderately-High
Sea ice	Vessel discharge	Petroleum product (large accidental)	Moderately-High
Thick-billed murre	Vessel discharge	Petroleum product (large accidental)	Moderately-High
Benthic invertebrates	Vessel at rest	Pathogens/NIS (fouling organisms)	Moderately-High
Kelp beds and other macroalgae	Vessel at rest	Pathogens/NIS (fouling organisms)	Moderately-High
Narwhal	Submarine cables	Noise disturbance (Acoustic Surveying)	Moderately-High
Bowhead whale	Trap/pot fishing gear	Bycatch/entanglement	Moderately-High
Bowhead whale	Bottom-set gillnet fishing gear	Bycatch/entanglement	Moderately-High
Benthic invertebrates	Digby dredge fishing gear	Bycatch	Moderately-High
Benthic invertebrates	Digby dredge fishing gear	Habitat alteration/removal	Moderately-High
Walrus	Digby dredge fishing gear	Habitat alteration/removal	Moderately-High
Walrus	Icebreaking	Noise disturbance	Moderate
Phytoplankton	Vessel discharge	Petroleum product (large accidental)	Moderate
Phytoplankton	Vessel discharge	Contaminants (scrubber effluent)	Moderate
Walrus	Scientific research – data collection	Noise disturbance	Moderate
Thick-billed murre	Scientific research – data collection	Noise disturbance	Moderate
Common eider	Scientific research – data collection	Noise disturbance	Moderate
Walrus	Recreation and tourism – wildlife interactions	Noise disturbance	Moderate
Kelp beds and other macroalgae	Vessel underway	Habitat alteration (sedimentation due to vessel wake/propeller wash)	Moderate

Esc	Activity	Stressor	Overall Risk
Kelp beds and other macroalgae	Submarine cables	Habitat alteration/removal	Moderate
Bowhead whale	Vessel discharge (ballast water)	Pathogens/NIS	Moderate
Walrus	Vessel discharge (ballast water)	Pathogens/NIS	Moderate
Benthic invertebrates	Vessel discharge (ballast water)	Pathogens/NIS	Moderate
Kelp beds and other macroalgae	Vessel discharge (ballast water)	Pathogens/NIS	Moderate
Arctic cod	Vessel discharge (ballast water)	Pathogens/NIS	Moderate
Arctic cod	Otter trawl fishing gear	Bycatch	Moderate
Benthic invertebrates	Otter trawl fishing gear	Bycatch	Moderate
Arctic cod	Vessel underway	Noise disturbance	Low
Barren-ground caribou	Vessel underway	Noise disturbance	Low
Common eider	Vessel underway	Noise disturbance	Low
Common eider	Vessel underway	Vessel strikes	Low
Common eider	Vessel underway	Water Displacement	Low
Benthic invertebrates	Vessel underway	Habitat alteration (sedimentation due to vessel wake/propeller wash)	Low
Other forage fish	Vessel underway	Habitat alteration (sedimentation due to vessel wake/propeller wash)	Low
Benthic invertebrates	Vessel discharge	Biological material	Low
Kelp beds and other macroalgae	Vessel discharge	Biological material	Low
Phytoplankton	Vessel discharge	Biological material	Low
Other forage fish	Vessel discharge	Biological material	Low
Arctic cod	Vessel discharge	Biological material	Low
Polynya habitat	Vessel discharge	Atmospheric emissions	Low
Sea ice	Vessel discharge	Atmospheric emissions	Low
Thick-billed murre	Vessel discharge	Petroleum product (small operational)	Low
Common eider	Vessel discharge (ballast water)	Pathogens/NIS	Low
Zooplankton	Vessel at rest	Disturbance from artificial light	Low
Arctic char	Vessel at rest	Disturbance from artificial light	Low
Arctic cod	Vessel at rest	Disturbance from artificial light	Low
Beluga	Vessel at rest	Noise disturbance	Low
Narwhal	Vessel at rest	Noise disturbance	Low
Walrus	Vessel at rest	Noise disturbance	Low
Ringed seal	Vessel at rest	Noise disturbance	Low
Bowhead whale	Vessel at rest	Noise disturbance	Low
Arctic cod	Vessel at rest	Noise disturbance	Low
Ringed seal	Vessel underway	Noise disturbance	Low
Bearded seal	Vessel underway	Noise disturbance	Low

Esc	Activity	Stressor	Overall Risk
Bowhead whale	Vessel underway	Vessel strikes	Low
Walrus	Icebreaking	Habitat alteration/removal	Low
Ringed seal	Icebreaking	Habitat alteration/removal	Low
Bearded seal	Icebreaking	Habitat alteration/removal	Low
Narwhal	Icebreaking	Habitat alteration/removal	Low
Beluga	Icebreaking	Habitat alteration/removal	Low
Polynya habitat	Icebreaking	Habitat alteration/removal	Low
Sea ice	Icebreaking	Habitat alteration/removal	Low
Common eider	Icebreaking	Habitat alteration/removal	Low
Arctic cod	Icebreaking	Noise disturbance	Low
Polar bear	Icebreaking	Noise disturbance	Low
Ringed seal	Icebreaking	Noise disturbance	Low
Bearded seal	Icebreaking	Noise disturbance	Low
Common eider	Icebreaking	Noise disturbance	Low
Ringed seal	Icebreaking	Vessel strikes	Low
Bearded seal	Icebreaking	Vessel strikes	Low
Benthic invertebrates	Anchoring and mooring	Habitat alteration/removal	Low
Kelp beds and other macroalgae	Anchoring and mooring	Habitat alteration/removal	Low
Bowhead whale	Submarine cables	Noise disturbance (acoustic surveying)	Low
Walrus	Submarine cables	Noise disturbance (acoustic surveying)	Low
Ringed seal	Submarine cables	Noise disturbance (acoustic surveying)	Low
Bearded seal	Submarine cables	Noise disturbance (acoustic surveying)	Low
Arctic cod	Submarine cables	Noise disturbance (acoustic surveying)	Low
Walrus	Scientific research – data collection	Biota encounters/handling	Low
Thayer’s gull	Scientific research – data collection	Noise disturbance	Low
Bowhead whale	Scientific research – data collection	Noise disturbance	Low
Ringed seal	Scientific research – data collection	Noise disturbance	Low
Bearded seal	Scientific research – data collection	Noise disturbance	Low
Beluga	Scientific research – data collection	Noise disturbance	Low
Narwhal	Scientific research – data collection	Noise disturbance	Low
Common eider	Scientific research – data collection	Biota encounters/handling	Low
Benthic invertebrates	Scientific research (bottom trawls)	Habitat alteration/removal	Low

Esc	Activity	Stressor	Overall Risk
Polar bear	Recreation and tourism – wildlife interactions	Biota encounters	Low
Common eider	Recreation and tourism – wildlife interactions	Biota encounters/handling	Low
Thick-billed murre	Recreation and tourism – wildlife interactions	Noise disturbance	Low
Benthic invertebrates	Trap/pot fishing gear	Bycatch	Low
Arctic cod	Trap/pot fishing gear	Bycatch	Low
Kelp beds and other macroalgae	Trap/pot fishing gear	Habitat alteration/removal	Low
Arctic cod	Arctic char gillnet fishing gear	Bycatch	Low
Arctic cod	Bottom-set gillnet fishing gear	Bycatch	Low
Bearded seal	Bottom-set gillnet fishing gear	Bycatch/entanglement	Low
Thick-billed murre	Bottom-set gillnet fishing gear	Bycatch/entanglement	Low
Other forage fish	Otter trawl fishing gear	Bycatch	Low
Arctic cod	Digby dredge fishing gear	Bycatch	Low
Arctic cod	Digby dredge fishing gear	Habitat alteration/removal	Low

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12.0 References

Aars, J., Lunn, N.J., and Derocher, A.E. 2006. Polar Bears: Proceedings of the 14th Working Meeting of the IUCN/SSC Polar Bear Specialist Group, 20-24 June 2005, Seattle, Washington, USA. IUCN, Gland, Switzerland and Cambridge, UK. 189 p. https://doi.org/10.2305/IUCN.CH.1999.SSC-AP.7.en

Aars, J., Marques, T.A., Buckland, S.T., Andersen, M., Belikov, S., Boltunov, A., and Wiig, O. 2009. Estimating the Barents Sea polar bear subpopulation size. Mar. Mamm. Sci. 25: 35-52.

Abdulla, A. and Linden, O. 2008. Maritime traffic effects on biodiversity in the Mediterranean Sea: Review of impacts, priority areas and mitigation measures. IUCN Centre for Mediterranean Cooperation, Malaga, Spain. Available at: https://www.iucn.org/sites/dev/files/import/downloads/maritime_v1_lr.pd

Abraham, K.F. and Finney, G.H. 1986. Eiders of the eastern Canadian Arctic. *In* Eider ducks in Canada. *Edited by* Reed, A. Canadian Wildlife Service Report Series No. 47, Ottawa. pp. 55-73. Available at: https://publications.gc.ca/collections/collection_2018/eccc/cw65-8/CW65-8-47.pdf

Ackleh, A.S., Ioup, G.E., Ioup, J.W., Ma, B., Newcomb, J.J., Pal, N., Sidorovskaia, N.A., and Tiemann, C. 2012. Assessing the Deepwater Horizon oil spill impact on marine mammal population through acoustics: Endangered sperm whales. J. Acoust. Soc. Am. 131: 2306-2314.

Adams, W.A. 1975. Light intensity and primary productivity under sea ice containing oil. Beaufort Sea Technical Report 29. Department of the Environment, Victoria, B.C., Canada. 156 p. Available at: https://publications.gc.ca/collections/collection_2019/eccc/En3-6-29-eng.pdf

AECOM and Arctic Fibre Inc. 2013. Arctic Fibre Submarine Cable System - Project Description / Project Proposal. [s.n.], Guelph, ON and Toronto, ON. 226 p. Available at: http://media.ktoo.org/2013/12/Arctic-Fibre-Project-Summary-English.pdf

Agnico Eagle. 2022. Agnico Eagle Meadowbank Complex shipping management plan – version 4. Appendix 56 of Meadowbank Complex – 2021 annual report. Rep. num. 61-000-100-REP-004.

Ahlund, M. and Gotmark, F. 1989. Gull predation on Eider ducklings *Somateria mollissima*: effects of human disturbance. Biol. Conserv. 48: 115-127.

Airoldi, L. 2003. The effects of sedimentation on rocky coast assemblages. Oceanogr. Mar. Biol. 41: 161-236. Available at: https://www.researchgate.net/publication/228458759_The_Effects_of_Sedimentation_on_Rocky_Coast_Assemblages

Aker, J., Ford, J., Serdynska, A., and Koropatnick, T. 2014. Ecological risk assessment of the St. Anns Bank Area of Interest. Can. Tech. Rep. Fish. Aquat. Sci. 3047: iv + 161 p.

Aksoyoglu, S., Baltensperger, U., and Prevot, A.S. 2016. Contribution of ship emissions to the concentration and deposition of air pollutants in Europe. Atmos. Chem. Phys. 16: 1895-1906. https://doi.org/10.5194/acp-16-1895-2016

Al-Habahbeh, A.K., Kortsch, S., Bluhm, B.A., Beuchel, F., Guliksen, B., Ballantine, C., Cristini, D., and Primicerio, R. 2020. Arctic coastal benthos long-term responses to perturbations under climate warming. Philos. Trans. Royal Soc. A. 378(2181): 20190355. https://doi.org/10.1098/rsta.2019.0355

Alliston, W.G. 1980. The distribution of ringed seals in relation to winter icebreaking activities near McKinley Bay, N.W.T., January-June 1980. Rep. from LGL Ltd., Toronto, ON, for Dome Petrol. Ltd., Calgary, AB. 52 p.

Alliston, W.G. 1981. The distribution of ringed seals in relation to winter icebreaking activities in Lake Melville, Labrador. Rep. from LGL Ltd., St. John's, NL, for Arctic Pilot Project, Petro-Canada, Calgary, AB. 13 p.

Arctic Monitoring and Assessment Programme (AMAP). 2010. Assessment 2007: Oil and gas activities in the Arctic – Effects and potential effects. Volume 2. AMAP, Oslo, Norway. vii + 277 p. Available at: https://www.amap.no/documents/download/1016/inline

Arctic Monitoring and Assessment Programme (AMAP). 2017. Snow, Water, Ice and Permafrost in the Arctic (SWIPA) 2017. AMAP, Oslo, Norway. Xiv + 269 pp.

Arctic Shipping Safety and Pollution Prevention Regulations. 2017. Available at: https://laws-lois.justice.gc.ca/eng/regulations/SOR-2017-286/index.html [Date accessed: May 7, 2024].

Arctic Waters Pollution Prevention Act. 1985. Available at: https://laws-lois.justice.gc.ca/eng/acts/A-12/ [Date accessed: May 7, 2024].

Amiraux R., Yurkowski, D.J., Archambault, P., Pierrjean, M., and Mundy, C.J. 2022. Top predator sea stars are the benthic equivalent to polar bears of the pelagic realm. PNAS. 120: e2216701120.

Andersen, M., Hjelset, A.M., Gjertz, I., Lydersen, C., and Gulliksen, B. 1999. Growth, age at sexual maturity and condition in bearded seals (*Erignathus barbatus*) from Svalbard, Norway. Polar Biol. 21: 179-185. https://doi.org/10.1007/s003000050350

Anderson Hansen, K., Hernandez, A., Mooney, T.A., Rasmussen, M.H., Sorensen, K., and Wahlberg, M. 2020. The common murre (*Uria aalge*), an auk seabird, reacts to underwater sound. J. Acoust. Soc. Am. 147: 4069-4074. https://doi.org/10.1121/10.0001400

Andreakis, N. and Schaffelke, B. 2012. Invasive marine seaweeds: Pest or prize? *In* Seaweed Biology: Novel Insights into Ecophysiology, Ecology and Utilization. *Edited by* Wiencke, C. and Bischof, K. Springer-Verlag, Berlin, Germany. pp. 235-262. Available at: https://link.springer.com/book/10.1007/978-3-642-28451-9

Andrulewicz, E., Napierska, D., and Otremba, Z. 2003. The environmental effects of the installation and functioning of the SwePol Link HVDC transmission line: a case study of the Polish Marine Area of the Baltic Sea. J. Sea Res. 49: 337-345.

Antrim, L., Bathis, L., and Cooksey, C. 2018. Submarine cables in Olympic Coast National Marine Sanctuary: History, impact, and management lessons. Marine Sanctuaries Conservation Series ONMS-18-01. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries, Silver Spring, MD. 53 p. + appendices. Available at: https://repository.library.noaa.gov/view/noaa/19557.

Archambault, P., Snelgrove, P.V., Fisher, J.A., Gagnon, J.M., Garbary, D.J., Harvey, M., Kenchington, E.L., Lesage, V., Levesque, M., Lovejoy, C., and Mackas, D.L. 2010. From sea to sea: Canada's three oceans of biodiversity. PLoS One. 5(8): p.e12182.

Arctic Council. 2009. Arctic marine shipping assessment 2009 report. Arctic Council, Tromsø, NO. 194 p. Available at: https://www.pmel.noaa.gov/arcticzone/detect/documents/AMSA_2009_Report_2nd_print.pdf

Arrigo, K.R. and van Dijken, G.L. 2004. Annual cycles of sea ice and phytoplankton in Cape Bathurst polynya, southeastern Beaufort Sea, Canadian Arctic. Geophys. Res. Lett. 31(8): L08304. https://doi.org/10.1029/2003GL018978

Asselin, N.C., Ferguson, S.H., Richard, P.R., and Barber, D.G. 2012. Results of narwhal (*Monodon monoceros*) aerial surveys in northern Hudson Bay, August 2011. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/037. iii + 23 p.

Assis, J., Serrão, E.A., Duarte, C.M., Fragkopoulou, E., and Krause-Jensen, D. 2022. Major expansion of marine forests in a warmer Arctic. Front. Mar. Sci. 9: 850368.

Astles, K.L., Gibbs, P.J., Steffe, A.S., and Green, M. 2009. A qualitative risk-based assessment of impacts on marine habitats and harvested species for a data deficient wild capture fishery. Biol. Conserv. 142: 2759-2773.

Auld, A.H. and Schubel, J.R. 1978. Effects of suspended sediment on fish eggs and larvae: A laboratory experiment. Estuar. Coast. Shelf Sci. 6: 153-164. https://doi.org/10.1016/0302-3524(78)90097-X.

Aumack, C.F., Dunton, K.H., Burd, A.B., Funk, D.W., and Maffione, R.A. 2007. Linking light attenuation and suspended sediment loading to benthic productivity within and Arctic kelp-bed community. J. Phycol. 43: 853-863.

Auster, P., Lindholm, J., Cramer, A., Nenandovic, M., Prindle, C., and Tamsett, A. 2013. The seafloor habitat recovery monitoring project (SHRMP) at Stellwagen Bank National Marine Sanctuary. Final Report.

Austin, S., Wyllie-Echeverria, S., and Groom, M.J. 2004. A comparative analysis of submarine cable installation methods in Northern Puget Sound, Washington. J. Marine Env. Engg. 7: 173-183. Available at: https://www.vliz.be/imisdocs/publications/ocrd/217191.pdf

Babb, D.G., Kirillov, S., Kuzyk, Z.Z., Netser, T., Liesch, J., Kamula, C.M., Zagon, T., Barber, D.G., and Ehn, J.K. 2022. On the Intermittent Formation of an Ice Bridge *(Nunniq)* across Roes Welcome Sound, Northwestern Hudson Bay, and Its Use to Local Inuit Hunters. Arctic. 75(2): 198-224. https://doi.org/10.14430/arctic74957

Back, D.Y., Ha, S.Y., Else, B., Hanson, M., Jones, S.F., Shin, K.H., Tatarek, A., Wiktor, J.M., Cicek, N., Alam, S., and Mundy, C.J. 2021. On the impact of wastewater effluent on phytoplankton in the Arctic coastal zone: a case study in the Kitikmeot Sea of the Canadian Arctic. Sci. Total Environ. 759: 143861. https://doi.org/10.1016/j.scitotenv.2020.143861

Bain, H., Thomson, U., Foy, M., and Griffiths, W. 1977. Marine ecology of fast-ice edges in Wellington Channel and Resolute Passage, NWT. LGL Ltd., Toronto, ON. 307 p.

Balata, D., Piazzi, L., and Cinelli, F. 2007. Increase of sedimentation in a subtidal system: Effects on the structure and diversity of macroalgal assemblages. J. Exp. Mar. Biol. Ecol. 351: 73-82. https://doi.org/10.1016/j.jembe.2007.06.019

Ballast Water Regulations. 2021. Available at: https://laws-lois.justice.gc.ca/eng/regulations/SOR-2021-120/index.html [Date accessed: May 7, 2024].

Barber, D.G. and Massom, R.A. 2007. The role of sea ice in Arctic and Antarctic polynyas. *In* Polynyas: Windows to the World. *Edited by* Smith, W.O. and Barber, D,G. Elsevier, Amsterdam. pp. 1-43. https://doi.org/10.1016/S0422-9894(06)74001-6

Barry, W., Rubinstein, N., Melzian, B., and Hill, B. 2003. The biological effects of suspended and bedded sediment (SABS) in aquatic ecosystems: A review. Internal report. US Environmental Protection Agency.

BC CDC (British Columbia Centre for Disease Control). 2022. Clostridium perfringens. Available at: http://www.bccdc.ca/health-info/diseases-conditions/clostridium-perfringens [Date accessed: December 15, 2023].

Bejder, L. 2005. Linking short and long-term effects of nature-based tourism on cetaceans. Ph.D. Thesis, Dalhousie University.

Bejder, L., Samuels, A., Whitehead, H., Gales, N., Mann, J., Connor, R., Heithaus, M., Watson-Capps, J., and Flaherty, C. 2006. Decline in relative abundance of bottlenose dolphins exposed to long-term disturbance. Conserv. Biol. 20: 1791-1798.

Bell, J.J., McGrath, E., Biggerstaf, A., Bates, T., Bennett, H., Marlow, J., and Shaffer, M. 2015. Sediment impacts on marine sponges. Mar. Poll. Bull. 94(1): 5-13.

Bellard, C., Leroy, B., Thuiller, W., Rysman, J.F., and Courchamp, F. 2016. Major drivers of invasion risk throughout the world. Ecosphere. 7(3): e01241. https://doi.org/10.1002/ecs2.1241

Bender, M.L., Giebichenstein, J., Teisrud, R.N., Laurent, J., Frantzen, M., Meador, J.P., Sørensen, L., Hansen, B.H., Reinardy, H.C., Laurel, B., and Nahrgang, J. 2021. Combined effects of crude oil exposure and warming on eggs and larvae of an arctic forage fish. Sci. Rep. 11: 8410. https://doi.org/10.1038/s41598-021-879322

Bengtson, J.L., Hiruki-Raring, L.M., Simpkins, M.A., and Boveng, P.L. 2005. Ringed and Bearded Seal densities in the eastern Chukchi Sea, 1999–2000. Polar Biol. 28: 833-845.

Benoit, D., Simard, Y., Gagne, J., Geoffroy, M., and Fortier, L. 2010. From polar night to midnight sun: photoperiod, seal predation, and the diel vertical migrations of polar cod *(Boreogadus saida)* under land fast ice in the Arctic Ocean. Polar Biol. 33(11): 1505-1520. https://doi.org/10.1007/s00300-010-0840-x

Benoît, H.P., Hurlbut, T., and Chassé, J. 2010. Assessing the factors influencing discard mortality of demersal fishes using a semi-quantitative indicator of survival potential. Fish. Res. 106: 436-447.

Berge, J., Geoffroy, M., Daase, M., Cottier, F., Priou, P., Cohen, J.H., Johnsen, G., McKee, D., Kostakis, I., Renaud, P.E., and Vogedes, D. 2020. Artificial light during the polar night disrupts Arctic fish and zooplankton behaviour down to 200 m depth. Commun. Biol. 3 (1): 102. https://doi.org/10.1038/s42003-020-0807-6

Bergerud, A.T. 1978. Caribou. *In* Big game of North America: Ecology and management. E*dited by* Schmidt, J.L. and Gilbert, D.L. Stackpole Books, Harrisburg, PA. pp. 83-101.

Bergmann, M., Beare, D.J., and Moore, P.G. 2001. Damage sustained by epibenthic invertebrates discarded in the *Nephrops* fishery of the Clyde Sea area, Scotland. J. Sea Res. 45: 105-118.

BERR (Department for Business, Enterprise & Regulatory Reform). 2008. Review of Cabling Techniques and Environmental Effects Applicable to the Offshore Wind Farm Industry. Department for Business, Enterprise & Regulatory Reform, London, EN. 164 p. Available at: https://tethys.pnnl.gov/sites/default/files/publications/Cabling_Techniques_and_Environmental_Effects.pdf

Bessell-Browne, P., Negri, A.P., Fisher, R., Clode, P.L., Duckworth, A., and Jones, R. 2017. Impacts of turbidity on corals: The relative importance of light limitation and suspended sediments. Mar. Poll. Bull. 117: 161-170.

BIM (Baffinland Iron Mine Corporation). 2012. Baffinland Iron Mine Corporation's Final Environmental Impact Statement for the Mary River Project.

BirdLife International. 2018a. *Somateria mollissima*. The IUCN Red List of Threatened Species 2018: e.T22680405A132525971. https://dx.doi.org/10.2305/IUCN.UK.20182.RLTS.T22680405A132525971.en

BirdLife International. 2018b. *Uria lomvia*. The IUCN Red List of Threatened Species 2018: e.T22694847A132066134. https://dx.doi.org/10.2305/IUCN.UK.20182.RLTS.T22694847A132066134.en

BirdLife International. 2019. *Larus glaucoides* (amended version of 2018 assessment). The IUCN Red List of Threatened Species 2019: e.T22729877A155595584. https://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T22729877A155595584.en

Black, A. 2005. Light induced seabird mortality on vessels operating in the Southern Ocean: incidents and mitigation measures. Antarct. Sci. 17(1): 67-68.

Blackburn, T.M., Bellard, C., and Ricciardi, A. 2019. Alien versus native species as drivers of recent extinctions. Front. Ecol. Environ. 17(4): 203-207. https://doi.org/10.1002/fee.2020

Blane, J.M. and Jaakson, R. 1994. The impact of ecotourism boats on the St Lawrence beluga whales. Environ. Conserv. 21: 267-269.

Bocetti, C.I. 2011. Cruise ships as a source of avian mortality during fall migration. Wilson J. Ornith. 123(1): 176-178.

Boebel, O., Clarkson, P., Coates, R., Larter, R., O'Brien, P.E., Ploetz, J., Summerhayes, C., Tyack, T., Walton, D.W., and Wartzok, D. 2005. Risks posed to the Antarctic marine environment by acoustic instruments: a structured analysis. Antarct. Sci. 17(4): 533-540. https://doi.org/10.1017/S0954102005002956

Boehm, P.D., Neff, J.M., and Page, D.S. 2007. Assessment of polycyclic aromatic hydrocarbon exposure in the waters of Prince William Sound after the Exxon Valdez oil spill: 1989-2005. Mar. Poll. Bull. 54(3): 339-356.

BOEM (Bureau of Ocean Energy Management). 2018. Liberty Development and Production Plan Beaufort Sea, Alaska Environmental Impact Statement Volume 1. Executive Summary and Chapters 1 through 6. OCS EIS/EA BOEM 2018-050. Available at: https://www.boem.gov/sites/default/files/about-boem/BOEM-Regions/Alaska-Region/Leasing-and-Plans/Plans/Vol-1-Liberty-FEIS.pdf

Boenish, R. 2018. Spatio-temporal dynamics of Atlantic cod bycatch in the Maine lobster fishery and its impacts on stock assessment. Ph.D. Thesis, University of Maine. Available at: https://www.researchgate.net/publication/326506569_Spatio-Temporal_Dynamics_of_Atlantic_Cod_Bycatch_in_the_Maine_Lobster_Fishery_and_Its_Impacts_on_Stock_Assessment

Boersma, P.D., Clark, J.A., and Hillgarth, N. 2002. Seabird conservation. *In* Biology of Marine Birds. *Edited by* Schreiber, E.A. and Burger, J. CRC Press, New York, NY. pp. 559-579.

Bolam, S.G. 2011. Burial survival of benthic macrofauna following deposition of simulated dredged material. Environ. Monit. Assess. 181: 13-27.

Bolgan, M., O'Brien, J., Rountree, R.A., and Gammell, M. 2016. Does the Arctic charr Salvelinus alpinus produce sounds in a captive setting?. J. Fish. Biol. 89(3): 1857-1865.

Bolgan, M., O'Brien, J., Chorazyczewska, E., Winfield, I.J., McCullough, P., and Gammell, M. 2018. The soundscape of Arctic char spawning grounds in lotic and lentic environments: Can passive acoustic monitoring be used to detect spawning activities? Bioacoustics. 27(1): 57-85.

Bonner, W.N. 1982. Seals and man: A study of interactions. University of Washington Press, Seattle, WA. 170 p.

Bonsell, C. and Dunton, K.H. 2021. Slow community development enhances abiotic limitation of benthic community structure in a high Arctic kelp bed. Front. Mar. Sci. 8: 592295.

Born, E.W., Gjertz, I., and Reeves, R.R. 1995. Population assessment of Atlantic walrus. Norsk Polarinstitutt Meddelererser. 138. 100 p.

Born, E.W., Riget, F.F., Dietz, R., and Andriashek, D. 1999. Escape responses of hauled out ringed seals *(Phoca hispida)* to aircraft disturbance. Polar Biol. 21(3): 171-178.

Boudreaux, M.L., Walters, L.J., and Rittschof, D. 2009. Interactions between native barnacles, non-native barnacles, and the Eastern Oyster *(Crassostrea virginica)*. Bull. Mar. Sci. 84(1): 43-57. Available at: https://www.ingentaconnect.com/content/umrsmas/bullmar/2009/00000084/00000001/art00003#

Boutillier, P.D., Boutillier, J.A., and Gillespie, G.E. 2019. British Columbia corals: A synopsis of information on their taxonomy, occurrences, distribution, threats, and general status. Can. Tech. Rep. Fish. Aquat. Sci. 3322: vii + 260 p.

Boyd, W.S, Bowman, T.D., Savard, J.-P., and Dickson, R.D. 2015. Conservation of North American sea ducks. *In* Ecology and Conservation of North American sea ducks. *Edited by* Savard, J.-P., Derksen, D.V., Esler, D., and Eadie, J.M. Stud. Avian Biol. No. 46. Cooper Ornithological Society and CRC Press. pp. 529-559. https://doi.org/10.1201/b18406

Blue Planet Marine. 2016. Information document: Review of multibeam echosounder surveys and potential impacts on marine mammals. BPM-16-MDC-Review of multibeam echosounder surveys and marine mammals v1.2. Available at: https://www.marlborough.govt.nz/repository/libraries/id:1w1mps0ir17q9sgxanf9/hierarchy/Documents/Environment/Coastal/Seabed%20Habitat%20Mapping%20List/Review_of_multibeam_echosounder_surveys_and_marine_mammals.pdf

Bradshaw, C.J., Boutin, S., and Hebert, D.M. 1997. Effects of petroleum exploration on woodland caribou in northeastern Alberta. J. Wildl. Manage. 61(4): 1127-1133. https://doi.org/10.2307/3802110

Brakstad, O.G., Nonstad. I., Faksness, L-G., and Brandvik, P.J. 2008. Responses of microbial communities in the Arctic sea ice after contamination by crude petroleum oil. Microb. Ecol. 55: 540-552. https://doi.org/10.1007/s00248-007-9299-x

Breton-Honeyman, K., Hammill, M.O., Furgal, C.M., and Hickie, B. 2016. Inuit Knowledge of beluga whale (Delphinapterus leucas) foraging ecology in Nunavik (Arctic Quebec), Canada. Can. J. Zool. 94: 713-726.

Brewer, K.D., Gallagher, M.L., Regos, P.R., Isert, P.E., and Hall, J.D. 1993. ARCO Alaska, Inc. Kuvlum #1 exploration prospect/Site specific monitoring program final report. Rep. from Coastal & Offshore Pacific Corp., Walnut Creek, CA, for ARCO Alaska Inc., Anchorage, AK. 80 p.

Brinklow, T.R., Chan, F.T., Etemad, M., Deb, J.C., and Bailey, S.A. 2022. Vessel biofouling as a vector for nonindigenous species introductions in Canada. DFO Sci. Advis. Sec. Res. Doc. 2022/072. iv + 49 p.

Brisson-Curadeau, É. and Elliott, K.H. 2019. Prey capture and selection throughout the breeding season in a deep-diving generalist seabird, the thick-billed murre. J. Avian Biol. 50(7). https://doi.org/10.1111/jav.01930

Broad, A., Rees, M.J., and Davis, A.R. 2020. Anchor and chain scour as disturbance agents in benthic environments: trends in the literature and charting a course to more sustainable boating and shipping. Mar. Poll. Bull. 161: 111683. https://doi.org/10.1016/j.marpolbul.2020.111683

Brooke, S.D., Holmes, M.W., and Young, C.M. 2009. Sediment tolerance of two different morphotypes of the seep-sea coral *Lophelia pertusa* from the Gulf of Mexico. Mar. Ecol. Prog. Ser. 390: 137-144.

Brueggeman, J.J., Green, G.A., Grotefendt, R.A., Smultea, M.A., Volsen, D.P., Rowlett, R.A., Swanson, C.C., Malme, C.I., Mlawski, R., and Burns, J.J. 1992. 1991 marine mammal monitoring program (walrus and polar bear) Crackerjack and Diamond prospects Chukchi Sea. Rep. from EBASCO Environmental, Bellevue, WA, for Shell Western E & P Inc. and Chevron USA Inc.

Brueggeman, J.J. 1993. Walrus response to offshore drilling operations. J. Acous. Soc. Am. 94(3): 1828.

Bruneau, J., Babb, D., Chan, W., Kirillov, S., Ehn, J., Hanesiak, J., and Barber, D.G. 2021. The ice factory of Hudson Bay: Spatiotemporal variability of the Kivalliq Polynya. Elem. Sci. Anth. 9(1): 00168.

Brussaard, C.P., Peperzak, L., Beggah, S., Wick, L.Y., Wuerz, B., Weber, J., Arey, J.S., van der Burg, B., Jonas, A., Huisman, J., and van der Meer, J.R. 2016. Immediate ecotoxicological effects of short-lived oil spills on marine biota. Nat. Commun. 7: 11206. https://doi.org/10.1038/ncomms11206

Bue, B.G., Sharr, S., and Seeb, J.E. 1998. Evidence of Damage to Pink Salmon Populations Inhabiting Prince William Sound, Alaska, Two Generations after the Exxon Valdez Oil Spill. Trans. Am. Fish. Soc. 127(1): 35-43. https://doi.org/10.1577/15488659(1998)127%3C0035:EODTPS%3E2.0.CO;2

Burek, K.A., Gulland, F.M., and O'Hara, T.M. 2008. Effects of climate change on Arctic marine health. Ecol. Appl. 18(SI2): S126-S134. https://doi.org/10.1890/06-0553.1

Burger, A.E. 1993. Estimating the mortality of seabirds following oil spills: Effects of spill volume. Mar. Poll. Bull. 26: 140-143. https://doi.org/10.1016/0025-326X(93)90123-2

Burger, J. 2018. Productivity of waterbirds in potentially impacted areas of Louisiana in 2011 following the Deepwater Horizon oil spill. Environ. Monitor. Assess. 190: 131. https://doi.org/10.1007/s10661-017-6428-y

Burns, J.J. and Seaman, G.A. 1985. Investigations of Beluga whales in coastal waters of western and northern Alaska. II. Biology and ecology. Rep. from Alaska Dep. Fish & Game, Fairbanks, AK, for U.S. Natl. Oceanic & Atmos. Admin. (R.U. 612, Contr. No. NA 81 RAC 00049). 129 p.

Bursian, S.J., Alexander, C.R., Cacela, D., Cunningham, F.L., Dean, K.M., Dorr, B.S., Ellis, C.K., Godard-Codding, C.A., Guglielmo, C.G., Hanson-Dorr, K.C., Harr, K.E., Healy, K.A., Hooper, M.J., Horak, K.E., Isanhart, J.P., Kennedy, L.V., Link, J.E., Maggini, I., Moye, J.K., Perez, C.R., Pritsos, C.A., Shriner, S.A, Trust, K.A., and Tuttle, P.L. 2017. Reprint of: Overview of avian toxicity studies for the Deepwater Horizon Natural Resource Damage Assessment. Ecotoxicol. Environ. Safe. 146: 4-10. http://dx.doi.org/10.1016/j.ecoenv.2017.03.046

Buskey, E.J., White, H.K., and Esbaugh, A.J. 2016. Impact of oil spills on marine life in the Gulf of Mexico: Effects on plankton, nekton, and deep-sea benthos. Oceanogr. 29(3): 174-181. http://dx.doi.org/10.5670/oceanog.2016.81

Buxton, R.T., Galvan, R., McKenna, M.F., White, C.L., and Seher, V. 2017. Visitor noise at a nesting colony alters the behavior of a coastal seabird. Mar. Ecol. Prog. Ser. 570: 233-246. Available at: http://www.int-res.com/abstracts/meps/v570/p233-246/

Cameron, M.F., Bengtson, J.L., Boveng, P.L., Jansen, J.K., Kelly, B.P., Dahle, S.P., Logerwell, E.A., Overland, J.E., Sabine, C.L., Waring, G.T., and Wilder, J.M. 2010. Status review of the bearded seal *(Erignathus barbatus)*. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-211, 246 p. Available at: https://www.fisheries.noaa.gov/resource/document/status-review-bearded-seal-erignathus-barbatus

Campbell, J.S. and Simms, J.M. 2009. Status report on coral and sponge conservation in Canada. Fisheries and Oceans Canada, vii + 87p.

Camus, L. 2017. Unique Arctic Communities and Oil Spill Response Consequences: "Oil Biodegradation & Persistence" and "Oil Spill Response Consequences Resilience and Sensitivity". AOSRT, London, EN. 188 p. Available at: http://www.arcticresponsetechnology.org/wp-content/uploads/2017/11/Report-Environmental-Effects-Phase-2-report.pdf

Canada Shipping Act. 2001. Available at: https://laws-lois.justice.gc.ca/eng/acts/C-10.15/ [Date accessed: May 7, 2024].

Canadian Hydrographic Service. 2022. Canadian Sailing directions: Hudson Strait, Hudson Bay, and adjoining waters. ARC 401. Available at: https://publications.gc.ca/collections/collection_2022/mpo-dfo/Fs74-6-2021-12-eng.pdf

Carlyle, C.G., Florko, K.R., Young, B.G., Yurkowski, D.J., Michel, C., and Ferguson, S.H. 2021. Marine mammal biodiversity and rare narwhal *(Monodon monoceros)* observations near northern Ellesmere Island, Canada. Ecosphere. 12(6): e03534. 10.1002/ecs2.3534

Caron, L.M. and Sergeant, D.E. 1988. Yearly variation in the frequency of passage of beluga whales *(Delphinapterus leucas)* at the mouth of the Saguenay River, Québec, over the past decade. Nat. Can. 115(2): 111-116.

Caron, L.M. and Smith, T.G. 1990. Philopatry and site tenacity of belugas *(Delphinapterus leucas)* hunted by the Inuit at the *Nastapoka* Estuary, eastern Hudson Bay. Can. J. Fish. Aquat. Sci. 224: 69-79.

Carter, L., Burnett, D., and Davenport, T. 2014. The relationship between submarine cables and the marine environment. *In* Submarine Cables: The Handbook of Law and Policy. *Edited by* Burnett, D.R., Beckman, R., and Davenport, T.M. Martinus Nijhoff, Leiden, EN. pp. 179-212. Available at: https://brill.com/view/book/edcoll/9789004260337/B9789004260337_009.xml

Carvalho, P.C., Smith, A., Bakker, A., Lavoie, C., Veenaas, C., Desmond, D., Hostetler, G., Schuster, J., Ji, M., Cai, Q., Hubert, C., and Stern, G. 2019. R/V William Kennedy Leg 4 Cruise Report (Sep 1-15, 2019): Cruise along the Kivalliq transportation corridor (Hudson Bay). Technical Report. Available at: https://www.researchgate.net/publication/338083956_RV_William_Kennedy_Leg_4_Cruise_Report_Sep_1-15_2019_Cruise_along_the_Kivalliq_transportation_corridor_Hudson_Bay

Cassoff, R.M., Moore, K.M., McLellan, W.A., Barco, S.G., Rotstein, D.S., and Moore, M.J. 2011. Lethal entanglement in baleen whales. Dis. Aquat. Org. 96(3): 75-185.

Castellani, G., Losch, M., Lange, B.A., and Flores, H. 2017. Modeling Arctic sea-ice algae: Physical drivers of spatial distribution and algae phenology. J. Geophys. Res. Oceans 122: 7466-7487. https://doi:10.1002/2017JC012828

Castro de la Guardia, L., Filbee-Dexter, K., Reimer, J., MacGregor, K.A., Garrido, I., Singh, R.K., Belanger, S., Konar, B., Iken, K., Johnson, L.E., Archambault, P., Sejr, M.K., Soreide, J.E., Mundy, C.J. 2023. Increasing depth distribution of Arctic kelp with increasing number of open water days with light. Elem. Sci. Anth. 11(1): 00051. https://doi.org/10.1525/elementa.2022.00051

CEQA (California Environmental Quality Act). 2001. Giant and Bull Kelp Commercial and Sportfishing Regulations. Chapter 4 - Environmental Impacts. Available at: https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=36799&inline

Chambellant, M. 2010. Hudson Bay ringed seal: ecology in a warming climate. *In* A Little Less Arctic: Top Predators in the World's Largest Northern Inland Sea, Hudson Bay. *Edited by* Ferguson, S.H., Loseto, L.L., and Mallory, M.L. Springer, New York, USA. pp. 137-158.

Chan, F.T., Bronnenhuber, J.E., Bradie, J.N., Howland, K., Simard, N., and Bailey, S.A. 2011. Risk assessment for ship-mediated introductions of aquatic nonindigenous species to the Canadian Arctic. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/105. vi + 93 p.

Chan, F.T., MacIsaac, H., and Bailey, S.A. 2015. Relative importance of vessel hull fouling and ballast water as transport vectors of non-indigenous species to the Canadian Arctic. Can J. Fish. Aquat. Sci. 72: 1230-1242. https://doi.org/10.1139/cjfas-2014-0473

Chan, F.T., MacIsaac, H., and Bailey, S.A. 2016. Survival of ship biofouling assemblages during and after voyages to the Canadian Arctic. Mar. Biol. 163: 250. https://doi.org/10.1007/s00227-016-3029-1

Chan, F.T., Stanislawczyk, K., Sneekes, A.C., Dvoretsky, A., Gollasch, S., Minchin, D., David, M., Jelmert, A., Albretsen, J., and Bailey, S.A. 2019. Climate change opens new frontiers for marine species in the Arctic: Current trends and future invasion risks. Glob. Chang. Biol. 25(1): 25-38. https://doi.org/10.1111/gcb.14469

Chan, F.T., Ogilvie, D., Sylvester, F., and Bailey, S.A. 2022. Ship biofouling as a vector for non-indigenous aquatic species to Canadian arctic coastal ecosystems: a survey and modeling-based assessment. Front. Mar. Sci. 9: 808055.

Chapman, A.R. and Lindley, J.E. 1980. Seasonal growth of *Laminaria solidungula* in the Canadian High Arctic in relation to irradiance and dissolved nutrient concentrations. Mar. Biol. 57: 1-5.

Chardine, J. and Mendenhall, V. 1998. Human disturbance at Arctic seabird colonies. C.I. Secretariat, Hafnarstraeti, Iceland. iii + 18 p. Available at: http://hdl.handle.net/11374/162.

Charette, J., Melling, H., Duerksen, S., Johnson, H., Dawson, K., Brandt, C., Remnant, R., and Michel, R. 2020. Biophysical and Ecological Overview of the Tuvaijuittuq Area. Can. Tech. Rep. Fish. Aquat. Sci. 3408: xi + 110 p.

Chaves-Barquero, L.G., Luong, K.H., Mundy, C.J., Knapp, W.W., Hanson, M.L., and Wong, C.S. 2016. The release of wastewater contaminants in the Arctic: A case study from Cambridge Bay, Nunavut, Canada. Environ. Pollut. 218: 542-550.

Cholewiak, D., DeAngelis, A., Palka, D., Corkeron, P., and Van Parijs, S. 2017. Beaked whales demonstrate a marked acoustic response to the use of shipboard echosounders. R. Soc. Open Sci. 4(12): 170940. https://doi.org/10.1098/rsos.170940

Christiansen, J.S., Sparboe, M., Sæther, B.S., and Siikavupio, S.I. 2015. Thermal behaviour and the prospect spread of an invasive benthic top predator onto the Euro-Arctic shelves. Divers. Distrib. 21: 1004-1013. https://doi.org/10.1111/ddi.12321

Christie, H., Fredriksen, S., and Rinde, E. 1998. Regrowth of kelp and colonization of epiphyte and fauna community after kelp trawling at the coast of Norway. *In* Recruitment, Colonization and Physical-Chemical Forcing in Marine Biological Systems. *Edited by* Baden, S., Phil, L., Rosenberg, R., Stromberg, J.-O., Svane, I., and Tiselius, P. Springer, Dordrecht, Netherlands. pp. 49-58.

Christie, H., Bekkby, T., Norderhaug, K.M., Beyer, J., and Jørgensen, N.M. 2019. Can sea urchin grazing of kelp forests in the Arctic make rocky shore systems more vulnerable to oil spills? Polar Biol. 42: 557-567. https://doi.org/10.1007/s00300-018-02450-8

Churchill, J.H. 1989. The effect of commercial trawling on sediment resuspension and transport over the Middle Atlantic Bight continental shelf. Cont. Shelf Res. 9(9): 841-864

Citta, J.J., Burns, J.J., Quakenbush, L.T., Vanek, V., George, J.C., Small, R.J., Heide-Jørgensen, M.P., and Browner, H. 2013. Potential for bowhead whale entanglement in cod and crab pot gear in the Bering Sea. Mar. Mammal Sci. 30(2): 445-459.

Coad, B.W. and Reist, J.D. (eds.). 2018. Marine Fishes of Arctic Canada. University of Toronto Press, Toronto. Available at: https://www.jstor.org/stable/10.3138/j.ctt1x76h0b

CSL (Coastal Shipping Limited). n.d. CSL fleet. Available at: https://www.woodwardgroup.ca/csl-fleet.html [Date accessed: March 6, 2024].

Cohen, A.N. and Carlton, J.T. 1998. Accelerating invasion rate in a highly invaded estuary. Science. 279(5350): 555-558.

Cohen, D.M., Inada, T., Iwamoto, T., and Scialabba, N. 1990. FAO species catalogue. Vol. 10. *Gadiform* fishes of the world (Order *Gadiformes*). An annotated and illustrated catalogue of cods, hakes, grenadiers and other *Gadiform* fishes known to date. FAO Fish. Synop. 125(10). FAO, Rome. 442 p. Available at: http://www.fao.org/3/T0243E/t0243e.pdf

Cohen, J.H., Berge, J., Moline, M.A., Sørensen, A.J., Last, K., Falk-Petersen, S., Renaud, P.E., Leu, E.S., Grenvald, J., Cottier, F., Cronin, H., Menze, S., Norgren, P., Øystein, V., Daase, M., Darnis, G., and Johnsen, G. 2015. Is ambient light during the high Arctic polar night sufficient to act as a visual cue for zooplankton? PLoS One. 10(6): e0126247. https://doi.org/10.1371/journal.pone.0126247

Cole, A.K., Brillant, S.W., and Boudreau, S.A. 2021. Effects of time-area closures on the distribution of snow crab fishing effort with respect to entanglement threat to North Atlantic right whales. ICES J. Mar. Sci. 78(6): 2109-2119. https://doi.org/10.1093/icesjms/fsab103

Coleman, R.A., Hoskin, M.G., von Carlshausen, E., and Davis, C.M. 2013. Using a no-take zone to assess the impacts of fishing: sessile epifauna appear insensitive to environmental disturbances from commercial potting. J. Exp. Mar. Biol. Ecol. 440: 100-107.

Collie, J.S., Escanero, G.A., and Valentine, P.C. 1997. Effects of bottom fishing on the benthic megafauna of Georges Bank. Mar. Ecol. Prog. Ser. 155: 159-172. Available at: https://www.int-res.com/articles/meps/155/m155p159.pdf

Collins, C.A. 1983. Marine mammals of the Melville Peninsula Southampton Island area. A report prepared for Land Use Information Series Department of Environment and Lands Directorate. 80 p.

Collins, K.J., Suonpää, A.M., and Mallinson, J.J. 2010. The impacts of anchoring and mooring in seagrass, Studland Bay, Dorset, UK. Underw. Technol. 29(3): 117-123. https://doi.org/10.3723/ut.29.117

Conlan, K.E. and Kvitek, R.G. 2005. Recolonization of soft-sediment ice scours on an exposed Arctic coast. Mar. Ecol. Prog. Ser. 286: 21-42.

Cooke, J.G. and Reeves, R. 2018. *Balaena mysticetus*. The IUCN Red List of Threatened Species 2018: e.T2467A50347659. https://dx.doi.org/10.2305/IUCN.UK.2018-1.RLTS.T2467A50347659.en

Corbett, J.J., Lack, D.A., Winebrake, J.J, Harder, S., Silberman, J.A., and Gold, M. 2010. Arctic shipping emissions inventories and future scenarios. Atmos. Chem. Phys. 10(19): 9689-9704. https://doi.org/10.5194/acp-10-9689-2010

Cosens, S.E. and Dueck, L.P. 1988. Response of migrating narwhal and beluga to icebreaker traffic at the Admiralty Inlet ice-edge, N.W.T. in 1986. *In* Port and ocean engineering under arctic conditions. Vol II. *Edited by* Sackinger, W.M. Geophysical Institute, Univ. Alaska, Fairbanks. pp. 39-54.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2006. COSEWIC assessment and update status report on the Atlantic walrus *(Odobenus rosmarus rosmarus)* in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa, ON. ix + 65 p.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2009. COSEWIC assessment and update status report on the Bowhead Whale *(Balaena mysticetus)*, Bering-Chukchi-Beaufort population and Eastern Canada-West Greenland population, in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa, ON. vii + 49 p.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2014. COSEWIC assessment and status report on the Beluga Whale *(Delphinapterus leucas)*, St. Lawrence Estuary population, in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa, ON. xii + 64 p.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2017. COSEWIC assessment and status report on the Atlantic Walrus *(Odobenus rosmarus rosmarus)*, High Arctic population, Central-Low Arctic population and Nova Scotia-Newfoundland-Gulf of St. Lawrence population in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa, ON. xxxi + 89 p.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2019. COSEWIC assessment and status report on the Ringed Seal *(Pusa hispida)* in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa, ON. xii + 82 p.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2020. COSEWIC assessment and status report on the Beluga Whale *(Delphinapterus leucas)*, Eastern High Arctic - Baffin Bay population, Cumberland Sound population, Ungava Bay population, Western Hudson Bay population, Eastern Hudson Bay population and James Bay population in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa, ON. xxxv + 84 p.

Couturier, S., Côté, S.D., Otto, R.D., Weladji, R.B., and Huot, J. 2009. Variation in calf body mass in migratory caribou: the role of habitat, climate, and movements. J. Mammal. 90(2): 442-452. https://doi.org/10.1644/07-MAMM-A-279.1

Cramp, S. 1980. Handbook of the birds of Europe, the Middle East and North Africa: The birds of the western Palearctic (Vol. I). Oxford University Press, Oxford, UK. 722 p.

Craven, H.R., Brand, A.R., and Stewart, B.D. 2013. Patterns and impacts of fish bycatch in a scallop dredge fishery. Aquat. Conserv. Mar. Freshwater Ecosyst. 23(1): 152-170.

Crawford, R.E. 2002. Secondary wake turbidity from small boat operation in a shallow sandy bay. J. Coastal Res. SI 37: 50-65. Available at: https://www.jstor.org/stable/25736342

Creed, J.C. and Filho, G.M. 1999. Disturbance and recovery of the macroflora of a seagrass *(Halodule wrightii* Ascherson) meadow in the Abrolhos Marine National Park, Brazil: an experimental evaluation of anchor damage. J. Exp. Mar. Biol. Ecol. 235: 285-306. https://doi.org/10.1016/S0022-0981(98)00188-9

Cross, W.E., Wilce, R.T., and Fabijan, M.F. 1987. Effects of experimental releases of oil and dispersed oil on Arctic nearshore macrobenthos. III. Macroalgae. Arctic. 40(Supp.1): 211-219.

Crowell, S.C. 2016. Measuring in-air and underwater hearing in seabirds. Adv. Exp. Med. Biol. 875: 1155-1160.

CSRIC (Communications Security Reliability and Interoperability Council). 2014. Final report – Protection of submarine cables through spatial separation. Federal Communications Commission. Working group 8. Available at: https://transition.fcc.gov/pshs/advisory/csric4/CSRIC_IV_WG8_Report1_3Dec2014.pdf

Culhane, F.E., Briers, R.A, Tett, P., and Fernandes, T.F. 2019. Response of a marine benthic invertebrate community and biotic indices to organic enrichment from sewage disposal. J. Mar. Biolog. Assoc. U.K. 99: 1721-1734. https://doi.org/10.1017/S0025315419000857

Cusson, M., Archambault, P., and Aitken, A. 2007. Biodiversity of benthic assemblages on the Arctic continental shelf: historical data from Canada. Mar. Ecol. Prog. Ser. 331: 291-304.

Dainko, S. and Phelps, A. 2017. Recreational Boating and Waterfowl. North American Lake Management Society. Available at: https://www.nalms.org/wp-content/uploads/2017/10/37-3-8.pdf

Das, N. and Chandran, P. 2011. Microbial degradation of petroleum hydrocarbon contaminants: An overview. Biotechnol. Res. Int. 2011: 941810. https://doi.org/10.4061/2011/941810

Dauphiné, T.C. 1976. Biology of the Kaminuriak population of barren-ground caribou – Part 4: Growth, reproduction and energy reserves. Canadian Wildlife Service Report Series 38. 71 p. Available at: https://publications.gc.ca/collections/collection_2018/eccc/cw65-8/CW65-8-38-eng.pdf

Davenport, J. and Davenport, J.L. 2006. The impact of tourism and personal leisure transport on coastal environments: A review. Estuar. Coast. Shelf. Sci. 67: 280-292. https://doi.org/10.1016/j.ecss.2005.11.026

Davidson, E.R. and Hussey, N.E. 2019. Movements of a potential fishery resource, porcupine crab *(Neolithodes grimaldii)* in Northern Davis Strait, Eastern Canadian Arctic. Deep Sea Res. Part I. 154: 103143. Available at: https://www.sciencedirect.com/science/article/pii/S0967063719302894

Davis, J.E. and Anderson, S.S. 1976. Effects of oil pollution on breeding grey seals. Mar. Poll. Bull. 7(6): 115-118.

Davis, R.A. and Malme, C.I. 1997. Potential effects on ringed seals of ice-breaking ore carriers associated with the Voisey's Bay nickel project. LGL Report No. TA2147-1. Rep. by LGL Limited for Voisey's Bay Nickel Company Limited.

Davis, A.R., Broad, A., Gullett, W., Reveley, J., Steele, C., and Schofield, C. 2016. Anchors away? The impacts of anchor scour by ocean-going vessels and potential response options. Mar. Policy. 73: 1-7. http://dx.doi.org/10.1016/j.marpol.2016.07.021

Davoren, G.K. 2007. Effects of gill-net fishing on marine birds in a biological hotspot in the northwest Atlantic. Conserv. Biol. 21(4): 1032-1045.

Dawson, J., Pizzolato, L., Howell, S.E., Copland, L., and Johnston, M.E. 2018. Temporal and spatial patterns of ship traffic in the Canadian Arctic from 1990 to 2015. Arctic 71(1): 15-26. Available at: https://journalhosting.ucalgary.ca/index.php/arctic/article/view/67736/51632

Day, R.H., Prichard, A.K., Rose, J.R., Streever, B., and Swem, T. 2017. Effects of a hazing-light system on migration and collision avoidance of eiders at an artificial oil-production island, Arctic Alaska. Arctic. 70: 13-24. Available at: http://www.jstor.org/stable/26379720

Dayton, P.K., Thrush, S.F., Agardy, M.T., and Hofman, R.J. 1995. Environmental effects of marine fishing. Aquat. Conserv. Mar. Freshwater Ecosyst. 5: 205-232.

de Borger, E., Tiano, J., Braeckman, U., Rijnsdorp, A.D., and Soetaert, K. 2020. Impact of bottom trawling on sediment biogeochemistry: a modelling approach. Biogeosciences. Preprint. https://doi.org/10.5194/bg-2020-328

de Jong, K., Amorim, M.C., Fonseca, P.J., Fox, C.J., and Keubel, K.U. 2018. Noise can affect acoustic communication and subsequent spawning success in fish. Environ. Pollut. 237: 814-823. https://doi.org/10.1016/j.envpol.2017.11.003

de Jong, K., Forland, T.N., Amorim, M.C., Rieucau, G., Slabbekoorn, H., and Sivle, L.D. 2020. Predicting the effects of anthropogenic noise on fish reproduction. Rev. Fish. Biol. Fisheries 30: 245-268. https://doi.org/10.1007/s11160-020-09598-9

Dean, T.A. and Jewett, S.C. 2001. Habitat-specific recovery of shallow subtidal communities following the Exxon Valdez oil spill. Ecol. Appl. 11(5): 1456-1471. https://doi.org/10.2307/3060932

Dehn, L.A., Sheffield, G.G., Follmann, E.H., Duffy, L.K., Thomas, L.D., and O'Hara, T.M. 2007. Feeding ecology of phocid seals and some walrus in the Alaskan and Canadian Arctic as determined by stomach contents and stable isotope analysis. Polar Biol. 30: 167-181. 10.1007/s00300-006-0171-0

DeMaster, D. and Stirling, I. 1981. *Ursus maritimus*. Mamm. Species. 145: 1-7. https://doi.org/10.2307/3503828

Dempson, B.J., Shears, M., Furey, G., and Bloom, M. 2008. Resilience and stability of north Labrador Arctic charr, *Salvelinus alpinus*, subject to exploitation and environmental variability. Environ. Biol. Fish. 82: 57-67.

Derocher, A.E. and Stirling, I. 1991. Oil contamination of polar bears. Polar Rec. 27(160): 56-57. https://doi.org/10.1017/S0032247400019896

Descamps, S., Jenouvrier, S., Gilchrist, H.G., and Forbes, M.R. 2012. Avian cholera, a threat to the viability of an arctic seabird colony? PLoS ONE. 7: e29659. https://doi.org/10.1371/journal.pone.0029659

Desgagnés. n.d. A Canadian fleet that stands out. Available at: https://desgagnes.com/en/fleet/ [Date accessed: March 6, 2024].

Desmond, D.S., Saltymakova, D., Smith, A., Wolfe, T., Snyder, N., Polcwiartek, K., Bautista, K., Lemes, M., Hubert, C.R., Barber, D.G., Isleifson, D., and Stern, G.A. 2021. Photooxidation and biodegradation potential of a light crude oil in first-year sea ice. Mar. Poll. Bull. 165: 112154.

DHNRDAT (Deepwater Horizon Natural Resource Damage Assessment Trustees). 2016. Deepwater Horizon oil spill: Final programmatic damage assessment and restoration plan and final programmatic environmental impact statement. Available at: https://www.gulfspillrestoration.noaa.gov/restoration-planning/gulf-plan

Dias, V., Oliveira, F., Boavida, J., Serrao, E.A., Goncalves, J.S., and Coelho, M.G. 2020. High Coral Bycatch in Bottom-Set Gillnet Coastal Fisheries Reveals Rich Coral Habitats in Southern Portugal. Front. Mar. Sci. 7: 603438. https://doi.org/10.3389/fmars.2020.603438

Dick, M.H. and Donaldson, W. 1978. Fishing vessel endangered by crested auklet landings. Condor. 80: 235-236.

Dickins, D. 2011. Behavior of Oil Spills in Ice and Implications for Arctic Spill Response. OTC Arctic Technology Conference. Houston, TX, 7-9 February 2011. p. 15.

Dietz, R., Born, E.W., Stewart, R.E., Heide-Jørgensen, M.P., Stern, H., Rigét, F., Toudal, L., Lanthier, C., Jensen, M.V., and Teilmann, J. 2013. Movements of walruses *(Odobenus rosmarus)* between Central West Greenland and Southeast Baffin Island, 2005-2008. NAMMCO Sci. Publ. 9: 53-74. https://doi.org/10.7557/3.2605

Dohler, G. 2007. Tides and tidal currents in Hudson Bay. *In* Tides in Canadian waters. Monograph, Canadian Hydrographic Service, Cat. Num. Fs72-40/2007E. Available at: https://publications.gc.ca/collections/collection_2020/eccc/en32/En32-25-1974-eng.pdf

Dome Petroleum Ltd. 1981. Oil and gas under sea ice. Report CV1, Canadian Offshore Oil Spill Research Association (COOSRA), Calgary, AB vol. I and II. 286 p.

Doniol-Valcroze, T., Gosselin, J-F., Pike, D.G., Lawson, J.W., Asselin, N.C., Hedges, K., and Ferguson, S.H. 2020. Narwhal abundance in the Eastern Canadian High Arctic in 2013. NAMMCO Sci. Publ. 11: 1-26.

Dooling, R.J. and Therrien, S.C. 2012. Hearing in birds: What changes from air to water. Adv. Exp. Med. Biol. 730: 7782.

Drake, J.M. and Lodge, D.M. 2007. Hull fouling is a risk factor for intercontinental species exchange in aquatic ecosystems. Aquat. Invasions. 2(2): 121-131. https://doi.org/10.3391/ai.2007.2.2.7

Ducklow, H.W. and Mitchell, R. 1979. Bacterial populations and adaptations in the mucus layers on living corals. Limnol. Oceanogr. 24(4): 715-725.

Duggins, D.O., Simenstad, C.A., and Estes, J.A. 1989. Magnification of secondary production by kelp detritus in coastal marine ecosystems. Science. 245(4914): 170-173.

Dunham, A., Pegg, J.R., Carolsfield, W., Davies, S., Murfitt, I., and Boutillier, J. 2015. Effects of submarine power transmission cables on a glass sponge reef and associated megafaunal community. Mar. Env. Res. 107: 50-60. https://doi.org/10.1016/j.marenvres.2015.04.003

Dunton, K.H. and Schell, D.M. 1987. Dependence of consumers on macroalgal *(Laminaria solidungula)* carbon in an arctic kelp community: δ13C evidence. Mar. Biol. 93(4): 615-625.

Dunton, K.H., Reimnitz, E.R., and Schonberg, S. 1982. An arctic kelp community in the Alaskan Beaufort Sea. Arctic. 35(4): 465-484.

DuPaul, W.D., Brust, J.C., and Kirkley, J.E. 1995. Bycatch in the United States and Canadian Sea Scallop Fishery. Virginia Institute of Marine Science. 21 p.

Durner, G.M., Douglas, D.C., Nielson, R.M., Amstrup, S.C., McDonald, T.L., Stirling, I., Mauritzen, M., Born, M.E., Wiig, Ø., DeWeaver, E., Serreze, M.C., Belikov, S.E., Holland, M.M., Maslanik, J., Aars, J., Bailey, D.C, and Derocher, A.E. 2009. Predicting 21st century polar bear habitat distribution from global climate models. Ecol. Mono. 79(1): 2558. https://doi.org/10.1890/07-2089.1

Dyck, M.G. and Baydack, R.K. 2004. Vigilance behavior of polar bears *(Ursus maritimus)* in the context of wildlife viewing activities at Churchill, Manitoba, Canada. Biol. Conserv. 116(3): 343-350. http://dx.doi.org/10.1016/S0006-3207(03)00204-0

Eckhardt, S., Hermansen, O., Grythe, H., Fiebig, M., Stebel, K., Cassiani, M., Baecklund, A., and Stohl, A. 2013. The influence of cruise ship emissions on air pollution in Svalbard – a harbinger of a more polluted Arctic? Atmos. Chem. Phys. 13(16): 8401-8409. https://doi.org/10.5194/acp-13-8401-2013

Edwards, D.D., McFeters, G.A., and Venkatsean, M.I. 1998. Distribution of Clostridium perfringens and fecal sterols in a benthic coastal marine environment influenced by the sewage outfall from McMurdo Station, Antarctica. Appl. Environ. Microbiol. 64(7): 2596-2600. https://doi.org/10.1128/aem.64.7.2596-2600.1998

Elliott, K.H., Woo, K.J., Gaston, A.J., Benvenuti, S., Dall'Antonia, L., and Davoren, G.K. 2009. Central-place foraging in an arctic seabird provides evidence for Storer-Ashmole's Halo. The Auk. 126(3): 613-625.

Ellis, S., Franks, D.W., Nattrass, S., Currie, T.E., Cant, M.A., Giles, D., Balcomb, K.C., and Croft, D.P. 2018. Analyses of ovarian activity reveal repeated evolution of post-reproductive lifespans in toothed whales. Sci. Rep. 8(1): 1-10.

Elmgren, R., Hansson, S., Larsson, U., Sundelin, U., and Boehm, P.D. 1983. The "Tsesis" oil spill: Acute and long-term impact on the benthos. Mar. Biol. 73: 51-65. Available at: https://link.springer.com/article/10.1007/BF00396285

Endres, S., Maes, F., Hopkins, F., Houghton, K., Mårtensson, E.M., Oeffner, J., Quack, B., Singh, P., and Turner, D. 2018. A new perspective at the ship-air-sea-interface: The environmental impacts of exhaust gas scrubber discharge. Front. Mar. Sci. 5: 139. https://doi.org/10.3389/fmars.2018.00139

Engelhardt, F.R. 1978. Petroleum hydrocarbons in Arctic ringed seals *(Phoca hispida)* following experimental oil exposure. *In* Proceedings of the Conference on the Assessment of the Ecological Impacts of Oil Spills, 14 17 June 1978, Keystone, CO. American Institute of Biological Science. pp. 614-628.

Engelhardt, F.R. 1981. Oil pollution in polar bears: exposure and clinical effects. *In* Proc. 4th Arctic Marine Oil spill Program technical seminar, Edmonton, Alta. Envir. Protect. Serv., Ottawa. pp. 139-179.

Engelhardt, F.R. 1982. Hydrocarbon metabolism and cortisol balance in oil exposed ringed seals *(Phoca hispida)*. Comp. Biochem. Physiol. 72(C): 133-136.

Engelhardt, F.R. 1983. Petroleum effects marine mammals. Aquat. Toxic. 4: 199-217.

Eno, N.C., MacDonald, D.S., Kinnear, J.A., Amos, S.C., Chapman, C.J., Clark, R.A., Bunker, F., and Munro, C. 2001. Effects of crustacean traps on benthic fauna. ICES J. Mar. Sci. 58: 11-20.

ECCC (Environment and Climate Change Canada). 2022a. Update on Murre harvest and hunting regulations. Available at: https://www.canada.ca/en/environment-climate-change/services/migratory-game-bird-hunting/regulations-provincial-territorial-summaries/newfoundland-labrador/update-murre-harvest-hunting-regulations.html [Date accessed: December 13, 2023].

ECCC (Environment and Climate Change Canada). 2022b. Common eider harvest: voluntary reduction in take. Available at: https://www.canada.ca/en/environment-climate-change/services/migratory-game-bird-hunting/regulations-provincial-territorial-summaries/prince-edward-island/common-eider-harvest-voluntary-reduction-in-take.html [Date accessed: December 13, 2023].

Erbe, C., Marley, S.A., Schoeman, R.P., Smith, J.N., Trigg, L.E., and Embling, C.B. 2019. The effects of ship noise on marine mammals—a review. Front. Mar. Sci. 606. https://doi.org/10.3389/fmars.2019.00606

Esler, D., Bowman, K.B., Trust, K.A., Ballachey, B.E., Dean, T.A., Jewett, S.C., and O'Clair, C.E. 2002. Harlequin Duck Population Recovery Following the Exxon Valdez Oil Spill: Progress, Process and Constraints. Mar. Ecol. Prog. Ser. 241: 271-286. http://dx.doi.org/10.3354/meps241271

Esler, D., Trust, K.A., Ballachey, B.E., Iverson, S.A., Lewis, T.L., Rizzolo, D.J., Mulcahy, D.M., Miles, A.K., Woodin, B.R., Stegeman, J.J., Henderson, J.D., and Wilson, B.W. 2010. Cytochrome P4501A biomarker indication of oil exposure in Harlequin Ducks up to 20 years after the Exxon Valdez oil spill. Environ. Toxicol. Chem. 29: 1138-1145. https://doi.org/10.1002/etc.129

Estrada, R., Harvey, M., Gosselin, M., Starr, M., Galbraith, P.S., and Straneo, F. 2012. Late-summer zooplankton community structure, abundance, and distribution in the Hudson Bay system (Canada) and their relationships with environmental conditions, 2003-2006. Prog. Oceanogr. 101(1): 121-145.

European Commission. 2021. Overview of EU actions in the Arctic and their impact. Final Report. EPRD Office for Economic Policy and Regional Development Ltd. Kielce, Poland. Available at: https://eprd.pl/wp-content/uploads/2021/06/EU-Policy-Arctic-Impact-Overview-Final-Report.pdf

Evans, T.J., Fischbach, A., Schliebe, S., Manly, B., Kalxdorff, S., and York, G. 2003. Polar bear aerial survey in the eastern Chukchi sea: A pilot study. Arctic. 56(4): 359-366. https://doi.org/10.14430/arctic633

Eyring, V., Kohler, H.W., van Aardenne, J., and Lauer, A. 2005. Emissions from international shipping: 1. The last 50 years. J. Geophys. Res. 110(D17). https://doi.org/10.1029/2004JD005619

FAO (Food and Agriculture Organization of the United Nations). 1980. Fishing with bottom gillnets. Available at: https://www.fao.org/3/X6935E/X6935E00.htm

Fay, F.H. 1982. Ecology and biology of the Pacific Walrus, *Odobenus rosmarus divergens illiger*. North American Fauna 74, United States Department of the Interior, Washington, DC.

Fay, F.H., Kelly, B.P., Gehnrich, P.H., Sease, J.L., and Hoover, A.A. 1984. Modern populations, migrations, demography, trophics, and historical status of the Pacific walrus. Outer Cont. Shelf Environ. Assess. Program, NOAA. Anchorage, AK. Available at: https://espis.boem.gov/final%20reports/280.pdf [Date accessed: December 14, 2023].

Fay, F.H., Eberhardt, L.L., Kelly, B.P., Burns, J.J., and Quakenbush, L.T. 1997. Status of the Pacific walrus population, 1950-1989. Mar. Mamm. Sci. 13: 537-565.

Feder, H.M., Turner, C.H., and Limbaugh, C. 1974. Observations on fishes associated with kelp beds in Southern California. State of California – The Resources Agency of California. Department of Fish and Game. Available at: http://content.cdlib.org/view?docId=kt9t1nb3sh&brand=calisphere&doc.view=entire_text

Ferguson, S.H., Stirling, I., and McLoughlin, P. 2005. Climate change and ringed seal (Phoca hispida) recruitment in western Hudson Bay. Mar. Mammal Sci. 21(1): 121-135. https://doi.org/10.1111/j.1748-7692.2005.tb01212.x

Ferguson, S.H., Young, B.G., Yurkowski, D.J., Anderson, R., Willing, C., and Nielsen, O. 2017. Demographic, ecological, and physiological responses of ringed seals to an abrupt decline in sea ice availability. PeerJ. 5: e2957. 10.7717/peerj.2957

Fernandes, P., Cook, R., Florin, A., Lorance, P., and Nedreaas, K. 2015. *Boreogadus saida (*Europe assessment*).* The IUCN Red List of Threatened Species 2015: e.T18125034A45095947. Available at: https://www.iucnredlist.org/species/18125034/45095947

Fetzer, I., Lønne, O., and Pearson, T. 2002. The distribution of juvenile benthic invertebrates in an arctic glacial fjord. Polar Biol. 25: 303-315. https://doi.org/10.1007/s00300-001-0345-8

Fiala, M. and Delille, D. 1999. Annual changes of microalgae biomass in Antarctic Sea ice contaminated by crude oil and diesel fuel. Polar Biol. 21: 391-396. https://doi.org/10.1007/s003000050378

Filbee-Dexter, K. and Scheibling, R. E. 2014. Sea urchin barrens as alternative stable states of collapsed kelp ecosystems. Mar. Ecol. Prog. Ser. 495: 1-25.

Filbee-Dexter, K., Feehan, C.J., and Scheibling, R.E. 2016. Large-scale degradation of a kelp ecosystem in an ocean warming hotspot. Mar. Ecol. Prog. Ser. 543: 141-152.

Filbee-Dexter, K., MacGregor, K.A., Lavoie, C., Garrido, I., Goldsmit, J., Castro De La Guardia, L., Howland, K., Johnson, L.E., Konar, B., McKindsey, C.W., Mundy, C.J., Schlegel, R.W., and Archambault, P. 2022. Sea ice and substratum shape extensive kelp forests in the Canadian Arctic. Front. Mar. Sci. 31(9): 754074. https://doi.org/10.3389/fmars.2022.754074

Fingas, M.F. and Hollebone, B.P. 2003. Review of behaviour of oil in freezing environments. Mar. Poll. Bull. 47(912): 333-340. https://doi.org/10.1016/S0025-326X(03)00210-8

Fingas, M.F. and Hollebone, B.P. 2014. Oil behaviour in ice-infested waters. *In* International Oil Spill Conference Proceedings. 2014(1): 1239-1250. American Petroleum Institute.

Finley, K.J., Miller, G.W., Davis, R.A., and Greene, C.R. 1990. Reactions of belugas, *Delphinapterus leucas*, and narwhals, *Monodon monoceros*, to ice-breaking ships in the Canadian high arctic. Can. Bull. Fish. Aquat. Sci. 224: 97-117.

Fischbach, A.S., Monson, D.H., and Jay, C.V. 2009. Enumeration of Pacific walrus carcasses on beaches of the Chukchi Sea in Alaska following a mortality event, September 2009: U.S. Geological Survey Open File Report 2009-1291. 10 p.

Fischbach, A.S., Kochnev, A., Garlich-Miller, J.L., and Jay, C.V. 2016. Pacific walrus coastal haul out database, 1852-2016 – Background report. Report number: 2016-1108. https://doi.org/10.3133/ofr20161108

Fish, J.F. and Vania, J.S. 1971. Killer whale, *Orcinus orca*, sounds repel white whales, *Delphinapterus leucas*. Fish. Bull. 69(3): 531-535.

Fisher, C.R., Hsing, P.-Y., Kaiser, C.L., Yoerger, D.R., Roberts, H.H., Shedd, W.W., Cordes, E.E., Shank, T.M., Berlet, S.P., Saunders, M.G., Larcom, E.A., and Brooks, J.M. 2014. Footprint of Deepwater Horizon blowout impact to deepwater coral communities. PNAS. 111(32): 11744-11749. https://doi.org/10.1073/pnas.1403492111

Fisheries Act. 1985. Available at: https://laws.justice.gc.ca/eng/acts/f-14/index.html [Date accessed: May 7, 2024].

Fisheries and Oceans Canada (DFO). 2006. Impacts of trawl gears and scallop dredges on benthic habitats, populations and communities. DFO Can. Sci. Advis. Sec. Res. Doc.: 2006/025. 13 p.

Fisheries and Oceans Canada (DFO). 2008a. Cumberland Sound Greenland halibut (turbot) inshore fishery. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2008/040. 20 p.

Fisheries and Oceans Canada (DFO). 2008b. Total allowable harvest recommendations for Nunavut narwhal and beluga populations. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2008/035. 7 p.

Fisheries and Oceans Canada (DFO). 2010. Potential Impacts of Fishing Gears (Excluding Mobile Bottom-Contacting Gears) on Marine Habitats and Communities. DFO Can. Sci. Advis. Sec. Res. Doc.: 2010/003. 24 p.

Fisheries and Oceans Canada (DFO). 2011a. The marine environment and fisheries of Georges Bank, Nova Scotia: Consideration of the potential interactions associated with offshore petroleum activities. Can. Tech. Rep. Fish. Aquat. Sci. 2945: xxxv + 492 p.

Fisheries and Oceans Canada (DFO). 2011b. 2011-2015 Integrated Fisheries Management Plan for Atlantic Seals. Available at: https://www.dfo-mpo.gc.ca/fisheries-peches/seals-phoques/reports-rapports/mgtplan-planges20112015/mgtplan-planges20112015-eng.html#c3.6.2 [Date accessed: December 14, 2023].

Fisheries and Oceans Canada (DFO). 2014a. Cambridge Bay Arctic char commercial fishery (summary version) – Effective 2014. Integrated fishery management plan. Available at: https://www.dfo-mpo.gc.ca/fisheries-peches/ifmp-gmp/arctic-char-omble-chev/arctic-char-omble-chev-eng.html [Date accessed: May 3, 2024].

Fisheries and Oceans Canada (DFO). 2014b. Arctic Char. Available at: https://www.dfo-mpo.gc.ca/fisheries-peches/sustainable-durable/fisheries-peches/char-omble-eng.html [Date accessed: May 3, 2024].

Fisheries and Oceans Canada (DFO). 2015a. Abundance estimates of narwhal stocks in the Canadian High Arctic in 2013. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2015/046. v + 36 p.

Fisheries and Oceans Canada (DFO). 2015b. Coral & sponge conservation strategy for Eastern Canada. 72 p.

Fisheries and Oceans Canada (DFO). 2015c. Updated abundance estimates and harvest advice for the Eastern Canada-West Greenland bowhead whale population. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2015/052. 11 p.

Fisheries and Oceans Canada (DFO). 2016. Porcupine crab. Available at: https://www.dfo-mpo.gc.ca/species-especes/profiles-profils/porcupine-crab-araignee-mer-eng.html [Date accessed: December 14, 2023].

Fisheries and Oceans Canada (DFO). 2018a. Atlantic walrus in the Nunavut Settlement Area. Integrated fisheries management plan. Available at: https://www.dfo-mpo.gc.ca/fisheries-peches/ifmp-gmp/walrus-atl-morse/walrus-nunavut-morse-eng.html#toc6 [Date accessed: December 14, 2023].

Fisheries and Oceans Canada (DFO). 2018b. Northern shrimp and striped shrimp – Shrimp fishing areas 0, 1, 4-7, the Eastern and Western Assessment Zones and North Atlantic Fisheries Organization (NAFO) Division 3M. 23 p. Available at: https://www.dfo-mpo.gc.ca/fisheries-peches/ifmp-gmp/shrimp-crevette/shrimp-crevette-2018-002-eng.html [Date accessed: December 14, 2023].

Fisheries and Oceans Canada (DFO). 2019a. Mitigation Buffer Zones for Atlantic Walrus *(Odobenus rosmarus rosmarus)* in the Nunavut Settlement Area. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep.: 2018/055. 27 p.

Fisheries and Oceans Canada (DFO). 2019b. Greenland halibut – northwest Atlantic fisheries organization subarea 0. 74 p. Available at: https://www.dfo-mpo.gc.ca/fisheries-peches/ifmp-gmp/groundfish-poisson-fond/2019/halibut-fletan-eng.htm

Fisheries and Oceans Canada (DFO). 2019c. Integrated fisheries management plan for narwhal in the Nunavut Settlement Area. Available at: https://www.dfo-mpo.gc.ca/fisheries-peches/ifmp-gmp/narwhal-narval/index-eng.html [Date accessed: December 15, 2023].

Fisheries and Oceans Canada (DFO). 2019d. Northern Shrimp Shrimp Fishing Areas (SFAs) 0-7 and the Flemish Cap. 80 p. Available at: https://www.dfo-mpo.gc.ca/fisheries-peches/ifmp-gmp/shrimp-crevette/shrimp-crevette-2007-eng.html

Fisheries and Oceans Canada (DFO). 2019e. Scallop – Newfoundland and Labrador Region. Fisheries and Oceans Canada. Available at: https://www.dfo-mpo.gc.ca/fisheries-peches/ifmp-gmp/scallop-petoncle/2019/index-eng.html#toc2 [Date accessed: December 15, 2023].

Fisheries and Oceans Canada (DFO). 2020a. Supplement to the biophysical and ecological overview for Southampton Island (SI) EBSA to include additional areas within the Southampton Island area of interest (AOI). DFO Can. Sci. Advis. Sec. Sci. Resp. 2020/055. 53 p.

Fisheries and Oceans Canada (DFO). 2020b. Identification of ecological significance, potential conservation objectives, knowledge gaps and vulnerabilities for the Southampton Island ecologically and biologically significant area. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep.: 2020/057. 14 p.

Fisheries and Oceans Canada (DFO). 2020c. Assessment of Scotian Shelf snow crab. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2020/042. 28 p.

Fisheries and Oceans Canada (DFO). 2021a. Assessment of 2J3KL capelin in 2019. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2021/045. 19 p.

Fisheries and Oceans Canada (DFO). 2021b. Snow crab – Estuary and Northern Gulf of St. Lawrence inshore areas (12a, 12b, 12c, 13, 14, 15, 16, 16a and 17). Available at: https://www.dfo-mpo.gc.ca/fisheries-peches/ifmp-gmp/snow-crab-neige/2021/index-eng.html#toc4 [Date accessed: December 14, 2023].

Fisheries and Oceans Canada (DFO). 2022. An assessment to support decisions on authorizing scientific surveys with bottom-contacting gears in protected areas in the newfoundland and Labrador bioregion. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2022/045. 24 p.

Fisheries and Oceans Canada (DFO). 2023a. Record of Discussion: Local expert review of the Southampton Island Area of Interest (AOI) ecological risk assessment. Marine Planning and Conservation, Outreach and Engagement. Internal document.

Fisheries and Oceans Canada (DFO). 2023b. Conservation harvesting plan (CHP) for NAFO division 0A Greenland halibut fishery January 1 – December 31, 2023. Available at: https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/363822.pdf [Date accessed: October 13, 2023].

Fisheries and Oceans Canada (DFO). 2024. Science Advice on the Ecological Risk Assessment for the Southampton Island Area of Interest (AOI). DFO Can. Sci. Advis. Sec. Sci. Resp. 2024/019.

Fliessbach, K.L., Borkenhagen, K., Guse, N., Markones, N., Schwemmer, P. and Garthe, S. 2019. A Ship traffic disturbance vulnerability index for northwest European seabirds as a tool for marine spatial planning. Front. Mar. Sci. 6: 192. https://doi.org/10.3389/fmars.2019.00192

Florko, K.R., Derocher, A.E., Breiter, C.J., Ghazal, M., Hedman, D., Higdon, J.W., Richardson, E.S., Sahanatien, V., Trim, V., and Petersen, S.D. 2020. Polar bear denning, distribution in the Canadian Arctic. Polar Biol. 43: 617-621.

Fortune, S.M., Ferguson, S.H., Trites, A.W., LeBlanc, B., LeMay, V., Hudson, J.M., and Baumgartner, M.F. 2020. Seasonal diving and foraging behaviour of Eastern Canada-West Greenland bowhead whales. Mar. Ecol. Prog. Ser. 643: 197-217.

Fraker, M.A. 1977a. The 1976 white whale monitoring program, Mackenzie Estuary, N.W.T. Rep. from F.F. Slaney & Co. Ltd., Vancouver, B.C., for Imperial Oil Ltd., Calgary, AB. 76 p.

Fraker, M.A. 1977b. The 1977 white whale monitoring program, Mackenzie Estuary, N.W. T. Rep. from F.F. Slaney & Co. Ltd., Vancouver, B.C., for Imperial Oil Ltd., Calgary, AB.

Fraker, M.A. 1978. The 1978 whale monitoring program/Mackenzie Estuary, N.W.T. Rep. from F.F. Slaney & Co. Ltd., Vancouver, B.C., for Esso Resources Canada Ltd., Calgary, AB. 28 p.

Fraker, M.A. 1980. Status and harvest of the Mackenzie stock of white whales *(Delphinapterus leucas)*. Rep. Int. Whal. Comm. 30: 451-458.

Fraker, M.A. and Fraker, P.N. 1979. The 1979 whale monitoring program, Mackenzie Estuary. Prepared for Esso Resources Canada Ltd., Edmonton, Alberta, by LGL Ltd., Sidney, BC.

Frasier, K.E., Solsona-Berga, A., Stokes, L., and Hildebrand, J.A. 2020. Impacts of the Deepwater Horizon oil spill on marine mammals and sea turtles. *In* Deep Oil Spills. *Edited by* Murawski, S.A., Ainsworth, C.H., Gilbert, S., Hollander, D.J., Paris, C.B., Schlüter, M., and Wetzel, D.L. Springer, Cham, Switzerland. pp. 431-462. 10.1007/978-3-030-11605-7_26

Freyhof, J. and Kottelat, M. 2008. *Salvelinus alpinus.* The IUCN Red List of Threatened Species 2008: e.T19877A9102572. https://dx.doi.org/10.2305/IUCN.UK.2008.RLTS.T19877A9102572.en

Fritt-Rasmussen, J., Wegeberg, S., Gustavson, K., Sørheim, K.R., Daling, P.S., Jørgensen, K., Tonteri, O., and Holst-Andersen, J.P. 2018. Heavy fuel oil (HFO) – A review of fate and behaviour of HFO spills in cold seawater, including biodegradation, environmental effects and oil spill response. TemaNord 2018: 549. 79 p. + appendices.

Frost, K.J., Lowry, L.F., and Nelson, R.R. 1984. Belukha whale studies in Bristol Bay, Alaska. *In* Proc. Workshop on biological interactions among marine mammals and commercial fisheries in the southeastern Bering Sea, Oct. 1983, Anchorage, AK. *Edited by* Melteff, B.R. and Rosenberg, D.H. Univ. Alaska Sea Grant Rep. 84-1. Univ. Alaska, Fairbanks, AK. pp. 187-200.

Fuller, S., Picco, C., Ford, J., Tsao, C.-F., Morgan, L. Hangaard, D., and Chuenpagdee, R. 2008. How we fish matters: Addressing the ecological impacts of Canadian fishing gear. Ecology Action Centre. Living Oceans Society, and Marine Conservation Biology Institute. Delta, BC, Canada.

Funk, D.W., Reiser, C.M., Ireland, D.S., Rodrigues, R., and Koski, W.R. (eds.). 2013. Joint Monitoring Program in the Chukchi and Beaufort seas, 2006-2010. LGL Alaska Final Report P1213-2, Report from LGL Alaska Research Associates Inc., LGL Ltd., Greeneridge Sciences Inc., and JASCO Research Ltd., for Shell Offshore Inc. and Other Industry Contributors, and National Marine Fisheries Service, U.S. Fish and Wildlife Service. 592 p. + appendices.

Furgal, C. and Laing, R. 2012. A synthesis and critical review of the traditional ecological knowledge literature on narwhal *(Monodon monoceros)* in the eastern Canadian Arctic. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/131. iv + 47 p.

Gabel, F., Lorenz, S., and Stoll, S. 2017. Effects of ship-induced waves on aquatic ecosystems. Sci. Total Environ. 601-602: 926-939. http://dx.doi.org/10.1016/j.scitotenv.2017.05.206

Galicia, M.P., Thiemann, G.W., Dyck, M.G., Ferguson, S.H., and Higdon, J.W. 2016. Dietary habits of polar bears in Foxe Basin, Canada: possible evidence of a trophic regime shift mediated by a new top predator. Ecol. Evol. 6(16): 6005-6018.

Gallagher, C.P. and Dick, T.A. 2010. Historical and current population characteristics and subsistence harvest of Arctic char from the Sylvia Grinnell River, Nunavut, Canada. N. Americ. J. Fish. Manage. 30: 126-141.

Garde, E. and Heide-Jørgensen, M.P. 2022. Tusk anomalies in narwhals *(Monodon monoceros)* from Greenland. Pol. Res. 41: 3843. 10.33265/polar.v41.8343

Garde, E., Hansen, S.H., Ditlevsen, S., Tvermosegaard, K.B., Hansen, J., Harding, K.C., and Heide-Jørgensen, M.P. 2015. Life history parameters of narwhals *(Monodon monoceros)* from Greenland. J. Mammal. 96: 866-879. 10.1093/jmammal/gyv110

Garde, E., Jung-Madsen, S., Ditlevsen, S., Hansen, R.G., Zinglersen, K.B. and Heide-Jørgensen, M.P. 2018. Diving behavior of the Atlantic walrus in high Arctic Greenland and Canada. J. Exper. Mar. Biol. Ecol. 500: 89-99.

Garlich-Miller, J.L. and Stewart, R.E. 1999. Female reproductive patterns and fetal growth of Atlantic walruses *(Odobenus rosmarus rosmarus)* in Foxe Basin, Northwest Territories, Canada. Mar. Mamm. Sci. 15: 179-191.

Garneau, M.-E., Michel, C., Meisterhans, G., Fortin, N., King, T.L., Greer, C.W., and Lee, K. 2016. Hydrocarbon biodegradation by Arctic sea-ice and sub-ice microbial communities during microcosm experiments, Northwest Passage (Nunavut, Canada). FEMS Microbiol. Ecol. 92(10): fiw130. https://doi.org/10.1093/femsec/fiw130

Garthe, S. and Hüppop, O. 2004. Scaling possible adverse effects of marine wind farms on seabirds: developing and applying a vulnerability index. J. Appl. Ecol. 41(4): 724-734.

Gass S.E. and Willison, J.M. 2005. An assessment of the distribution of deep sea corals in Atlantic Canada by using both scientific and local forms of knowledge. *In* Cold-water corals and ecosystems. *Edited by* Freiwald A. and Roberts, J.M. Springer-Verlag, Berlin, Germany. pp. 223-245.

Gaston, A.J. 2002. Studies of high-latitude seabirds. 5. Monitoring Thick-billed Murres in the eastern Canadian Arctic, 1976-2000. CWS Occ. Pap. No. 106, Ottawa, ON. Available at: https://publications.gc.ca/collections/collection_2011/ec/CW69-1-106-eng.pdf

Gaston, A.J. and Elliott, K.H. 2014. Seabird diet changes in northern Hudson Bay, 1981-2013, reflect the availability of schooling prey. Mar. Ecol. Prog. Ser. 513: 211-223.

Gaston, A.J. and Hipfner, J.M. 2020. Thick-billed Murre *(Uria lomvia)*. *In* Birds of the World. *Edited by* Billerman, S.M. Cornell Lab of Ornithology, Ithaca, NY, USA. https://doi.org/10.2173/bow.thbmur.01

Gaston A.J., Decker, R., Cooch, F.G., and Reed, A. 1986. The distribution of larger species of birds breeding on the coasts of Foxe Basin and northern Hudson Bay, Canada. Arctic. 39(4): 285-296.

Gaston, A.J., de Forest, L.N., Donaldson, G., and Noble, D.G. 1994. Population parameters of Thick-billed Murres at Coats Island, Northwest Territories, Canada. Condor. 96: 935-948. Available at: https://sora.unm.edu/sites/default/files/journals/condor/v096n04/p0935-p0948.pdf

Gaston, A.J., Mallory, M.L., and Gilchrist, H.G. 2012. Populations and trends of Canadian Arctic seabirds. Polar Biol. 35: 1221-1232. 10.1007/s00300-012-1168-5

Gavaris, S., Clark, K.J., Hanke, A.R., Purchase, C.F., and Gale, J. 2010. Overview of discards from Canadian commercial fisheries in NAFO Divisions 4V, 4W, 4X, 5Y and 5Z for 2002-2006. Can. Tech. Rep. Fish. Aquat. Sci. 2873: vi + 112 p.

GENIVAR. 2013. Évaluation environnementale stratégique sur la mise en valeur des hydrocarbures dans les bassins d'Anticosti, de Madeleine et de la baie des Chaleurs (ESS2). Présentée au Ministère des Ressources naturelles par GENIVAR Inc. Available at: https://mern.gouv.qc.ca/documents/energie/EES2_Rapport_final.pdf

Geoffroy, M., Robert, D., Darnis, G., and Fortier, L. 2011. The aggregation of polar cod *(Boreogadus saida)* in the deep Atlantic layer of ice-covered Amundsen Gulf (Beaufort Sea) in winter. Polar Biol. 34(12): 1959-1971. 10.1007/s00300-011-1019-9

Geoffroy, M., Majewski, A., LeBlanc, M., Gauthier, S., Walkusz, W., Reist, J.D., and Fortier, L. 2016. Vertical segregation of age-0 and age-1+ polar cod *(Boreogadus saida)* over the annual cycle in the Canadian Beaufort Sea. Pol. Biol. 39(6): 1023-1037. 10.1007/s00300-015-1811-z

Geoffroy, M., Lagbehn, T., Priou, P., Varpe, Ø., Johnsen, G., Le Bris, A., Fisher, J.A., Daase, M., McKee, D., Cohen, J., and Berge, J. 2021. Pelagic organisms avoid white, blue, and red artificial light from scientific instruments. Sci. Rep. 11: 14941. https://doi.org/10.1038/s41598-021-94355-6

George, J.C., Clark, C., Carroll, G.M., and Ellison, W.T. 1989. Observations on the ice-breaking and ice navigation behaviour of migrating bowhead whales *(Balaena mysticetus)* near Point Barrow, Alaska, Spring, 1985. Arctic. 42(1): 24-30.

George, J.C., Philo, L.M., Hazard, K., Withrow, D., Carroll, G.M., and Suydam, R. 1994. Frequency of killer whale *(Orcinus orca)* attacks and ship collisions based on scarring on bowhead whales *(Balaena mysticetus)* of the Bering-Chukchi-Beaufort seas stock. Arctic. 47(3): 247-255.

George, J.C., Bada, J., Zeh, J., Scott, L., Brown, S.R., O'Hara, T., and Suydam, R. 1999. Age and growth estimates of bowhead whales *(Balaena mysticetus)* via aspartic acid racemization. Can. J. Zool. 77: 571-580.

Geraci, J.R. 1990. Cetaceans and oil: Physiologic and toxic effects. *In* Sea Mammals and Oil: Confronting the Risks. *Edited by* Geraci, J.R. and St. Aubin, D.J. Academic Press, San Diego, CA. pp. 167-197.

Geraci, J.R. and Smith, T.G. 1976. Direct and indirect effects of oil on ringed seals *(Phoca hispida)* of the Beaufort Sea. J. Fish. Res. 33: 1976-1984.

Geraci, J.R. and St. Aubin, D.J. 1980. Offshore petroleum resource development and marine mammals: A review and research recommendations. Mar. Fish. Rev. 42: 1-12.

Geraci, J.R. and St. Aubin, D.J. 1982. Study of the Effects of Oil on Cetaceans. Report from University of Guelph for US Bureau of Land Management, Washington, DC. NTIS PB83-152991. 274 pp.

Geraci, J.R. and St. Aubin, D.J. 1990. Sea Mammals and Oil: Confronting the Risks. Academic Press, New York, NY.

GESAMP (Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection). 2007. Estimates of oil entering the marine environment from sea-based activities. Rep. Stud. GESAMP. No. 75. 96 p.

Giglio, V.J., Ternes, M.L., Mendes, T.C., Cordeiro, C.A., and Ferreira, C.E. 2017. Anchoring damages to benthic organisms in a subtropical scuba dive hotspot. J. Coast. Conserv. 21: 311-316. https://doi.org/10.1007/s11852-017-0507-7

Gilbert, M.J., Donadt, C.R., Swanson, H.K., and Tierney, K.B. 2016. Low annual fidelity and early upstream migration of anadromous Arctic char in a variable environment. Trans. Am. Fish. Soc. 145(5): 931-942. https://doi.org/10.1080/00028487.2016.1173095

Girard, F. and Fisher, C.R. 2018. Long-term impact of the Deepwater Horizon oil spill on deep-sea corals detected after seven years of monitoring. Biol. Conserv. 225: 117-127. https://doi.org/10.1016/j.biocon.2018.06.028

Girard, F., Shea, K., and Fisher, C.R. 2018. Projecting the recovery of a long-lived deep-sea coral species after the Deepwater Horizon oil spill using state-structured models. J. App. Ecol. 55: 1812-1822. https://doi.org/10.1111/1365-2664.13141

Girard, R., Cruz, R., Glickman, O., Harpster, T., and Fisher, C.R. 2019. In situ growth of deep-sea octocorals after the Deepwater Horizon oil spill. Elem. Sci. Anth. 7(1): 12. https://doi.org/10.1525/elementa.349

Givens, G.H., Mocklin, J.A., Vate Brattstrom, L., Tudor, B.J., Koski, W.R., Zeh, J.E., Suydam, R., and George, J.C. 2018. Adult Survival Rate and 2011 Abundance of Bering-Chukchi-Beaufort Seas Bowhead Whales from Photo-identification Data Over Three Decades. Paper SC/67B/AWMP/01 presented to the Int. Whal. Comm. Sci. Committee, Bled, Slovenia, 21 April - 6 May, 2018. 24 p. Available at: https://www.north-slope.org/wp-content/uploads/2022/03/PhotoID-v2_2011_abundance.pdf

Gjertz, I., Kovacs, K.M., Lydersen, C., and Wiig, O. 2000. Movements and diving of bearded seal *(Erignathus barbatus)* mothers and pups during lactation and post-weaning. Polar Biol. 23: 559-566.

Glaeser, J.L. and Vance, G. 1971. A study of the behaviour of oil spills in the Arctic. Report number 714/08/A/001,002, United States Coast Guard, Washington, DC. 53 p.

Glasby, T.M. and West, G. 2018. Dragging the chain, quantifying continued losses of seagrasses from boat moorings. Aquat. Conserv. 28: 383-394. https://doi.org/10.1002/aqc.2872

Glass, A.H., Cole, T.V., Garron, M., Merrick, R.L., and Pace III, R.M. 2008. Mortality and serious injury determinations for baleen whale stocks along the United States eastern seaboard and adjacent Canadian maritimes, 2002-2006. U.S. Department of Commerce, Northeast Fisheries Science Center Reference Document 08-04. 18 p.

Goertz, C.E., Polasek, L., Burek, K., Suydam, R., and Sformo, T. 2017. Demography and pathology of a pacific walrus *(Odobenus rosmarus divergens)* mass-mortality event at Icy Cape, Alaska, September 2009. Polar Biol 40: 989-996. https://doi.org/10.1007/s00300-016-2023-x

Golder. 2021. Mary River Project: 2020 Marine Mammal Aerial Survey. Rep. by Golder Associates Ltd., Vancouver, BC to Baffinland Iron Mines Corporation, Oakville, ON. Rep. no. 1663724-270-R-Rev1-39000. 79 p. + appendices.

Goldsmit, J., McKindsey, C.W., Archambault, P., and Howland, K.L. 2019. Ecological risk assessment of predicted invasions in the Canadian Arctic. PLoS ONE. 14(2): e0211815. https://doi.org/10.1371/journal.pone.0211815

Goldsmit, J., McKindsey, C.W., Schlegel, R.W., Stewart, D.B., Archambault, P., and Howland, K.L. 2020. What and where? Predicting invasion hotspots in the Arctic marine realm. Glob. Change Biol. 26: 4752-4771. https://doi.org/10.1111/gcb.15159

Goldsmit, J., McKindsey, C.W., Stewart, D.B., and Howland, K.L. 2021a. Screening for high-risk marine invaders in the Hudson Bay Region, Canadian Arctic. Front. Ecol. Evol. 9: 627497. https://doi.org/10.3389/fevo.2021.627497

Goldsmit, J., Schlegel, F.W., Filbee-Dexter, K., MacGregor, K.A., Johnson, L.E., Mundy, C.J., Savoie, A.M., McKindsey, C.W., Howland, K.L., and Archambault, P. 2021b. Kelp in the Eastern Canadian Arctic: current and future predictions of habitat suitability and cover. Front. Mar. Sci. 18: 742209.

Gomes, A., Christensen, J.H, Gründger, F., Kjeldsen, K.U., Rysgaard, S., and Vergeynst, L. 2022. Biodegradation of water accommodated aromatic oil compounds in the Arctic seawater at 0º. Chemosphere. 286: 131751. https://doi.org/10.1016/j.chemosphere.2021.131751

Goudie, R.I., Robertson, G.J., and Reed, A. 2000. Common Eider *(Somateria mollissima).* Version 2.0. *In* The birds of North America. *Edited by* Poole, A.F. and Gill, F.B. Cornell Lab of Ornithology, Ithaca, NY, USA.

Goudie, R.I., Robertson, G.J., and Reed, A. 2020. Common Eider *(Somateria mollissima). In* Birds of the World. *Edited by* Billerman, S.M. Cornell Lab of Ornithology, Ithaca, NY, USA. https://doi.org/10.2173/bow.comeid.01

GoC (Government of Canada). 2015. Discharges to water. Available at: https://tc.canada.ca/en/marine-transportation/arctic-shipping/discharges-water [Date accessed: December 13, 2023].

GoC (Government of Canada). 2021a. Government of Canada supports Nunavut's fishing and sealing industries. Available at: https://www.canada.ca/en/northern-economic-development/news/2021/03/government-of-canada-supports-nunavuts-fishing-and-sealing-industries.html [Date accessed: October 25, 2023].

GoC (Government of Canada). 2021b. Bearded Seal *(Erignathus barbatus)*. Species at risk public registry. Available at: https://species-registry.canada.ca/index-en.html#/species/344-0#cosewic_assessment [Date accessed: October 25, 2023].

GoC (Government of Canada). 2023. Chesterfield Inlet – 05140. Government of Canada. Available at: https://www.tides.gc.ca/en/stations/05140/2023-02-08?tz=CST&unit=m [Date accessed: December 13, 2023].

GN (Government of Nunavut). 2010. Nunavut Coastal Resource Inventory: Chesterfield Inlet. Nunavut Department of Environment, Fisheries and Sealing Division, Iqaluit, NU. 167p.

GN (Government of Nunavut). 2011. Nunavut coastal resources inventory – Naujaat. Nunavut Department of Environment, Fisheries and Sealing Division, Iqaluit, NU. 96 p.

GN (Government of Nunavut). 2012. Nunavut Coastal Resource Inventory: Coral Harbour. Nunavut Department of Environment, Fisheries and Sealing Division, Iqaluit, NU. 152 p.

GN (Government of Nunavut). 2021. Sport fishing guide, Nunavut, April 1, 2021 to March 31, 2022. Available at: https://www.gov.nu.ca/sites/default/files/publications/2022-01/sport_fishing_guide_2021-2022_eng.pdf [Date accessed: May 3, 2024].

GNL (Government of Newfoundland and Labrador). N.d. Red Atlantic King Crab *(Neolithodes grimaldii)*. Department of Fisheries and Aquaculture. Available at: https://www.gov.nl.ca/ffa/files/research-development-fdp-pdf-atlantic-red-king-crab.pdf [Date accessed: July 7, 2023].

Grainger, E.H. 1959. The annual oceanographic cycle at Igloolik in the Canadian Arctic: The zooplankton and physical and chemical observations. J. Fish. Res. 16(4): 453-501

Granskog, M.A., Rösel, A., Dodd, P.A., Divine, D.V., Gerland, S., Martma, T., and Leng, M.J. 2017. Snow contribution to first-year and second-year Arctic Sea ice mass balance north of Svalbard. J. Geophys. Res.: Oceans. 122: 2539-2549. http://dx.doi.org/10.1002/2016JC012398

Grant, N., Matveev, E., Kahn, A., Archer, S., Dunham, A., Bannister, R., Eerkes-Medrano, D., and Leys, S. 2019. Effects of suspended sediments on the pumping rates of three species of glass sponge in situ. Mar. Ecol. Prog. Ser. 615: 79-100. https://doi.org/10.3354/meps12939

Greer, R.D., Day, R.H., and Bergman, R.S. 2010. Literature review, synthesis, and design of monitoring of ambient artificial light intensity in the outer continental shelf in regard to potential effects on resident marine fauna. U.D.o.t.I.M.M. Service, Anchorage, AK. 96 p. Available at: https://espis.boem.gov/final%20reports/5398.pdf

Groner, M.L., Burge, C.A., Kim, C.J., Rees, E., Van Alstyne, K.L., Yang, S., Wyllie-Echeverria, S., and Harvell, C.D. 2016. Plant characteristics associated with widespread variation in eelgrass wasting disease. Dis. Aquat. Organ. 118(2): 159-168.

Gulka, J., Carvalho, P.C., Jenkins, E., Johnson, K., Maynard, L., and Davoren, G.K. 2017. Dietary niche shifts of multiple marine predators under varying prey availability on the northeast Newfoundland coast. Front. Mar. Sci. 4: 324. https://doi.org/10.3389/fmars.2017.00324

Gunn, G. 2014. Polynya formation in Hudson Bay during the winter period. M.Sc. Thesis, University of Manitoba.

Gunnarsdóttir, R., Jenssen, P.D., Jensen, P.E., Villumsen, A., and Kallenborn, K. 2013. A review of wastewater handling in the Arctic with special reference to pharmaceuticals and personal care products (PPCPs) and microbial pollution. Ecol. Eng. 50: 76-85. http://dx.doi.org/10.1016/j.ecoleng.2012.04.025

Gupta, K., Mukhopadhyay, A., Babb, D., Barber, D., and Ehn, J.K. 2022. Landfast sea ice in Hudson Bay and James Bay: Annual cycle, variability and trends, 2000–2019. Elem. Sci. Anth. 10(1): 00073.

Haggarty, D., McCorquodale, B., Johannessen, D., Levings, C., and Ross, P. 2003. Marine environmental quality in the central coast of British Columbia, Canada: A review of contaminant sources, types and risks. Can. Tech. Rep. Fish. Aquat. Sci. 2507: x + 153 p.

Halliday, W.D., Pine, M.K., and Insley, S.J. 2020. Underwater noise and Arctic marine mammals: Review and policy recommendations. Environ. Rev. 28: 438-448. https:// doi.org/10.1139/er-2019-0033

Halliday, W.D., Dawson, J., Yurkowski, D.Y., Doniol-Valcroze, T., Ferguson, S.H., Gjerdrum, C., Hussey, C.H., Kochanowicz, Z., Mallory, M.L., Marcoux, M., Watt, C.A., and Wong, S.N. 2022. Vessel risks to marine wildlife in the Tallurutiup Imanga National Marine Conservation Area and the eastern entrance to the Northwest Passage. Environ. Sci. Policy. 127: 181-195. doi.org/10.1016/j.envsci.2021.10.026

Hammerschlag, N., Meyer, C., Grace, M., Kessel, S., Sutton, T., Harvey, E., Paris-Limouzy, C., Kerstetter, D., and Cooke, S. 2017. Shining a light on fish at night: an overview of fish and fisheries in the dark of night, and in deep and polar seas. Bull. Mar. Sci. 93(2): 253-284. https://doi.org/10.5343/bms.2016.1082

Hammerstrom, K.K., Kenworthy, W.J., Whitfield, P.E., and Merello, M.F. 2007. Response and recovery dynamics of seagrasses *Thalassia testudinum* and *Syringodium filiforme* and macroalgae in experimental motor vessel disturbances. Mar. Ecol. Prog. Ser. 345: 83-92. https://doi.org/10.3354/meps07004

Hammill, M.O., Stenson, G.B., Mosnier, A., and Doniol-Valcroze, T. 2014. Abundance Estimates of Northwest Atlantic Harp seals and management advice for 2014. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/022. v + 33 p.

Hammill, M.O., Monsier, A., Gosselin, J.F., Higdon, J.W., Stewart, D.B., Doniol-Valcroze, T., Ferguson, S.H., and Dunn, J.B. 2016a. Estimating abundance and total allowable removals for walrus in the Hudson Bay-Davis Strait and south and east Hudson Bay stocks during September 2014. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/036. v + 37p.

Hammill, M.O., Doniol-Valcroze, T., Mosnier, A., and Gosselin, J.F. 2016b. Modelling walrus population dynamics: A direction for future assessments. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/050. v + 47 p.

Hannah, L., Thornborough, K., Murray, C.C., Nelson, J., Locke, A., Mortimor, J., and Lawson, J. 2020. Pathways of effects conceptual models for marine commercial shipping in Canada: Biological and ecological effects. Can Sci. Advis. Sec. Res. Doc. 2020/077. viii + 193 p.

Harding, H., Bruintjes, R., Radford, A.N., and Simpson, S.D. 2016. Measurement of hearing in the Atlantic salmon (Salmo salar) using Auditory Evoked Potentials, and effects of pile driving playback on salmon behaviour and physiology. Scott. Mar. Freshwater Sci. 7(11). 10.7489/1701-1

Harrington, F.H. and Veitch, A.M. 1991. Short-term impacts of low-level jet-fighter training on caribou in Labrador. Arctic. 44(4): 318-327. https:jstor.org/stable/40511288

Harris, R.E., Miller, G.W., Elliott, R.E., and Richardson, W.J. 1997. Seals. *In* Northstar marine mammal monitoring program, 1996: marine mammal and acoustical monitoring of a seismic program in the Alaskan Beaufort Sea. *Edited by* Richardson, W.J. pp. 41-442. LGL Rep. TA2121-2. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 245 p.

Harris, R.E., Balla-Holden, A.N., MacLean, S.A., and Richardson, W.J. 1998. Seals. *In* Marine mammal and acoustical monitoring of BP Exploration (Alaska)'s open-water seismic program in the Alaskan Beaufort Sea, 1997. *Edited by* Richardson, W.J. pp. 41-454. LGL Rep. TA2150-3. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and U.S. Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 318 p.

Harris, R.E., Miller, G.W., and Richardson, W.J. 2001. Seal responses to airgun sounds during summer seismic surveys in the Alaskan Beaufort Sea. Mar. Mamm. Sci. 17(4): 795-812.

Harris, R.E., Elliott, T., and Davis, R.A. 2007. Results of mitigation and monitoring program, Beaufort Span 2-D marine seismic program, open-water season 2006. LGL Rep. TA4319-1. Rep. from LGL Ltd., King City, Ont., for GX Technol. Corp., Houston, TX. 48 p.

Harris, R.E., Lewin, A., Abgrall, P., Fitzgerald, M., and Hauser, D. 2009. Marine mammal mitigation and monitoring for GX Technology's Canadian Beaufort Span 2-D marine seismic program, open-water season 2008. LGL Report TA4460-2A. Draft final report prepared for GX Technology Inc., Houston, Texas by LGL Limited, King City, ON. 116 p.

Harris, L.N., Yurkowski, D.J., Malley, B.K., Jones, S.F., Else, G.T., Tallman, R.F., Fisk, A.T., and Moore, J.-S. 2022. Acoustic telemetry reveals the complex nature of mixed-stock fishing in Canada's largest Arctic char commercial fishery. N. Americ. J. Fish. Manage. 42: 1250-1268. 10.1002/nafm.10816

Harwood, L.A., Norton, P., Day, B., and Hall, P.A. 2002. The harvest of beluga whales in Canada's Western Arctic: Hunter-based monitoring of the size and composition of the catch. Arctic. 10-20.

Harwood, L.A., McLaughlin, F., Allen, R.M., Lillasiak, J. Jr., and Alikamik, J. 2005. First-ever marine mammal and bird observations in the deep Canada Basin and Beaufort/Chukchi seas: expeditions during 2002. Polar Biol. 28: 250-253.

Harwood, L.A., Sandstrom, S.J., Papst, M.H., and Melling, H. 2013. Kuujjua River Arctic char: monitoring stock trends using catches from an under-ice subsistence fishery, Victoria Island, Northwest Territories, Canada, 1991-2009. Arctic. 66(3): 291-300.

Hawkins, A.D. and Johnstone, A.D. 1978. The hearing of the Atlantic Salmon, Salmo salar. J. Fish. Biol. 13: 655-673.

Hawkins, A.D. and Popper, A.N. 2017. A sound approach to assessing the impact of underwater noise on marine fishes and invertebrates. ICES. J. Mar. Sci. 74(3): 635-651. https://doi.org/10.1093/icesjms/fsw205

Hawkins, A.D., Hazelwood, R.A., and Popper, A.N. 2021. Substrate vibrations and their potential effects upon fishes and invertebrates. J. Acoust. Soc. Am. 149(4): 2782-2790. https://doi.org/10.1121/10.0004773

He, P. 2005. Characteristics of bycatch of porcupine crabs, *Neolithodes grimaldii* (Milne-Edwards and Bouvier, 1894) from deepwater turbot gillnets in the northwest Atlantic. Fish. Res. 74(1-3): 35-43. Available at: https://www.sciencedirect.com/science/article/pii/S0165783605001232

Hedd, A., Regular, P.M., Wilhelm, S.I., Rail, J.-F., Drolet, B., Fowler, M., Pekarik, C., and Robertson, G.J. 2015. Characterization of seabird bycatch in eastern Canadian waters, 1998–2011, assessed from onboard fisheries observer data. Aquat. Conserv. 26: 530-548.

Heide-Jørgensen, M.P. 2018. Narwhal: *Monodon monoceros*. *In* Encyclopedia of Marine Mammals. *Edited by* Wursig, B., Thewissen, J.G., and Kovacs, K.M. Academic Press. pp. 627-631. https://doi.org/10.1016/B978-0-12-804327-1.00013-3

Heide-Jørgensen, M.P. and Dietz, R 1995. Some characteristics of narwhal, *Monodon monoceros*, diving behaviour in Baffin Bay. Can. Zool. 73: 2120-2132.

Heide-Jørgensen, M.P. and Garde, E. 2011. Fetal growth of narwhals *(Monodon monoceros)*. Mar. Mamm. Sci. 27(3): 659-664.

Heide-Jørgensen, M.P., Richard, P.R., and Rosing-Asvid, A. 1998. Dive patterns of belugas *(Delphinapterus leucas)* in waters near eastern Devon Island. Arctic. 51(1): 17-26.

Heide-Jørgensen, M.P., Richard, P., Ramsay, M., and Akeeagok, S. 2002. Three recent ice entrapments of Arctic cetaceans in West Greenland and the eastern Canadian High Arctic. NAMMCO Sci. Publ. 4: 143-148.

Heide-Jørgensen, M.P., Laidre, K.L., Jensen, M.V., Dueck, L., and Postma, L.D. 2006. Dissolving stock discreteness with satellite tracking: bowhead whales in Baffin Bay. Mar. Mamm. Sci. 22(1): 34-45.

Heide-Jørgensen, M.P., Laidre, K.L., Quakenbush, L.T., and Citta, J.J. 2011. The northwest passage opens for bowhead whales. Biol. Lett. 8(2): 270-273. doi:10.1098/rsbl.2011.0731

Heide-Jørgensen, M.P., Richard, P.R., Dietz, R., and Laidre, K.L. 2013a. A metapopulation model for Canadian and West Greenland narwhals. Anim. Conserv. 16(3): 331-343. doi:10.1111/acv.12000

Heide-Jørgensen, M.P., Hansen, R.G., Westdal, K., Reeves, R.R., and Mosbech, A. 2013b. Narwhals and seismic exploration: is seismic noise increasing the risk of ice entrapments? Biol. Conserv. 158(5931): 50-54. doi:10.1016/j.biocon.2012.08.005

Heide-Jørgensen, M.P., Nielsen, N.H., Hansen, R.G., Schmidt, H.C., Blackwell, S.B., and Jørgensen, O.A. 2015. The predictable narwhal: satellite tracking shows behavioural similarities between isolated subpopulations. J. Zool. 297(1): 54-65. https://doi.org/10.1111/jzo.12257

Heide-Jørgensen, M.P., Blackwell, S.B., Tervo, O.M., Samson, A.L., Garde, E., Hansen, R.G., Ngô, M.G., Conrad, A.S., Trinhammer, P., Schmidt, H.C., Sinding, M.-H.S., Williams, T.M., and Ditlevsen, S. 2021.

Behavioral response study on seismic airgun and vessel exposures in narwhals. Front. Mar. Sci. 8: 658173.

Helm, R.C., Coasta, D.P., DeBruyn, T.D., O'Shea, T.J., Wells, R.C., and Williams, T.M. 2015. Overview of effects of oil spills on marine mammals. *In* Handbook of Oil Spill Science and Technology. *Edited by* Fingas, M. John Wiley & Sons, Hoboken, NJ. pp. 455-475.

Henri, D. 2007. The Integration of Inuit Traditional Ecological Knowledge and Western Science in Wildlife Management in Nunavut, Canada: The Case of Avian Cholera Outbreaks among Common Eider Ducks in the West Hudson Strait and North James Bay Area. M.Sc. Thesis, Oxford University.

Henri, D.A., Jean-Gagnon, F., and Gilchrist, H.G. 2018. Using Inuit traditional ecological knowledge for detecting and monitoring avian cholera among Common Eiders in the eastern Canadian Arctic. Ecol. Soc. 23(1): 22. https://doi.org/10.5751/

Henry, L.-A. and Hart, M. 2005. Regeneration from injury and resource allocation in sponges and corals – a review. Internat. Rev. Hydrobiol. 90(2): 125-158.

Henry, L.-A., Kenchington, E.L., and Silvaggio, A. 2003. Effects of mechanical experimental disturbance on aspects of colony responses, reproduction, and regeneration in the cold-water octocoral *Gersemia rubiformis*. Can. J. Zool. 81: 1691-1701. https://doi.org/10.1139/Z03-161

Herbert, R.J., Crowe, T.P., Bray, S., and Sheader, M. 2009. Disturbance of intertidal soft sediment assemblages caused by swinging boat moorings. Hydrobiologia. 625(1): 105-116. https://doi.org/10.1007/s10750-008-9700-x

Hiddink, J.G., Moranta, J., Balestrini, S., Sciberras, M., Cendrier, M., Bowyer, R., Kaiser, M.J., Skold, M., Jonsson, P., Bastardie, F., and Hinz, H. 2016. Bottom trawling affects fish condition through changes in the ratio of prey availability to density of competitors. J. App. Ecol. 53: 1500-1510.

Hiddink, J.G., Jennings, S., Sciberras, M., Szostek, C.L., Hughes, K.M., Ellis, N., Rijnsdorp, A.D., McConnaughey, R.A., Mazor, T., Hilborn, R., Collie, J.S., Pitcher, C.R., Amoroso, R.O., Parma, A.M., Suuronen, P., and Kaiser, M.J. 2017. Global analysis of depletion and recovery of seabed biota after bottom trawling disturbance. Proc. Natl. Acad. Sci. U.S.A. 114(31): 8301-8306. https://doi.org/10.1073/pnas.1618858114

Hiddink, J.G., Jennings, S., Sciberras, M., Bolam, S.G., Cambiè, G., McConnaughey, G.A., Mazor, T., Hilborn, R., Collie, J.S., Pitcher, R., Parma, A.M., Suuronen, P., Kaiser, M.J., and Rijnsdorp, A.M. 2018. Assessing bottom-trawling impacts based on the longevity of benthic invertebrates. J. Appl. Ecol. 56(5): 1075-1084. https://doi.org/10.1111/1365-2664.13278

Higdon, J.W. 2017. Mapping critical whale habitat in the Nunavut Settlement Area. A report prepared for WWF-Canada, Iqaluit, NU. 41 p.

Higdon, J.W., Stewart, D.B., and Stewart, R.E.A. 2022. Atlantic walrus *(Odobenus rosmarus rosmarus)* in northern Hudson Bay – status, research needs, and monitoring opportunities. Prepared by Higdon Wildlife Consulting for Oceans North. Available at: https://www.oceansnorth.org/wp-content/uploads/2022/07/Atlantic-Walrus-in-Northern-Hudson-Bay-2.pdf

Hill, V.J., Light, B., Steele, M., and Zimmerman, R.C. 2018. Light availability and phytoplankton growth beneath Arctic sea ice: Integrating observations and modeling. J. Geophys. Res. 123: 3651-3667. https://doi.org/10.1029/2017JC013617

Hinchey, E.K., Schaffner, L.C., Hoar, C.C., Vogt, B.W., and Batte, L.P. 2006. Responses of estuarine benthic invertebrates to sediment burial: the importance of mobility and adaptation. Hydrobiologia. 556: 85-98.

Hobbs, R.C., Shelden, K.E., Rugh, D.J., Sims, C.L., and Waite, J.M. 2015. Estimated abundance and trend in aerial counts of beluga whales, *Delphinapterus leucas*, in cook inlet, Alaska, 1994-2012. Mar. Fish. Rev. 77: 11-31.

Hobday, A.J., Smith, A.D., Stobutzki, I.C., Bulman, C., Daley, R., Dambacher, J.M., Deng, R.A., Dowdney, J., Fuller, M., Furlani, D., and Griffiths, S.P. 2011. Ecological risk assessment for the effects of fishing. Fish. Res. 108(2-3): 372-384.

Holeton, C., Chambers, P.A., and Grace, L. 2011. Wastewater release and its impacts on Canadian waters. Can. J. Fish. Aquat. Sci. 68(10): 1836-1859.

Honda, M. and Suzuki, N. 2020. Toxicities of polycyclic aromatic hydrocarbons for aquatic animals. Int. J. Environ. Res. Public Health 17(4): 1363. https://doi.org/10.3390/ijerph7041363

Hop, H., Welch, H.E., and Crawford, R.E. 1997. Population structure and feeding ecology and feeding ecology of Arctic Cod schools in the Canadian High Arctic. Amer. Fish. Soc. Symp. 19: 68-80.

Hopper, T. 2013. 'We have no choice but to kill them all': Beluga whales trapped by Nunavut ice providing feast for polar bears and people. National Post, February 19, 2013. Available at: https://nationalpost.com/news/canada/we-have-no-choice-but-to-kill-them-all-beluga-whales-trapped-by-nunavut-ice-providing-feast-for-polar-bears-and-people [Date accessed: December 13, 2023].

Hsiao, S.I. 1978. Effects of crude oils on the growth of Arctic marine phytoplankton. Environ. Pollut. 17: 93-107. https://doi.org/10.1016/0013-9327(78)90043-5

Hsing, P.-Y., Fu, B., Larcom, E.A., Berlet, S.P., Shank, T.M., Govindarajan, A.F., Lukasiewicz, A.J., Dixon, P.M., and Fisher, C.R. 2013. Evidence of lasting impact of the Deepwater Horizon oil spill on a deep Gulf of Mexico coral community. Elem. Sci. Anth. 1: 000012. https://doi.org/10.12952/journal.elementa.000012

Hubley, P.B., Zisserson, B., Cameron, B., and Choi, J. 2018. Assessment of Scotian Shelf Snow Crab in 2016. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/053. vii + 136 p.

Huddart, D. and Stott, T. 2020. Adventure Tourism in the Canadian Arctic. *In* Adventure Tourism: Environmental Impacts and Management. *Edited by* Stott, T. Palgrave Macmillan, Cham Switzerland. pp. 141-181. https://doi.org/10.1007/978-3-030-18623-4_6

Hughes, L. 2017. Background information for community oil spill response planning in Pond inlet, Resolute, Grise Fiord, and Arctic Bay. Report to WWF Canada. Available at: http://awsassets.wwf.ca/downloads/170405___oilspillresponseframeworknunavut_web.pdf

Huntington, H.P., Daniel, R., Hartsig, A., Harun, K., Heiman, M., Meehan, R., Noongwook, G., Pearson, L., Prior-Parks, M., Robards, M., and Stetson, G. 2015. Vessels, risks, and rules: Planning for safe shipping in Bering Strait. Mar. Policy. 51: 119-127. https://doi.org/10.1016/j.marpol.2014.07.027

Huserbråten, M.B., Eriksen, E., Gjøsæter, H., and Vikebø, F. 2019. Polar cod in jeopardy under the retreating Arctic sea ice. Commun. Biol. 2: 407. https://doi.org/10.1038/s42003-019-0649-2

Hutchinson, T.H., Solbe, J., and Kloepper-Sams, P.J. 1998. Analysis of the ECETOC aquatic toxicity (EAT) database III – comparative toxicity of chemical substances to different life stages of aquatic organisms. Chemosphere. 36(1): 129-142. https://doi.org/10.1016/S0045-6535(97)10025-X

Idlout, L. 2020. Southampton Island area of interest: Assessment phase Inuit Qaujimajatuqangit workshop. NVision Insight Group Inc. report submitted to Fisheries and Oceans, Marine Planning and Conservation. 56 p. + appendices.

Iken, K., Bluhm, B., and Blanchard, A. 2012. Sea raspberry: *Gersemia rubiformis* (Ehrenberg, 1834). Arctic Ocean Diversity, Census of Marine Life. Available at: http://www.arcodiv.org/seabottom/cnidaria/Gersemia_rubiformis.html# [Date accessed: December 13, 2023].

International Maritime Organization (IMO). 2015. Investigation of appropriate control measures (Abatement Technologies) to reduce Black Carbon emissions from international shipping. International Maritime Organization, London, UK. 104 p. Available at: https://www.uncclearn.org/wp-content/uploads/library/1_0.pdf

Irons, D.B., Kendall, S.J., Erickson, W.P., McDonald, L.L., and Lance, B.K. 2000. Nine years after the Exxon Valdez Oil Spill: Effects on marine bird populations in Prince William Sound, Alaska. Condor. 102: 723-737. Available at: https://sora.unm.edu/sites/default/files/journals/condor/v102n04/p0723-p0737.pdf

Ivanova, S.V., Kessel, S.T., Espinoza, M., McLean, M.F., O'Neill, C., Landry, J., Hussey, N.E., Williams, R., Vagle, S., and Fisk, A.T. 2020. Shipping alters the movement and behavior of Arctic cod *(Boreogadus saida)*, a keystone fish in Arctic marine ecosystems. Ecol. Appl. 30(3): e02050. https://doi.org/10.1002/eap.2050

Jägerbrand, A.K., Brutemark, A., Sveden, J.B., and Gren, M. 2019. A review on the environmental impacts of shipping on aquatic and nearshore ecosystems. Sci. Total Environ. 695: 133637.

Jansen, J.K., Boveng, P.L., Dahle, S.P., and Bengtson, J.L. 2010. Reaction of harbor seals to cruise ships. J. Wildl. Manag. 74(6): 1186-1194.

Jenkins, S.R., Beukers-Stewart, B.D., and Brand, A.R. 2001. Impact of scallop dredging on benthic megafauna: a comparison of damage levels in captured and non-captured organisms. Mar. Ecol. Prog. Ser. 215: 297-301

Jennings, S. and Kaiser, M.J. 1998. The effects of fishing on marine ecosystems. Fish. Sci. Aqua.: 1-51. Available at: https://fish.gov.au/ArchivedReports/2014/Documents/2014_refs/Jennings%20et%20al%201998.pdf

Jennings, S., Kaiser, M., and Reynolds, J.D. 2001a. Marine Fisheries Ecology. Blackwell Science, Malden, MA. Available at: http://refhub.elsevier.com/S0025-326X(20)30801-8/rf0295

Jennings, S., Pinnegar, J.K., Polunin, N.V., and Warr, K.J. 2001b. Impacts of trawling disturbance on the trophic structure of benthic invertebrate communities. Mar. Ecol. Prog. Ser. 213: 127-142. 10.3354/meps213127

Johansson, S., Larsson, U., and Boehm, P. 1980. The Tsesis oil spill impact on the pelagic ecosystem. Mar. Poll. Bull. 11(10): 284-293. https://doi.org/10.1016/0025-326X(80)90166-6

Johnson, C.R. and Mann, K.H. 1988. Patterns of adaptation, and stability of Nova Scotian kelp beds. Ecol. Monogr. 58: 129-154.

Johnson, S.R., Herter, D.R., and Bradstreet, M. 1987. Habitat use and reproductive success of Pacific Eiders *Somateria mollisima v-nigra* during a period of industrial activity. Biol. Conserv. 41: 77-89. https://doi.org/10.1016/0006-3207(87)90112-1

Johnson, S.R., Burns, J.J., Malme, C.I., and Davis, R.A. 1989. Synthesis of information on the effects of noise and disturbance on major haul out concentrations of Bering Sea pinnipeds. OCS Study MMS 88-0092. Rep. from LGL Alaska Res. Assoc. Inc., Anchorage, AK, for U.S. Minerals Manage. Serv., Anchorage, AK. 267 p.

Johnson, A.F., Gorelli, G., Jenkins, S.R., Hiddink, J.G., and Hinz, H. 2015. Effects of bottom trawling on fish foraging and feeding. Proc. R. Soc. B. 282: 20142336. http://dx.doi.org/10.1098/rspb.2014.2336

Johnston, M., Dawson, J., De Souza, E. and Stewart, E.J. 2017. Management challenges for the fastest growing marine shipping sector in Arctic Canada: pleasure crafts. Polar Rec. 53(1): 67-78. 10.1017/s0032247416000565

Jónasdóttir, S.H., Naustvoll, L., Teglhus, F.W., Agersted, M.D., Grenwald, J.C., Melle, W., and Nielsen, T.G. 2022. Calanus finmarchicus basin scale life history traits and role in community carbon turnover during spring. ICES J. Mar. Sci. 79: 785-802. https://doi.org/10.1093/icesjms/fsac013

Jones, L.A., Hiscock, K., and Connor, D.W. 2000. Marine habitat reviews. A summary of ecological requirements and sensitivity characteristics of the conservation and management of marine SACs. Joint Nature Conservation Committee, Peterborough. 178 p.

Jørgensen, L.L., Archambault, P., Blicher, M., Denisenko, N., Guðmundsson, G., Iken, K., Roy, V., Sørensen, J., Anisimova, N., Behe, C., Bluhm, B.A., Denisenko, S., Metcalf, V., Olafsdottir, S., Schiøtte, T., Tendal, O., Ravelo, A., Kędra, M., and Peipenburg, D. 2017. Benthos. *In* State of the Arctic Marine Biodiversity Report. *Edited by* Barr, T., Price, C., Olsen, M., Christensen, T., and Frederiksen, M. Conservation of Arctic Flora and Fauna (CAFF), Akureyri, Iceland. pp. 85-108. Available at: https://epic.awi.de/id/eprint/46697/

Kaartvedt, S. 2000. Life history of Calanus finmarchicus in the Norwegian Sea in relation to planktivorous fish. ICES J. Mar. Sci. 57: 1819-1824. https://doi.org/10.1006/jmsc.2000.0964

Kaiser, M.J., Collie, J.S., Hall, S.J., Jennings, S., and Poiner, I.R. 2001. Impacts of fishing gear on marine benthic habitats. *In* Responsible Fisheries in the Marine Ecosystem. *Edited by* Sinclair, M. and Valdimarsson, G. CABI Publishing, Cambridge, MA. pp. 197-217.

Karlsen, J., Bisther, A., Lydersen, C., Haug, T., and Kovacs, K. 2002. Summer vocalizations of adult male white whales *(Delphinapterus leucas)* in Svalbard, Norway. Polar Biol. 25(11): 808-817.

Kates Varghese, H., Lowell, K., Miksis-Olds, J., DiMarzio, N., Moretti, D., and Mayer, L. 2021. Spatial analysis of beaked whale foraging during two 12 kHz multibeam echosounder surveys. Front. Mar. Sci. 8: 1139. https://doi.org/10.3389/fmars.2021.654184

Katsanevakis, S., Wallentinus, I., Zenetos, A., Leppäkoski, E., Çinar, M.E., Oztürk, B., Grabowski, M., Golani, D., and Cardoso, A.C. 2014. Impacts of invasive alien marine species on ecosystem services and biodiversity: a pan-European review. Aquat. Invasions. 9(4): 391-423. Available at:

https://www.academia.edu/download/42022393/Impacts_of_invasive_alien_marine_species2016020330232-1iuzjny.pdf

Kay, M.F. and Gilchrist, H.G. 1998. Distraction displays made by female Common Eiders, *Somateria mollissima borealis*, in response to human disturbance. Can. Field-Nat. 112: 629-532. Available at: https://www.biodiversitylibrary.org/item/106776

Keats, D.W., Steele, D.H., Green, J., and Martel, G.M. 1993. Diet and population size structure of the Arctic shanny, *Stichaeus punctatus* (Pisces: *Stichaeidae*), at sites in eastern Newfoundland and the eastern Arctic. Environ. Biol. Fish. 37(2): 173-180.

Keck, A., Kortsch, S., Bluhm, B., Gulliksen, B., Ballantine, C., Cristini, D., and Primicerio, R. 2020. Arctic coastal benthos long-term responses to perturbations under climate warming. Phil. Trans. R. Soc. A. 378: 20190355. http://dx.doi.org/10.1098/rsta.2019.0355

Kellar, N.M., Speakman, T., Smith, C., Lane, S., Balmer, B.C., Trego, M.L., Catelani, K.N., Robbins, M.N., Allen, C.D., Wells, R.S., Zolman, E., Rowles, T., and Schwacke, L. 2017. Low reproductive success rates of common Bottlenose dolphins *Tursiops truncatus* in the northern Gulf of Mexico following the Deepwater Horizon disaster (2010-2015). Endang. Species Res. 33: 143-158.

Kenchington, E.L., Kenchington, T.J., Henry, L-A., Fuller, S., and Gonzalez, P. 2007. Multi-decadal changes in the megabenthos of the Bay of Fundy: The effects of fishing. J. Sea Res. 58: 220-240.

Kenchington, E., Link, H., Roy, V., Archambault, P., Siferd, T., Treble, M., and Wareham, V. 2011. Identification of mega- and macrobenthic Ecologically and Biologically Significant Areas (EBSAs) in the Hudson Bay Complex, the Western and Eastern Canadian Arctic. DFO Can. Sci. Advis. Sec. Res. Doc.: 2011/072. 52 p.

Kenworthy, W.J., Fonseca, M.S., Whitfield, P.E., and Hammerstrom, K.K. 2002. Analysis of seagrass recovery in experimental excavations and propeller-scar disturbances in the Florida Keys National Marine Sanctuary. J. Coast. Res. SI 37: 75-85. Available at: https://www.jstor.org/stable/25736344

Kilabuk, P. 1998. Final Report on a Study of Inuit Knowledge of the Southeast Baffin Beluga: Report. Nunavut Wildlife Management Board.

Kim, Y., Aw, T.G., and Rose, J.B. 2016. Transporting Ocean Viromes: Invasion of the Aquatic Biosphere. PLoS One. 11(4): e0152671. 10.1371/journal.pone.0152671

Kingsley, M.C. 2006. The Northern Common Eider: Status, Problems, Solutions. Greenland Institute of Natural Resources Technical Report 64. x + 61 p. Available at: https://natur.gl/wp-content/uploads/2005/02/64-The-Northern-Common-Eider-Status-Problems-Solutions.-Report-of-an-International-Workshop.pdf

Kitching, E. 2022. Physical processes driving phytoplankton production around Southampton Island, Nunavut in late summer 2018 and 2019. M.Sc. Thesis, University of Manitoba. Available at: https://mspae.lib.umanitoba.ca/handle/1993/36865

Kjøholt, J., Aakre, S. Jürgensen, C., and Lauridsen, J. 2012. Assessment of possible impacts of scrubber water discharges on the marine environment. COWI, Danish Environmental Protection Agency, Environmental Project No. 1431.

Klaczek, M.R., Johnson, C.J., and Cluff, H.D. 2016. Wolf-caribou dynamics within the central Canadian Arctic. J. Wildl. Manag. 80(5): 837-849. https:doi.org/10.1002/jwmg.1070

Klein, G., Kaczmarska, I., and Ehrman, J.M. 2009. The diatom Chaetoceros in ships' ballast waters – survivorship of stowaways. Acta Bot. Croat. 68(2): 325-338. Available at: https://hrcak.srce.hr/file/65027

Kleinenberg, S.E., Yablokov, A.V., Bel'kocich, B.M., and Tarasevich, M.N. 1964. Beluga (Delphinapterus leucas)/Investigation of the species. In Russian: English translation 1969. Israel Program for Scientific Translations, Jerusalem. 376 pp.

Knowlton, A.R. 1997. The regulation of shipping to protect North Atlantic right whales: need and feasibility. M.M.A. Thesis, University of Rhode Island.

Knowlton, A.R., Hamilton, P.K., Marx, M.K., Pettis, H.M., and Kraus, S.D. 2012. Monitoring North Atlantic right whale Eubalaena glacialis entanglement rates: a 30 yr retrospective. Mar. Ecol. Prog. Ser. 466: 293-302. 10.3354/meps09923

Knudsen, F.R., Enger, P.S., and Sand, O. 1992. Awareness reactions and avoidance responses to sound in juvenile Atlantic salmon, Salmo salar L. J. Fish Biol. 40(4): 523-534. https://doi.org/10.1111/j.1095-8649.1992.tb02602.x

Kogan, I., Paull, C.K., Kuhnz, L.A., Burton, E.J., Von Thun, S., Greene, H.G., and Barry, J.P. 2006. ATOC/Pioneer seamount cable after 8 years on the seafloor: Observations, environmental impact. Cont. Shelf Res. 26: 771-787.

Kohlbach, D., Ferguson, S.H., Brown, T.A., and Michel, C. 2019. Landfast sea ice-benthic coupling during spring and potential impacts of system changes on food web dynamics in Eclipse Sound, Canadian Arctic. Mar. Ecol. Prog. Ser. 627: 33-48. https://doi.org/10.3354/meps13071

Kohlbach, D., Duerksen, S.W., Lange, B.A., Charette, J., Reppchen, A., Tremblay, P., Campbell, K.L., Ferguson, S.H., and Michel, C. 2020. Fatty acids and stable isotope signatures of first-year and multi-year sea ice in the Canadian High Arctic. Elem. Sci. Anth. 8(1): 1-15. https://doi.org/10.1525/elementa.2020.054

Konar, B. 2013. Lack of recovery from disturbance in high-arctic boulder communities. Polar Biol. 36(8): 1205-1214.

Koperqualuk, L. and Ell-Kanayuk, M. 2022. Op-ed: Inuit voices to be heard at IMO on critical shipping issues. Nunatsiaq News, January 29, 2022. Available at: https://nunatsiaq.com/stories/article/op-ed-inuit-voices-to-be-heard-at-imo-on-critical-shipping-issues/ [Date accessed: February 6, 2023].

Kopperud, K.L. and Grace, M.S. 2017. Circadian rhythms of retinal sensitivity in the Atlantic tarpon, Megalops atlanticus. Bull. Mar. Sci. 93(2): 285-300. https://doi.org/10.5343/bms.2016.1045

Koropatnick, T., Baxter, L., Bone, B., Irlich, U., Marotte, E., McConney, L., Pardy, G., Rozalska, K., Schram, C., and Will, E. 2023. Ecological risk assessment of the Fundian Channel-Browns Bank Area of Interest. Can. Tech. Rep. Fish. Aquat. Sci. 3550: v + 325 p.

Koski, W.R. 1980. Distribution and migration of marine mammals in Baffin Bay and eastern Lancaster Sound, May-July 1979. Rep. by LGL Ltd., Toronto, Ont., for Petro-Canada Exploration Inc., Calgary, AB. 317 p.

Koski, W.R. and Johnson, S.R. 1987. Behavioral studies and aerial photogrammetry. Sect. 4 In: Responses of bowhead whales to an offshore drilling operation in the Alaskan Beaufort Sea, autumn 1986. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Shell Western Expl. & Prod. Inc., Anchorage, AK. 371 p.

Koski, W.R. and Davis, R.A. 1994. Distribution and numbers of narwhals (Monodon monoceros) in Baffin Bay and Davis Strait. Medd. Grønl. Biosci. 39: 15-40.

Koski, W.R., Miller, G.W. and Davis, R.A. 1988. The potential effects of tanker traffic on the bowhead whales in the Beaufort Sea. Rep. from LGL Ltd., King City, Ont., for Department of Indian Affairs and Northern Development, Ottawa, ON., Canada. 150 p.

Koski, W.R., Davis, R.A., Miller, G.W., and Withrow, D.E. 1993. Reproduction. *In* The Bowhead Whale. *Edited by* Burns, J.J., Montague, J.J., and Cowles, C.J. Spec. Publ. 2, Soc. Mar. Mamm., Lawrence, KS. pp. 157-199.

Koski, W.R., Thomas, T.A., Miller, G.W., Elliott, R.E., Davis, R.A., and Richardson, W.J. 2002. Rates of movement and residence times of bowhead whales in the Beaufort Sea and Amundsen Gulf during summer and autumn. *In* Bowhead whale feeding in the eastern Alaskan Beaufort Sea: Update of scientific and traditional information. *Edited by* Richardson, W.J. and Thomson, D.H. OCS Study MMS 2002-012; LGL Rep. TA2196–7. Rep. from LGL Ltd., King City, Ontario, for U.S. Minerals Management Service, Anchorage, Alaska, and Herndon, Virginia, USA. NTIS PB2006–100382. 11-1 to 11-41.

Koski, M., Stedmon, C., and Trapp, S. 2017. Ecological effects of scrubber water discharge on coastal plankton: Potential synergistic effects of contaminants reduce survival and feeding of the copepod Acartia tonsa. Mar. Environ. Res. 129: 374-385. http://dx.doi.org/10.1016/j.marenvres.2017.06.006

Kottsieper, J., Schwemmer, P., Markones, N., Fox, A.D., and Garthe, S. 2019. An invasive alien bivalve apparently provides a novel food source for moulting and wintering benthic feeding sea ducks. Helgoland Mar. Res. 73: 11. https://doi.org/10.1186/s10152-019-0532-z

Kourantidou, M., Kaiser, B., and Fernandez, L. 2015. Towards Arctic resource governance of marine invasive species. *In* Arctic Yearbook 2015. *Edited by* Heininen, L., Exner-Pirot, H., and Plouffe, J. pp. 175-194. Available at: http://www.joomag.com/magazine/arctic-yearbook-2015/0357456001446028961?short

Koutsouveli, V., Cárdenas, P., Conejero, M., Rapp, H.T., and Riesgo, A. 2020. Reproductive biology of Geodia species (Porifera, Tetractinellida) from Borea-Arctic North Atlantic deep-sea sponge grounds. Front. Mar. Sci. 7: 59567. https://doi.org/10.3389/fmars.2020.595267

Kovacs, K.M. 2016. Erignathus barbatus. The IUCN Red List of Threatened Species 2016: e.T8010A45225428. http://dx.doi.org/10.2305/IUCN.UK.2016-1.RLTS.T8010A45225428.en

Kovacs, K.M. and Lydersen, C. (eds). 2006. Birds and Mammals of Svalbard. Polarhåndbok No. 13, Norwegian Polar Institute, Tromsø, Norway, Grafisk Nord AS, Finnsnes, Norway.

Kovacs, K.M., Lydersen, C., and Gjertz, I. 1996. Birth-site characteristics and prenatal molting in bearded seals (Erignathus barbatus). J. Mamm. 77(4): 1085-1091.

Kovacs, K.M., Lydersen, C., Overland, J.E., and Moore, S.E. 2011. Impacts of Changing Sea-Ice Conditions on Arctic Marine Mammals. Mar. Biodivers. 41: 181-194. doi:10.1007/s12526-010-0061-0

Kraus, C. and Carter, L. 2018. Seabed recovery following protective burial of subsea cables – Observations from the continental margin. Ocean Eng. 157(1): 251-261. https://doi.org/10.1016/j.oceaneng.2018.03.037

Krause-Jensen, D., Marbà, N., Olesen, B., Sejr, M.K., Christensen, P.B., Rodrigues, J., Renaud, P.E., Balsby, T.J., and Rysgaard, S. 2012. Seasonal sea ice cover as principal driver of spatial and temporal variation in depth extension and annual production of kelp in Greenland. Glob. Change Biol. 18(10): 2981-2994.

Krause-Jensen, D., Duarte, C.M., Sand-Jensen, K., and Cartensen, J. 2021. Century-long records reveal shifting challenges to seagrass recovery. Glob. Change Biol. 27: 563-575.

Krepakevich, A. and Pospelova, V. 2010. Tracing the influence of sewage discharge on coastal bays of Southern Vancouver Island (BC, Canada) using sedimentary records of phytoplankton. Cont. Shelf Res. 30(18): 1924-1940. https://doi.org/10.1016/j.csr.2010.09.002

Krumhansl, K.A. and Scheibling, R.E. 2012. Production and fate of kelp detritus. Mar. Ecol. Prog. Ser. 467: 281-302.

Krumhansl, K.A., Lee, J.M., and Scheibling, R.E. 2011. Grazing damage and encrustation by an invasive bryozoan reduce the ability of kelp to withstand breakage by waves. J. Exp. Mar. Biol. Ecol. 407: 12-18.

Krumhansl, K.A., Lauzon-Guay, J.S., and Scheibling, R.E. 2014. Modeling effects of climate change and phase shifts on detrital production of a kelp bed. Ecology. 95: 763-774.

Krumhansl, K.A., Krkosek, W.H., Greenwood, M., Ragush, C., Schmidt, J., Grant, J., Barrell, J., Lu, L., Lam, B., Gagnon, G.A., and Jamieson, R.C. 2015. Assessment of Arctic community wastewater impacts on marine benthic invertebrates. Environ. Sci. Technol. 49: 760-766. https://doi.org/10.1021/es503330n

Krumhansl, K., Jamieson, R., and Krkosek, W. 2016. Using species traits to assess human impacts on near shore benthic ecosystems in the Canadian Arctic. Ecol Indic. 60: 495-502.

Kville, K., Prokopchuk, I.P., and Stige, L.C. 2022. Environmental effects on Calanus finmarchicus abundance and depth distribution in the Barents Sea. J. Mar. Sci. 79(3): 815-828. https://doi.org/10.1093/icesjms/fsab133

Lacharité, M. and Metaxas, A. 2013. Early life history of deep-water gorgonian corals may limit their abundance. PLoS ONE. 8(6): e65394. https://doi.org/10.1371/journal.pone.0065394

Lack, D.A. and Corbett, J.J. 2012. Black carbon from ships: A review of the effects of ship speed, fuel quality and exhaust gas scrubbing. Atmos. Chem. Phys. 12: 3985-4000. https://doi.org/10.5194/acp-12-3985-2012

Lacoursiere-Roussel, A., Bock, D.G., Cristescu, M.E., Guichard, F., Girard, P., Legendres, P., and McKindsey, C.W. 2012. Disentangling invasion processes in a dynamic shipping-boating network. Mol. Ecol. 21: 4227-4241.

Laidre, K.L. and Heide-Jørgensen, M.P. 2005. Arctic sea ice trends and narwhal vulnerability. Biol. Conserv. 121: 509-517.

Laidre, K.L., Heide-Jørgensen, M.P., Dietz, R., Hobbs, R.C., and Jørgensen, O.A. 2003. Deep-diving by narwhals, Monodon monoceros: differences in foraging behavior between wintering areas? Mar. Ecol. Prog. Ser. 261: 269-281.

Laidre, K., Heide-Jørgensen, M.P., Stern, H., and Richard, P. 2012. Unusual narwhal sea ice entrapments and delayed autumn freeze-up trends. Polar Biol. 35: 149-154. 10.007/s00300-001-1036-8

Laidre, K.L., Stern, H., Kovacs, K.M., Lowry, L., Moore, S.E., Regehr, E.V., Ferguson, S.H., Wiig, Ø., Boveng, P., Angliss, R.P., Born, E.W., Litovka, D., Quakenbush, L., Lydersen, C., Vongraven, D., and Ugarte, F.

2015. Arctic marine mammal population status, sea ice habitat loss, and conservation recommendations for the 21st century. Conserv. Biol. 29: 724-737. https://doi.org/10.1111/cobi.12474

Lair, S., Martineau, D., and Measures, L.N. 2014. Causes of mortality in St. Lawrence Estuary beluga (Delphinapterus leucas) from 1983 to 2012. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/119. iv + 37 pp.

Laist, D.W. 1997. Impacts of marine debris: entanglement of marine life in marine debris including a comprehensive list of species with entanglement and ingestion records. *In* Marine Debris. *Edited by* Coe, J.M. and Rogers, D.B. Springer, New York, USA. pp. 99-139.

Laist, D.W., Knowlton, A.R., Mead, J.G., Collet, A.S., and Podesta, M. 2001. Collisions between ships and whales. Mar. Mamm. Sci. 17: 35-75.

Lambert, W., Levin, P., and Berman, J. 1992. Changes in the structure of a New England (USA) kelp bed: the effects of an introduced species? Mar. Ecol. Prog. Ser. 88: 303-307.

Landry, J.J., Kessel, S.T., McLean, M.F., Ivanova, S.V., Hussey, N.E., O'Neil, C., Vagle, S., Dick, T.A., and Fisk, A.T. 2019. Movement types of an Arctic benthic fish, shorthorn sculpin (Myoxocephalus scorpius), during open-water periods in response to biotic and abiotic factors. Can. J. Fish. Aquat. Sci. 76: 626-635. dx.doi.org/10.1139/cjfas-2017-0389

Lane, S.M., Smith, C.R., Mitchell, J., Balmer, B.C., Barry, K.P., McDonald, T., Mori, C.S., Rosel, P.E., Rowles, T.K., Speakman, T., Townsend, F.I., Tumlin, M.C., Wells, R.S., Zolman, E.S. and Schwacke, L.H. 2015. Reproductive outcome and survival of common bottlenose dolphins sampled in Barataria Bay, Louisiana, USA, following the Deepwater Horizon oil spill. Proc. R. Soc. B. 282: 20151944. DOI:10.1098/rspb.2015.1944

Lange, B. 2015. Impacts of scrubbers on the environmental situation in ports and coastal waters. Umwelt Bundesamt. Texte 65/2015. 80 p. + annexes.

Lange, B.A., Flores, H., Michel, C., Beckers, J.F., Bublitz, A., Casey, J.A., Castellani, G., Hatam, I., Reppchen, A., and Rudolph, S.A. 2017. Pan-Arctic sea ice-algal chl a biomass and suitable habitat are largely underestimated for multiyear ice. Glob. Change Biol. 23(11): 4581-4597. https://doi.org/10.1111/gcb.13742

Larsson, A.I and Purser, A. 2011. Sedimentation on the cold-water coral *Lophelia pertusa:* Cleaning efficiency from natural sediments and drill cuttings. Mar. Pollut. Bull. 62: 1159-1168.

Last, E.K., Ferguson, M., Serpetti, N., Narayanaswamy, B.E., and Hughes, D.J. 2019. Geodia and other massive sponges on Atlanto-Arctic upper bathyal coarse sediment. *In* Marine Life Information Network: Biology and Sensitivity Key Information Reviews, [online]. *Edited by* Tyler-Walters, H. and Hiscock, K. Plymouth: Marine Biological Association of the United Kingdom. Available at: https://www.marlin.ac.uk/habitats/detail/1190/geodia_and_other_massive_sponges_on_atlanto-arctic_upper_bathyal_coarse_sediment

Latour, P.B., Leger, J., Hines, J.E., Mallory, M.L., Mulders, D.L., Gilchrist, H., Smith, P., and Dickson, D.L. 2008. Key migratory bird terrestrial sites in the Northwest Territories and Nunavut, third edition. CWS Occ. Pap. No. 114, Ottawa, ON.

Laurel, B.J., Copeman, L.A., Iseri, P., Spencer, M., Hutchinson, G., Nordtug, T., Donald, C.E., Meier, S., Allan, S.E., Boyd, D.T., and Ylitalo, G. 2019. Embryonic crude oil exposure impairs growth and lipid allocation in a keystone Arctic forage fish. iScience. 19: 1101-1113. https://doi.org/10.1016/j.isci.2019.08.051

Lazado, C.C., Nagasawa, K., Babiak, I., Kumaratunga, H.P., and Fernandes, J.M. 2014. Circadian rhythmicity and photic plasticity of myosin gene transcription in fast skeletal muscle of Atlantic cod *(Gadus morhua).* Mar. Genomics. 18(A): 21-29. https://doi.org/10.1016/j.margen.2014.04.011

Leahy, S.M., McCormick, M.I., Mitchell, M.D., and Ferrari, M.C. 2011. To fear or to feed: the effects of turbidity on perception of risk by a marine fish. Biol. Lett. 7(6): 811-813. https://doi.org/10.1098/rsbl.2011.0645

Leatherbarrow, K.E. 2003. Monitoring Environmental Impacts of Recreational Boat Anchoring on Eelgrass and Benthic Invertebrates in the Gulf Islands National Park Reserve of Canada. M.Sc. Thesis, University of Victoria. Available at: https://dspace.library.uvic.ca/handle/1828/1858

Leatherbarrow, K.E. 2009. Monitoring environmental impacts of recreational boat anchoring on eelgrass and benthic invertebrates in the Gulf of Islands National Park Reserve of Canada. M.Sc. Thesis, University of Victoria. Available at: http://hdl.handle.net/1828/1858

LeBlanc, M., Geoffroy, M., Bouchard, C., Gauthier, S., Majewski, A., Reist, J.D., and Fortier, L. 2019. Pelagic production and the recruitment of juvenile polar cod *Boreogadus saida* in Canadian Arctic seas. Polar Biol. 43(8): 1043-1054. Available at: https://link.springer.com/content/pdf/10.1007/s00300-019-02565-6.pdf

Lee, R.K. 1980. A catalogue of the marine algae of the Canadian Arctic. Nat. Mus. Can. Publ. Bot. 9: 1-82.

Lee, K., Boufadel, M., Chen, B., Foght, J., Hodson, P., Swanson, S., and Venosa, A. 2015. Behaviour and environmental impacts of crude oil released into aqueous environments. Roy. Soc. Can, Ottawa, ON. 489 p. Available at: https://rsc-src.ca/en/behaviour-and-environmental-impacts-crude-oil-released-into-aqueous-environments

Lemcke, S., Holding, J., Møller, E.F., Thyrring, J., Gustavson, K., Juul-Pedersen, T., and Sejr, M.K. 2018. Acute oil exposure reduces physiological process rates in Arctic phyto- and zooplankton. Ecotoxicol. 28: 26-36. https://doi.org/10.1007/s10646-018-1995-4

Lerczak, J.A., Shelden, K., and Hobbs, R.C. 2000. Application of suction-cup-attached VHF Transmitters to the study of beluga, *Delphinapterus leucas*, surfacing behavior in Cook Inlet, Alaska. Mar. Fish. Rev. 62: 99-111.

Lesage, V., Barrette, C., Kingsley, M.C., and Sjare, B. 1999. The effect of vessel noise on the vocal behavior of belugas in the St. Lawrence River Estuary, Canada. Mar. Mamm. Sci. 15(1): 65-84.

Leu, E., Mundy, C., Assmy, P., Campbell, K., Gabrielsen, T., Gosselin, M., Juul-Pedersen, T., and Gradinger, R. 2015. Arctic spring awakening – Steering principles behind the phenology of vernal ice algal blooms. Prog. Oceanogr. 139: 151-170. https://doi.org/10.1016/j.pocean.2015.07.012

Levenson, D.H. and Schusterman, R. 1997. Pupillometry in seals and sea lions: ecological implications. Can. J. Zool. 75: 2050-2057.

Levin, P.S., Coyer, J., Petrik, R., and Good, T.P. 2002. Community-wide effects of nonindigenous species on temperate rocky reefs. Ecol. 83(11): 3182-3193.

Lewis, C.F., Slade, S.L., Maxwell, K.E., and Matthews, T.R. 2009. Lobster trap impact on coral reefs: effects of wind-driven trap movement. New Zeal. J. Mar. Fresh. 43: 271-282.

Lewis, K.M., Arntsen, A.E., Couple, P., Joy-Warren, H., Lowry, K.E., Matsuoka, A., Mills, M.M., van Dijken, G., Selz, V., and Arrigo, K.R. 2019. Photoacclimation of Arctic Ocean phytoplankton to shifting light and nutrient limitation. Limnol. Oceanogr. 64(1): 284-301. https://doi.org/10.1002/lno.11039

LGL Limited and Greeneridge. 1986. Reactions of beluga whales and narwhals to ship traffic and ice-breaking along ice edges in the eastern Canadian High Arctic: 1982-1984. Environ. Stud. 37. Indian & Northern Affairs Canada, Ottawa, ON. 301 p.

LGL Limited and Greeneridge. 1987. Responses of bowhead whales to an offshore drilling operation in the Alaskan Beaufort Sea, autumn 1986. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Shell Western E & P. Inc., Anchorage, AK. 371 p.

LGL Limited. 2014. Environmental Assessment Update: Shell Canada Limited's Shelburne Basin Venture Seabed Survey. LGL Rep. SA1249. Rep. by LGL Limited, St. John's, NL and Mahone Bay, NS, for Shell Canada Limited, Calgary, AB. 24 p. + appendices.

Lieske, D.J., McFarlane Tranquilla, L., Ronconi, R., and Abbott, S. 2019. Synthesizing expert opinion to assess the at-sea risks to seabirds in the western North Atlantic. Biol. Conser. 233: 41-50. http://dx.doi.org/10.1016/j.biocon.2019.02.026

Linden, O., Elmgren, R., and Boehm, P. 1979. The Tsesis oil spill; its impact on the coastal ecosystem of the Baltic Sea. Ambio. 8: 248-253.

Lindholm, T., Svartström, M., Spoof, L., and Meriluoto, J. 2001. Effects of ship traffic on archipelago waters off the Långnäs harbour in Åland, SW Finland. Hydrobiologia. 444: 217-225.

Liu, X., Bogaert, K., Engelen, A.H., Leliaert, F., Roleda, M., and De Clerck, O. 2017. Seaweed reproductive biology: environmental and genetic controls. Bot. Mar. 60(2): 89-108. https://doi.org/10.1515/bot-2016-0091

Loewen, T.N., Hornby, C., and Hydesmith, E. 2020a. Summary data for species that occur, or potentially occur, in the Southampton Island Ecologically and Biologically Significant Area. Can. Data Rep. Fish. Aquat. Sci. 1308: vii + 75 p.

Loewen, T.N., Hornby, C.A., Johnson, M., Chambers, C., Dawson, K., MacDonell, D., Bernhardt, W., Gnanapragasam, R., Pierrejean, M., and Choy, E. 2020b. Ecological and Biophysical Overview of the Southampton Proposed Area of Interest for the Southampton Island Ecologically and Biologically Significant Area. DFO Can. Sci. Advis. Sec. Res.: 2020/032. vi + 96 p.

Løkkeborg, S. 2005. Impacts of Trawling and Scallop Dredging on Benthic Habitats and Communities. FAO Fisheries Technical Paper 472. FAO, Rome. 58 p. Available at: https://www.fao.org/3/y7135e/y7135e01.pdf

Lomac-MacNair, K., Pedro-Andrade, J., and Esteves, E. 2019. Seal and polar bear behavioral response to an icebreaker vessel in northwest Greenland. Hum-Wildl. Interact. 13(2): 277-289.

López-Olmeda, J.F., Blanco-Vives, B., Pujante, I., Wunderink, Y.S., Mancera, J.M., and Sanchez-Vazqueza, F.J. 2013. Daily rhythms in the hypothalamus-pituitary-inerrenal axis and acute stress responses in a teleost flatfish, *Solea senegalensis*. Chronobiol. Int. 30(4): 530-539. https://doi.org/10.3109/07420528.2012.754448

Lowry, L. 2016a. *Odobenus rosmarus*. The IUCN Red List of Threatened Species 2016: e.T15106A45228501. 16 p.

Lowry, L. 2016b. *Pusa hispida*. The IUCN Red List of Threatened Species 2016: e.T41672A45231341. 17 p.

Lowry, L.F., Frost, K.J., and Burns, J.J. 1980. Variability in the diet of ringed seals, *Phoca hispida*, in Alaska. Can. J. Fish. Aquat. Sci. 37: 2254-2261.

Lowry, L.F., Sheffield, G., and George, J.C. 2004. Bowhead whale feeding in the Alaskan Beaufort Sea based on the stomach content analyses. J. Cetacean Res. Manag. 6: 215-223.

Lowry, L., Laidre K., and Reeves, R. 2017. *Monodon monoceros*. The IUCN Red List of Threatened Species 2017: e. T13704A50367651. 20 p.

Ludvigsen, M., Berge, J., Geoffroy, M., Cohen, J.H., De La Torre, P., Nornes, S.M., Singh, H., Sørensen, A.J., Daase, M., and Johnsen, G. 2018. Use of an autonomous surface vehicle reveals small-scale diel vertical migrations of zooplankton and susceptibility to light pollution under low solar irradiance. Sci. Adv. 4: eaap9887. https://www.science.org/doi/epdf/10.1126/sciadv.aap9887

Lunn, N.J., Stirling, I., and Nowicki, S.N. 1997. Distribution and abundance of ringed (*Phoca hispida*) and bearded seals (*Erignathus barbatus*) in western Hudson Bay. Can. J. Fish. Aquat. Sci. 54(4): 914-921. https://doi.org/10.1139/f96-346

Lurton, X. and DeRuiter, S. 2011. Sound radiation of seafloor-mapping echosounders in the water column, in relation to the risks posed to marine mammals. The Int. Hydrographic Rev. 6.

Lutz-Collins, V., Ramsay, A., Quijon, P.A., and Davidson, J. 2009. Invasive tunicates fouling mussel lines: evidence of their impact on native tunicates and other epifaunal invertebrates. Aquat. Invasions. 4(1): 213-220.

Lydersen, C. and Hammill, M.O. 1993. Diving in ringed seal *(Phoca hispida)* pups during the nursing period. Can. J. Zool. 71: 991-996.

Lydersen, C., Hammill, M.O., and Kovacs, K.M. 1994. Diving activity in nursing bearded seal *(Erignathus barbatus)* pups. Can. J. Zool. 72: 96-103.

MacGillivray, A., Moulton, V.D., and Racca, R. 2004. Acoustic measurement and marine mammal monitoring of the Canadian Coast Guard Ship Nahidik's seafloor mapping program, Canadian Beaufort Sea, 2003. LGL Rep. TA2896 2. Rep. by LGL Limited, St. John's, Newfoundland, for Geological Survey of Canada, Halifax, Nova Scotia and Canadian Hydrographic Service, Burlington, Ontario. 39 p.

MacGillivray, A.O., Racca, R., and Zizheng, L. 2014. Marine mammal audibility of selected shallow-water survey sources. J. Acoust. Soc. Am. 135(1): El-35-EL40.

Maerospace (Corp.). 2020. Spatial analysis of vessel traffic in the Canadian Arctic Southampton Island AOI. Contract No. 9F013-160288/001/MTB; TAR: 0003. Rep. by Maerospace Corp., Waterloo, ON for Canadian Space Agency, St. Hubert, Quebec. 46 p.

Maggini, I., Kennedy, L.V., Macmillan, A., Elliott, K.H., Dean, K., and Guglielmo, C.G. 2017a. Light oiling of feathers increases flight energy expenditure in a migratory shorebird. J. Exp. Biol. 220: 2372-2379. https://doi.org/10.1242/jeb.158220

Maggini, I., Kennedy, L.V., Elliott, K.H., Dean, K.M., MacCurdy, R., Macmillan, A., Pritsos, C.A., and Guglielmo, C.G. 2017b. Reprint of: Trouble on takeoff: Crude oil on feathers reduces escape performance of shorebirds. Ecotoxicol. Environ. Safe. 146: 111-117. https://doi.org/10.1016/j.ecoenv.2017.05.018

Maggini, I., Kennedy, L.V., Bursian, S.J., Dean, K.M., Gerson, A.R., Harr, K.E., Link, J.E., Pritsos, C.A., Pritsos, K.L., and Guglielmo, C.G. 2017c. Toxicological and thermoregulatory effects of feather contamination with artificially weathered MC 252 oil in western *sandpipers (Calidris mauri)*. Ecotoxicol. Environ. Safe. 146: 118-128. https://doi.org/10.1016/j.ecoenv.2017.04.025

Maher, P. 2012. Expedition cruise visits to protected areas in the Canadian Arctic: Issues of sustainability and change for an emerging market. Tourism. 60(1): 55-70. Available at: https://www.researchgate.net/publication/285863145_Expedition_cruise_visits_to_protected_areas_in_the_Canadian_Arctic_Issues_of_sustainability_and_change_for_an_emerging_market

Mahtab, M., Stanton, K.S., and Roma, V.R. 2005. Environmental impacts of blasting for stone quarries near the Bay of Fundy. *In* The Changing Bay of Fundy: Beyond 400 Years: Proceedings of the 6th Bay of Fundy Workshop Cornwallis, Nova Scotia September 29th – October 2nd, 2004. *Edited by* Percy, J.A., Evans, A.J., Wells, P.G., and Rolston, S.J. Environment Canada, Dartmouth, Nova Scotia and Sackville, New Brunswick. pp. 87-97. Available at: https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.485.7068&rep=rep1&type=pdf

Maier, J.A., Murphy, S.M., White, R.G., and Smith, M.D. 1998. Responses of caribou to overflights by low-altitude jet aircraft. J. Wildl. Manag. 62(2): 752-766. https:doi.org/10.2307/3802352

Majewski, A.R., Walkusz, W., Lynn, B.R., Atchison, S., Eert, J., and Reist, R.D. 2016. Distribution and diet of demersal Arctic Cod, Boreogadus saida, in relation to habitat characteristics in the Canadian Beaufort Sea. Polar Biol. 39(6): 1087-1098. https://doi.org/10.1007/s00300-015-1857-y

Mallory, M. 2016. Reactions of ground-nesting marine birds to human disturbance in the Canadian Arctic. Arctic Sci. 2: 67-77. https://doi.org/10.1139/as-2015-0029

Mallory, M.L. and Fontaine, F.J. 2004. Key marine habitat sites for migratory birds in Nunavut and the Northwest Territories. CWS Occ. Pap. No. 109, Ottawa, ON. Available at: https://publications.gc.ca/collections/collection_2011/ec/CW69-1-109-eng.pdf

Mallory, M.L., Woo, K., Gaston, A.J., Davies, W.E., and Mineau, P. 2004. Walrus *(Odobenus rosmarus)* predation on adult Thick-billed Murres *(Uria lomvia)* at Coats Island, Nunavut, Canada. Polar Res. 23(1): 111-114.

Mallory, M.L., Gaston, A.J., Provencher, J.F., Wong, S., Anderson, C., Elliott, K.H., Gilchrist, H.G., Janssen, M., Lazarus, T., Patterson, A., Pirie-Dominix, L., and Spencer, N.C. 2019. Identifying key marine habitat sites for seabirds and sea ducks in the Canadian Arctic. Environ. Rev. 27: 215-240. https://doi.org/10.1139/er-2018-0067

Malme, C.I., Miles, P.R., Miller, G.W., Richardson, W., Roseneau, D., Thomson, D.H., and Greene, C.R. Jr. 1989. Analysis and ranking of the acoustic disturbance potential of petroleum industry activities and other sources of noise in the environment of marine mammals in Alaska. BBN Rep. 6945; OCS Study MMS89-0006. Rep. From BBN systems & Technol. Corp., Cambridge, MA, for U.S. Minerals Manage. Serv., Anchorage, AK.

Mann, K.H. 1973. Seaweeds: Their Productivity and Strategy for Growth: The role of large marine algae in coastal productivity is far more important than has been suspected. Science. 182(4116): 975-981.

Mansfield, A.W. 1959. The walrus in the Canadian arctic. Fish. Res. Board Can. Arctic Unit Circ. 2: 1-13.

Mansfield, A.W. 1963. Seals of arctic and eastern Canada. Fish. Res. Bd. Can. Bull. 137: 35 p.

Mansfield, A.W. and St. Aubin, D.J. 1991. Distribution and abundance of the Atlantic walrus, *Odobenus rosmarus rosmarus,* in the Southampton Island-Coats Island Region of northern Hudson Bay. Can. Field-Nat. 105(1): 95-100.

Marangoni, L.F., Davies, T., Smyth, T., Rodríguez, A., Hamann, H., Duarte, C., Pendoley, K., Berge, J., Maggi, E., and Levy, O. 2022. Impacts of artificial light at night in marine ecosystems – A review. Glob. Change Biol. 00: 1-22. https://doi.org/10.1111/gcb.16264

Marine Mammal Regulations. 2018. Available at: https://laws-lois.justice.gc.ca/eng/regulations/SOR-93-56/index.html [Date accessed: May 7, 2024].

Markowitz, T. and McGuire, T. (eds.) 2007. Temporal-spatial distribution, movements, and behavior of beluga whales near the Port of Anchorage, Alaska. Prepared for Integrated Concepts and Research Corporation and the U.S. Department of Transportation Maritime Administration by LGL Alaska Research Associates, Inc., Anchorage, AK.

Marks, A.A. and King, M.D. 2014. The effect of snow/sea ice type on the response of albedo and light penetration depth (e-folding depth) to increasing black carbon. Cryosphere. 8(5): 1625-1638. https://doi.org/10.5194/tc-8-1625-2014

Martin, A.R., Smith, T.G., and Cox, O.P. 1998. Dive form and function in belugas *(Delphinapterus leucas)* of the eastern Canadian High Arctic. Polar Biol. 20(3): 218-228.

Matcott, J., Clarke, R., and Baylis, S. 2019. The influence of petroleum oil films on the feather structure of tropical and temperate seabird species. Mar. Poll. Bull. 138: 135-144. https://doi.org/10.1016/j.marpolbul.2018.11.010

Matthes, L.C., Ehn, J., Dalman, L., Babb, D., Peeken, I., Harasyn, M., Kirillov, S., Lee, J., Bélanger, S., Tremblay, J.-É., Barber, D., and Mundy, C.J. 2021. Environmental drivers of spring primary production in Hudson Bay. Elem. Sci. Anth. 9(1): 00160. https://doi.org/10.1525/elementa.2020.00160

Matthews, C.J. and Ferguson, S.H. 2015. Weaning age variation in beluga whales *(Delphinapterus leucas)*. J. Mamm. 96(2): 425-437.

Matthews, C.J., Watt, C.A., Asselin, N.C., Dunn, J.B., Young, B.G., Montsion, L.M., Westdal, K.H., Hall, P.A., Orr, J.R., Ferguson, S.H., and Marcoux, M. 2017. Estimated abundance of the Western Hudson Bay beluga stock from the 2015 visual and photographic aerial survey. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/061. v + 20 p.

Maurer, D., Keck, R.T., Tinsman, J.C., and Leathem, W.A. 1981. Vertical migration and mortality of benthos in dredged material—Part I: Mollusca. Mar. Environ. Res. 4(4): 299-319.

Mayette, A., Loseto, L., Pearce, T., Hornby, C.A., and Marcoux, M. 2002. Group characteristics and spatial organization of the Eastern Beaufort Sea beluga whale *(Delphinapterus leucas)* population using aerial photographs. Ca. J. Zool. 100(6): 363-375. https://doi.org/10.1139/cjz-2021-0232

McConnaughey, R.A. and Syrjala, S.E. 2014. Short-term effects of bottom trawling and a storm event on soft-bottom benthos in the eastern Bering Sea. ICES J. Mar. Sci. 71(9): 2469-2483. https://doi.org/10.1093/icesjms/fsu054

McConnaughey, R.A., Hiddink, J.G., Jennings, S., Pitcher, C.R., Kaiser, M.J., Suuronen, P., Sciberras, M., Rijnsdorp, A.D., Collie, J.S., Mazor, T., Amoroso, R.O., Parma, A., and Hilborn, R. 2020. Choosing best practices for managing impacts of trawl fishing on seabed habitats and biota. Fish Fish. 21(2): 319-337. https://doi.org/10.1111/faf.12431

McFarland, V.A. and Peddicord, R.K. 1980. Lethality of a suspended clay to a diverse selection of marine and estuarine macrofauna. Arch. Environm. Contam. Toxicol. 9: 733-741.

McFarland, S.E. and Aerts, L.A. 2015. Assessing disturbance responses of Pacific walrus (Odobenus rosmarus divergens) to vessel presence in the Chukchi Sea. Chukchi Sea Environmental Studies Program (CSESP), Anchorage, Alaska, USA.

McMurray, S.E. and Pawlik, J.R. 2009. A novel technique for the reattachment of large coral reef sponges. Restor. Ecol. 17(2): 192-195. https://doi.org/10.1111/j.1526-100X.2008.00463.x

Mead, C. and Baillie, S. 1981. Seabirds and oil: the worst winter. Nature. 292: 10-11. https://doi.org/10.1038/292010a0

Meinander, O., Kazadzis, S., Arola, A., Riihelä, A., Räisänen, P., Kivi, R., Kontu, A., Kouznetsov, R., Sofiev, M., Svensson, J., Suokanerva, H., Aaltonen, V., Manninen, T., Roujean, J., and Hautecoeur, O. 2013. Spectral albedo of seasonal snow during intensive melt period at Sodankylä, beyond the Arctic Circle. Atmos. Chem. Phys. 13(7): 3793-3810. https://doi.org/10.5194/acp-13-3793-2013

Melnikov, I.A., Kolosova, E., Welch, H.E., and Zhitina, L.S. 2002. Sea ice biological communities and nutrient dynamics in the Canada Basin of the Arctic Ocean. Deep Sea Res. Part II. 49(9): 1623-1649. https://doi.org/10.1016/S0967-0637(02)00042-0

Menden-Deuer, S., Lawrence, C., and Franzè, G. 2018. Herbivorous protist growth and grazing rates at in situ and artificially elevated temperatures during an Arctic phytoplankton spring bloom. PeerJ. 6: e5264. http://dx.doi.org/10.7717/peerj.5264

Mendenhall, V.M. and Milne, H. 1985. Factors affecting duckling survival of eiders *Somateria mollissima* in northeast Scotland. Ibis. 127(2): 148-158.

Merkel, F.R. 2004. Impact of hunting and gillnet fishery on wintering eiders in Nuuk, Southwest Greenland. Waterbirds. 27: 469-479.

Merkel, F.R. and Johansen, K.L. 2011. Light-induced bird strikes on vessels in Southwest Greenland. Mar. Poll. Bull. 62: 2330-2336. doi:10.1016/j.marpolbul.2011.08.040

Merkel, F.R., Mosbech, A., and Riget, F. 2009. Common Eider *Somateria mollissima* feeding activity and the influence of human disturbances. Ardea. 97(1): 99-107.

Migratory Birds Regulations, 2022. 2022. Available at: https://laws-lois.justice.gc.ca/PDF/SOR-2022-105.pdf [Date accessed: May 7, 2024].

Mikola, J., Miettinen, M., Lehikoinen, E., and Lehtilä, K. 1994. The effects of disturbance caused by boating on survival and behaviour of velvet scoter *Melanitta fusca* ducklings. Biol. Conserv. 67(2): 119-124.

Miller, G.W., Davis, R.A, Koski, W.R., Crone, M.J., Rugh, D.J., and Fraker, M.A. 1992. Calving intervals of bowhead whales - an analysis of photographic data. Rep. Int. Whal. Comm. 42: 501-506.

Miller, D.C., Muir, C.L., and Hauser, O.A. 2002. Detrimental effects of sedimentation on marine benthos: what can be learned from natural processes and rates? Ecol. Eng. 19: 211-232.

Misiuk, B. and Aitken, A. 2020. Benthic habitats of Chesterfield Inlet, Nunavut. A report prepared for the Government of Nunavut, Fisheries and Sealing Division. 21 p.

Moffett, C., Chen, Y., and Hunter, M. 2012. Preliminary study of trap bycatch in the Gulf of Maine's Northern Shrimp fishery. N. Americ. J. Fish. Manage. 32(4): 704-715.

Molis, M., Beuchel, F., Laudien, J., Włodarska-Kowalczuk, M., and Buschbaum, C. 2019. Ecological drivers of and responses by Arctic benthic communities, with an emphasis on Kongsfjorden, Svalbard. *In* The Ecosystem of Kongsfjorden, Svalbard. *Edited by* Hop, H. and Wiencke, C. Springer Nature Switzerland, Cham, Switzerland. pp. 423-481.

Montagna, P.A. and Girard, F. 2020. Deep-sea benthic faunal impacts and community evolution before, during, and after the Deepwater Horizon event. *In* Deep oil spills: facts, fate, and effects. *Edited by* Murawski, S.A. et al. Springer Nature Switzerland, Cham, Switzerland. pp. 355-373.

Montefalcone, M., Chiantore, M.C., Lanzone, A., Morri, C., Albertelli, G., and Bianchi, C.N. 2008. BACI design reveals the decline of the seagrass *(Posidonia oceanica)* induced by anchoring. Mar. Poll. Bull. 56: 1637-1645. https://doi.org/10.1016/j.marpolbul.2008.05.013

Montevecchi, W.A. 2006. Influences of artificial light on marine birds. *In* Ecological consequences of artificial night lighting. *Edited by* Rich, C. and Longcore, T. Island Press, Washington, DC. pp. 94-113.

Montevecchi, W., Fifield, D., Burke, C., Garthe, S., Hedd, A., Rail, J., and Robertson, G. 2012. Tracking long-distance migration to assess marine pollution impact. Biol. Lett. 8: 218-221. https://doi.org/10.1098/rsbl.2011.0880

Moore, M.J. and van der Hoop, J.M. 2012. The painful side of trap and fixed net fisheries: chronic entanglement of large whales. J. Mar. Biol. 2012: 1-4.

Moore, J.-S., Harris, L.N., Tallman, R.F., and Taylor, E.B. 2013. The interplay between dispersal and gene flow in anadromous Arctic char (*Salvelinus alpinus*): implications for potential for local adaptation. Can. J. Fish. Aquat. Sci. 70(9): 1327-1338. https://doi.org/10.1139/cjfas-2013-0138

Moore, J.-S., Harris, L.N., Kessel, S.T., Bernatchez, L., Tallman, R.F., and Fisk, A.T. 2016. Preference for nearshore and estuarine habitats in anadromous Arctic Char *(Salvelinus alpinus)* from the Canadian high Arctic (Victoria Island, Nunavut) revealed by acoustic telemetry. Can. J. Fish. Aquat. Sci. 73(9): 1434-1445. https://doi.org/10.1139/cjfas-2015-0436

Moore, A.B., Heney, C., Lincoln, H., Colvin, C., Newell, H., Turner, R., McCarthy, I.D., and Hold, N. 2023. Bycatch in northeast Atlantic lobster and crab pot fisheries (Irish Sea, Celtic Sea and Bristol Channel). Fish. Res. 265: 106745.

Morales Maqueda, M.A., Willmott, A.J. and Biggs, N.R. 2004. Polynya dynamics: A review of observations and modeling. Rev. Geophys. 42(1): RG1004.

Morandin, L.A. and O'Hara, P.D. 2016. Offshore oil and gas, and operational sheen occurrence: is there potential harm to marine birds? Environ. Rev. 24: 285-318. http://dx.doi.org/10.1139/er-2015-0086

Morrison, K.M., Meyer, H.K., Roberts, E.M., Rapp, H., Colaço, A., and Pham, C.K. 2020. The first cut is the deepest: Trawl effects on a deep-sea sponge ground are pronounced four years on. Front. Mar. Sci. 7: 605281. https://doi.org/10.3389/fmars.2020.605281

Morys, C., Brüchert, V., and Bradshaw, C. 2021. Impacts of bottom trawling on benthic biogeochemistry in muddy sediments: Removal of surface sediment using an experimental field study. Mar. Environ. Res. 169: 105384

Moulton, V.D. and Lawson, J. 2002. Seals, 2001. *In* Marine mammal and acoustical monitoring of WesternGeco's open water seismic program in the Alaskan Beaufort Sea, 2001. p. 3-1 to 3-48. *Edited by* Richardson, W.J. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for WesternGeco, Houston, TX, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. LGL Rep. TA25644.

Moulton, V.D. and Williams, M.T. 2002. Incidental sightings of polar bears during monitoring activities for BP's Northstar oil development, Alaskan Beaufort Sea, 2001. LGL Rep. TA25702. Rep. from LGL Ltd., King City, Ont., and LGL Alaska Res. Assoc. Inc., Anchorage, AK, for BP Explor. (Alaska) Inc., Anchorage, AK, and U.S. Fish. Serv., Anchorage, AK. 13 p.

Moulton, V.D., Elliott, R.E., McDonald, T.L., Miller, G.W., Richardson, W.J., and Williams, W.T. 2000. Fixed-wing aerial surveys of seals near BP's Northstar and Liberty sites, 1999. *In* Monitoring of ringed seals during construction of ice roads for BP's Northstar oil development, Alaskan Beaufort Sea, 1999. p. 3-1 to 3-71. *Edited by* Richardson, W.J. and Williams, M.T. Final Rep. from LGL Ltd., King City, Ont., and LGL Alaska Res. Assoc. Inc., Anchorage, AK, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. xiv + 153 p.

Moulton, V.D., Richardson, W., Williams, M.T., and Blackwell, S.B. 2003. Ringed seal densities and noise near an icebound artificial island with construction and drilling. Acoust. Res. Lett. Online. 4(4): 112-117. Available at: http://scitation.aip.org/arlo/

Moulton, V.D., Elliott, R.E., and Davis, R.A. 2012. Marine Mammals in Baffinland Iron Mine Corporation's Final Environmental Impact Statement for the Mary River Project, February 2012.

Mundy, C.J. 2020. The Southampton Island Marine Ecosystem Project 2019 cruise report, 5-29 August, MV William Kennedy. SIMEP 2019 Cruise Report. 48 p. + appendices. Available at: https://mspace.lib.umanitoba.ca/xmlui/bitstream/handle/1993/34664/SIMEP%202019%20Data%20Report.pdf?sequence=1&isAllowed=y

Mundy, C.J., Gosselin, M., Gratton, Y., Brown, K., Galindo, Y., Campbell, K., Levasseur, M., Barber, D., Papakyriakou, T., and Bélanger, S. 2014. Role of environmental factors on phytoplankton bloom initiation under landfast sea ice in Resolute Passage, Canada. Mar. Ecol. Prog. Ser. 497: 39-49. http://dx.doi.org/10.3354/meps10587

Murchy, K.A., Vagle, S., and Juanes, F. 2022. Anchored bulk carriers have substantial impacts on the underwater soundscape in Cowichan Bay, British Columbia. Mar. Poll. Bull. 182: 113921. https://doi.org/10.1016/j.marpolbul.2022.113921

Murray, C.C., Mach, M.E., Martone, R.G., Singh, G.G., O, M., and Chan, K.M. 2016. Supporting risk assessment: Accounting for indirect risk to ecosystem components. PLOS One. 11(9): e0162932. https://doi.org/10.1371/journal.pone.0162932

Nagy, J.A, Johnson, D., Larter, N.C., Campbell, N.W., Derocher, A.E., Kelly, A., Dumond, M., Allaire, D., and Croft, B. 2011. Subpopulation structure of caribou *(Rangifer tarandus L.*) in arctic and subarctic Canada. Ecol. Appl. 21(6): 2334-2348. https://doi.org/10.1890/10-1410.1

Nakashima, D.J. 1990. Application of Native Knowledge in EIA: Inuit, Eiders and Hudson Bay Oil. Report Prepared for the Canadian Environmental Assessment Research Council. 30 p.

NAMMCO (North Atlantic Marine Mammals Commission). 2018. Report of the Global Review of Monodontids. 13-16 March 2017, Hillerød, Denmark. Available at: https://nammco.no/wp-content/uploads/2018/05/report-global-review-of-monodontids-nammco-2018_after-erratum-060518_2.pdf

NAMMCO (North Atlantic Marine Mammals Commission). 2020a. Bowhead Whale. Available at: https://nammco.no/bowhead-whale/#1475844711542-eedf1c7b-5dde [Date accessed: November 3, 2022].

NAMMCO (North Atlantic Marine Mammals Commission). 2020b. Bearded Seal. Available at: https://nammco.no/bearded-seal/#1475844711542-eedf1c7b-5dde [Date accessed: November 3, 2022].

NAMMCO (North Atlantic Marine Mammals Commission). 2021. Ringed Seal. Available at: https://nammco.no/ringed-seal/#1475844513273-d6d59198-d3a0 [Date accessed: November 3, 2022].

NAMMCO (North Atlantic Marine Mammal Commission). 2022a. Report to the joint disturbance workshop of the NAMMCO scientific committee working group on the population status of narwhal and beluga in the north Atlantic, and the Canada/Greenland joint commission on conservation and management of narwhal and beluga scientific working group. December 2022, Copenhagen, Denmark. Available at: https://nammco.no/scientific-working-group-reports/

NAMMCO (North Atlantic Marine Mammals Commission). 2022b. Beluga. Available at: https://nammco.no/beluga/#1475844711542-eedf1c7b-5dde [Date accessed: October 31, 2022].

National Academy of Sciences. 2002. Effects of Trawling and Dredging on Seafloor Habitat. National Academies Press, Washington, DC. 136 p. Available at: https://books.google.ca/books?hl=en&lr=&id=WV6bAgAAQBAJ&oi=fnd&pg=PA1&dq=effects+of+bottom+gillnet+on+benthic+biota+and+habitat&ots=91epHDqrNy&sig=bNlaMmSjBeSzcnh7mMUS7pkMJz4#v=onepage&q&f=false

Nedelec, S.L., Simpson, S.D, Morley, E., Nedelec, B., and Radford, A. 2015. Impacts of regular and random noise on the behaviour, growth and development of larval Atlantic cod *(Gadus morhua)*. Proc. R. Soc. B Biol. Sci. 282(1817): 1-7. https://doi.org/10.1098/rspb.2015.1943

Neilson, J.D., Waiwood, K.G., and Smith, S.J. 1989. Survival of Atlantic Halibut *(Hippoglossus hippoglossus)* Caught by Longline and Otter Trawl Gear. Can. J. Fish. Aquat. Sci. 46: 887-897

Nelson-Smith, A. 1982. Biological consequences of oil-spills in Arctic waters. *In* The Arctic Ocean: The Hydrographic Environment and the Fate of Pollutants. *Edited by* Rey, L. Macmillan Press Ltd., London, UK. pp. 275-293. Available at: https://link.springer.com/book/10.1007/978-1-349-05919-5

Newman R.C., Ellis, T., Davison, P.I., Ives, M.J., Thomas, R.J., Griffiths, S.W., and Riley, W.D. 2015. Using novel methodologies to examine the impact of artificial light at night on the cortisol stress response in dispersing Atlantic salmon *(Salmo salar L.)* fry. Conserv Physiol. 3(1): cov051. https://doi.org/10.1093/conphys/cov051

Nichol, D.G. and Chilton, E.A. 2006. Recuperation and behaviour of Pacific cod after barotrauma. ICES J. Mar. Sci. 63: 83-94

Nicol-Harper, A., Wood, K.A., Diamond, A.W., Major, H.L., Petersen, A., Tertitski, G., Doncaster, G., Ezard, T.H., and Hilton, G. 2021. Vital rate estimates for the common eider *Somateria mollissima*, a data-rich exemplar of the seaduck tribe. Ecol. Sol. Evid. 2: e12108. https://doi.org/10.1002/2688-8319.12108

Nightingale, B., Longcore, T., and Simenstad, C.A. 2006. Artificial night lighting and fishes. *In* Ecological consequences of artificial night lighting. *Edited by* Rich, C. and Longcore, T. Island Press, Washington, DC. pp. 257-276.

National Oceanic and Atmospheric Administration (NOAA). 2010. Draft environmental impact statement – initial regulatory impact review – initial regulatory flexibility analysis: For proposed effort control measures for the American lobster fishery. 304 p. Available at: https://www.greateratlantic.fisheries.noaa.gov/nero/nr/nrdoc/10/10LobsterDEIS.pdf

National Oceanic and Atmospheric Administration (NOAA). 2018. Submarine cables in Olympic Coast National Marine Sanctuary: History, impact, and management lessons. Marine Sanctuaries Conservation Series. Available at: https://repository.library.noaa.gov/view/noaa/19557

National Oceanic and Atmospheric Administration (NOAA). 2022a. Bearded seal. Available at: https://www.fisheries.noaa.gov/species/bearded-seal [Date accessed: December 11, 2023].

National Oceanic and Atmospheric Administration (NOAA). 2022b. 2010-2014 cetacean unusual mortality event in Northern Gulf of Mexico (Closed). Available at: https://www.fisheries.noaa.gov/national/marine-life-distress/2010-2014-cetacean-unusual-mortality-event-northern-gulf-mexico#more-information

Noble, D.G., Gaston, A.J., and Elliot, R.D. 1991. Preliminary estimates of survivorship and recruitment for Thick-billed Murres at Coats Island. *In* Studies of high-latitude seabirds. 2. Conservation biology of Thick-billed Murres in the Northwest Atlantic. *Edited by* Gaston, A.J. and Elliot, R.D. CWS Occ. Pap. No. 69, Ottawa, ON. pp. 45-51. Available at: https://publications.gc.ca/collections/collection_2018/eccc/CW69-1-69-eng.pdf

NORCOR Engineering and Research Ltd. 1975. The interaction of crude oil with arctic sea ice. Beaufort Sea Technical Report, no. 27, Beaufort Sea Project. Department of the Environment, Victoria BC. 201 p.

Northwest Territories Fishery Regulations. 2020. Available at: https://laws-lois.justice.gc.ca/eng/regulations/C.R.C.,_c._847/index.html [Date accessed: May 7, 2024].

NRDA (Deepwater Horizon Natural Resource Damage Assessment Trustees). 2016. Deepwater Horizon Oil Spill: Final Programmatic Damage Assessment and Restoration Plan and Final Programmatic Environmental Impact Statement. Chapter 4: Injury to Natural Resources. Available at: gulfspillrestoration.noaa.gov/restoration-planning/gulf-plan.

Nukik Corporation. 2023. Kivalliq hydro-fibre link. Available at: https://www.nukik.ca/kivalliq-hydro-fibre-link/ [Date accessed: December 13, 2023].

Nunavut Wildlife Management Board (NWMB). 2022. NWMB decision regarding the proposal to approve 2022 walrus sport hunt applications. Available at: https://www.nwmb.com/en/conservation-education/list-all-documents/decision-documents/marine-mammals/walrus-2/9583-2022-03-07-walrus-sport-hunt-applications-for-2022/file

O, M., Martone, R., Hannah, L., Grieg, L., Boutiliier, J., and Patton, S. 2015. An ecological risk assessment framework (ERAF) for ecosystem-based oceans management in the Pacific Region. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/072. vii + 59 p.

O'Brien, J.M. and Scheibling, R.E. 2018. Low recruitment, high tissue loss, and juvenile mortality limit recovery of kelp following large-scale defoliation. Mar. Biol. 165: 1-19.

Obbard, M.E., Thiemann, G.W., Peacock, E., and Debruyn, T.D. 2010. Polar bears: Proceedings of the 15th Working Meeting of the IUCN/SSC Polar Bear Specialist Group, 29 June-3 July 2009, Copenhagen, Denmark. IUCN, Gland, CH and Cambridge, UK. 235 p. Available at: https://portals.iucn.org/library/sites/library/files/documents/SSC-OP-043.pdf

Obbard, R.W., Sadri, S., Wong, Y.Q., Khitun, A.A., Baker, I., and Thompson, R.C. 2014. Global warming releases microplastic legacy frozen in Arctic Sea ice. Earth's Future. 2(6): 315-320.

Oceana. 2022. Ocean Fishes - Capelin *Mallotus vilosus*. Available at: https://oceana.ca/en/marine-life/capelin/ [Date accessed: December 11, 2023].

Oceans Act. 1996. Available at: https://laws-lois.justice.gc.ca/eng/acts/O-2.4/index.html [Date accessed: May 7, 2024].

O'Corry-Crowe, G.M. 2009. Beluga whale: *Delphinapterus leucas*. *In* Encyclopedia of marine mammals. *Edited by* Perrin, W.F., Wursig, B., and Thewissen, J.G. Academic Press. pp. 108-112.

Ogloff, W.R., Ferguson, S.H., Fisk, A.T., Marcoux, M., Hussey, N.E., Jaworenko, A., and Yurkowski, D.J. 2021. Long-distance movements and associated diving behaviour of ringed seals *(Pusa hispida)* in the eastern Canadian Arctic. Arctic Sci. 7(2): 494-511.

Okonek, D.C., Okonek, B., and Snively, M. 2007. Walrus Islands State Game Sanctuary Annual Report 2007. Alaska Department of Fish and Game, Anchorage, Alaska. 63 p.

Okonek, D.C., Okonek, B., and Snively, M. 2008. Walrus Islands State Game Sanctuary Annual Report 2008. Alaska Department of Fish and Game, Anchorage, Alaska. 60 p.

Olsen, G.H., Sva, E., Carroll, J., Camus, L., De Coen, W., Smolders, R., Øveraas, H., and Hylland, K. 2007. Alterations in the energy budget of Arctic benthic species exposed to oil-related compounds. Aquat. Toxicol. 83: 85-92. https://doi.org/10.1016/j.aquatox.2007.03.012

Olsson, O. and Gabrielsen, G.W. 1990. Effects of helicopters on a large and remote colony of Brunnich's Guillemots *(Uria lomvia)* in Svalbard. NR. 64. Norwegian Polar Research Institute Norsk Polarinstitutt Rapportserie, Oslo. 38 p.

Ordines, F. and Massutí, E. 2009. Relationships between macro-epibenthic communities and fish on the shelf grounds of the western Mediterranean. Aquat. Conserv. Mar. Freshwat. Ecosyst. 19: 370-383.

Ordines, F., Jordà, G., Quetglas, A., Flexas, M., Moranta, J., and Massutí, E. 2011. Connections between hydrodynamics, benthic landscape and associated fauna in the Balearic Islands, western Mediterranean. Cont. Shelf Res. 31(17): 1835-1844.

Øren, K., Kovacs, K.M., Yoccoz, Y. and Lydersen, C. 2018. Assessing site-use and sources of disturbance at walrus haul-outs using monitoring cameras. Polar Biol. 41(9): 1737-1750.

Øritsland, N.A., Engelhardt, F.R., Juck, F.A., Hurst, R., and Watts, P.D. 1981. Effect of crude oil on polar bears. Indian and Northern Affairs Canada. Environmental Studies. 24. Ottawa, ON, Canada.

OSPAR Commission. 2008. Background document on potential problems associated with power cables other than those for oil and gas activities. Available at: https://www.ospar.org/documents?v=7128

Outinen, O., Bailey, S.A., Casas-Monroy, O., Delacroix, S., Gorgula, S., Griniene, E., Kakkonen, J.E., and Srebaliene, G. 2024. Biological testing of ships' ballast water indicates challenges for the implementation of the Ballast Water Management Convention. Front. Mar. Sci. 11: 1334286. 10.3389/fmars.2024.1334286.

Outridge, P.M., Davis, W.J., Stewart, R.E.A, and Born, E.W. 2003. Investigation of the stock structure of Atlantic walrus *(Odobenus rosmarus rosmarus)* in Canada and Greenland using dental Pb isotopes derived from local geochemical environments. Arctic. 56: 82-90.

Ozhan, K., Parsons, M.L., and Bargu, S. 2014. How were phytoplankton affected by the Deepwater Horizon oil spill? BioScience. 64: 829-236. https://doi.org/10.1093/biosci/biu117

Paetkau, D., Amstrup, S.C., Born, E.W., Calvert, W., Derocher, A.E., Garner, G.W., Messier, F., Stirling, I., Taylor, M.K., Wiig, Ø., and Strobeck, C. 1999. Genetic structure of the world's polar bear populations. Mol. Ecol. 8(10): 15711584. https://doi.org/10.1046/j.1365-294x.1999.00733.x

Panigada, S., Pavan, G., Borg, J.A., Galil, B.S., and Vallini, C. 2008. Biodiversity impacts of ship movement, noise, grounding and anchoring. *In* Maritime traffic effects on biodiversity in the Mediterranean Sea: Review of impacts, priority areas and mitigation measures. *Edited by* Abdulla, A. and Linden, O. IUCN Centre for Mediterranean Cooperation, Malaga, Spain. pp. 9-56. Available at: https://core.ac.uk/download/pdf/83022125.pdf

Parker, G.R. 1972. Biology of the Kaminuriak population of barren-ground caribou – Part 1: Total numbers, mortality, recruitment, and seasonal distribution. Can. Wildl. Ser. Rep. Ser. 31. 93 p.

Patenaude, N.J., Richardson, W.J., Smultea, M., Koski, W., Miller, G.W., Würsig, B., and Greene, C.R. Jr. 2002. Aircraft sound and disturbance to bowhead and beluga whales during spring migration in the Alaskan Beaufort Sea. Mar. Mamm. Sci. 18(2): 309335.

Patterson, A., Gilchrist, H.G., Gaston, A., and Elliott, K.H. 2021. Northwest range shifts and shorter wintering period of an Arctic seabird in response to four decades of changing ocean climate. Mar. Ecol. Prog. Ser. 679: 163-179.

Patterson, A., Gilchrist, H.G., Benjaminsen, S., Bolton, M., Bonnet-Lebrun, A.S., Davoren, G.K., Descamps, S., Erikstad, K.E., Frederiksen, M., Gaston, A.J., and Gulka, J. 2022. Foraging range scales with colony size in high-latitude seabirds. Curr. Biol. 32(17): 3800-3807. https://doi.org/10.1016/j.cub.2022.06.084

Peacock, E., Sahanatien, V., Stapleton, S., Derocher, A., and Garshelis, D. 2009. Foxe Basin Polar Bear Project 2009 Interim Report. Wildlife Research Section, Government of Nunavut. Available at: https://www.gov.nu.ca/sites/default/files/foxe_basin_polar_bear_project_interim_report_2009.pdf

Peckol, P., Levings, S.C., and Garrity, S.D. 1990. Kelp response following the World Prodigy oil spill. Mar. Poll. Bull. 21(10): 473-476. https://doi.org/10.1016/0025-326X(90)90066-H

Percopo, I., Ruggiero, M.V., Balzano, S., Gourvil, P., Lundolm, N., Siano, R., Tammilehto, A., Vaulot, D., and Sarno, D. 2016. *Pseudo-nitzshia arctica* sp. Nov., a new cold-water cryptic *Pseudo-nitzchia* species within the *P. pseudodelicatissima* complex. J. Phycol. 152: 184-199.

Peterson, C.H., Rice, S.D., Short, J.W., Esler, D., Bodkin, J.L., Ballachey, B.E., and Irons, D.B. 2003. Long-term ecosystem response to the Exxon Valdez oil spill. Sci. 302: 2082-2086. https://doi.org/10.1126/science.1084282

Piatt, J.F. and Ford, R.G. 1996. How many seabirds were killed by the Exxon Valdez oil spill? Am. Fish. Soc. Symp. 18: 712-719.

Pierrejean, M., Babb, D.G., Maps, F., Nozais, C., and Archambault, P. 2020. Spatial distribution of epifaunal communities in the Hudson Bay system. Elem. Sci. Anth. 8(1): 00044. https://doi.org/10.1525/elementa.00044

Pine, M.K., Hannay, D.E., Insley, S.J., Halliday, W.D., and Juanes, F. 2018. Assessing vessel slowdown for reducing auditory masking for marine mammals and fish of the western Canadian Arctic. Mar. Pollut. Bull. 135: 290-302. Available at: https://www.ncbi.nlm.nih.gov/pubmed/30301040

Pippard, L. 1985. Status of the St. Lawrence River population of beluga, *Delphinapterus leucas*. Can. Field-Nat. 99(3): 438-450.

Pitcher, C.R., Ellis, N., Jennings, S., Hiddink, J.G., Mazor, T., Kaiser, M.J., Kangas, M.I., McConnaughey, R.A., Parma, A.M., Rijnsdorp, A.D., Suuronen, P., Collie, J.S., Amoroso, R., Hughes, K.M., and Hilborn, R. 2017. Estimating the sustainability of towed fishing-gear impacts on seabed habitats: a simple quantitative risk assessment method applicable to data-limited fisheries. Methods Ecol. Evol. 8(4): 472-480. https://doi.org/10.1111/2041-210X.12705

Pomerleau, C., Lesage, V., Ferguson, S.H., Winkler, G., Petersen, S.D., and Higdon, J.W. 2012. Prey assemblage isotopic variability as a tool for assessing diet and the spatial distribution of bowhead whale Balaena mysticetus foraging in the Canadian eastern Arctic. Mar. Ecol. Prog. Ser. 469: 161-174.

Poon, F.E., Provencher, J., Mallory, M.L., Braune, B.M., and Smith, P. 2017. Levels of Ingested Debris Vary Across Species in Canadian Arctic Seabirds. Mar. Poll. Bull. 116(1-2): 517-520.

Poplawski, K., Setton, E., McEwen, B., Hrebenyk, D., Graham, M., and Keller, P. 2011. Impact of cruise ship emissions in Victoria, BC, Canada. Atmos. Enviro. 45(4): 824-833. https://doi.org/10.1016/j.atmosenv.2010.11.029

Popper, A.N. and Hawkins, A.D. 2018. The importance of particle motion to fishes and invertebrates. J. Acoust. Soc. Am. 143(1): 470-488. https://doi.org/10.1121/1.5021594

Popper, A.N. and Hawkins, A.D. 2019. An overview of fish bioacoustics and the impacts of anthropogenic sounds on fishes. J. Fish Biol. 94(5): 692-713. https://doi.org/10.1111/jfb.13948

Poulin, M., Daugbjerg, N., Gradinger, R., Ilyash, L., Ratkova, T., and von Quillfeldt, C. 2011. The pan-Arctic biodiversity of marine pelagic and sea-ice unicellular eukaryotes: a first-attempt assessment. Mar. Biodivers. 41: 13-28.

Priest, H. and Usher, P.J. 2004. The Nunavut Wildlife Harvest Study. Iqaluit, NU: Nunavut Wildlife Management Board. 822 p.

Qikiqtani Inuit Association. 2021. Tusaqtavut: What we heard – Mary River mine project. Available at: https://www.qia.ca/wp-content/uploads/2022/03/qia-tusaqtavut-report_2021_web.pdf

Quick, N., Scott-Hayward, L., Sadykova, D., Nowacek, D., and Read, A. 2017. Effects of a scientific echo sounder on the behavior of short-finned pilot whales *(Globicephala macrorhynchus).* Can. J. Fish. Aquat. Sci. 74(5): 716-726.

Quigg, A., Parsons, M., Bargu, S., Ozhan, K., Daly, K.L., Chakraborty, S., Kamalanathan, M., Erdner, D., Cosgrove, S., and Buskey, E. 2021. Marine phytoplankton responses to oil and dispersant exposures: Knowledge gained since the Deepwater Horizon oil spill. Mar. Poll. Bull. 164: 112074. https://doi.org/10.1016/j.marpolbul.2021.112074

Quinn, P.K., Bates, T.S., Baum, E., Doubleday, N., Fiore, A., Flanner, M., Fridlind, A., Garrett, T.J., Koch, D., Menon, S., Shindell, D., Stohl, A. and Warren, S.G. 2008. Short-lived pollutants in the Arctic: their climate impact and possible mitigation strategies. Atmos. Chem. Phys. 8(6): 1723-1735. https://doi.org/10.5194/acp-8-1723-2008

Quintillion (Global Communication). 2022. Quintillion's System Asia & Europe. Available at: https://www.quintillionglobal.com/system/out-asia-europe/ [Date accessed: December 11, 2023].

Ragnarsson, S.Á., Burgos, J.M., Kutti, T., van den Beld, I., Egilsdóttir, H., Arnaud-Haond, S., and Grehand, A. 2016. The impact of anthropogenic activity on cold-water corals. *In* Marine Animal Forests. *Edited by* Rossi, S., Bramanti, L., Gori, A., and Orejas, C. Springer. pp. 1-35. https://doi.org/10.1007/978-3-319-17001-5_27-1

Ramsay, M.A. and Stirling, I. 1988. Reproductive biology and ecology of female polar bears (Ursus maritimus). J. Zool. 214: 601-634. http://dx.doi.org/10.1111/j.1469-7998.1988.tb03762.x

Randelhoff, A., Lacour, L., Marec, C., Laymarie, E., Lagunas, J., Xing, X., Darnis, G., Penkerc'h, C., Sampei, M., Fortier, L, D'Ortenzio, F., Claustre, H., and Babin, M. 2020. Arctic mid-winter phytoplankton growth revealed by autonomous profilers. Sci. Adv. 6: eabc2678. https://doi.org/10.1126/sciadv.abc2678

Rapinski, M., Cuerrier, A., Harris, C., and Lemire, M. 2018. Inuit perception of marine organisms: from folk classification to food harvest. J. Ethno. 38(3): 333-355.

Raut, J.-C., Law, K.S., Onishi, T., Daskalakis, N., and Marelle, L. 2016. Impact of shipping emissions on air pollution and pollutant deposition over the Barents Sea. Environ. Pollut. 298: 118832. 10.1016/j.envpol.2022.118832

Reddin, D.G., Johnson, R., and Downton, P. 2002. A study of by-catches in herring bait nets in Newfoundland, 2001. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2002/031. 20 p.

Reeves, R.R. 1998. Distribution, abundance and biology of ringed seals *(Phoca hispida):* an overview. NAMMCO Sci. Publ. 1: 9-45.

Reeves, R.R., Stewart, B.S., and Leatherwood, S. 1992. The Sierra Club Handbook of Seals and Sirenians. Sierra Club Books, San Francisco, California. xvi + 359 p.

Reeves, R.R., Rosa, C., George, C.J., Sheffield, G., and Moore, M. 2012. Implications of Arctic industrial growth and strategies to mitigate future vessel and fishing gear impacts on bowhead whales. Mar. Pol. 36(2): 454-462. https://doi.org/10.1016/j.marpol.2011.08.005

Reeves, R.R., McClellan, K., and Werner, T.B. 2013. Marine mammal bycatch in gillnet and other entangling net fisheries, 1990 to 2011. Endanger. Species Res. 20: 71-97.

Regehr, E.V., Wilson, R.R., Rode, K.D., and Runge, M.C. 2015. Resilience and risk—A demographic model to inform conservation planning for polar bears: U.S. Geological Survey Open-File Report 2015- 1029. 56 p. http://dx.doi.org/10.3133/ofr20151029

Regular, P., Montevecchi, W., Hedd, A., Robertson, G., and Wilhelm, S. 2013. Canadian fishery closures provide a large-scale test of the impact of gillnet bycatch on seabird populations. Biol. Lett. 9: 20130088.

Reijnders, P., Brasseur, S., van der Toorn, J., van der Wolf, P., Boyd, I., Harwood, J., Lavigne, D., and Lowry, L. 1993. Seals, fur seals, sea lions, and walrus. Status survey and conservation action plan. Seal Specialist Group, IUCN. 88 p.

Reimer, J.R., Caswell, H., Derocher, A.E., and Lewis, M.A. 2019. Ringed seal demography in a changing climate. Ecol. Appl. 29(3): e01855. https://doi.org/10.1002/eap.1855

Reiss, H. and Krönke, I. 2005. Seasonal variability of benthic indices: an approach to test the applicability of different indices for ecosystem quality assessment. Mar. Pollut. Bull. 50: 1490-1499. https://doi.org/10.1016/j.marpolbul.2005.06.017

Ricciardi, A. and MacIsaac, H.J. 2000. Recent mass invasion of the North American Great Lakes by Ponto–Caspian species. Trends Ecol. Evol. 15(2): 62-65. https://doi.org/10.1016/S0169-5347(99)01745-0

Rice, J. 2006. Impacts of Mobile Bottom Gears on Seafloor Habitats, Species, and Communities: A Review and Synthesis of Selected International Reviews. DFO Can. Sci. Advis. Sec. Res. Doc.: 2006/057. iv + 35 p.

Rice, S.D., Thomas, R.E., Carls, M., Heintz, R.A, Wertheimer, A.C., Murphy, M.L., Short, J.W., and Moles, A. 2001. Impacts to pink salmon following the Exxon Valdez oil spill: Persistence, toxicity, sensitivity, and controversy. Rev. Fish. Sci. 9(3): 165-211. https://doi.org/10.1080/20016491101744

Richard, P.R., Heide-Jørgensen, M.P., and Orr, J.R. 2001. Summer and autumn movements of belugas of the eastern Beaufort Sea Stock. Arctic. 54: 2203-236.

Richards, J. and Gaston A.J. (eds.). 2018. The Birds of Nunavut. University of British Columbia Press, Vancouver, BC. 820 p.

Richardson, W.J. and Finely, K.J. 1989. Comparison of behavior of bowhead whales of the Davis Strait and Bering/Beaufort stocks. OCS Study MMS88-0056. Rep. from LGL Ltd., King City, Ont., for U.S. Minerals Manage. Serv., Herndon, VA. 131p. NTIS PB89195556.

Richardson, W.J. and Malme, C.I. 1993. Man-made noise and behavioral responses. *In* The Bowhead Whale. *Edited by* Burns, J.J., Montague, J.J., and Cowles, C.J. Spec. Publ. 2, Soc. Mar. Mamm., Lawrence, KS. pp. 631-700.

Richardson, W.J., Davis, R.A., Evans, C.R., and Norton, P. 1985a. Distribution of bowheads and industrial activity, 1980-84. *In* Behavior, disturbance responses and distribution of bowhead whales Balaena mysticetus in the eastern Beaufort Sea, 1980-84. *Edited by* Richardson, W.J. OCS Study MMS 85-0034. Rep. from LGL Ecol. Res. Assoc. Inc., Bryan, TX, for U.S. Minerals Manage. Serv., Reston, VA. NTIS PB87-124376. pp. 89-196

Richardson, W.J., Fraker, M.A., Würsig, B., and Wells, R.S. 1985b. Behaviour of bowhead whales *Balaena mysticetus* summering in the Beaufort Sea: reactions to industrial activities. Biol. Conserv. 32(3): 195-230.

Richardson, W.J., Wells, R.S., and Wursig, B. 1985c. Disturbance responses of bowheads, 1980-84. *In* Behavior, disturbance responses and distribution of bowhead whales Balaena mysticetus in the eastern Beaufort Sea, 1980-84. *Edited by* Richardson, W.J. OCS Study MMS 85-0034. Rep. from LGL Ecol. Res. Assoc. Inc., Bryan, TX, for U.S. Minerals Manage. Serv., Reston, VA. NTIS PB87-124376. pp. 89-196.

Richardson, W.J., Thomson, D.H., Greene, C.R. Jr., and Malme, C.I. 1995a. Marine mammals and noise. Academic Press, San Diego, CA. 576 p.

Richardson, W.J., Greene, C.R. Jr., Hanna, J.S., Koski, W.R., Miller, G.W., Patenaude, N.J., and Smultea, M.A. with Blaylock, R., Elliott, R. and Würsig, B. 1995b. Acoustic effects of oil production activities on bowhead and white whales visible during spring migration near Pt. Barrow, Alaska - 1991 and 1994 phases. OCS Study MMS 95-0051; LGL Re. TA954. Rep. from LGL Ltd., King City, Ont., for U.S. Minerals Manage. Serv., Herndon, VA. 539 p. NTIS PB98-107667.

Richardson, E.S., Davis, C., Stirling, I., Derocher, A.E., Lunn, N.J., and Malenfant, R. 2020. Variance in lifetime reproductive success of male polar bears. Behav. Ecol. 31(5): 1224-1232. Available at: https://academic.oup.com/beheco/article-pdf/31/5/1224/33864811/araa074.pdf

Riera, A., Rountree, R.A., Pine, M.K., and Juanes, F. 2018. Sounds of Arctic cod *(Boreogadus saida)* in captivity: A preliminary description. J. Acoust. Soc. Amer. 143: EL317. https://doi.org/10.1121/1.5035162

Riley, C., Drolet, D., Goldsmit, J., Hill, J.M., Howland, K.L., Lavoie, M., McKenzie, M., Simard, N., and McKindsey, C.W. 2022. Experimental analysis of survival and recovery of ship fouling mussels during transit between marine and freshwaters. Front. Mar. Sci. 8: 808007. https://doi.org/10.3389/fmars.2021.808007

Robbins, J., Knowlton, A.R., and Landry, S. 2015. Apparent survival of North Atlantic right whales after entanglement in fishing gear. Biol. Conserv. 191: 421-427. https://doi.org/10.1016/j.biocon.2015.07.023

Rodriguez, A., Garcia, D., Rodriguez, B., Cardona, E., Parpal, L., and Pons, P. 2015. Artificial lights and seabirds: is light pollution a threat for the threatened Balearic petrels? J. Ornithol. 156: 893-902. http://dx.doi.org/10.1007/s10336-015-1232-3

Roff, J.C., Pett, R.J., and Rogers, G. 1980. A study of plankton ecology in Chesterfield Inlet, NWT: An Arctic estuary. *In* Estuarine Perspectives. *Edited by* Kennedy, V.S. Academic Press Inc. pp. 185-197.

Roff, J.C., Giangioppi, M., Gerhartz-Abraham, A., Merritt, W., James, T.D., Keenan, E., and Davidson, E. 2020. Marine Ecological Conservation for the Canadian Eastern Arctic–A Systematic Planning Approach for Identifying Priority Areas for Conservation. Word Wildlife Fund (Canada), Toronto, ON. xxii + 281 p.

Rogers, C.S. and Garrison, V.H. 2001. Ten years after the crime, lasting effects of damage from a cruise ship anchor on a coral reef in St. John, U.S. Virgin Islands. B. Mar. Sci. 69: 793-803. Available at: http://refhub.elsevier.com/S0025-326X(20)30801-8/rf0460

Roleda, M.Y. 2016. Stress physiology and reproductive phenology of Arctic endemic kelp *Laminaria solidungula* J. Agardh. Polar Biol. 39: 1967-1977. https://doi.org/10.1007/s00300-015-1813-x

Rolland, R.M., Graham, K.M., Stimmelmayr, R., Suydam, R.S., and George, J.C. 2019. Chronic stress from fishing gear entanglement is recorded in baleen from a bowhead whale *(Balaena mysticetus).* Mar. Mamm. Sci. 35: 1625-1642. 10.1111/mms.12596

Ronconi, R.A., Allard, K.A., and Taylor, P.D. 2015. Bird interactions with offshore oil and gas platforms: Review of impacts and monitoring techniques. J. Enviro. Manag. 147: 34-45.

Ronowicz, M., Kuklinski, P., and Włodarska-Kowalczuk, M. 2018. Diversity of kelp holdfast-associated fauna in an Arctic fjord – inconsistent responses to glacial mineral sedimentation across different taxa. Estuarine, Coastal and Shelf Sci. 205: 100-109.

Roth, E.H., Schmidt, V., Hildebrand, J.A., and Wiggins, S.M. 2013. Underwater radiated noise levels of a research icebreaker in the central arctic ocean. J. Acoust. Soc. Am. 133(4): 1971-1980. https://doi.org/10.1121/1.4790356

Rowe, S. and Hutchings, J.A. 2004. The function of sound production by Atlantic Cod as inferred from patterns of variation in drumming muscle mass. Can. J. Zool. 82(9): 1391-1398.

Rowe, S. and Hutchings, J.A. 2006. Sound production by Atlantic Cod during spawning. Trans. Am. Fish. Soc. 135: 529-538.

Rowe, S. and Hutchings, J.A. 2008. A link between sound producing musculature and mating success in Atlantic Cod. J. Fish Biol. 72(3): 500-511.

Rubao, J., Ashjian, C.J., Campbell, R.G., Chen, C., Gao, G., Davis, C.S., Cowles, G.W., and Beardsley, R.C. 2012. Life history and biogeography of Calanus copepods in the Arctic Ocean: An individual-based modeling study. Prog. Oceanogr. 96: 40-56. http://dx.doi.org/10.1016/j.pocean.2011.10.001

Ruberg, E.J., Elliott, J.E., and Williams, T.D. 2021. Review of petroleum toxicity and identifying common endpoints for future research on diluted bitumen toxicity in marine mammals. Ecotoxicol. 30: 537-551.

Rugh, D. 1990. Bowhead whales reidentified through aerial photography near Point Barrow, Alaska. Rep. Int. Whal. Comm., Special Issue. 12: 289-294.

Rugh, D.J., Shelden, K., and Mahoney, B.A. 2000. Distribution of beluga whale, *Delphinapterus leucas*, in Cook Inlet, Alaska, during June/July 1993-2000. Mar. Fish. Rev. 63(3): 6-21.

Ruiz, G.M., Rawlings, T.K., Dobbs, F.C., Drake, L., Mullady, T., Huq, A., and Colwell, R.R. 2000. Global spread of microorganisms by ships. Nature. 408(6808): 49-50.

Rummer, J.L. and Bennett, W.A. 2005. Physiology Effects of Swim Bladder Overexpansion and Catastrophic Decompression on Red Snapper. Trans. Am. Fish. Soc. 134: 1457-1470.

Ryan, P.G. 1991. The impact of the commercial lobster fishery on seabirds at the Tristan da Cunha Islands, South Atlantic Ocean. Biol. Conserv. 57: 339-350.

Ryan, K.P., Ferguson, S.H., Koski, W.R., Young, B.G., Roth, J.D., and Watt, C.A. 2022. Use of drones for the creation and development of a photographic identification catalogue for an endangered whale population. Arct. Sci. 8(4): 1191-1201 dx.doi.org/10.1139/AS-2021-0047.

Ryer, C.H., Ottmar, M.L., and Sturm, E.A. 2004. Behavioral impairment after escape from trawl codends may not be limited to fragile fish species. Fish. Res. 66: 261-269.

Sahanatien, V., Peacock, E., and Derocher, A.E. 2015. Population substructure and space use of Foxe Basin polar bears. Ecol. Evol. 5(14): 2851-2864. https://doi.org/10.1002%2Fece3.1571

Salter, R.E. 1979. Site utilization, activity budgets, and disturbance responses of Atlantic walruses during terrestrial haul-out. Can. J. Zool. 57(6): 1169-1180.

Sameoto, D.D. and Herman, A.W. 1990. Life cycle and distribution of *Calanus finmarchicus* in deep basins on the Nova Scotia shelf and seasonal changes in *Calanus* spp. Mar. Ecol. Prog. Ser. 66: 225-237. Available at: https://www.int-res.com/articles/meps/66/m066p225.pdf

Samhouri, J.F. and Levin, P.S. 2012. Linking land- and sea-based activities to risk in coastal ecosystems. Biol. Conserv. 145: 118-129.

Savoca, M.S., Brodie, S., Welch, H., Hoover, A., Benaka, L.R., Bograd, S.J., and Hazen, E.L. 2020. Comprehensive bycatch assessment in US fisheries for prioritizing management. Nat. Sustainability. 3(6): 472-480.

Sayinli, B., Dong, Y., Park, Y., Bhatnagar, A., and Sillanpää, M. 2022. Recent progress and challenges facing ballast water treatment–a review. Chemosphere. 291: 132776.

SCAR (Scientific Committee on Antarctic Research ad hoc group on marine acoustic technology and the environment). 2002. Impacts of marine acoustic technology on the Antarctic environment. Version 1.2. Available at: https://www.geoscience.scar.org/geophysics/acoustics_1_2.pdf

Scheibling, R. 1986. Increased macroalgal abndance following mass mortalities of sea urchins *(Strongylocentrus droebachiensis)* along the Atlantic coast of Nova Scotia. Oecologia. 68(2): 186-198.

Scheibling, R. and Anthony, S. 2001. Feeding, growth and reproduction of sea urchins *(Strongylocentrotus droebachiensis)* on single and mixed diets of kelp *(Laminaria spp.)* and the invasive alga Codium fragile *ssp. tomentosoides*. Mar. Biol. 139(1): 139-146.

Scheibling, R.E. and Gagnon, P. 2006. Competitive interactions between the invasive green algal Codium fragile *spp. tomentosoides* and native canopy-forming seaweeds in Nova Scotia (Canada). Mar. Ecol. Prog. Ser. 325: 1-14.

Scheibling, R. and Gagnon, P. 2009. Temperature-mediated outbreak dynamics of the invasive bryozoan *Membranipora membranacea* in Nova Scotian kelp beds. Mar. Ecol. Prog. Ser. 390: 1-13.

Schoeman, R.P., Patterson-Abrolat, C., and Plön, S. 2020. A global review of vessel collisions with marine animals. Front. Mar. Sci. 7: 292.

Schwacke, L.H., Marques, T.A., Thomas, L., Booth, C., Balmer, B.C., Barratclough, A., Colegrove, K., De Guise, S., Garrison, L.P., Gomez, F.M., and Morey, J.S. 2021. Modeling population impacts of the Deepwater Horizon oil spill on a long-lived species with implications and recommendations for future environmental disasters. Conserv. Biol. 36(4): e13878. doi:10.1111/cobi.13878.

Schwemmer, P., Mendel, B., Sonntag, N., Dierschke, V., and Garthe, S. 2011. Effects of ship traffic on seabirds in offshore waters: implications for marine conservation and spatial planning. Ecol. Appl. 21: 1851-1860. https://doi.org/10.1890/10-0615.1

Science Advisory Panel. 2002. The impact of cruise ship wastewater discharge on Alaska waters. Commercial passenger vessel environmental compliance program, Alaska Department of Environmental Conservation. xviii + 256 p.

Scott, W.B. and Scott, M.G. 1988. Atlantic fishes of Canada. University of Toronto Press, Toronto, Can. 731 p.

Seaman, G.A. and Burns, J.J. 1981. Preliminary results of recent studies of belukhas in Alaskan waters. Rep. Int. Whal. Comm. 31: 567-574.

Sephton, D., Vercaemer, B., Silva, A., Stiles, L., Harris, M., and Godin, K. 2017. Biofouling monitoring for aquatic invasive species (AIS) in DFO Maritimes Region (Atlantic shore of Nova Scotia and southwest New Brunswick): May-November, 2012-2015. Can. Tech. Rep. Fish. Aquat. Sci. 3158: ix + 111 p. + appendices.

Sergeant, D.E. 1965. Migrations of harp seals *Pagophilus groenlandicus* (Erxleben) in the Northwest Atlantic. J. Fish Res. Board Can. 22: 433-464.

Sergeant, D.E. 1973. Biology of white whales *(Delphinapterus leucas)* in Western Hudson Bay. J. Fish. Res. Board. Can. 30: 1065-1090.

Sergeant, D.E. 1976. History and present status of populations of harp and hooded seals. Biol. Conserv. 10: 95-118.

Sergeant, D.E. 1991. Harp seals, man and ice. Can. J. Fish. Aquat. Sci. 114: 1-153.

Serrano, A., Sanchez, F., Preciado, I., Parra, S., and Frutos, I. 2006. Spatial and temporal changes in the benthic communities of the Galician continental shelf after the Prestige oil spill. Mar. Pollut. Bull. 53: 315-331.

Shapiro, A.D. 2006. Preliminary evidence for signature vocalizations among free-ranging narwhales *(Monodon monoceros).* J. Acoust. Soc. Am. 120(3): 1695-1705.

Shapiro, O.H., Fernandez, V.I., Garren, M., Guasto, J.S., Debaillon-Vesque, F.P., Kramarsky-Winter, E., Vardi, A., and Stocker, R. 2014. Vortical ciliary flows actively enhance mass transport in reef corals. PNAS. 111(37): 13391-13396.

Shata, A.A. 2010. Recovery of oil spills by dispersants in marine arctic regions. Research spring 2010. Department of Mathematics and Natural Sciences, Faculty of Science and Technology, University of Stavanger, Stavanger, Norway. vii + 82 p. Available at: http://hdl.handle.net/11250/182414

Sherwood, J., Chidgey, S., Crockett, P., Gwyther, D., Ho, P., Stewart, S., Strong, D., Whitely, B., and Williams, A. 2016. Installation and operational effects of a HVDC submarine cable in a continental shelf setting: Bass Strait, Australia. J. Ocean Eng. Sci. 1: 337-353. http://dx.doi.org/10.1016/j.joes.2016.10.001

Shideler, D. 1993. Deterrent methods. *In* Guidelines for oil and gas operations in polar bear habitats. *Edited by* Truett, J.C. OCS Study MMS 93-0008. Rep. from LGL Ecol. Res. Assoc. Inc., Bryan, TX, for U.S. Minerals Manage. Serv., Anchorage, AK. pp. 35-50.

Sierra-Flores, R., Atack, T., Migaud, H., and Davie, A. 2015. Stress response to anthropogenic noise in Atlantic cod *Gadus morhua*. L. Aquac. Eng. 67: 67-76. https://doi.org/10.1016/j.aquaeng.2015.06.003

Siferd, T. 2010. By-catch in the shrimp fishery from Shrimp Fishing Areas 0-3, 1979 to 2009. DFO Can. Sci. Advis. Sec. Res. Doc.: 2010/037. vi + 77 p.

Sills, J.M., Reichmuth, C., Southall, B.L., Whiting, A., and Goodwin, J. 2020. Auditory biology of bearded seals *(Erignathus barbatus).* Polar Biol. 43: 1681-1691.

Silversea Cruises Ltd. 2022. Silver explorer. Available at: https://www.silversea.com/ships/silver-explorer.html [Date accessed: August 3, 2022].

Slabbekoorn, H., Bouton, N., van Opzeeland, I., Coers, A., Cate, C., and Popper, A.N. 2010. A noisy spring: the impact of globally rising underwater sound levels on fish. Trends Ecol. Evol. 25(7): 419-427. https://doi.org/10.1016/j.tree.2010.04.005

Slattery, M. and Bockus, D. 1997. Sedimentation in McMurdo Sound, Antarctica: a disturbance mechanism for benthic invertebrates. Polar Biol. 18: 172-179. https://doi.org/10.1007/s003000050174

Smart, M.M., Rada, R.G., Nielsen, D.N., and Claflin, T.O. 1985. The effect of commercial and recreational traffic on the resuspension of sediment in navigation pool 9 of the upper Mississippi River. Hydrobiologia. 126: 263-274.

Smith, T.G. 1975. Ringed seals in James Bay and Hudson Bay: population estimates and catch statistics. Arctic. 28(3): 170-182.

Smith, T.G. 1981. Notes on the bearded seal*, Erignathus barbatus*, in the Canadian Arctic. Can. Tech. Rep. Fish. Aquat. Sci. 1042: 58 p.

Smith, T.G. 1987. The ringed seal, *Phoca hispida*, of the Canadian western Arctic. Can. Bull. Fish. Res. and Aquat. Sci. 216: x + 81 p.

Smith, S.D. and Simpson, R.D. 1998. Recovery of benthic communities at Macquarie Island (sub-Antarctic) following a small oil spill. Mar. Biol. 131: 567-581. https://doi.org/10.1007/s002270050349

Smith, T.G. and Sjare, B. 1990. Predation of belugas and narwhals by polar bears in nearshore areas of the Canadian High Arctic. Arctic: 43(2): 99-102.

Smith, T.S., Partridge, S.T., Amstrup, S.C., and Schliebe, S. 2007. Post-den emergence behavior of polar bears *(Ursus maritimus)* in Northern Alaska. Arctic. 60(2): 187-194.

Smith, H.R., Moulton, V.D., Raborn, S., Abgrall, A., Elliott, R., and Fitzgerald, M. 2017. Shore-based monitoring of narwhals and vessels at Bruce Head, Milne Inlet, 2016. LGL Report No. FA0089-1. Prepared by LGL Limited, King City, ON for Baffinland Iron Mines Corporation, Oakville, ON. 87 p. + appendices.

Smith-Veniz, W.F., Fernandes, P., Heessen, H., and Collette, B. 2015. *Mallotus villosus* (Europe assessment). The IUCN Red List of Threatened Species 2015: e.T18155925A56707167. Available at: https://www.iucnredlist.org/species/18155925/56707167

Smultea, M.A. and Würsig, B. 1995. Behavioral reactions of bottlenose dolphins to the Mega Borg oil spill, Gulf of Mexico 1990. Aquat. Mamm. 21: 171-181.

Smultea, M.A., Mobley, J.R., Fertl, D., and Fulling, G.L. 2008. An Unusual Reaction and Other Observations of Sperm Whales Near Fixed-Wing Aircraft. Gulf Caribb. Res. 20(1): 75-80. doi:10.18785/gcr.2001.10.

Smultea, M.A., Brueggeman, J., Robertson, F., Fertl, D., Bacon, C., Rowlett, F.A., and Green, G. 2016. Polar bear *(Ursus maritimus)* behavior near icebreaker operations in the Chukchi Sea, 1991. Arctic. 69(2): 177-184. http://dx.doi.org.10.14430/arctic4566

Snell, R.R., Pyle, P., and Patten, M. 2020. Iceland Gull *(Larus glaucoides)*. *In* Birds of the World. *Edited by* Rodewald, P.G. and Keeney, B.K. Cornell Lab of Ornithology, Ithaca, NY, USA. https://doi.org/10.2173/bow.y00478.01

Southall, B.L., Rowles, T., Gulland, F., Baird, R.W., and Jepson, P. 2013. Final report of the Independent Scientific Review Panel investigating potential contributing factors to a 2008 mass stranding of melon-headed whales *(Peponocephala electra)* in Antsohihy, Madagascar. Available at: http://iwc.int/2008-mass-stranding-in-madagascar

Southall, B.L., Finneran, J.J., Reichmuth, C., Nachtigall, P.E., Ketten, D.R., Bowles, A.E., Ellison, W.T., Nowacek, D.P., and Tyack, P.L. 2019. Marine mammal noise exposure criteria: Updated scientific recommendations for residual hearing effects. Aquat. Mamm. 45(2): 125-232.

Species at Risk Act. 2002. Available at: https://laws-lois.justice.gc.ca/eng/acts/s-15.3/ [Date accessed: May 7, 2024].

Spraker, T.R., Lowry, L.F., and Frost, K.J. 1994. Gross necropsy and histopathological lesions found in harbor seals. *In* Marine Mammals and the Exxon Valdez. *Edited by* Loughlin, T.R. Academic Press, San Diego, CA. pp. 281-311.

Spurkland, T. and Iken, K. 2011. Kelp bed dynamics in estuarine environments in subarctic Alaska. J. Coast. Res. 275: 133-143.

St. Aubin, D.J. 1990. Physiological and toxic effects on pinnipeds. *In* Sea Mammals and Oil: Confronting the Risks. *Edited by* Geraci, J.R. and St. Aubin, D.J. Academic Press, San Diego, CA. pp. 103-127.

St. Aubin, D.J., Geraci, J.R., Smith, T.G., and Friesen, T. 1985. How do bottlenose dolphins, *Tursiops truncatus*, react to oil films under different light conditions? Can. J. Fish. Aquat. Sci. 42: 430-436.

Stafford-Smith, M. and Ormond, R. 1992. Sediment-rejection mechanisms of 42 species of Australian scleractinian corals. Mar. Freshw. Res. 43: 683-705.

Stanley, J.A., Van Parijs, S.M., and Hatch, L.T. 2017. Underwater sound from vessel traffic reduces the effective communication range in Atlantic cod and haddock. Sci. Rep. 7: 14633. 10.1038/s41598-017-14743-9

Stapleton, S., Peacock, E., and Garshelis, D. 2016. Aerial surveys suggest long-term stability in the seasonally ice-free Foxe Basin (Nunavut) polar bear population. Mar. Mamm. Sci. 32: 181-201.

Steen, H., Moy, F.E., Bodvin, T., and Husa, V. 2016. Regrowth after kelp harvesting in Nord-Trøndelag, Norway. ICES J. Mar. Sci. 73(10): 2708-2720.

Steneck, R.S., Graham, M.H., Bourque, B.J., Corbett, D., Erlandson, J.M., Estes, J., and Tegner, M.J. 2002. Kelp forest ecosystems: biodiversity, stability, resilience and future. Environ. Conserv. 29: 436-459. https://doi.org/10.1017/S0376892902000322

Stephenson, S.A. and Hartwig, L. 2010. The Arctic Marine Workshop: Freshwater Institute Winnipeg, Manitoba, February 16-17, 2010. Can. Manuscript Rep. Fish. Aquat. Sci. 2934: vi + 67p.

Stewart, R.E. 2002. Review of Atlantic walrus (Odobenus rosmarus rosmarus) in Canada. Can. Sci. Adv. Sec. Res. Doc. 2002/091. 20 p.

Stewart, R.E. 2008. Redefining walrus stocks in Canada. Arctic. 61(3): 292-308.

Stewart, D.B. and Howland, K.L. 2009. An Ecological and Oceanographical Assessment of the Alternate Ballast Water Exchange Zone in the Hudson Strait Region. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/008. vi + 96 p.

Stewart, D.B. and Barber, D.G. 2010. The ocean-sea ice-atmosphere system of the Hudson Bay Complex. *In* A Little Less Arctic: Top Predators in the World's Largest Northern Inland Sea, Hudson Bay. *Edited by* Ferguson, S.H., Loseto, L.L., and Mallory, M.L. Springer, New York, USA. pp. 1-38.

Stewart, B.S., Evans, W.E., and Awbrey, F.T. 1982. Effects of man-made waterborne noise on behavior of Belukha whales *(Delphinapterus leucas)* in Bristol Bay, Alaska. HSWRI Tech. Rep. 82-145. Rep. from Hubbs/Sea World Res. Inst., San Diego, CA, for U.S. Natl. Oceanic & Atmos. Admin., Juneau, AK. 29 p.

Stewart, R.E., Campana, S.E., Jones, C.M., and Stewart, B.E. 2006. Bomb radiocarbon dating calibrates beluga *(Delphinapterus leucas)* age estimates. Can. J. Zool. 84(12): 1840-1852.

Stewart, E.J., Tivy, A., Howell, S., Dawson, J., and Draper, D. 2010. Cruise Tourism and Sea Ice in Canada's Hudson Bay Region. Arctic. 63(1): 57-66. 10.14430/arctic647

Stewart, R.E., Lesage, V., Lawson, J.W., Cleator, H., and Martin, K.A. 2012. Science Technical Review of the draft Environmental Impact Statement (EIS) for Baffinland's Mary River Project. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/086. vi + 62 p.

Stewart, D.B., Nudds, S., Howland, K.L., Hannah, C., and Higdon, J.W. 2015. An ecological and oceanographical assessment of alternate blast water exchange zones in the Canadian eastern Arctic. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/037. vi + 64 p.

Stewart, D.B., Higdon, J.W., and Stewart, R.E.A. 2020. Threats and effects pathways of shipping related to non-renewable resource developments on Atlantic walruses *(Odobenus rosmarus rosmarus)* in Hudson Strait and Foxe Basin, Nunavut. Can. Tech. Rep. Fish. Aquat. Sci. 3283: x + 59 p.

Stirling, I. 1980. The biological importance of polynyas in the Canadian Arctic. Arctic. 33(2): 303-315. https://doi.org/10.14430/arctic2563

Stirling, I. 1988a. Polar bears. University of Michigan Press, Ann Arbor, Michigan. 232 p.

Stirling, I. 1988b. Attraction of polar bears Ursus maritimus to offshore drilling sites in the eastern Beaufort Sea. Polar Rec. 24: 1-8.

Stirling, I. 2005. Reproductive rates of ringed seals and survival of pups in Northwestern Hudson Bay, Canada, 1991-2000. Polar Biol. 28: 381-387.

Stirling, I. 2009. Polar bear: *Ursus maritimus*. *In* Encyclopedia of marine mammals. *Edited by* Wursig, B., Thewissen, J.G., and Kovacs, K.M. Academic Press, London, UK. pp. 888-890.

Stirling, I. and Cleator, H. 1981. Polynyas in the Canadian Arctic. Canadian Wildlife Service Occasional Paper. No. 45. 72 p.

Stirling, I., Kingsley, M., and Calvert, W. 1982. The distribution and abundance of seals in the Eastern Beaufort Sea, 1974-79. Canadian Wildlife Service Occasional Paper. No. 47. 25 p.

Stirling, I., Andriashek, D.A., and Calvert, W. 1993. Habitat preferences of polar bears in the western Canadian Arctic in late winter and spring. Polar Rec. 29: 13-24. http://dx.doi.org/10.1017/S0032247400023172

Stirling, I., Lunn, N.J., and Iacozza, J. 1999. Long-term trends in the population ecology of polar bears in western Hudson Bay in relation to climatic change. Arctic. 52(3): 294-306. http://dx.doi.org/10.14430/arctic935

Strand, J.E., Aarseth, J.J, Hanebrekke, T.L., and Jorgensen, E.H. 2008. Keeping track of time under ice and snow in a sub-arctic lake: plasma melatonin rhythms in Arctic charr overwintering under natural conditions. J. Pineal Res. 44(3): 227-233. https://doi.org/10.1111/j.1600-079x.2007.00511.x

Streftaris, N., Zenetos, A., and Papathanassiou, E. 2005. Globalisation in marine ecosystems: the story of non-indigenous marine species across European seas. Oceanogr. Mar. Biol.: Annu. Rev. 43: 419-453.

Strehlow, B.W., Pineda, M.C., Duckworth, A., Kendrick, G.A., Renton, M., Wahab, M.A., Webster, N.S., and Clode, P.L. 2017. Sediment tolerance mechanisms identified in sponges using advanced imaging techniques. PeerJ. 5: e3904.

Strömberg, S.M. and Larsson, A.I. 2017. Larval behavior and longevity in the cold-water coral *Lophelia pertusa* indicate potential for long distance dispersal. Front. Mar. Sci. 4: 411. https://doi.org/10.3389/fmars.2017.00411

Suchanek, T.H. 1993. Oil Impacts on marine invertebrate populations and communities. Amer. Zool. 33(6): 510-523. https://doi.org/10.1093/icb/33.6.510

Sultzmann, C., Halter, H.A., Craig, R.K., Meyer, D., Ruggieri, J.A., and Spurgeon, J. 2002. A professional jury report on the biological impacts of submarine fiber optic cables on shallow reefs off Hollywood, Florida. Tech. Rep. 2002. Available at: http://www.peer.org/assets/docs/fl/fiber_optic_cable_report.pdf

Suryan, R.M. and Harvey, J.T. 1999. Variability in reactions of Pacific harbor seals, *Phoca vitulina richardsi*, to disturbance. Fish. Bull. 97(2): 332-339.

Svensen, C., Halvorsen, E., Vernet, M., Franze, G., Dmoch, K., Lavrentyev, P.J., and Kwasniewski, S. 2019. Zooplankton communities associated with new and regenerated production in the Atlantic inflow north of Svalbard. Front. Mar. Sci. 6: 293.

Swanson, C. and Isaji, T. 2006. Simulation of sediment transport and deposition from cable burial operations for the alternative site of the Cape Wind Energy Project. ASA Final Report 05-128. Available at: https://www.boem.gov/sites/default/files/renewable-energy-program/Studies/CWfiles/SL-ASA2006SimulationofSediment.pdf

Sweeney, S.O., Terhune, J.M., Frouin-Mouy, H., and Rouget, P.A. 2022. Assessing potential perception of shipping nose by marine mammals in an arctic inlet. J. Acoust. Soc. Am. 151: 2310-2350.

Szczybelski, A.S., van den Huevel-Greve, H., Kampen, T., Wang, C., van den Brink, N.W., and Koelmans, A.A. 2016. Bioaccumulation of polycyclic aromatic hydrocarbons, polychlorinated biphenyls and hexachlorobenzene by three Arctic benthic species from Kongsfjorden (Svalbard, Norway). Mar. Pollut. Bull. 112: 65-74. http://dx.doi.org/10.1016/j.marpolbul.2016.08.041

Szekeres, P., Wilson, A., Haak, C., Danylchuk, A., Brownscombe, J.W., Elvidge, C.K., Schultz, A., Birnie-Gauvin, K., and Cooke, S.J. 2017. Does coastal light pollution alter the nocturnal behavior and blood physiology of juvenile bonefish (*Albula vulpes*)? Bull. Mar. Sci. 93(2): 491-505. https://doi.org/10.5343/bms.2016.1061

Takeshita, R., Bursian, S.J., Colegrove, K.M., Collier, T., Deak, K., Dean, K.M., De Guise, S., DiPinto, L.M., Elferink, C., Esbaugh, A.J., Griffitt, R.J., Grosell, M., Harr, K.E., Incardona, J.P., Kwok, R.K., Lipton, J., Mitchelmore, C.L., Morris, J.M., Peters, E.S., Roberts, A.P., Rowles, T.K., Rusiecki, J.A., Schwacke, L.H., Smith, C.R., Wetzel, D.L., Ziccardi, M.H., and Hall, A.J. 2021. A review of the toxicology of oil in vertebrates: what we have learned following the Deepwater Horizon oil spill. J. Toxicol. Environm. Health, Part B. 24(8): 355-394.

Talbot, S.L., Sonsthagen, S.A., Pearce, J.M., and Scribner, K.T. 2015. Phylogenetics, phylogeography, and population genetics of North American sea ducks *(Tribe Mergini*). *In* Ecology and Conservation of North American sea ducks. *Edited by* Savard, J.-P.L., Derksen, D.V., Esler, D. and Eadie, J.M. CRC Press, Boca Raton, FL. pp. 29-61. https://doi.org/10.1201/b18406

Tang, D., Sun, J., Zhou, L., Wang, S., Singh, R.P., and Pan, G. 2019. Ecological response of phytoplankton to the oil spills in the oceans. Geomat. Nat. Haz. Risk 10(1): 853-872. https://doi.org/10.1080/19475705.2018.1549110

Taormina, B. 2019. Potential impacts of submarine power cables from marine renewable energy projects on benthic communities. Université de Bretagne occidentale – Brest. English. NNT: 2019BRES0101. Available at: https://tel.archives-ouvertes.fr/tel-03078936

Tarling, G.A. 2015. Marine ecology: a wonderland of marine activity in the Arctic night. Curr. Biol. 25(22): R1088-R1091. https://doi.org/10.1016/j.cub.2015.09.067

Tarpley, R.J., Hillmann, D.J., George, J.C., Zeh, J.E., and Suydam, R.S. 2016. Morphometric correlates of the ovary and ovulatory corpora in the bowhead whale, Balaena mysticetus. Anat. Rec. 299 (6): 769-797.

Tarpley, R.J., Hillmann, D.J., George, J.C., and Thewissen, G.M. 2021. Female and male reproduction. *In* The Bowhead Whale. *Edited by* George, J.C. and Thewissen, J.G. Academic Press, San Diego, CA. pp. 185-212.

Taylor, M. and Lee, J. 1995. Distribution and abundance of Canadian polar bear populations: a management perspective. Arctic. 48(2): 147-154. Available at: https://www.jstor.org/stable/40511638

Taylor, M.K., Laake, J., McLoughlin, P., Born, E.W, Cluff, H.D., Ferguson, S.H., Rosing-Asvid, A., Schweinsburg, R., and Messier, F. 2005. Demography and viability of a hunted population of polar bears. Arctic. 58(2): 203-215. Available at: https://www.jstor.org/stable/40512692

Teagle, H., Hawkins, S.J., Moore, P.J., and Smale, D.A. 2017. The role of kelp species as biogenic habitat formers in coastal marine ecosystems. J. Exp. Mar. Bio. Ecol. 492: 81-98.

Tegner, M.J., Dayton, P.K., Edwards, P., Riser, K.L., Chadwick, D., Dean, T.A., and Deysher, L. 1995. Effects of a large sewage spill on a kelp forest community: Catastrophe or disturbance? Mar. Env. Res. 40(2): 181-224. https://doi.org/10.1016/0141-1136(94)00008-D

Teuchies J., Cox, T., Itterbeeck, K.V., Meysman, F.J., and Blust, R. 2020. The impact of scrubber discharge on the water quality in estuaries and ports. Enviro. Sci. Euro. 32: 103. https://doi.org/10.1186/s12302-020-00380-z

Thomas, D.C. and Barry, S.J. 1990a. Age-specific fecundity of the Beverly herd of barren-ground caribou. Rangifer 10(Special Issue 3): 257-263. https://doi.org/10.7557/2.10.3.867

Thomas, D.C. and Barry, S.J. 1990b. A life table for female barren-ground caribou in north-central Canada. Rangifer. 10(3): 177-184. https://doi.org/10.7557/2.10.3.854

Thomas, T.A., Koski, W.R., and Richardson, W.J. 2002. Correction factors to calculate bowhead whale numbers from aerial surveys of the Beaufort Sea. *In* Bowhead whale feeding in the eastern Alaskan Beaufort Sea: Update of Scientific and Traditional Information. *Edited by* Richardson, W.J. and Thomson, D.H. OCS Study MMS 2002012; LGL Rep. TA2196-7. Rep. from LGL Ltd., King City, Ontario, for US Minerals Management Service, Anchorage, Alaska and Herndon Virginia, USA. xliv+420pp. Available at: National Technical Information Service, Springfield, Virginia, USA, Rep. No. NTIS PB2004-101568. 282pp.

Thomas, T.A., Raborn, S., Elliott, R.E., and Moulton, V.D. 2016. Marine mammal aerial surveys in Eclipse Sound, Milne Inlet and Pond Inlet, 1 August – 17 September 2015. LGL Draft Report No. FA0059-2. Prepared by LGL Limited, King City, ON for Baffinland Iron Mines Corporation, Oakville, ON. 85 p. + appendices.

Thorne, R.E. and Thomas, G.L. 2008. Herring and the "Exxon Valdez" oil spill: an investigation into historical data conflicts. ICES. J. Mar. Sci. 65(1): 44-50 https://doi.org/10.1093/icesjms/fsm176

Tiano, J.C., Witbaard, R., Bergman, M.J.N., van Rijswijk, P., Tramper, A., van Oevelen, D., and Soetaert, K. 2019. Acute impacts of bottom trawl gears on benthic metabolism and nutrient cycling. ICES J. Mar. Sci. 76(6): 1917-1930.

Tigano, A., Shultz, A.J., Edwards, S.V., Robertson, G.J., and Friesen, V.L. 2017. Outlier analyses to test for local adaptation to breeding grounds in a migratory arctic seabird. Ecol. Evol. 7: 2370-2381. https://doi.org/10.1002/ece3.2819

Tillin, H.M., Hiddink, J., Jennings, S., and Kaiser, M.J. 2006. Chronic bottom trawling alters the functional composition of benthic invertebrate communities on a sea-basin scale. Mar. Ecol. Prog. Ser. 318: 31-45. http://dx.doi.org/10.3354/meps318031

Tomasino, M.P., Aparício, M., Ribeiro, I., Santos, F., Caetano, M., Almeida, C., de Fátima Carvalho, M., and Mucha, A.P. 2021. Diversity and hydrocarbon-degrading potential of deep-sea microbial community from the Mid Atlantic Ridge, south of the Azores (North Atlantic Ocean). Microorganisms. 9: 2389. https://doi.org/10.3390/microorganisms9112389

Tompkins-Macdonald, G.J. and Leys, S.P. 2008. Glass sponges arrest pumping in response to sediment: Implications for the physiology of the hexactinellid conduction system. Mar. Biol. 154: 973-984.

Traiger, S.B. and Konar, B. 2017. Supply and survival: glacial melt imposes limitations at the kelp microscopic life stage. Bot. Mar. 60(6): 603-317. https://doi.org/10.1515/bot-2017-0039

Transport Canada (TC). 2018. Understanding Anchorages in Canada. Available at: https://tc.canada.ca/en/marine-transportation/ports-harbours-anchorages/understanding-anchorages-canada. [Date accessed: February 25, 2023].

Transport Canada (TC). 2021. List of Canada's designated alternate ballast water exchange areas and fresh waters (Edition 10, 26 May 2021). TP 13617E (05/2021). v + 8 p. Available at: https://tc.canada.ca/sites/default/files/2021-06/tp13617e.pdf

Transport Canada (TC). 2022. Managing biofouling. Available at: https://tc.canada.ca/en/marine-transportation/marine-pollution-environmental-response/preventing-aquatic-invasive-species-marine-transportation/managing-biofouling [Date accessed: 4 April, 2024].

Treble, M.A. and Stewart, R.E. 2009. Impacts and risks associated with a Greenland Halibut *(Reinhardtius hippoglossoides)* gillnet fishery in inshore areas of NAFO Subarea 0. DFO Can. Sci. Advis. Sec. Res. Doc.: 2010/032. vi + 18 p.

Transportation Safety Board of Canada (TSBC). 2022. Marine transportation safety investigations and reports. Government of Canada. Available at: https://www.tsb.gc.ca/eng/raports-reports/marine/index.html

Uncles, R.J., Stephens, J., and Smith, R.E. 2002. The dependence of estuarine turbidity on tidal intrusion length, tidal range and residence time. Cont. Shelf Res. 22: 1835-1856.

US EPA (U.S. Environmental Protection Agency). 2010. Control of emissions from new marine compression-ignition engines at or above 30 liters per cylinder. Final rule. Fed. Reg. 75(83; April 30): 22896-23065. Available at: https://www.govinfo.gov/content/pkg/FR-2010-04-30/pdf/2010-2534.pdf

US EPA (U.S. Environmental Protection Agency). 2011. Graywater Discharges from Vessels. Office of Wastewater Management, Washington, DC. 20460. Available at: https://www3.epa.gov/npdes/pubs/vgp_graywater.pdf

US FWS (U.S. Fish and Wildlife Service). 2010. Effects of oil on wildlife and habitat. U.S. Fish and Wildlife Service, Washington, DC. 2 p. Available at: https://www.fws.gov/home/dhoilspill/pdfs/dhjicfwsoilimpactswildlifefactsheet.pdf

Vard Marine Inc. 2018. Canadian Arctic greywater report: estimates, forecasts, and treatment technologies. Report #360-000, Rev. 2. Prepared for WWF Canada. Available at: https://wwf.ca/wp-content/uploads/2020/03/CANADIAN-ARCTIC-GREYWATER-REPORT_may-2018.pdf

Venn-Watson, S., Garrison, L., Litz, J., Fougeres, E., Mase, B., Rappucchi, G., Stratton, E., Carmichael, R., Odell, D., Shannon, D., Shippee, S., Smith, S., Staggs, L., Tumlin, M., Whitehead, H., and Rowles, T. 2015. Demographic clusters identified within the northern Gulf of Mexico common bottlenose dolphin *(Tursiops truncatus)* unusual mortality event: January 2010-June 2013. PLoS ONE. 10(2): e0117248.

Vergeynst, L., Christensen, J.H., Kjeldsen, K.U., Meire, L., Boone, W., Malmquist, L., and Rysgaard, S. 2019. In situ biodegradation, photooxidation and dissolution of petroleum compounds in Arctic seawater and sea ice. Water Res. 148: 459-468. https://doi.org/10.1016/j.watres.2018.10.066

Vessel Pollution and Dangerous Chemicals Regulations. 2012. Available at: https://laws-lois.justice.gc.ca/eng/regulations/sor-2012-69/ [Date accessed: May 7, 2024].

Viengkone, M., Derocher, A.E., Richardson, E.S., Malenfant, R.M., Miller, J.M., Obbard, M.E., Dyck, M.G., Lunn, N.J., Sahanatien, V., and Davis, C.S. 2016. Assessing polar bear *(Ursus maritimus)* population structure in the Hudson Bay region using SNPs. Ecol. Evol. 6(23): 8474-8484.

Viengkone, M., Derocher, A.E., Richardson, E.S., Obbard, M.E., Dyck, M.G., Lunn, N.J., Sahanatien, V., Robinson, B.G., and Davis, C.S., 2018. Assessing spatial discreteness of Hudson Bay polar bear *(Ursus maritimus)* populations using telemetry and genetics. Ecosphere. 9(7): e02364.

Vistnes, I. and Nellemann, C. 2007. The matter of spatial and temporal scales: a review of reindeer and caribou response to human activity. Polar Biol. 31: 399-407. https://doi.org/10.1007/s00300-007-0377-9

Vollset, K.W., Lennox, R.J., Thorstad, E.B., Auer, S., Bär, K., Larsen, M.H., Mahlum, S., Näslund, J., Stryhn, H., and Dohoo, I. 2020. Systematic review and meta-analysis of PIT tagging effects on mortality and growth of juvenile salmonids. Rev. Fish. Biol. Fish. 30(4): 553-568. doi:10.1007/s11160-020-09611-1

von Friesen, L.W., Granberg, M.E., Pavlova, O., Magnusson, K., Hassellöv, M., and Gabrielsen, G.W. 2020. Summer sea ice melt and wastewater are important local sources of microliter to Svalbard waters. Environ. Int. 139: 105511. https://doi.org/10.1016/j.envint.2020.105511

Vos, D.J., Shelden, K.E., Friday, N.A., and Mahoney, B.A. 2020. Age and growth analyses for the endangered belugas in Cook Inlet, Alaska. Mar. Mamm. Sci. 36: 293-304.

Wade, P.R. 1998. Calculating limits to the allowable human-caused mortality of cetaceans and pinnipeds. Mar. Mamm. Sci. 14(1): 1-37.

Walker, D., Lukatelich, R., Bastyan, G., and McComb, A. 1989. Effect of boat moorings on seagrass beds near Perth, Western Australia. Aquat. Bot. 36(1): 69-77. https://doi.org/10.1016/0304-3770(89)90092-2

Walker, K.A., Trites, A.W., Haulena, M., and Weary, D.M. 2012. A review of the effects of different marking and tagging techniques on marine mammals. Wildl. Res. 39(1): 15-30. doi:10.1071/wr10177

Walker, T.R., Adebambo, O., Del Aguila Feijoo, M.C., Elhaimer, E., Hossain, T., Edwards, S.J., Morrison, C.E., Romo, J., Sharma, N., Taylor, S., and Zomorodi, S. 2019. Environmental Effects of Marine Transportation. *In* World Seas: an Environmental Evaluation. *Edited by* Sheppard, C. Academic Press, Cambridge, MA. pp. 505-530.

Walkusz, W., Atchison, S., Hedges, K., and Deslauriers, D. 2020. Assessment of potential impacts of bycatch mortality on the Arctic Cod *(Boreogadus saida)* populations from the Northern *(Pandalus borealis)* and Striped *(Pandalus montagui)* shrimp fisheries in Shrimp Fishing Areas 1, 2, and 3. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/073. iv + 8 p.

Ward, J., Hughey, K., and Urlich, S. 2002. A Framework for Managing the Biophysical Effects of Tourism on the Natural Environment in New Zealand. J. Sustain. Tour. 10(3): 239-259. doi:10.1080/09669580208667165

Wartzok, D., Watkins, W.A., Würsig, B., and Malme, C.I. 1989. Movements and behaviors of bowhead whales in response to repeated exposures to noises associated with industrial activities in the Beaufort Sea. Rep. from Purdue Univ., Fort Wayne, IN, for Amoco Production Col, Anchorage, AK. 228 p.

Watanabe, S., Scheibling, R., and Metaxas, A. 2010. Contrasting patterns of spread in interacting invasive species*: Membranipora memranacea* and *Codium fragile* of Nova Scotia. Biol. Invasions. 12: 2329-2342.

Watling, L., Findlay, R.H., Mayer, L.M., and Schick, D.F. 2001. Impact of a scallop drag on the sediment chemistry, microbiota, and faunal assemblages of a shallow subtidal marine benthic community. J. Sea Res. 46: 309-324.

Watt, C.A., Heide-Jørgensen, M.P., and Ferguson, S.H. 2013. How adaptable are narwhal? A comparison of foraging patterns among the world's three narwhal populations. Ecosphere. 4(6): 1-15.

Watt, C.A., Orr, J., and Ferguson, S.H. 2016. A shift in foraging behaviour of beluga whales *Delphinapterus leucas* from the threatened Cumberland Sound population may reflect a changing Arctic food web. Endang. Spec. Res. 31: 259-270.

Watt, C.A., Hornby, C., and Hudson, J. 2020a. Narwhal *(Monodon monoceros)* abundance estimate from the 2018 aerial survey of the Northern Hudson Bay population. DFO Can. Sci. Advis. Sec. Res. Doc. 2020/073. iv + 15 p.

Watt, C.A., Marcoux, M., Ferguson, S.H., Hammill, M.O., and Matthews, C.J. 2020b. Population dynamics of the threatened Cumberland Sound beluga *(Delphinapterus leucas).* Arct. Sci. 7(2): 545-566. https://doi.org/10.1139/as-2019-0030

Watts, P.D., Ferguson, K.L., and Draper, B. 1991. Energetic output of subadult polar bears *(Ursus maritimus)*: Resting, disturbance and locomotion. Comp. Biochem. Physiol. 98A(2): 191-193. https://doi.org/10.1016/0300-9629(91)90518-H

Waugh, D., Pearce, T., Ostertag, S.K., Pokiak, V., Collings, P., and Loseto, L.L. 2018. Inuvialuit traditional ecological knowledge of beluga whale *(Delphinapterus leucas)* under changing climatic conditions in Tuktoyaktuk, NT. Arct. Sci. 4(3): 242-258.

Wein, E.E., Freeman, M., and Makus, J.C. 1996. Use of and preference for traditional foods among the Belcher Island Inuit. Arctic. 49(3): 256-264.

Wegeberg, S., Hansson, S., van Beest, F., Fritt-Rasmussen, J., and Gustavson, K. 2020. Smooth or smothering? The self-cleaning potential and photosynthetic effects of oil spill on arctic macro-algae *Fucus distichus*. Mar. Poll. Bull. 150: 110604. https://doi.org/10.1016/j.marpolbul.2019.110604

Wei, C.L., Cusson, M., Archambault, P., Belley, R., Brown, T., Burd, B.J., Edinger, E., Kenchington, E., Gilkinson, K., Lawton, P., and Link, H. 2020. Seafloor biodiversity of Canada's three oceans: Patterns, hotspots and potential drivers. Divers. Distrib. 26(2): 226-241.

West, E.J., Barnes, P.B., Wright, J.T., and Davis, A.R. 2007. Anchors aweigh: Fragment generation of invasive *Caulerpa taxifolia* by boat anchors and its resistance to desiccation. Aquat. Bot. 87: 196-202. https://doi.org/10.1016/j.aquabot.2007.06.005

Westdal, K.H., Richard, P.R., and Orr, J.R. 2010. Migration route and seasonal home range of the northern Hudson Bay narwhal *(Monodon monoceros). In* A Little Less Arctic. *Edited by* S.H Ferguson, L.L. Loseto, and M.L. Mallory. Springer, Dordrecht, Netherlands. pp. 71-92.

Wharton, W.G. and Mann, K.H. 1981. Relationship between destructive grazing by the sea urchin, *Strongylocentrotus droebachiensis*, and the abundance of American lobster, *Homarus americanus*, on the Atlantic coast of Nova Scotia. Can. J. Fish. Aquat. Sci. 38(11): 1339-1349.

White, H.K., Hsing, P.-Y., Cho, W., Shank, T.M., Cordes, E., Quattrini, A.M., Nelson, R. Camilli, R., Demopoulos, A.W., German, C.R., Brooks, J.M., Roberts, H.H., Shedd, W., Reddy, C.M., and Fisher, C.R. 2012. Impact of the Deepwater Horizon oil spill on a deep-water coral community in the Gulf of Mexico. PNAS. 109(50): 2030320308. https://doi.org/10.1073/pnas.1118029109

Woods Hole Oceanographic Institute (WHOI). 2022. Phytoplankton. Available at: https://www.whoi.edu/know-your-ocean/ocean-topics/ocean-life/phytoplankton/ [Date accessed: 7 December, 2023].

Wiese, F.K. and Robertson, G.J. 2004. Assessing seabird mortality from chronic oil discharges at sea. J. Wildl. Manag. 68: 627-638. https://doi.org/10.2193/0022-541X(2004)068[0627:ASMFCO]2.0.CO;2

Wiese, F.K., Montevecchi, W.A., Davoren, G.K., Huettmann, F., Diamond, A.W., and Linke, J. 2001. Seabirds at risk around offshore oil platforms in the North-west Atlantic. Mar. Poll. Bull. 42: 1285-1290. https://doi.org/10.1016/S0025-326X(01)00096-0

Wiig, Ø., Amstrup, S., Atwood, T., Laidre, K., Lunn, N., Obbard, M., Regehr, E., and Thiemann, G. 2015. *Ursus maritimus*. The IUCN Red List of Threatened Species 2015: e.T22823A14871490. https://dx.doi.org/10.2305/IUCN.UK.2015-4.RLTS.T22823A14871490.en

Wilber, D.H. and Clarke, D.G. 2001. Biological effects of suspended solids: A review of suspended sediment impacts on fish and shellfish with relation to dredging activities in estuaries. N. Am. J. Fish. Manag. 21: 855-875. https://doi.org/10.1577/1548-8675(2001)021<0855:BEOSSA>2.0.CO;2

Wilkin, S.M., Rowles, T.K., Stratton, E., Adimey, N., Field, C.L., Wissmann, S., Shigenaka, G., Fougères, E., Mase, B., and Network, S.R. 2017. Marine mammal response operations during the Deepwater Horizon oil spill. Endang. Sp. Res. 33: 107-118.

Williams, T.M., Blackwell, B., Richter, S.B., Sinding, M.H-S., and Heide-Jørgensen, M.P. 2017. Paradoxical escape responses by narwhals *(Monodon monoceros).* Science. 23, 1328-1331. 10.1126/science.aao2740

Williamson, E.A., Strychar, K.B., Withers, K., and Sterba-Boatwright, B. 2011. Effects of salinity and sedimentation on the Gorgonian coral, *Leptogorgia virgulata* (Lamarck 1815). J. Exp. Mar. Biol. Ecol. 409: 331-338.

Wilson, B. and Evans, D. 2009. Groundfish Trawl Fishery, Pacific Walrus, and Local Fishery Interactions in Northern Bristol Bay – A Discussion Paper. North Pacific Fishery Management Council, Anchorage, AK. 36 p.

Wilson, S.C., Trukhanova, I., Dmitrieva, L., Dolgova, E., Crawford, I., Baimukanov, M., Baimukanov, T., Ismagambetov, B., Pazylbekov, M., Jüssi, M., and Goodman, S.J. 2017. Assessment of impacts and potential mitigation for icebreaking vessels transiting pupping areas of an ice-breeding seal. Biol. Conserv. 214: 213-222. https://doi.org/10.1016/j.biocon.2017.05.028

Wise Jr, J.P., Wise, J.T., Wise, C.F., Wise, S.S., Gianios Jr, C., Xie, H., Walter, R., Boswell, M., Zhu, C., Zheng, T., and Perkins, C. 2018. A three-year study of metal levels in skin biopsies of whales in the Gulf of Mexico after the Deepwater Horizon oil crisis. Comp. Biochem. Physiol. C Toxicol. Pharmacol. 205: 15-25.

Witting, L. 2014. On population dynamics of eastern Canada-West Greenland bowhead whales. Rep. Int. Whal. Comm. SC/63/AWMP3. Available at: https://iwc.int/private/downloads/Pvo6ySe6_J2JYORrBjvjAQ/SC-63-AWMP3.pdf

Wlodarska-Kowalczuk, M., Pearson, T.H., and Kendall, M.A. 2005. Benthic response to chronic natural physical disturbance by glacial sedimentation in an Arctic fjord. Mar. Ecol. Prog. Ser. 303: 31-41. https://doi.org/10.3354/meps303031

Wonham, M.J., Walton, W.C., Ruiz, G.M., Frese, A.M., and Galil, B.S. 2001. Going to the source: role of the invasion pathway in determining potential invaders. Mar. Ecol. Prog. Ser. 215: 1-12.

WSP (Canada Inc.). 2014a. Risk assessment for marine spills in Canadian water: Phase 2, Part B: spills of oil and select hazardous and noxious substances (HNS) north of the 60th parallel north [Final report]. Rep. by WSP Canada Inc. for Transport Canada. xxx + 93 p. + appendices.

WSP (Canada Inc.). 2014b. Risk assessment for marine spills in Canadian waters Phase 1, Oil spills south of the 60th parallel [Final Version]. Rep. by WSP Canada Inc. for Transport Canada. xxviii + 165 p. Available at: https://www.wcel.org/sites/default/files/file-downloads/131-17593-00_ERA_Oil-Spill-South_150116_pp1-124.pdf

Würsig, B. 1990. Cetaceans and oil: Ecologic perspectives. *In* Sea Mammals and Oil: Confronting the Risks. *Edited by* J.R. Geraci and D.J. St. Aubin. Academic Press, San Diego, CA. pp. 129-165.

Würsig, B. and Koski, W.R. 2021. Natural and potentially disturbed behavior of bowhead whales. *In* The Bowhead Whale. *Edited by* George, J.C. and Thewissen, J.G. Academic Press, San Diego, CA. pp. 339-363.

WWF (World Wildlife Fund). n.d. Oil spill response capacity in Nunavut and the Beaufort Sea. WWF-Canada. 47 p. Available at: https://wwf.ca/wp-content/uploads/2020/03/Oil-Spill-Response-capacity_March-2017.pdf

WWF (World Wildlife Fund). 2019. 1.5 billion litres of grey water have likely been dumped along the B.C. coast: WWF Canada study. Available at: https://wwf.ca/media-releases/1-5-billion-litres-of-grey-water-have-likely-been-dumped-along-the-b-c-coast-wwf-canada-study/ [Date accessed: December 7, 2023].

WWF (World Wildlife Fund). 2020. The impacts of shipping on benthic habitats. Reducing impacts from shipping in marine protected areas: A toolkit for Canada. WWF-Canada. 14 p. Available at: https://wwf.ca/wp-content/uploads/2021/02/WWF-MPA-3-Impacts-Benthic-Habitat-v4.pdf

Yang. S.L., Zhang, J., and Zhu, J. 2004. Response of suspended sediment concentration to tidal dynamics at a site inside the mouth of an inlet: Jiaozhou Bay (China). Hydrol. Earth Syst. Sci. 892): 170-182.

Yang, Z., Shah, K., Laforest, S., Hollebone, B.P., Lambert, P., Brown, C.E., Yang, C., and Goldthorp, M. 2018. A study of the 46-year-old arrow oil spill: Persistence of oil residues and variability in oil contamination along Chedabucto Bay, Nova Scotia, Can. J. Cleaner Prod. 198: 1459-1473.

York, D. 1994. Recreational-Boating Disturbances of Natural Communities and Wildlife: An Annotated Bibliography. U.S. Department of the Interior. National Biological Survey, Washington, DC.

Young, B.G., Ferguson, S.H., and Lunn, N.J. 2015. Variation in ringed seal density and abundance in western Hudson Bay estimated from aerial surveys, 1995 to 2013. Arctic. 3: 301-309. https://doi.org/10.14430/arctic4503

Young, B., Koski, B., Ryan, K., Kilabuk, R., and Kilabuk, E. 2019. Field Report: 2019 Cumberland Sound Bowhead and Clearwater Fiord Beluga. Report for Fisheries and Oceans Canada. Winnipeg, MB. 7 p.

Ytreberg, E., Hasselløv, I.-M., Nylund, A.T., Hdblom, M., Al-Handal, A., and Wulff, A. 2019. Effects of scrubber wash water discharge on microplankton in the Baltic Sea. Mar. Poll. Bull. 145: 316-324. https://doi.org/10.1016/j.marpolbul.2019.05.023

Ytreberg, E., Karlberg, M., Hasselløv, I., Hedblom, M., Nyllund, A.T., Salo, K., Imberg, H., Turner, D., Tripp, L., Yong, J., and Wulff, A. 2021. Effects of seawater scrubbing on a microplanktonic community during a summer-bloom in the Baltic Sea. Environ. Pollut. 291: 118251. https://doi.org/10.1016/j.envpol.2021.118251

Yurkowski, D.J., Young, B.G., Dunn, H., and Ferguson, S.H. 2019. Spring distribution of ringed seals *(Pusa hispida)* in Eclipse Sound and Milne Inlet, Nunavut: implications for potential icebreaking activities. Arctic Sci. 5(1): 54-61. http://dx.doi.org/10.1139/as-2018-0020

Zeh, J.E., Clark, C.W., George, J.C., Withrow, D., Carroll, G.M., and Koski, W.R. 1995. Current population size and dynamics. *In* The Bowhead Whale. *Edited by* Burns, J.J., Montague, J.J., and Cowles, C.J. Spec. Publ. 2, Soc. Mar. Mamm., Lawrence, KS. pp. 409-489.

Zeh, J., Poole, D., Miller, G., Koski, W., Baraff, L., and Rugh, D. 2002. Survival of bowhead whales, Balaena mysticetus, estimated from 1981-98 photo-identification data. Biometrics. 58: 832-840.

Zucco, C., Wende, W., Merck, T., Köchling, I., and Köppel, J. (Eds.). 2006. Ecological research on offshore wind farms: International exchange of experiences. Part B: Literature review of ecological impacts. BfN-Skripten 186. 290 p. Available at: https://docs.wind-watch.org/Ecological-research-offshore-wind-farms.pdf

Žydelis, R., Bellebaum, J., Österblom, H., Vetemaa, M., Schirmeister, B., Stipniece, A., Dagys, M., van Eerden, M., and Garthe, S. 2009. Bycatch in gillnet fisheries – An overlooked threat to waterbird populations. Biol. Conserv. 142(7): 1269-1281.

Žydelis, R., Small, C., and French, G. 2013. The incidental catch of seabirds in gillnet fisheries: A global review. Biol. Conserv. 162: 76-88.

Appendix A: Priority Area Association and Interaction Summary Tables

Table A-1. Priority area associations and interaction summaries for beluga whale. ESC = Ecologically significant component. FES = Fisher and Evans Straits. CIN = Chesterfield Inlet/Narrows. DYB/WI = Duke of York Bay/White Island. RWS = Roes Welcome Sound. EB = East Bay. RB/FS = Repulse Bay/Frozen Strait. AOI = area of interest. AIS = Automatic Identification System.

ESC Sub-component & activity – stressor (interaction)	ESC	Priority Area Assessed	ESC sub-component priority area use	Description of activity - stressor	Other priority areas		
					Other priority areas found	ESC sub-component priority area use	Change in activity - stressor
Beluga Vessel underway – noise disturbance	3,4, 6	East Bay	Migratory pathway, summer feeding, and calving/rearing	Vessel traffic density low overall in AOI, and low in this priority area compared with FES and CIN.	CIN; FES; DYB/WI; RWS	Migration, summer feeding in all, and calving/ rearing in DYB/WI and RWS.	Vessel traffic density low overall in AOI, higher in CIN and FES, lower in DYB/WI.
Beluga Ice-breaking – noise disturbance	3,4, 6	East Bay	Same as above	Active icebreaking is expected to be rare in the AOI. Overlap between icebreaker AIS data and sea ice cover was not recorded in EB from 2012-2019.	Same as above	Same as above	Active icebreaking is expected to be rare in the AOI. Overlap between icebreaker AIS data and sea ice cover was highest in FES where it was recorded approx. every other year from 2012-2019.
Beluga Ice-breaking – habitat alteration	3,4, 6	East Bay	Same as above	Same as above	Same as above	Same as above	Same as above
Beluga Discharge – petroleum product (large accidental spill; heavy fuel oil)	3,4, 6	East Bay	Same as above	Vessel traffic density low overall in AOI, and low in this priority area compared with CIN, FES. Spill could occur any time vessel is present.	Same as above	Same as above	Vessel traffic density low overall in AOI, higher in FES and CIN. Spill could occur any time vessel is present.
Beluga Vessel at rest – noise disturbance	3,4, 6	Chesterfield Inlet/ Narrows	Migratory pathway and summer feeding	Vessels known to remain at rest for a prolonged period in this area (up to 2 weeks); noted community concern.	EB; FES; DYB/WI; RWS	Migration, summer feeding in all, and calving/ rearing in EB, DYB/WI, and RWS.	Vessels at rest are expected to occur at lower densities in other areas.
Beluga Scientific research –	3,4, 6	East Bay	Migratory pathway, summer	Noise disturbance from aerial research	CIN; FES; DYB/WI; RWS	Migration, summer feeding in all,	Noise disturbance from aerial

ESC Sub-component & activity – stressor (interaction)	ESC	Priority Area Assessed	ESC sub-component priority area use	Description of activity - stressor	Other priority areas		
					Other priority areas found	ESC sub-component priority area use	Change in activity - stressor
noise disturbance			feeding, and calving/ rearing.	platforms is expected to occur rarely.		and calving/ rearing in DYB/WI and RWS.	research platforms is expected to occur rarely.

Table A-2. Priority area associations and interaction summaries for narwhal. ESC = Ecologically significant component. FES = Fisher and Evans Straits. CIN = Chesterfield Inlet/Narrows. DYB/WI = Duke of York Bay/White Island. RWS = Roes Welcome Sound. EB = East Bay. RB/FS = Repulse Bay/Frozen Strait. BWD = ballast water discharge. AOI = area of interest. AIS = Automatic Identification System.

ESC Sub-component & activity – stressor (interaction)	ESC	Priority Area Assessed	ESC sub-component priority area use	Description of activity - stressor	Other priority areas		
					Other priority areas found	ESC sub-component priority area use	Change in activity - stressor
Narwhal Vessel underway – noise disturbance	3,4, 6	Repulse Bay/ Frozen Strait	Critical migratory pathway, summer feeding and calving/ rearing	Vessel traffic density low overall in AOI, and low in this priority area compared with FES and CIN.	DYB/WI; CIN; FES	Summer feeding and calving/ rearing, less so in FES	Vessel traffic density low overall in AOI, higher in FES and CIN.
Narwhal Ice-breaking – noise disturbance	3,4, 6	Repulse Bay/ Frozen Strait	Critical migratory pathway, summer feeding and calving/ rearing	Active icebreaking is expected to be rare in the AOI. Overlap between icebreaker AIS data and sea ice cover was only recorded for one trip in RB/FS from 2012-2019.	Same as above	Same as above	Active icebreaking is expected to be rare in the AOI. Overlap between icebreaker AIS data and sea ice cover was highest in FES where it was recorded approx. every other year from 2012-2019.
Narwhal Ice-breaking – habitat alteration	3,4, 6	Repulse Bay/ Frozen Strait	Critical migratory pathway, summer feeding and calving/ rearing	Same as above	Same as above	Same as above	Same as above
Narwhal Discharges – pathogens/ NIS (ballast water)	3,4, 6	Repulse Bay/ Frozen Strait	Critical migratory pathway, summer feeding and calving/ rearing	Vessel traffic density low overall in AOI, and low in this priority area compared with FES and CIN. Considering existing measures, BWD expected to be a rare occurrence.	Same as above	Same as above	Vessel traffic density low overall in AOI, higher in FES and CIN. BWD rate expected to be low throughout.

ESC Sub-component & activity – stressor (interaction)	ESC	Priority Area Assessed	ESC sub-component priority area use	Description of activity - stressor	Other priority areas		
					Other priority areas found	ESC sub-component priority area use	Change in activity - stressor
Narwhal Discharge – petroleum product (large accidental spill; heavy fuel oil)	3,4, 6	Repulse Bay/ Frozen Strait	Critical migratory pathway, summer feeding and calving/ rearing	Vessel traffic density low overall in AOI, and low in this priority area compared with CIN, FES. Spill could occur any time vessel is present.	Same as above	Same as above	Vessel traffic density low overall in AOI, higher in FES and CIN. Spill could occur any time vessel is present.
Narwhal Vessel at rest – noise disturbance	3,4, 6	Chesterfield Inlet/ Narrows	Summer feeding and calving/ rearing	Vessels known to remain at rest for a prolonged period in this area (up to 2 weeks); noted community concern.	RB/FS; DYB/WI; FES	Critical migratory pathway in RB/FS, summer feeding and calving/ rearing in all, less so in FES.	Vessels at rest expected to occur at lower densities in other areas.
Narwhal Submarine cables – acoustic surveying	3,4, 6	Chesterfield Inlet/Narrows	Same as above	Acoustic surveys likely to occur during open water, summer months, CIN along possible cable route.	Same as above	Same as above	Only FES along possible cable route, acoustic surveys unlikely to occur during winter months
Narwhal Scientific research – noise disturbance	3,4, 6	Duke of York Bay/ White Island area	Summer feeding and calving/ rearing	Noise disturbance from aerial research platforms is expected to occur rarely.	CIN; RB/FS; FES	Critical migratory pathway in RB/FS, summer feeding and calving rearing in all, less so in FES.	Noise disturbance from aerial research platforms is expected to occur rarely.

Table A-3. Priority area associations and interaction summaries for bowhead whale. ESC = Ecologically significant component. FES = Fisher and Evans Straits. CIN = Chesterfield Inlet/Narrows. DYB/WI = Duke of York Bay/White Island. RWS = Roes Welcome Sound. EB = East Bay. RB/FS = Repulse Bay/Frozen Strait. BWD = ballast water discharge. AOI = area of interest. AIS = automatic identification system.

ESC Sub-component & activity – stressor (interaction)	ESC	Priority Area Assessed	ESC sub-component priority area use	Description of activity - stressor	Other priority areas		
					Other priority areas found	ESC sub-component priority area use	Change in activity - stressor
Bowhead Vessel underway – noise disturbance	3,4, 6	Fisher and Evans Straits	Migratory pathway, summer feeding, calving/ rearing.	Vessel traffic density low overall in AOI, and low in this priority area compared with others except CIN.	DYB/WI; RWS	Migration, summer feeding in both, and also calving/ rearing in DYB/WI.	Vessel traffic density low overall in AOI, lower in DYB/WI and RWS.

ESC Sub-component & activity – stressor (interaction)	ESC	Priority Area Assessed	ESC sub-component priority area use	Description of activity - stressor	Other priority areas		
					Other priority areas found	ESC sub-component priority area use	Change in activity - stressor
Bowhead Vessel underway – vessel strikes	3,4, 6	Fisher and Evans Straits	Same as above	Same as above	Same as above	Same as above	Same as above
Bowhead Ice-breaking – noise disturbance	3,4, 6	Fisher and Evans Straits	Same as above	Active icebreaking is expected to be rare in the AOI. Overlap between icebreaker AIS data and sea ice cover was highest in FES where it was recorded approx. every other year from 2012-2019.	Same as above	Same as above	Active icebreaking is expected to be rare in the AOI. Overlap between icebreaker AIS data and sea ice cover occurred on only one trip each in RWS and RB/FS from 2012-2019.
Bowhead Vessel at rest – noise disturbance	3,4, 6	Fisher and Evans Straits	Migratory pathway, summer feeding, calving/ rearing	Vessels known to remain at rest for up to 1 week.	DYB/WI; RWS	Migration, summer feeding in both, and also calving/ rearing in DYB/WI.	Vessels at rest are expected to occur at lower densities DYB/WI and RWS.
Bowhead Discharge – pathogens/NIS (ballast water)	3,4, 6	Fisher and Evans Straits	Same as above	Vessel traffic density low overall in AOI, and high in this priority area compared with others. Considering existing measures, BWD expected to be a rare occurrence.	Same as above	Same as above	Vessel traffic density low overall in AOI, lower in DYB/WI and RWS. BWD rate expected to be low throughout.
Bowhead Discharge – petroleum product (large accidental spill; heavy fuel oil)	3,4, 6	Fisher and Evans Straits	Same as above	Vessel traffic density low overall in AOI, and high in this priority area compared with others. Spill could occur any time vessel is present.	Same as above	Same as above	Vessel traffic density low overall in AOI, lower in DYB/WI and RWS. Spill could occur any time vessel is present.
Bowhead Submarine cables – acoustic surveying	3,4, 6	Fisher and Evans Straits	Same as above	Acoustic surveys likely to occur during open water, summer months, FES along possible cable route.	Same as above	Same as above	RWS + DYB/WI not along possible cable route.

ESC Sub-component & activity – stressor (interaction)	ESC	Priority Area Assessed	ESC sub-component priority area use	Description of activity - stressor	Other priority areas		
					Other priority areas found	ESC sub-component priority area use	Change in activity - stressor
Bowhead Scientific research – noise disturbance	3,4, 6	Fisher and Evans Straits	Same as above	Noise disturbance from aerial research platforms is expected to occur rarely.	Same as above	Same as above	Noise disturbance from aerial research platforms is expected to occur rarely.

Table A-4. Priority area associations and interaction summaries for walrus. ESC = Ecologically significant component. FES = Fisher and Evans Straits. CIN = Chesterfield Inlet/Narrows. DYB/WI = Duke of York Bay/White Island. RWS = Roes Welcome Sound. EB = East Bay. RB/FS = Repulse Bay/Frozen Strait. BWD = ballast water discharge. AOI = area of interest. AIS = automatic identification system.

ESC Sub-component & activity – stressor (interaction)	ESC	Priority Area Assessed	ESC sub-component priority area use	Description of activity - stressor	Other priority areas		
					Other priority areas found	ESC sub-component priority area use	Change in activity - stressor
Walrus Vessel underway – noise disturbance	5	Fisher and Evans Straits	Summer and potentially year-round occupancy, haul-out sites	Vessel traffic density low overall in AOI, and high in this priority area compared with others.	RWS; CIN; EB; DYB/WI	Winter occupancy in RWS and CIN; summer haul-out sites DYBWI, EB.	Vessel traffic density lower during winter and in other priority areas than in FES.
Walrus Ice-breaking – noise disturbance	5	Fisher and Evans Straits	Same as above	Active icebreaking is expected to be rare in the AOI. Overlap between icebreaker AIS data and sea ice cover was highest in FES where it was recorded approx. every other year from 2012-2019.	Same as above	Same as above	Active icebreaking is expected to be rare in the AOI. Overlap between icebreaker AIS data and sea ice cover occurred on only one trip each in RWS and RB/FS from 2012-2019 and was not recorded in CIN and EB.
Walrus Ice-breaking – habitat alteration	5	Fisher and Evans Straits	Same as above	Same as above	Same as above	Same as above	Same as above
Walrus Vessel at rest – noise disturbance	5	Chesterfield Inlet/Narrows	Winter occupancy in CIN and known haul-out site at Depot Island	Vessels known to remain at rest for a prolonged period in this area (up to 2 weeks); noted community concern.	RWS; FES; EB; DYB/WI	Winter occupancy in RWS; summer haul-out sites DYBWI, EB; potentially year-round	Vessels at rest, especially large vessels, expected to occur at lower

ESC Sub-component & activity – stressor (interaction)	ESC	Priority Area Assessed	ESC sub-component priority area use	Description of activity - stressor	Other priority areas		
					Other priority areas found	ESC sub-component priority area use	Change in activity - stressor
						occupancy FES.	densities in other areas.
Walrus Discharges – pathogens/ NIS (ballast water)	5	Fisher and Evans Straits	Summer and potentially year-round occupancy, haul-out sites	Vessel traffic density low overall in AOI, and high in this priority area compared with others except CIN. Considering existing measures, BWD expected to be a rare occurrence.	Same as above	Winter occupancy in RWS and CIN; summer haul-out sites DYBWI, EB	Vessel traffic density lower during winter and in other priority areas than in FES.
Walrus Discharge – petroleum product (large accidental spill; heavy fuel oil)	5	Fisher and Evans Straits	Same as above	Vessel traffic density low overall in AOI, and high in this priority area compared with others. Spill could occur any time vessel is present.	Same as above	Same as above	Vessel traffic density lower during winter and in other priority areas than in FES. Spill could occur any time vessel is present.
Walrus Submarine cables (acoustic surveying) – noise disturbance	5	Fisher and Evans Straits	Same as above	Acoustic surveys likely to occur during open water, summer months, FES along possible cable route.	Same as above	Same as above	Only CIN along possible cable route, acoustic surveys unlikely to occur during winter months.
Walrus Scientific research – noise disturbance	5	Fisher and Evans Straits	Same as above	Aerial surveys generally focus on known haul-out sites.	Same as above	Same as above	Aerial surveys generally focus on known haul-out sites.
Walrus Scientific research – biota encounters/ handling	5	Fisher and Evans Straits	Same as above	Sampling often occurs at Walrus Island out of Coral Harbour.	Same as above	Same as above	Low density sampling may occur out of Naujaat in DYBWI and in other areas.
Walrus Recreation and tourism – noise disturbance	5	Fisher and Evans Straits	Same as above	Walrus-based tourism occurs during summer in FES, mainly from cruise ships.	Same as above	Same as above	Likely little walrus-based tourism in other priority areas.

Table A-5. Priority area associations and interaction summaries for bearded and ringed seals. ESC = Ecologically significant component. FES = Fisher and Evans Straits. CIN = Chesterfield Inlet/Narrows. DYB/WI = Duke of York Bay/White Island. RWS = Roes Welcome Sound. EB = East Bay. RB/FS = Repulse Bay/Frozen Strait. BWD = ballast water discharge. AOI = area of interest. AIS = automatic identification system.

ESC Sub-component & activity – stressor (interaction)	ESC	Priority Area Assessed	ESC sub-component priority area use	Description of activity - stressor	Other priority areas		
					Other priority areas found	ESC sub-component priority area use	Change in activity - stressor
Bearded seal Vessel underway – noise disturbance	5, 6	Fisher and Evans Straits	Summer and potentially year-round occupancy	Vessel traffic density low overall in AOI, and high in this priority area compared with others .	RWS; DYB/WI	Winter occupancy in RWS; summer and potentially year-round occupancy in DYBWI.	Vessel traffic density lower in priority areas other than CIN.
Bearded seal Ice-breaking – noise disturbance	5, 6	Fisher and Evans Straits	Same as above	Active icebreaking is expected to be rare in the AOI. Overlap between icebreaker AIS data and sea ice cover was highest in FES where it was recorded approx. every other year from 2012-2019.	Same as above	Same as above	Active icebreaking is expected to be rare in the AOI. Overlap between icebreaker AIS data and sea ice cover occurred on only one trip each in RWS and RB/FS from 2012-2019.
Bearded seal Ice-breaking – habitat alteration	5, 6	Fisher and Evans Straits	Same as above	Same as above	Same as above	Same as above	Same as above
Bearded seal Ice-breaking – vessel strikes	5, 6	Fisher and Evans Straits	Same as above	Same as above	Same as above	Same as above	Same as above
Bearded seal Discharges – pathogens/ NIS (ballast water)	5, 6	Fisher and Evans Straits	Same as above	Vessel traffic density low overall in AOI, and high in this priority area compared with others except CIN. Considering existing measures, BWD expected to be a rare occurrence.	Same as above	Same as above	Vessel traffic density lower in priority areas other than CIN.
Bearded seal Discharge – petroleum product (large accidental spill; heavy fuel oil)	5, 6	Fisher and Evans Straits	Same as above	Vessel traffic density low overall in AOI, and high in this priority area compared with others. Spill could occur any time vessel is present.	Same as above	Same as above	Vessel traffic density lower in priority areas other than CIN. Spill could occur any time vessel is present.
Bearded seal Submarine cables (acoustic surveying) – noise disturbance	5, 6	Fisher and Evans Straits	Same as above	Acoustic surveys likely to occur during open water, summer months, FES along possible cable route.	Same as above	Same as above	RWS + DYB/WI not along possible cable route.

ESC Sub-component & activity – stressor (interaction)	ESC	Priority Area Assessed	ESC sub-component priority area use	Description of activity - stressor	Other priority areas		
					Other priority areas found	ESC sub-component priority area use	Change in activity - stressor
Bearded seal Scientific research – noise disturbance	5, 6	Fisher and Evans Straits	Same as above	Noise disturbance from aerial research platforms is expected to occur rarely.	Same as above	Same as above	Noise disturbance from aerial research platforms is expected to occur rarely.
Ringed seal Vessel underway – noise disturbance	5, 6	Fisher and Evans Straits	Summer and potentially year-round occupancy	Vessel traffic density low overall in AOI, and high in this priority area compared with others.	RWS; DYB/WI	Winter occupancy in RWS; summer and possible year-round occupancy in DYB/WI.	Vessel traffic density lower in priority areas other than CIN.
Ringed seal Ice-breaking – noise disturbance	5, 6	Fisher and Evans Straits	Same as above	Active icebreaking is expected to be rare in the AOI. Overlap between icebreaker AIS data and sea ice cover was highest in FES where it was recorded approx. every other year from 2012-2019.	Same as above	Same as above	Active icebreaking is expected to be rare in the AOI. Overlap between icebreaker AIS data and sea ice cover occurred on only one trip each in RWS and RB/FS from 2012-2019.
Ringed seal Ice-breaking – habitat alteration	5, 6	Fisher and Evans Straits	Same as above	Same as above	Same as above	Same as above	Same as above
Ringed seal Ice-breaking – vessel strikes	5, 6	Fisher and Evans Straits	Same as above	Same as above	Same as above	Same as above	Same as above
Ringed seal Vessel at rest – noise disturbance	5, 6	Chesterfield Inlet/Narrows	Summer and potentially year-round occupancy	Vessels known to remain at rest for a prolonged period in this area (up to 2 weeks); noted community concern.	RWS; FES; DYB/WI	Winter occupancy in RWS; summer and possible year-round occupancy in DYB/WI and FES	Vessels at rest, especially large vessels, expected to occur at lower densities in other areas.
Ringed seal Discharge – petroleum product (large accidental spill; heavy fuel oil)	5, 6	Fisher and Evans Straits	Summer and potentially year-round occupancy	Vessel traffic density low overall in AOI, and high in this priority area compared with others. Spill could occur any time vessel is present.	RWS; CIN DYB/WI	Winter occupancy in RWS; summer and possible year-round occupancy in DYB/WI and CIN	Vessel traffic density lower during winter and in other priority areas than in FES. Spill could occur any time vessel is present.

ESC Sub-component & activity – stressor (interaction)	ESC	Priority Area Assessed	ESC sub-component priority area use	Description of activity - stressor	Other priority areas		
					Other priority areas found	ESC sub-component priority area use	Change in activity - stressor
Ringed seal Submarine cables – acoustic surveying	5, 6	Fisher and Evans Straits	Same as above	Acoustic surveys likely to occur during open water, summer months, FES along possible cable route.	Same as above	Same as above	RWS + DYB/WI not along possible cable route.
Ringed seal Scientific research – noise disturbance	5, 6	Fisher and Evans Straits	Same as above	Noise disturbance from aerial research platforms is expected to occur rarely.	Same as above	Same as above	Noise disturbance from aerial research platforms is expected to occur rarely.

Table A-6. Priority area associations and interaction summaries for marine and anadromous fishes (Arctic Char, Arctic cod, other forage fish). ESC = Ecologically significant component. FES = Fisher and Evans Straits. CIN = Chesterfield Inlet/Narrows. DYB/WI = Duke of York Bay/White Island. RWS = Roes Welcome Sound. EB = East Bay. RB/FS = Repulse Bay/Frozen Strait. BWD = ballast water discharge. AOI = area of interest. AIS = automatic identification system.

ESC Sub-component & activity – stressor (interaction)	ESC	Priority Area Assessed	ESC sub-component priority area use	Description of activity - stressor	Other priority areas		
					Other priority areas found	ESC sub-component priority area use	Change in activity - stressor
Arctic char Vessel underway – noise and vibration disturbance	5, 6,7	Chesterfield Inlet/ Narrows	Summer occupancy for adults and juveniles, feeding, migration corridor.	Vessel traffic density low overall in AOI, and high in this priority area compared with others except FES.	Through-out AOI, with higher densities noted in DYB/WI.	Summer occupancy for adults and juveniles, feeding, migration corridor.	Vessel traffic density low overall in AOI, and low in areas other than FES and CIN.
Arctic char Vessel at rest – disturbance from artificial light	5, 6,7	Chesterfield Inlet/ Narrows	Same as above	Vessels known to remain at rest for a prolonged period in this area (up to 2 weeks); noted community concern.	Same as above	Same as above	Vessels at rest, especially large vessels, expected to occur at lower densities in other areas.
Arctic char Discharges – pathogens/NIS (ballast water)	5, 6,7	Chesterfield Inlet/ Narrows	Same as above	Vessel traffic density low overall in AOI, and high in this priority area compared with others except FES. Considering existing measures, BWD expected to be a rare occurrence.	Same as above	Same as above	Vessel traffic density low overall in AOI, and lower in DYB/WI. BWD rate expected to be low throughout.
Arctic char	5, 6,7	Duke of York Bay/	Summer occupancy for adults and	Vessel traffic density low overall in AOI, and low in	Through-out AOI, with higher	Same as above	Vessel traffic density low overall in AOI,

ESC Sub-component & activity – stressor (interaction)	ESC	Priority Area Assessed	ESC sub-component priority area use	Description of activity - stressor	Other priority areas		
					Other priority areas found	ESC sub-component priority area use	Change in activity - stressor
Discharge – petroleum product (large accidental spill; heavy fuel oil)		White Island area	juveniles, feeding, migration corridor.	this priority area compared with FES and CIN. Spill could occur any time vessel is present.	densities noted in CIN.		and low throughout compared with FES and CIN. Spill could occur any time vessel is present.
Arctic cod Vessel underway – noise disturbance	5,7	Fisher and Evans Straits	FES a noted area of high abundance, though distribution not well known in AOI.	Vessel traffic density low overall in AOI, and high in this priority area compared with others.	Expected to occur throughout AOI.	All life history events expected in areas of occurrence.	Vessel traffic density low overall in AOI, and low in areas other than FES and CIN.
Arctic cod Ice-breaking – noise disturbance	5,7	Fisher and Evans Straits	Same as above	Active icebreaking is expected to be rare in the AOI. Overlap between icebreaker AIS data and sea ice cover was highest in FES where it was recorded approx. every other year from 2012-2019.	Same as above	Same as above	Active icebreaking is expected to be rare in the AOI. Overlap between icebreaker AIS data and sea ice cover occurred on only one trip each in RWS and RB/FS from 2012-2019 and was not recorded in CIN and EB.
Arctic cod Vessel at rest – disturbance from artificial light	5,7	Chesterfield Inlet/ Narrows	Occurrence records present for CIN; distribution not well known in AOI.	Vessels known to remain at rest for a prolonged period in this area (up to 2 weeks); noted community concern.	Expected to occur throughout AOI.	Same as above	Vessels at rest, especially large vessels, expected to occur at lower densities in other areas.
Arctic cod Vessel at rest – noise disturbance	5,7	Chesterfield Inlet/ Narrows	Same as above	Vessels known to remain at rest for a prolonged period in this area (up to 2 weeks); noted community concern.	Same as above	Same as above	Same as above
Arctic cod Discharges – pathogens/NIS (ballast water)	5,7	Fisher and Evans Straits	FES a noted area of high abundance, though distribution not well known in AOI.	Vessel traffic density low overall in AOI, and high in this priority area compared with others except CIN. Considering existing	Expected to occur throughout AOI.	Same as above	Vessel traffic density low overall in AOI, lower in areas other than CIN and FES. BWD rate expected to

ESC Sub-component & activity – stressor (interaction)	ESC	Priority Area Assessed	ESC sub-component priority area use	Description of activity - stressor	Other priority areas		
					Other priority areas found	ESC sub-component priority area use	Change in activity - stressor
				measures, BWD expected to be a rare occurrence.			be low throughout.
Arctic cod Discharge – petroleum product (large accidental spill; heavy fuel oil)	5,7	Fisher and Evans Straits	Same as above	Vessel traffic density low overall in AOI, and high in this priority area compared with others except CIN. Spill could occur any time vessel is present.	Same as above	Same as above	Vessel traffic density low overall in AOI, and lower in areas other than FES and CIN. Spill could occur any time vessel is present.
Arctic cod Submarine cables (acoustic surveying) – noise disturbance	5,7	Fisher and Evans Straits	Same as above	Acoustic surveys likely to occur during open water, summer months, FES along possible cable route.	Same as above	Same as above	Only CIN also along possible cable route, acoustic surveys unlikely to occur during winter months
Other forage fish (e.g., capelin) Vessel underway – habitat alteration/ removal (vessel wake and propellor wash)	5, 6,7	Chesterfield Inlet/ Narrows	Records for capelin and sand lance present in CIN, though distributions not well known throughout AOI.	Vessel traffic density low overall in AOI, and high in this priority area compared with others except FES.	Distribution not well known; capelin records present in RWS/FES, sand lance records present in FES.	Not well known; at minimum, occurrence.	Vessel traffic density lower in RWS and similar in FES compared with CIN.
Other forage fish (e.g., sculpin) Discharges – biological material	5, 6,7	Chesterfield Inlet/ Narrows	Records for sculpins present in CIN, though distributions not well known throughout AOI.	Vessel traffic density low overall in AOI, and high in this priority area compared with others. Sewage/ greywater discharge will not occur constantly from vessels.	Distribution not well known; sculpin records present in all priority areas except EB, RB/FS.	Same as above	Vessel traffic density lower in RWS and RB/FS priority areas than in CIN. Sewage/ greywater discharge will not occur constantly from vessels.

Table A-7. Priority area associations and interaction summaries for polar bear. ESC = Ecologically significant component. FES = Fisher and Evans Straits. CIN = Chesterfield Inlet/Narrows. DYB/WI = Duke of York Bay/White Island. RWS = Roes Welcome Sound. EB = East Bay. RB/FS = Repulse Bay/Frozen Strait. AOI = area of interest. AIS = automatic identification system.

ESC Sub-component & activity – stressor (interaction)	**ESC**	**Priority Area Assessed**	**ESC sub-component priority area use**	**Description of activity - stressor**	**Other priority areas**		
					Other priority areas found	**ESC sub-component priority area use**	**Change in activity - stressor**
Polar bear Icebreaking – noise disturbance	4,5	Fisher and Evans Strait	Foraging, migration.	Active icebreaking is expected to be rare in the AOI. Overlap between icebreaker AIS data and sea ice cover was highest in FES where it was recorded approx. every other year from 2012-2019.	East Bay; DYB/WI; RB/FS.	Nearby denning habitat, foraging, rearing.	Active icebreaking is expected to be rare in the AOI. Overlap between icebreaker AIS data and sea ice cover occurred on only one trip each in DYB/WI and RB/FS from 2012-2019 and was not recorded in EB.
Polar bear Discharge – petroleum product (large accidental spill; heavy fuel oil)	4,5	Fisher and Evans Straits	Foraging, migration.	Vessel traffic density low overall in AOI, and high in this priority area compared with others. Spill could occur any time vessel is present.	Same as above	Same as above	Vessel traffic density lower during winter and in other priority areas than in FES. Spill could occur any time vessel is present
Polar bear Recreation and tourism - noise disturbance (includes displacement due to visual/ olfactory cues)	4,5	Fisher and Evans Straits	Foraging, migration.	Disturbance from noise and visual/ olfactory cues from small boat traffic is currently limited.	Same as above	Same as above	NE and east coast of Southampton Island, including the priority areas mentioned, are not known to draw cruise ship traffic or boat tours from Coral Harbour-based outfitters.

Table A-8. Priority area associations and interaction summaries for sea ice and polynya habitat. ESC = Ecologically significant component. FES = Fisher and Evans Straits. CIN = Chesterfield Inlet/Narrows. DYB/WI = Duke of York Bay/White Island. RWS = Roes Welcome Sound. EB = East Bay. RB/FS = Repulse Bay/Frozen Strait. AOI = area of interest. AIS = automatic identification system.

ESC Sub-component & activity – stressor (interaction)	ESC	Priority Area Assessed	ESC sub-component priority area use	Description of activity - stressor	Other priority areas		
					Other priority areas found	ESC sub-component priority area use	Change in activity - stressor
Polynya habitat Discharges - atmospheric emissions	2	Chesterfield Inlet/ Narrows	Occurrence; extent is variable, but forms in winter. Important for Hudson Bay ice formation.	Vessel traffic density is low overall in AOI. High in this priority area compared with other areas, though remains low in winter.	RWS; RB/FS.	Occurrence; extent is variable, but forms in winter. RWS important for Hudson Bay ice formation, ice arch forms every 4 years.	Vessel traffic density lower in these priority areas than CIN.
Polynya habitat Discharge – petroleum product (large accidental spill; heavy fuel oil)	2	Chesterfield Inlet/ Narrows	Same as above	Vessel traffic density is low overall in AOI. High in this priority area compared with other areas, though remains low in winter. Spill could occur any time vessel is present.	Same as above	Same as above	Vessel traffic density lower in these priority areas than CIN. Spill could occur any time vessel is present.
Polynya habitat Icebreaking - habitat alteration	2	Chesterfield Inlet/ Narrows	Same as above	Active icebreaking is expected to be rare in the AOI. Overlap between icebreaker AIS data and sea ice cover was not recorded in CIN from 2012-2019.	Same as above	Same as above	Active icebreaking is expected to be rare in the AOI. Overlap between icebreaker AIS data and sea ice cover occurred on only one trip each in RWS and RB/FS from 2012-2019.
Sea ice Discharges - atmospheric emissions	2	Roes Welcome Sound	Occurrence; predominantly mobile pack ice, also landfast ice. Ice arch forms every 4 years.	Vessel traffic density is low overall in AOI, and low in this priority area compared with FES and CIN.	Sea ice occurs seasonally throughout all priority areas.	Occurrence; predominantly mobile pack ice, also landfast ice.	Vessel traffic is low overall in AOI.
Sea ice Discharges - petroleum product (large accidental spill; heavy fuel oil)	2	Roes Welcome Sound	Same as above	Vessel traffic density is low overall in AOI. Low in this priority area compared with FES and CIN. Spill could occur any time vessel is present.	Same as above	Same as above	Vessel traffic is low overall in AOI. Spill could occur any time vessel is present.

ESC Sub-component & activity – stressor (interaction)	ESC	Priority Area Assessed	ESC sub-component priority area use	Description of activity - stressor	Other priority areas		
					Other priority areas found	ESC sub-component priority area use	Change in activity - stressor
Sea ice Ice-breaking – habitat alteration	2	Roes Welcome Sound	Same as above	Active icebreaking is expected to be rare in the AOI. Overlap between icebreaker AIS data and sea ice cover occurred on only one trip in RWS from 2012-2019.	Same as above	Same as above	Active icebreaking is expected to be rare in the AOI. Overlap between icebreaker AIS data and sea ice cover was highest in FES where it was recorded approx. every other year from 2012-2019.

Table A-9. Priority area associations and interaction summaries for kelp beds and other macroalgae. ESC = Ecologically significant component. FES = Fisher and Evans Straits. CIN = Chesterfield Inlet/Narrows. DYB/WI = Duke of York Bay/White Island. RWS = Roes Welcome Sound. EB = East Bay. RB/FS = Repulse Bay/Frozen Strait. BWD = ballast water discharge. AOI = area of interest.

ESC Sub-component & activity – stressor (interaction)	ESC	Priority Area Assessed	ESC sub-component priority area use	Description of activity - stressor	Other priority areas		
					Other priority areas found	ESC sub-component priority area use	Change in activity - stressor
Kelp beds/ other macroalgae Vessel underway – habitat alteration/ removal (vessel wake and propeller wash)	8, 9	Chesterfield Inlet/ Narrows	High densities of macroalgae noted in this priority area.	Vessel traffic density low overall in AOI, and high in this priority area compared with others except FES.	RWS; RB/FS; FES; throughout much of the coastal habitat of the AOI.	High densities of macroalgae noted in these locations.	Vessel traffic density lower in RWS and RB/FS priority areas than in CIN, similar in FES.
Kelp beds/ other macroalgae Discharges – biological material	8, 9	Chesterfield Inlet/ Narrows	Same as above	Vessel traffic density low overall in AOI, and high in this priority area compared with others. Sewage/ greywater discharge will not occur constantly from vessels.	Same as above	Same as above	Vessel traffic density much lower in RWS and RB/FS priority areas than in CIN, lower in FES. Sewage/ greywater discharge will not occur constantly from vessels
Kelp beds/ other macroalgae	8, 9	Chesterfield Inlet/ Narrows	Same as above	Vessel traffic density low overall in AOI, and high	Same as above	Same as above	Vessel traffic density much lower in RWS

ESC Sub-component & activity – stressor (interaction)	ESC	Priority Area Assessed	ESC sub-component priority area use	Description of activity - stressor	Other priority areas		
					Other priority areas found	ESC sub-component priority area use	Change in activity - stressor
Discharges – pathogens/NIS (ballast water)				in this priority area compared with others except CIN. Considering existing measures, BWD expected to be a rare occurrence.			and RB/FS priority areas than in CIN, lower in FES. Considering existing measures, BWD expected to be a rare occurrence.
Kelp beds/ other macroalgae Discharges – petroleum product (large accidental spill; heavy fuel oil)	8, 9	Chesterfield Inlet/ Narrows	Same as above	Vessel traffic density low overall in AOI, and high in this priority area compared with others. Spill could occur any time vessel is present	Same as above	Same as above	Vessel traffic density lower in RWS and RB/FS priority areas than in CIN, similar in FES. Spill could occur any time vessel is present
Kelp beds/ other macroalgae Vessel at rest – pathogens/NIS	8, 9	Chesterfield Inlet/ Narrows	Same as above	Vessel traffic density low overall in AOI, and high in this priority area compared with others. Vessels known to remain at rest for a prolonged period in this area (up to 2 weeks); noted community concern.	Same as above	Same as above	Vessel traffic density much lower in RWS and RB/FS priority areas than in CIN, lower in FES. Large vessels not expected to remain anchored for extended periods.
Kelp beds/ other macroalgae Anchoring and mooring – habitat alteration/removal	8, 9	Chesterfield Inlet/ Narrows	Same as above	Vessel traffic density low overall in AOI, and high in this priority area compared with others. Vessels known to remain at rest for a prolonged period in this area (up to 2 weeks); noted community concern.	Same as above	Same as above	Vessel traffic density much lower in RWS and RB/FS priority areas than in CIN, lower in FES. Large vessels not expected to remain anchored for extended periods.
Kelp beds/ other macroalgae Submarine cables (installation) – habitat alteration/ removal	8, 9	Chesterfield Inlet/ Narrows	Same as above	Proposed submarine cable route extends into CIN priority area.	Same as above	Same as above	Known proposed submarine cable routes do not traverse RWS or RB/FS, though would traverse FES.

Table A-10. Priority area associations and interaction summaries for phytoplankton and zooplankton. ESC = Ecologically significant component. FES = Fisher and Evans Straits. CIN = Chesterfield Inlet/Narrows. DYB/WI = Duke of York Bay/White Island. RWS = Roes Welcome Sound. EB = East Bay. RB/FS = Repulse Bay/Frozen Strait. BWD = ballast water exchange. AOI = area of interest.

ESC Sub-component & activity – stressor (interaction)	ESC	Priority Area Assessed	ESC sub-component priority area use	Description of activity - stressor	Other priority areas		
					Other priority areas found	ESC sub-component priority area use	Change in activity - stressor
Phytoplankton Discharges - biological material	2	Chesterfield Inlet/Narrows	High primary production during spring bloom and other ice-free periods in summer/fall.	Vessel traffic density low overall in AOI, and high in this priority area compared with others. Sewage/ greywater discharge will not occur constantly from vessels.	RWS and RB/FS; also throughout AOI in varying abundances.	High primary production during ice-free periods, especially spring bloom.	Vessel traffic density lower in RWS and RB/FS than CIN.
Phytoplankton Discharges - contaminants (scrubber effluent)	2	Chesterfield Inlet/Narrows	Same as above	Vessel traffic density low overall in AOI, and high in this priority area compared with others. Scrubber effluent discharge will not occur constantly from vessels.	Same as above	Same as above	Vessel traffic density lower in RWS and RB/FS than CIN.
Phytoplankton Discharges – petroleum product (large accidental spill; heavy fuel oil)	2	Chesterfield Inlet/Narrows	Same as above	Vessel traffic density is low overall in AOI, and high in this priority area compared with others. Spill could occur any time vessel is present.	Same as above	Same as above	Vessel traffic density lower in RWS and RB/FS than CIN.
Zooplankton Vessel at rest - disturbance from artificial light	7	Chesterfield Inlet/Narrows	Occurrence, with abundance linked to primary production.	Vessels known to remain at rest for a prolonged period in this area (up to 2 weeks); noted community concern.	RWS; also throughout AOI in varying abundances.	Higher primary production during spring bloom and other ice-free periods in summer/fall.	Vessels at rest are expected to occur at lower densities in other areas.

Table A-11. Priority area associations and interaction summaries for benthic invertebrates. ESC = Ecologically significant component. FES = Fisher and Evans Straits. CIN = Chesterfield Inlet/Narrows. DYB/WI = Duke of York Bay/White Island. RWS = Roes Welcome Sound. EB = East Bay. RB/FS = Repulse Bay/Frozen Strait. BWD = ballast water exchange. AOI = area of interest.

ESC Sub-component & activity – stressor (interaction)	ESC	Priority Area Assessed	ESC sub-component priority area use	Description of activity - stressor	Other priority areas		
					Other priority areas found	ESC sub-component priority area use	Change in activity - stressor
Benthic invertebrates	7, 9	Chesterfield Inlet/ Narrows	Expected year-round occurrence.	Density of vessel traffic is low overall in AOI,	Expected to occur throughout	Expected year-round occurrence	Vessel traffic density lower in priority

ESC Sub-component & activity – stressor (interaction)	ESC	Priority Area Assessed	ESC sub-component priority area use	Description of activity - stressor	Other priority areas		
					Other priority areas found	ESC sub-component priority area use	Change in activity - stressor
Vessel underway – habitat alteration/ removal				and high in this priority area compared with others.	AOI; noted high diversity and biomass associated with mixed substrate or located near polynyas.	throughout, though poorly studied.	areas other than CIN.
Benthic invertebrates Discharges – biological material	7, 9	Chesterfield Inlet/ Narrows	Expected year-round occurrence.	Density of vessel traffic is low overall in AOI, and high in this priority area compared with others. Sewage/ greywater discharge will not occur constantly from vessels.	Same as above	Same as above	Vessel traffic density lower in priority areas other than CIN.
Benthic invertebrates Discharges – pathogens/NIS (ballast water)	7, 9	Chesterfield Inlet/ Narrows	Expected year-round occurrence.	Density of vessel traffic is low overall in AOI, and high in this priority area compared with others. Considering existing measures, BWD expected to be a rare occurrence.	Same as above	Same as above	Vessel traffic density lower in priority areas other than CIN.
Benthic invertebrates Discharge – petroleum product (large accidental spill; heavy fuel oil)	7, 9	Chesterfield Inlet/ Narrows	Expected year-round occurrence.	Vessel traffic density low overall in AOI, and high in this priority area compared with others. Spill could occur any time vessel is present.	Same as above	Same as above	Vessel traffic density lower in priority areas other than CIN. Spill could occur any time vessel is present.
Benthic invertebrates Vessel at rest – pathogens/NIS (fouling organisms)	7, 9	Chesterfield Inlet/ Narrows	Expected year-round occurrence.	Vessel traffic density is low overall in AOI, and high in this priority area compared with others. Vessels known to remain at rest for a prolonged period in this area (up to 2 weeks); noted community concern.	Same as above	Same as above	Vessel traffic density lower in priority areas other than CIN. Vessels at rest are expected to occur at lower densities in other areas.
Benthic invertebrates	7, 9	Chesterfield Inlet/ Narrows	Expected year-round occurrence.	Density of vessel traffic is low overall in AOI,	Same as above	Same as above	Vessel traffic density lower in priority

ESC Sub-component & activity – stressor (interaction)	ESC	Priority Area Assessed	ESC sub-component priority area use	Description of activity - stressor	Other priority areas		
					Other priority areas found	ESC sub-component priority area use	Change in activity - stressor
Anchoring and mooring – habitat alteration/ removal				and high in this priority area compared with others. Anchored vessels may remain for up to 2 weeks.			areas other than CIN. Large vessels not expected to remain anchored for extended periods.
Benthic invertebrates (corals and sponges) Submarine cables (installation) – habitat alteration/ removal	7, 9	Fisher and Evans Straits	Expected year-round occurrence.	Proposed submarine cable route spans entire FES priority area.	Expected to occur throughout AOI; distribution poorly studied.	Same as above	Proposed cable route does not extend into any other priority area besides CIN.

Table A-12. Priority area associations and interaction summaries for marine birds (thick-billed murre, Thayer's gull, common eider). ESC = Ecologically significant component. FES = Fisher and Evans Straits. CIN = Chesterfield Inlet/Narrows. DYB/WI = Duke of York Bay/White Island. RWS = Roes Welcome Sound. EB = East Bay. RB/FS = Repulse Bay/Frozen Strait. BWD = ballast water discharge. AOI = area of interest. AIS = automatic identification system.

ESC Sub-component & activity – stressor (interaction)	ESC	Priority Area Assessed	ESC sub-component priority area use	Description of activity - stressor	Other priority areas		
					Other priority areas found	ESC sub-component priority area use	Change in activity - stressor
Thick-billed murre Discharges – petroleum product (small operational spill; e.g., bilge water, small fuel leaks)	7	Fisher and Evans Straits	Foraging and chick-rearing in marine waters from two colonies on Coats Island from mid-May to October.	Vessel traffic density low overall in AOI, and high in this priority area compared with others. Small operational spills assumed to occur frequently.	RWS	Post-breeding foraging in late summer.	Vessel traffic density lower in RWS than in FES. Lower frequency of operational spills expected.
Thick-billed murre Discharges – petroleum product (large accidental spill; heavy fuel oil)	7	Fisher and Evans Straits	Same as above	Vessel traffic density low overall in AOI, and high in this priority area compared with others. Spill could occur any time vessel is present.	RWS	Post-breeding foraging in late summer.	Vessel traffic density lower in RWS than in FES. Spill could occur any time vessel is present.
Thick-billed murre Scientific research –	7	Fisher and Evans Straits	Same as above	Noise disturbance from aerial research platforms is expected to occur rarely.	RWS	Post-breeding foraging in late summer.	Noise disturbance from aerial research platforms is

ESC Sub-component & activity – stressor (interaction)	ESC	Priority Area Assessed	ESC sub-component priority area use	Description of activity - stressor	Other priority areas		
					Other priority areas found	ESC sub-component priority area use	Change in activity - stressor
noise disturbance							expected to occur rarely.
Thick-billed murre Recreation and tourism – noise disturbance	7	Fisher and Evans Straits	Same as above	Bird colony-based tourism occurs during summer in FES, mainly from cruise ships, and is expected to be limited.	RWS	Post-breeding foraging in late summer.	Seabird-based tourism is not known in this area.
Thayer's gull Scientific research – noise disturbance	7	Duke of York Bay/ White Island area	Breeding colonies are present on White Island and foraging occurs in nearby waters.	Noise disturbance from aerial research platforms is expected to occur rarely.	No other priority areas identified as important for Thayer's gull.	N/A	Noise disturbance from aerial research platforms is expected to occur rarely.
Common eider Vessel underway – noise disturbance	7	East Bay	Largest single breeding colony in Canadian Arctic in East Bay; nesting, brood-rearing, and foraging in nearby waters.	Vessel traffic density low overall in AOI, and low in this priority area compared with FES and CIN.	No other priority areas identified as important for Common Eider.	N/A	N/A
Common eider Vessel underway – water displacement	7	East Bay	Same as above	Same as above	Same as above	N/A	N/A
Common eider Vessel underway – vessel strikes	7	East Bay	Same as above	Same as above	Same as above	N/A	N/A
Common eider Ice-breaking – noise disturbance	7	East Bay	Same as above	Active icebreaking is expected to be rare in the AOI. Overlap between icebreaker AIS data and sea ice cover was not recorded in EB from 2012-2019.	Same as above	N/A	N/A
Common eider Icebreaking – habitat alteration	7	East Bay	Same as above	Same as above	Same as above	N/A	N/A
Common eider	7	East Bay	Same as above	Vessel traffic density low overall in AOI, and low in	Same as above	N/A	N/A

ESC Sub-component & activity – stressor (interaction)	ESC	Priority Area Assessed	ESC sub-component priority area use	Description of activity - stressor	Other priority areas		
					Other priority areas found	ESC sub-component priority area use	Change in activity - stressor
Discharges – pathogens/NIS (ballast water)				this priority area compared with FES and CIN. BWD rate expected to be low throughout.			
Common eider Data collection – noise disturbance	7	East Bay	Same as above	Noise disturbance from aerial research platforms is expected to occur rarely.	Same as above	N/A	N/A
Common eider Data collection – biota encounters/ handling	7	East Bay	Same as above	Disturbance from noise/visual cues from researchers using small boats is expected to be limited.	Same as above	N/A	N/A

Appendix B: Additional Activity and Sub-activity Level 1 Assessments

Activity Interactions

Potential activities and accompanying ESC interactions were identified in the pathway of effects (PoE) report for the Southampton Island AOI (Johnson et al. unpublished[35]). During initial level 1 assessments for this this ecological risk assessment, it was determined that several activities would not result in a measurable impact on any of the ESC subcomponents and/or were out of spatial or temporal scope, and therefore no level 2 assessment was conducted (see Section 4.0 Methods). These activities and the rationale to not proceed to a level 2 assessment are provided below.

Municipal Wastes

Wastewater

The municipalities of Chesterfield Inlet and Coral Harbour are immediately adjacent to the SI AOI and, as such, the footprint of human settlement in these areas extends into the marine environment of the AOI. Baker Lake, Rankin Inlet, and Naujaat are also located near the AOI (see Figure 1-1). This section focuses on activities associated with municipalities and are not covered elsewhere, including wastewater discharge and solid waste disposal.

Owing to the remoteness of communities in Nunavut, municipal wastewater treatment infrastructure is limited relative to other parts of Canada. Most communities in the territory use passive treatment methods, consisting of ponds or lagoons in combination with wetland treatment areas. These waterbodies accumulate sewage over time and either decant continuously to the marine environment or at scheduled times of the year, in accordance with their Type B water licenses administered by the Nunavut Water Board (*Nunavut Waters and Nunavut Surface Rights Tribunal Act* (2002)*; Nunavut Waters Regulations* (2013)). Of the communities adjacent to or near the AOI, Rankin Inlet is the only community with a mechanical treatment plant. Prior to the construction of this plant in 1996, untreated wastewater from the community was discharged directly into Johnston Cove (Johnson et al. 2014). Infrastructure challenges across Nunavut continue to lead to accidental releases of sewage and other contaminants that occur more frequently than in other parts of Canada (Nunavut Tunngavik Incorporated 2020). This has led to large accidental spills of sewage into the marine environment (e.g., in Rankin Inlet 2021 and Iqaluit 2019; McKay 2019; Rogers 2021). Due to local characteristics of the treatment systems and receiving environments, the quality of effluent ultimately discharged varies among communities (Johnson et al. 2014; Jamieson et al. 2015). Evidence from three communities (Pangnirtung, Kugaaruk, and Pond Inlet), which were deemed to be broadly representative of the conditions across all Nunavut communities, shows a small radius of impacts to benthic invertebrate communities in the immediate vicinity of the final discharge point (Jamieson et al. 2015; Krumhansl et al. 2016); however, broader cumulative effects have not been documented. There are more communities adjacent to or in the vicinity of SI AOI than other MPAs in the Canadian Arctic and the combined impacts of these settlements to the marine environment may warrant further investigation. In addition to water licensing, municipal wastewater effluent is also regulated under the *Fisheries Act* (1985) and the *Arctic Waters Pollution Prevention Act* (1985). The creation of new municipal wastewater regulations that would close regulatory gaps in Arctic communities (CCME 2009) is being studied by ECCC (Jamieson et al. 2015). The implications of any such regulations would warrant further consideration to understand how they may reduce

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[35] Johnson et al. 2019. Pathways of effects modelling for the ecological and biological components of the Southampton Island Area of Interest. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/nnn. vi + xx p.

impacts to the AOI; however, wastewater discharge from municipalities is beyond the scope of MPA regulations to address at this time and therefore was not considered further in the risk assessment.

Solid Waste Litter/Debris

Section 3.3 of the PoE report for the AOI (Johnson et al. unpublished[36]) addresses the import of waste/debris from sources outside the AOI of unspecific origin through ocean current transport. Separating the relative contributions of vessel-derived waste/debris versus that originating from community solid waste facilities, as well as that imported from outside the AOI via ocean currents, may not be possible without further study aimed at quantifying these contributions. Nonetheless, as waste disposal facilities in the communities around the AOI are all within a few kilometers of the coast, there are concerns about litter from community garbage dumps entering the marine environment and contaminating local food supplies (Brown 2021). Most communities in Nunavut, including those in the vicinity of the AOI, have sub-standard solid waste management facilities (Nunavut Tunngavik Incorporated 2020); containment measures such as compaction, cover material, and fencing are lacking, leading to widespread windblown litter. These facilities have also exceeded their intended capacity, but plans have not advanced for replacing or expanding existing sites (Nunavut Tunngavik Incorporated 2020; Brown 2021; Oceans North 2021). The geographic extent of impacts and the range of transport of litter from local point sources in the AOI have not been examined. Evidence from the European Arctic shows that larger plastic debris specifically tends to accumulate in fiords, canyons, and trenches, rather than on coastal shelves and slopes, though it is not clear whether these results would be applicable to the AOI given its relatively shallow bathymetry (see Figure 2-3). Microplastics are more ubiquitous and have been found throughout the Arctic environment, including in sea ice, sediments, snow, the water column, and biota (Hallanger and Gabrielsen 2018). Studies have shown uptake of plastics in marine biota, including fishes (Kühn et al. 2018; Morgana et al. 2018), seabirds (Poon et al. 2017), zooplankton (Cole et al. 2013; Coppock et al. 2019), and marine mammals (Baulch et al. 2014), but more work is needed to understand the potential toxicity of microplastics to marine biota and their synergistic effects with other contaminants (ECCC and Health Canada 2020).

It is recognized that litter from waste disposal facilities is a concern and is relevant to the management of a potential MPA. Currently, waste management is largely regulated under the Type B water licenses of each municipality, in concert between the Nunavut Water Board and Crown Indigenous Relations and Northern Affairs Canada. Other regulations under the *Territorial Lands Act* (1985) and Nunavut's *Environmental Protection Act* (1988) also apply to the release of contaminants. As such, regulation of solid waste per se is outside the scope of potential MPA regulations and was not considered further in this risk assessment.

Seabed mining

Seabed mining is an exploratory industry that aims to target valuable rare earth metal deposits on the seafloor. There is currently no regulatory process in place that allows for seabed mining to occur in Canada, and as such there are no proposed or existing exploration or exploitation activities in the AOI area or anywhere in the country. Therefore, seabed mining was not assessed in this risk assessment. Should the regulatory framework and industry develop sufficiently to allow for the possibility of this activity in the foreseeable future and interest is expressed, it may be included in the risk assessment process at that time.

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[36] Johnson et al. 2019. Pathways of effects modelling for the ecological and biological components of the Southampton Island Area of Interest. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/nnn. vi + xx p.

Sub-activity Interactions

The activities and ESC interactions identified in the PoE document for the SI AOI (Johnson et al. unpublished[37]) that were included in this ERA are described and assessed in Sections 5.0-10.0. Within these activities, level 1 assessments for several sub-activities were deemed to not result in measurable impacts and were not assessed. The level 1 assessments for these sub-activities is provided below.

Shipping and Vessel Traffic

Vessel Underway

Disturbance from Artificial Light

There can be several ecological responses to disturbance caused from artificial light generated by vessels underway but the transitory nature of the vessels and the overall low density of vessel traffic in the AOI are not expected to lead to measurable impacts on any ESC subcomponent. Toothed whales, such as beluga and narwhal, rely heavily on echolocation to navigate and there is little evidence that they would be directly affected by an increase in artificial light from vessels. Baleen whales and pinnipeds may be more susceptible than toothed whales but, overall, the effects of artificial light from vessel transits are transitory and considered of little consequence to marine mammals (Greer et al. 2010). Similarly, although certain species of fish and zooplankton demonstrate phototaxis, the transitory nature of the light from this pathway is not expected to result in measurable impacts on these organisms. Some seabirds, particularly petrels, have a known attraction to light (Montevecchi 2006; Rodriguez et al. 2015) and disorientation/contact is expected to negatively impact survival even if the collision is not immediately lethal (Ryan 1991; Black 2005; Kingsley 2006; Bocetti 2011). However, petrels do not occur in the AOI and negative effects from attraction to artificial light is not known for the species that do occur. Therefore, seabirds were not assessed for this stressor. No interactions were assessed for this pathway but see Section 5.3.2 for assessments investigating risks from artificial light emitted by vessels at rest for an extended period.

Pathogens/Non-indigenous Species

The impacts from the establishment of NIS are difficult to predict but have the potential to affect marine communities in the AOI (Goldsmit et al. 2020). The effects from fouling organisms were assessed collectively by the vessel at rest pathway (Section 5.3.3) as it would be impractical to tease apart potential impacts from fouling organisms that may be on an anchor against those that may be on the hull of a transiting vessel; therefore, separate assessments were not conducted for this stressor under the anchoring/mooring, grounding/foundering, or vessel underway pathways. A second set of assessments were included in Section 5.5.2 that examine ballast water. See these sections for more thorough introductions to the pathways and scoping rationales.

12.1.1.1 Vessel at Rest

Foreign Object/Obstacle

Due to the limited amount of vessel traffic currently within the AOI, this pathway is not expected to result in measurable impacts to any ESC subcomponent and level 2 assessments were not conducted.

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[37] Johnson et al. 2019. Pathways of effects modelling for the ecological and biological components of the Southampton Island Area of Interest. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/nnn. vi + xx p.

12.1.1.1 Grounding and Foundering

For the purposes of this assessment, grounding refers to the temporary impact of an operational vessel with marine substrate, which can be accidental or intentional. Accidental groundings are typically more common; however, in the Arctic, grounding of re-supply barges are necessary near several communities, including Coral Harbour, due to the lack of sufficient harbour infrastructure. In Coral Harbour, re-supply barges are grounded on purpose so that supplies can be unloaded, typically over the course of several hours.

Foundering refers to vessels that sink to the seafloor, becoming a shipwreck. Although foundered vessels can represent long-term sources of pollution through degrading debris and leaking contaminants, the risks from such activities will be inferred based on assessments in Section 5.5.

Habitat Alteration/Removal

Although a foundering event can increase the quantity of disturbed substrate, this resuspended sediment would likely persist for a short period of time and produce negligible impacts. Sediment resuspension and resettling are also possible effects of grounding, but in this case the effects would be similar to those exhibited by habitat alteration/removal from anchoring/mooring. Additionally, the density of this activity in the AOI is expected to be low. Thus, habitat alteration/removal from grounding was assessed by proxy through the anchoring and mooring pathway (Section 5.4).

Foreign Object/Obstacle

Although a grounded or foundered vessel has the potential to act as an obstacle for some species, there is no specific evidence of collisions with fish or marine mammals as these animals are capable of avoiding obstacles. Additionally, the density of this activity in the AOI is expected to be low. This stressor is not expected to generate any measurable impacts on any ESC subcomponent and level 2 assessments were not conducted.

Noise Disturbance

The temporary and minimal noise generated from grounding and foundering is not expected to result in measurable impacts on any ESC subcomponent and level 2 assessments were not conducted.

Contamination from Anti-fouling Compounds

This pathway refers to contaminants found in anti-fouling paints, which include tributyl-tin (TBT) in older vessels (the phase-out of TBT-based paints began in 2008; Sonak et al. 2009) and copper and zinc in newer anti-fouling paints. Grounding and foundering are the most likely sub-activities that may result in the release of anti-fouling compounds to marine environment. Although there is some evidence of effects from accumulation of copper and zinc to benthic invertebrates and fishes, it has generally been studied in high traffic areas (e.g., Panigada et al. 2008; Tornero and Hanke 2016 and references therein). Given the low density of vessel traffic in the AOI, no measurable impacts to any ESC subcomponent are expected and level 2 assessments were not conducted.

Pathogens/Non-indigenous species

Although a grounded or foundered vessel has the potential to act as vector for fouling non-indigenous species the density of such activities in the AOI is low. The risk from fouling non-indigenous species is expected to be greater from vessels at rest, which is a more frequent activity in the AOI; thus, this pathway was assessed by proxy through the vessel at rest pathway (Section 5.3.3).

12.1.1.1 Anchoring and Mooring

Foreign Object/Obstacle

Benthic invertebrates may colonize foreign structures, such as mooring buoys (Joschko et al. 2008). Fish may exhibit avoidance or attraction behaviour and marine mammals may collide with anchor chains; however, due to the relatively small spatial extent of most anchoring events and the low density of anchored vessels, these effects are likely limited and level 2 assessments were not conducted.

Noise Disturbance

The temporary and minimal noise generated from a vessel using an anchor or mooring device is not expected to result in measurable impacts on any ESC subcomponent; therefore, level 2 assessments were not conducted.

Entrapment/Entanglement/Smothering

Risk of entanglement or entrapment of marine biota during deployment and retrieval of anchors is low and it is not expected to affect marine invertebrates, fishes, and birds and most likely will not affect marine mammals. There was a documented encounter where a humpback whale became entangled with an anchor chain for 12 hours before it could be released (Bohrer 2017) and there have been numerous occurrences of cetaceans entangled in fishing gear buoy and ground lines, which can be similar to mooring lines (Johnson et al. 2005). The majority of known entanglements involve large whales, with smaller, more agile species (such as belugas, narwhals, and pinnipeds) unlikely to become entangled. The risk of cetacean entrapment/entanglement in anchoring and mooring lines would be similar to those exhibited by entanglement in fishing gear and the risk from this interaction will be informed by the assessment done in the fisheries and harvesting section (Section 9.2.3).

Pathogens/Non-Indigenous Species

The impacts from the establishment of NIS are difficult to predict but have the potential to affect marine communities in the study area (Goldsmit et al. 2020). The effects from fouling organisms were assessed collectively by the vessel at rest pathway (Section 5.3.3) as it would be impractical to tease apart potential impacts from fouling organisms that may be on an anchor against those that may be on the hull of a transiting vessel; therefore, separate assessments were not conducted for this stressor under the anchoring/mooring, grounding/foundering, or vessel underway pathways. A second set of assessments were included in Section 5.5.2 that examine ballast water. See these sections for more thorough introductions to the pathways and scoping rationales.

12.1.1.1 Discharges

Waste/Debris

Waste/debris is defined as any discarded food products, mismanaged garbage, and lost cargo of varying types that are discharged from marine vessels. This includes a broad array of possible pathways of effects that apply to debris regardless of its origin (which may be challenging to address in relation to regulations). The disposal of waste from ships within Canada and by Canadian ships in waters beyond Canada’s jurisdiction is prohibited unless explicitly permitted under the *Disposal at Sea Regulations* (2001) (GoC 2019). Residual risk is difficult to quantify because there are other sources of waste/debris in addition to vessels.

Solid waste management in Nunavut is rudimentary compared to other jurisdictions in Canada, with limited infrastructure, such as fencing and equipment/material to compact and cover waste, which are standard practices in solid waste management elsewhere. The solid waste disposal facilities in Nunavut communities are also largely within a few kilometers of the coast. Arguably, these facilities in the communities adjacent to the AOI act as permanent point sources of wind-blown waste/debris which may or may not be a larger source than waste/debris from ships. Section 3.3 of the PoE (Johnson et al. unpublished[38]) addresses the import of waste/debris from outside sources of unspecific origin through ocean current transport. Separating the relative contributions of vessel-derived waste/debris versus that originating from community solid waste facilities, as well as that imported from outside the AOI via ocean currents, is not practical. Risks from communities adjacent to the AOI are discussed qualitatively in the PoE report.

Observations from community members in communities near the AOI have also raised the concern that waste is being introduced in the vicinity of the AOI from subsistence harvesters from outside the area who travel by vessel to the community's harvesting area to hunt narwhals (Idlout 2020). This also may be an area of the risk assessment where partner input is required to document what is being observed, and to help gain a better understanding of the relative importance of different sources of waste/debris to the overall burden of this stressor in the AOI. At the time of writing, conducting risk assessments on specific vessel-derived solid waste/debris would require generalization across all activities/pervasive drivers that exert this stressor, and thus is not likely to yield informative results. Although a prohibition of littering could be included in the regulations specific to a future MPA, the effectiveness of this measure at mitigating the overall impacts of marine waste/debris in the AOI is uncertain since some of the sources of waste and debris are outside the MPA. Distinguishing the root activities that generate waste is likely not possible without extensive research; therefore, this pathway was not considered further in the assessment.

Scientific Data Collection

Biota Loss

The collection of scientific data can purposely (e.g., through collection of whole samples) or inadvertently (e.g., dietary analysis, collection of tissue for DNA analyses) result in the mortality of individual organisms. Marine mammal and seabird mortalities are not anticipated from scientific research activities. If they threaten researchers, polar bears may occasionally be killed in self-defence. However, many polar bear subpopulations in Canada are harvested at 4.5% and this has proven to be sustainable over the long-term, so it is unlikely that the occasional self-defence kill would result in a measurable impact on polar bear populations in the AOI and level 2 assessments were not conducted. See Section 7.0 for additional discussion on benthic research trawls.

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[38] Johnson et al. 2019. Pathways of effects modelling for the ecological and biological components of the Southampton Island Area of Interest. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/nnn. vi + xx p.

Appendix B References

Arctic Waters Pollution Prevention Act. 1985. Available at: https://laws-lois.justice.gc.ca/eng/acts/A-12/ [Date accessed: May 7, 2024].

Baulch, S. and Perry, C. 2014. Evaluating the impacts of marine debris on cetaceans. Mar. Pollut. Bull. 80(1-2): 210-221. https://doi.org/10.1016/j.marpolbul.2013.12.050

Black, A. 2005. Light induced seabird mortality on vessels operating in the Southern Ocean: incidents and mitigation measures. Antarct. Sci. 17(1): 67-68. https://doi.org/10.1017/S0954102005002439

Bocetti, C.I. 2011. Cruise ships as a source of avian mortality during fall migration. Wilson J. Ornith. 123(1): 176-178. https://doi.org/10.1676/09-168.1

Bohrer, B. 2017. Whale gets entangled in Alaska cruise-ship anchor for half a day. Seattle Times, August 29, 2017. Available at: https://www.seattletimes.com/seattle-news/whale-gets-entangled-in-alaska-cruise-ship-anchor-for-half-a-day/ [Date accessed: January 3, 2024].

Brown, B. 2021. Garbage in the water: how old landfills are harming Inuit communities' marine food chains. CBC News, March 24, 2021. Available at: https://www.cbc.ca/news/canada/north/garbage-in-the-water-landfills-inuit-communities-1.5962102 [Date accessed: December 14, 2023].

CCME (Canadian Council of Ministers of the Environment). 2009. Canada-wide Strategy for the Management of Municipal Wastewater Effluent. Available at: https://ccme.ca/en/res/mwwe_strategy_e.pdf

Cole, M., Lindeque, P., Fileman, E., Halsbrand, C., Goodhead, R., Moger, J., and Galloway, T.S. 2013. Microplastic ingestion by zooplankton. Environ. Sci. Technol. 47(12): 6646-6655. https://doi.org/10.1021/es400663f

Coppock, R.L., Galloway, T.S., Cole, M., Fileman, E.S., Queirós, A.M., and Lindeque, P.K. 2019. Microplastics alter feeding selectivity and faecal density in the copepod, *Calanus helgolandicus*. Sci. Total Environ. 687: 780-789. https://doi.org/10.1016/j.scitotenv.2019.06.009

Disposal at Sea Regulations. 2001. Available at: https://laws-lois.justice.gc.ca/eng/regulations/SOR-2001-275/index.html [Date accessed: May 7, 2024].

Environment and Climate Change Canada (ECCC) and Health Canada. 2020. Science Assessment of Plastic Pollution. Environment and Climate Change Canada, Ottawa, ON. Cat. No.: En14-424/2020E-PDF ISBN 978-0-660-35897-0. Available at : https://www.canada.ca/en/environment-climate-change/services/evaluating-existing-substances/science-assessment-plastic-pollution.html#toc1

Environmental Protection Act. 1988. Available at: https://www.canlii.org/en/nu/laws/stat/rsnwt-nu-1988-c-e-7/latest/rsnwt-nu-1988-c-e-7.html [Date accessed: May 7, 2024].

Fisheries Act. 1985. Available at: https://laws.justice.gc.ca/eng/acts/f-14/index.html [Date accessed: May 7, 2024].

GoC (Government of Canada). 2019. Disposal at sea legislation and regulations. Government of Canada. Available at: https://www.canada.ca/en/environment-climate-change/services/disposal-at-sea/legislation-regulations.html

Goldsmit, J., McKindsey, C.W., Schlegel, R.W., Stewart, D.B., Archambault, P., and Howland, K.L. 2020. What and where? Predicting invasion hotspots in the Arctic marine realm. Glob. Change Biol. 26: 4752-4771. https://doi.org/10.1111/gcb.15159

Greer, R.D., Day, R.H., and Bergman, R.S. 2010. Literature review, synthesis, and design of monitoring of ambient artificial light intensity in the outer continental shelf in regard to potential effects on resident marine fauna. OCS Study MMS 2007-055. U.D.o.t.I.M.M. Service, Anchorage, AK. 93 p. Available at: https://espis.boem.gov/final%20reports/5398.pdf

Hallanger, I.G. and Gabrielsen, G.W. 2018. Plastic in the European Arctic. Brief Report 045. Norwegian Polar Institute, Tromsø, Norway. 23 p. Available at: https://brage.npolar.no/npolar-xmlui/bitstream/handle/11250/2478285/Kortrapport45.pdf

Idlout, L. 2020. Southampton Island area of interest: Assessment phase Inuit Qaujimajatuqangit workshop. NVision Insight Group Inc. report submitted to Fisheries and Oceans, Marine Planning and Conservation. 56 p. + appendices.

Jamieson, R., Hayward, J., Poltarowicz, J., Ragush, C., and Schmidt, J. 2015. Treatment performance of municipal wastewater stabilization ponds in Nunavut. Centre for Water Resources Studies, Dalhousie University and Community and Government Services, Government of Nunavut.

Halifax, NS. 56 p. Available at: https://centreforwaterresourcesstudies.dal.ca/files/documents/Final%20report%20WSP%20performance%20-%2018-09-2015.pdf

Johnson, M.D. 2005. Habitat quality: A brief review for wildlife biologists. Trans. West. Sect. Wildl. Soc. 41: 11. Available at: https://www.researchgate.net/publication/242316218_Habitat_quality_a_brief_review_for_wildlife_biologists

Johnson, K., Prosko, G., and Lycon, D. 2014. The Challenges with Mechanical Wastewater Systems in the Far North. Proceedings of the Western Canada Water Conference and Exhibition, Regina, SK, September 23-26, 2014. Available at: https://issuu.com/cryofront/docs/2016_rev_bookmarked_northern_wastew

Joschko, T.J., Buck, B.H., Gutow, L., and Schröder, A. 2008. Colonization of an artificial hard substrate by *Mytilus edulis* in the German Bight. Mar. Biol. Res. 4(5): 350-360. https://doi.org/10.1080/17451000801947043

Kingsley, M.C. 2006. The Northern Common Eider: Status, Problems, Solutions. Greenland Institute of Natural Resources Technical Report 64. x + 61 p. Available at: https://natur.gl/wp-content/uploads/2005/02/64-The-Northern-Common-Eider-Status-Problems-Solutions.-Report-of-an-International-Workshop.pdf

Kühn, S., Schaafsma, K.L., van Werven, B., Flores, H., Bergmann, M., Egelkraut-Holtus, M., Tekman, M.B., and van Franeker, J.A. 2018. Plastic ingestion by juvenile polar cod (*Boreogadus saida*) in the Arctic Ocean. Polar Biol. 2018. 41(6): 1269-1278. https://doi.org/10.1007/s00300-018-2283-8

Krumhansl, K., Jamieson, R., and Krkosek, W. 2016. Using species traits to assess human impacts on near shore benthic ecosystems in the Canadian Arctic. Ecol. Indic. 60: 495-502. https://doi.org/10.1016/j.ecolind.2015.07.026

McKay, J. 2019. 950,000 litres of Iqaluit's raw sewage leaking into Frobisher Bay per day. CBC News, April 15, 2019. Available at: https://www.cbc.ca/news/canada/north/iqaluit-sewage-leak-1.5096768 [Date accessed: December 14, 2023].

Montevecchi, W.A. 2006. Influences of artificial light on marine birds. *In* Ecological consequences of artificial night lighting. *Edited by* Rich, C. and Longcore, T. Island Press, Washington, D.C. pp. 94-113.

Morgana, S., Ghigliotti, L., Estévez-Calvar, N., Stifanese, R., Wieckzorek, A., Doyle, T., Christiansen, J.S., Faimali, M., and Garaventa, F. 2018. Microplastics in the Arctic: A case study with sub-surface water and fish samples off Northeast Greenland. Environ. Pollut. 242(Pt B): 1078-1086. https://doi.org/10.1016/j.envpol.2018.08.001

Nunavut Tunngavik Incorporated. 2020. Nunavut's infrastructure gap. Nunavut Tunngavik Incoporated, Iqaluit, NU. Available at: https://www.tunngavik.com/files/2020/10/2020.10.20-Nunavuts_Infrastructure_Gap_Report_vf.pdf

Nunavut Water Regulations. 2013. Available at: https://laws-lois.justice.gc.ca/eng/regulations/SOR-2013-69/index.html [Date accessed: May 7, 2024].

Nunavut Waters and Nunavut Surface Rights Tribunal Act. 2002. Available at: https://laws-lois.justice.gc.ca/eng/acts/N-28.8/FullText.html [Date accessed: May 7, 2024].

Oceans North. 2021. Towards a waste-free Arctic. Oceans North, Ottawa, ON. Available at: https://www.oceansnorth.org/wp-content/uploads/2021/03/Towards-a-Waste-Free-Arctic.pdf

Panigada, S., Pavan, G., Borg, J.A., Galil, B.S., and Vallini, C. 2008. Biodiversity impacts of ship movement, noise, grounding and anchoring. *In* Maritime traffic effects on biodiversity in the Mediterranean Sea: Review of impacts, priority areas and mitigation measures. *Edited by* Abdulla, A. and Linden, O. IUCN Centre for Mediterranean Cooperation, Malaga, Spain. pp. 9-56. Available at: https://core.ac.uk/download/pdf/83022125.pdf

Poon, F.E., Provencher, J.F., Mallory, M.L., Braune, B.M., and Smith, P.A. 2017. Levels of ingested debris vary across species in Canadian Arctic Seabirds. Mar. Poll. Bull. 116(1-2): 517-520. https://doi.org/10.1016/j.marpolbul.2016.11.051

Rodriguez, A., Garcia, D., Rodriguez, B., Cardona, E., Parpal, L., and Pons, P. 2015. Artificial lights and seabirds: is light pollution a threat for the threatened Balearic petrels? J. Ornithol. 156(4): 893-902. http://dx.doi.org/10.1007/s10336-015-1232-3

Rogers, S. 2021. Nunavut government works to confine sewage leak near Rankin Inlet. Nunatsiaq News, June 11, 2021. Available at: https://nunatsiaq.com/stories/article/nunavut-government-works-to-confine-sewage-leak-near-rankin-inlet/ [Date accessed: December 11, 2023].

Ryan, P.G. 1991. The impact of the commercial lobster fishery on seabirds at the Tristan da Cunha Islands, South Atlantic Ocean. Biol. Conserv. 57(3): 339-350. https://doi.org/10.1016/0006-3207(91)90076-L

Sonak, S., Pangam, P., Giriyan, A., and Hawaldar, K. 2009. Implications of the ban on organotins for protection of global coastal and marine ecology. J. Environ. Manage. 90(Suppl. 1): S96-108. https://doi.org/10.1016/j.jenvman.2008.08.017

Stewart, D.B. and Howland, K.L. 2009. An Ecological and Oceanographical Assessment of the Alternate Ballast Water Exchange Zone in the Hudson Strait Region. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/008. vi + 96 p.

Territorial Lands Act. 1985. Available at: https://laws-lois.justice.gc.ca/eng/acts/T%2D7/FullText.html [Date accessed: May 7, 2024].

Tornero, V. and Hanke, G. 2016. Chemical contaminants entering the marine environment from sea-based sources: A review with a focus on European seas. Mar. Pollut. Bull. 112(1-2): 17-38. https://doi.org/10.1016/j.marpolbul.2016.06.091