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Pathways of Effects Conceptual Models for Marine Commercial Shipping in Canada: Biological and Ecological Effects

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

Vessels involved in commercial marine shipping in Canada engage in the movement of goods or people by sea on the Arctic, Atlantic, and Pacific oceans. To explore the ways that the activities associated with commercial shipping can impact the marine environment, a suite of activity-based Pathways of Effects (PoE) conceptual models were developed. PoE conceptual models describe the pathways (linkages) between human activities, associated stressors, and their effects on endpoints, based on current knowledge. A visual representation of each PoE model is supported by text describing each pathway linkage based on scientific literature or expert opinion. Indigenous and local knowledge were not used in the current work. PoE models are useful tools for the scoping phase of a variety of environmental assessment, such as ecological risk assessment, environmental impact assessment, and cumulative effect assessments as they clearly outline activities and stressors and clarify connections between human activities and potential effects on ecological endpoints, and provide a science-based foundation for decision-making.

The objective of these models and their supporting evidence is to provide a systematic review of the effects of shipping-associated activities on marine ecosystems. PoE models have been developed for five activities associated with commercial marine shipping in Canada: 1) anchoring and mooring, 2) vessel at rest, 3) grounding and sinking, 4) movement underway, and 5) discharge (divided into two PoE models: 'debris' and 'other'). The PoEs were developed to be broad enough to be adapted for application in a range of environments and locations and detail the potential stressors and effects that could be considered in an assessment. The activity-based PoE models contain fourteen stressors (e.g., substrate disturbance, vessel strikes) and are related to three effects (change in fitness, mortality, and change in habitat) on ten generic endpoints (e.g., marine mammals, physical habitat). The models only include activities related to the commercial movement of goods and people by vessels, not included in this document are other vessel activities such as fishing, seismic surveying, dredging, port operations (e.g., when at-berth and while berthing). Non-commercial vessels (e.g., recreational vessels) are also not specifically included in these models. Though endpoints have been identified for illustrative purposes here, ultimately the assessor is responsible for comprehensively scoping the specific endpoints (e.g., valued components) and stressors to be considered in any assessment. PoE models do not include any evaluation of the relative or absolute impact from these activities on specific endpoints; this would occur in a subsequent assessment step, such as risk assessment. The shipping PoE models should be considered "evergreen" and should be reviewed and updated when our understanding of these factors changes.

1 INTRODUCTION

1.1 CONTEXT

Vessels involved in commercial marine shipping in Canada engage in the movement of goods or people by sea. This work focuses on exploring the effects these vessels have on the marine environment in order to address a request by Transport Canada for Fisheries and Oceans Canada (DFO) Science to develop activity-based Pathways of Effects models for marine shipping in Canada. The PoE models developed will support Transport Canada's national Cumulative Effects of Marine Shipping initiative under the Oceans Protection Plan, but will also have relevance to sector management, ecosystem-based management, cumulative effects assessments, and marine spatial planning within DFO and other government departments.

Previously, DFO developed a working paper entitled "*Shipping Pathways of Effects: An Overview*" which was tabled for peer-review at a national Canadian Science Advisory Secretariat (CSAS) meeting in October 2013. The advice produced (DFO 2015) and the working paper from that process were used as a starting point to develop the activity-based conceptual models that are presented in this document. As our information and knowledge on this topic continues to expand, new iterations of the conceptual models will also continue to be updated.

1.1.1 Pathways of Effects models

Pathways of Effects (PoE) conceptual models are used to structure and describe the way that potential effects to the environment manifest from an anthropogenic activity through a suite of stressors based on peer-reviewed literature and expert elicitation, and are developed to be broadly applicable to a range of environments and locations. PoE models are useful as a scoping tool for environmental assessment, such as ecological risk assessment, environmental impact assessment, and cumulative effects assessment, as they describe the potential stressors and effects that could be considered in such assessments, but they do not include an assessment of relative or absolute impact, magnitude of change, or risk. PoE models are also of stand-alone relevance to managers, biologists, and impact assessment practitioners for assessment and mitigation purposes as they can help provide a science-based foundation for decision-making.

National guidelines were developed by the Government of Canada (Government of Canada 2012) for the format of these models which can range from small-scale, simple impact links, suitable for a species-specific habitat, to more complex, large-scale networks, suitable for a bioregion.

A PoE model consists of two parts:

1. a visual representation of the known linkages between a human activity, associated stressors, and effects; and
2. supporting text, providing a description for each pathway linkage identified including scientific justifications, where possible.

PoE models are described in more detail in Section 2.

1.2 OVERVIEW OF COMMERCIAL MARINE SHIPPING IN CANADA

1.2.1 Vessels engaged in commercial marine shipping

Commercial vessel traffic in Canadian marine waters is diverse and includes bulk carriers, container ships, general cargo, government vessels, icebreakers, oil and gas service and supply vessels, passenger ships (including cruise ships and ferries), tankers, and tugs/barges (Arctic Council 2009; Table 1). Nearly all types of vessel traffic are expected to increase in the future, though patterns will vary across regions and industries (Huntington et al. 2015). There are two major types of shipping services: shipload services, which move goods in bulk for one or a few shippers, and liner services, which carry relatively small shipments of general cargo for many clients on a more regular schedule.

Table 1. Standardised vessel categories relevant for all Canadian areas (after Arctic Council 2009).

Vessel type	Description
Icebreakers	An icebreaker is a special purpose ship or boat designed to move and navigate through ice-covered waters. For a ship to be considered an icebreaker it requires three components: a strengthened hull, an ice-clearing shape, and the power to push through ice, none of which are possessed by most ships.
Container Ships	Container ships are cargo ships that carry all of their load in large containers, in a technique called containerisation.
General Cargo	Ships designed for the carriage of various types and forms of cargo and the combined carriages of general cargo and passengers with 12 or less fare paying passengers.
Bulk Carriers	Ships specifically designed for bulk carriage of ore with additional facilities for alternative, but not simultaneous, carriage of oil or loose or dry cargo. Bulk carriers are segregated into the following: Handysize (10,000 to 35,000 DWT[1]), Handymax (35,000 to 55,000 DWT), Panamax (60,000 to 80,000 DWT), and Capesize (80,000 DWT and over).
Tanker Ships	Ships designed and constructed for the bulk carriage of liquids or compressed gas, as in the case of natural gas (Liquefied Natural Gas (LNG), carriers).
Passenger Ships	Ships that carry passengers, whether for transport purposes only, or where the voyage itself and the ship's amenities are part of the experience. Includes cruise ships and ferries.
Tug / Barge	A tug is a vessel designed for towing or pushing. Additional activities may include salvage, firefighting and work duties of a general nature. A barge is a non-propelled vessel for carriage of bulk or mixed cargoes on weather or protected decks; it may carry liquid cargo in holds or tanks. Some barges are modified for specific purposes (for example, crane barge).

[1] DWT, deadweight tonnage: The maximum weight a vessel can safely carry (tonnes).

1.3 REGIONAL DIFFERENCES IN MARINE SHIPPING IN CANADA

This work considers domestic and international marine shipping that occurs in the marine and coastal waters (including estuarine and intertidal environments) of the Arctic, Atlantic, and Pacific oceans of Canada. Each of these oceans is comprised of bioregions that related to biogeographic differences in ocean conditions and depth, with ice cover experienced in the Atlantic (seasonally) and the Arctic (both seasonally and year-round). The intensity and characteristics of marine shipping differ greatly between these three regions. For instance, between 2004-2011, 54% of all commercial vessel movements in Canada occurred in the Pacific, followed by 29% in the Great Lakes/St. Lawrence River and Estuary, 9% in the Maritimes, 7% in Newfoundland and Labrador, and 1% in Arctic Canada. Tanker traffic is predominantly concentrated in Atlantic Canada while solid cargo traffic is more prevalent in the Pacific and Central regions (CCA 2017). In addition, seasonality is a key feature of Arctic and some Atlantic shipping where ice formation, winter ice cover, and spring/summer ice break-up govern shipping patterns and vessels used. There has been a rise in marine shipping globally, but in Canada the climate-related reduction in ice extent and thickness in the Arctic region will result in a relatively greater increase in vessel activities there now and into the future (Arctic Council 2009). This increase has already been observed in the Arctic Ocean (all nations), where it comprises a 9.3% increase in shipping traffic between 2010 and 2014 (Eguíluz et al. 2016).

1.3.1 Pacific Ocean

The Pacific coast of Canada is a complex coastline of inlets, bays and fjords extending 29,000 km in the province of British Columbia (BC) (National Geospatial Intelligence Agency 2011). The coast is the eastern terminus of a major shipping corridor between Asia and North America and a series of 27 ice-free deep-water ports supports a large shipping industry (Linley et al. 2013). For the most part, ports in Pacific Canada are located in marine waters, although the salinities of terminals situated throughout the Port of Vancouver range from 1-34 parts per thousand (ppt), with the Fraser Surrey terminal being the only consistently freshwater terminal (1 ppt year-round) that receives regular ship traffic (Linley et al. 2013).

Shipping that passes through Canadian Pacific waters includes vessels that are travelling between Canadian ports and international destinations, vessels moving between domestic ports in BC, and those that are transiting through Canadian waters without stopping at a Canadian port. The latter may be the case for coastal movements of vessels between Alaska and ports in southern USA or international destinations. Such transits may also become more common if vessels increasingly use the Northern Passage as a shorter alternative to the Panama Canal.

Each year approximately 8,300 inbound deep-draft vessels enter the Strait of Juan de Fuca. Of these, 60% head to the Port of Vancouver and other ports in British Columbia and the remaining 40% head to Puget Sound ports (Dunagan 2019). Vessels bound for northern BC ports from outside the Exclusive Economic Zone (EEZ) generally do not use the Strait of Juan de Fuca. Domestic movements of vessels between ports within BC waters occur, though analysis of merchant vessel movements based on 2008 data identified no merchant vessels to be operating exclusively within BC waters (Linley et al. 2013). The fleet of BC Ferries plies approximately 27 routes within domestic waters. Some cruise ships operate exclusively within BC waters although there are many that make coastal voyages that encompass both the American and Canadian Pacific coast. Other vessel types moving within BC waters include Canadian Coast Guard (CCG) and government or private research vessels, based primarily in Victoria and Sidney, and Canadian Armed Forces vessels based primarily in Esquimalt.

The two largest commercial shipping ports in Pacific Canada are the Port of Vancouver and the Port of Prince Rupert, both of which are major container ports with high traffic intensity (Simard et al. 2014). The Port of Vancouver is Canada's largest and busiest port, with 27 marine cargo terminals, handling over 147 million tonnes (mt) of cargo in 2018, including 424,985 automobile units, 18.2 mt of breakbulk, 101.7 mt of bulk cargo (dry and liquid), and 26.7 mt of containerised cargo (in 3.4 million 20-foot container equivalent units)[1]. Most of the overall cargo was foreign (115.8 mt) rather than domestic (31.2 mt). The Port of Vancouver is also the largest cruise port

[1] Port Vancouver. Accessed November 2019.

in Canada with 241 sailings in 2018, carrying 889,162 passengers. At present, 3,160 vessels call at the Port of Vancouver each year (nine ships/day)[2]. The number of vessel calls to the Port of Vancouver is forecasted to increase to about 12 ships per day by 2026 (Vancouver Fraser Port Authority 2016).

The Port of Prince Rupert, is the fourth busiest Canadian Port Authority in terms of tonnage, and the third largest in terms of volume (Transport Canada 2019a, 2019b). In addition to being North America's closest port to Asia, by up to three days sailing, it is also the deepest natural harbour in North America. In 2019, it handled 29.9 mt of cargo, including one million TEUs (Twenty-Foot Equivalent Units) of containerised freight (Prince Rupert Port Authority 2020). The Port of Prince Rupert is Canada's fastest-growing port in the last decade, and growth is likely to continue given the Port's long-term plans for growth and diversification and an announcement in September 2019 of $153.7 million of federal investment in support of the Port (Transport Canada 2019a). Cruise ships also call at this port, with 26 vessels bringing 9,000 visitors to Prince Rupert in 2018 (Cocullo 2019).

In addition to relatively high vessel traffic volume, transits to these two Pacific ports are through narrow and shallow passages that represent hydrographic "choke points", with different types and magnitudes of potential effects than open-ocean shipping (Figure 1).

[2] Port of Vancouver 2018 Statistics overview. Accessed April 2019.

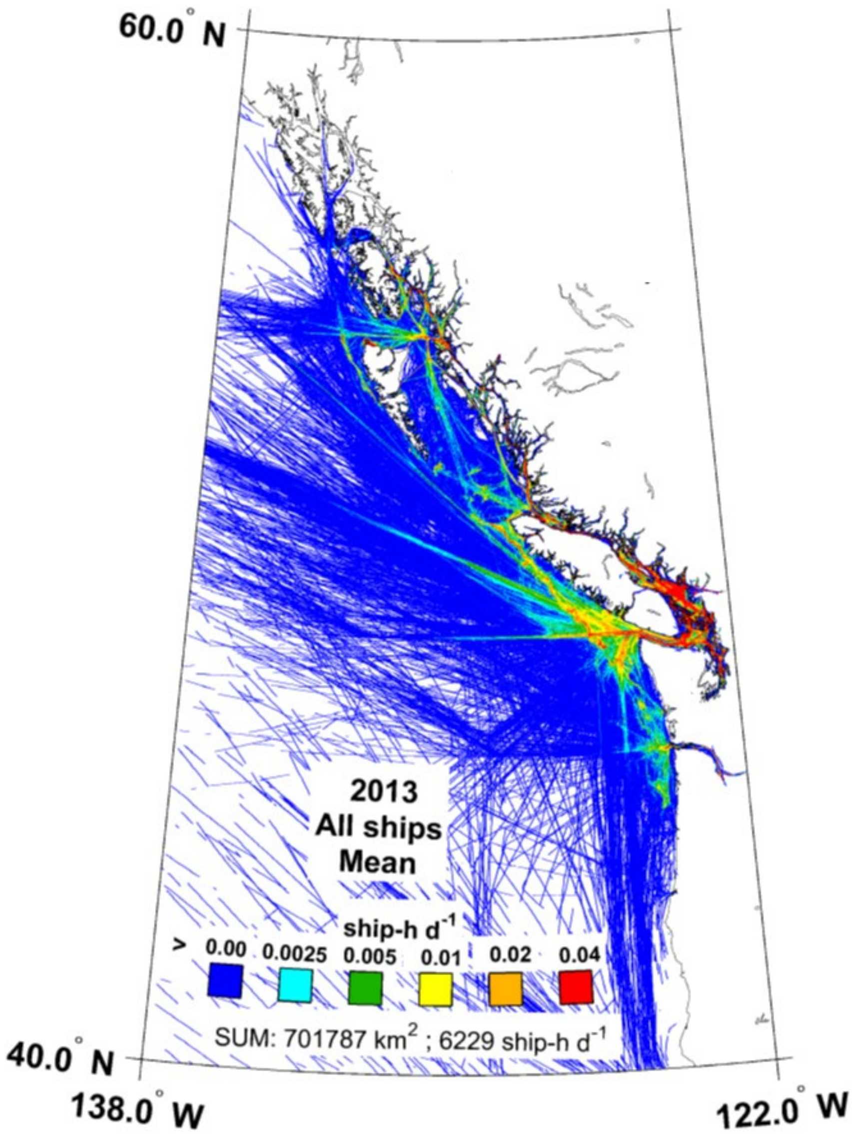

Figure 1. Mean traffic density of all ship movements in Pacific Canada, as tracked using vessel Automated Information System, in 2013 with corresponding cumulative histogram and sums (daily ship-h km-2 (adapted from Simard et al. 2014).

1.3.2 Arctic Ocean

The Canadian Arctic area extends approximately 2.1 million km² and the Port of Churchill in Hudson's Bay is Canada's only commercial deep-water shipping port in the Arctic. The Port of Churchill is connected by land via a rail line (also owned by the port) which was used to ship wheat from Manitoba. The future of the port was brought into question after it was closed in 2016, and the rail line suffered flood damage in 2017. However, the Arctic Gateway group has since taken over port operations and repaired the rail line in 2018, so port operations and movement of goods south are being renewed. There are currently two major shipping routes through the Arctic Ocean, the Northwest passage and the Northern sea route, but new routes are being developed as the warming climate offers new opportunities (Figure 2).

Arctic ship traffic has increased by more than 75% since 2005 (Carter et al. 2017) and doubled in the marine areas of the Nunavut Settlement Area in 25 years (Dawson et al. 2017; Peletz-Bohbot 2019). Increases in shipping activity are predominantly focused in the eastern Arctic (Figure 2), based on comparisons of the average number of kilometres of shipping activity in the Canadian Arctic between 1990-2000 and 2011-2015 (Carter et al. 2017). The increase in shipping in the Arctic is related to several factors, such as the growth of the resource development sector and community needs. The increased ability to navigate the area due to declining sea ice has allowed for greater cargo transport, fishing, and tourism (Peletz-Bohbot 2019; Pizzolato et al. 2016). Arctic shipping promotes social and economic development, and plays an important role in the context of sovereignty (Keil 2012).

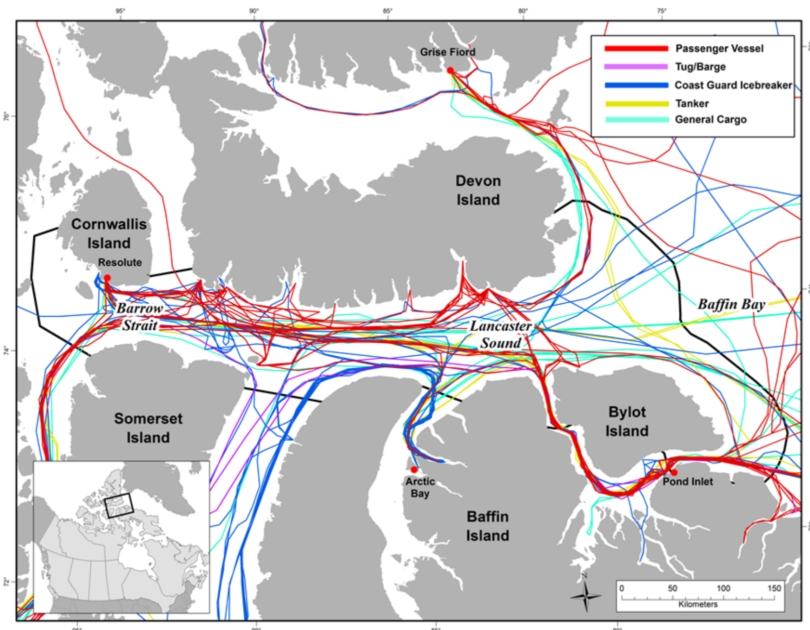

Figure 2. Shipping routes by vessel type in the Eastern Arctic. Source: Transport Canada, unpublished data, 2011

The majority of vessel traffic in the Arctic occurs during the ice-free season (e.g., July to November), although changes in the timing of freeze-up and break-up may prolong the season in the future (Huntington et al. 2015). Winter traffic requires significant ice-breaking capacity, which is primarily limited to research and search and rescue vessels, but the number of ice-strengthened commercial transits has increased (see DFO 2012) (Baffinland Iron Mines Corporation 2012). Decreases in sea-ice coverage has already led to increasing vessel movements through the Northwest Passage, the northern marine route between the Atlantic and the Pacific oceans spanning the Canadian Arctic. It has been projected that 300 more voyages per year will occur through the Northwest Passage by 2020 (Arctic Council 2009; Office of the Auditor General of Canada 2014; Peletz-Bohbot 2019).

The main types of shipping and vessel transits in the Arctic consist of arctic community re-supply, bulk transport of ore, oil and gas, tourism vessels, fishing vessels, icebreaker, and research. A 2004 study indicated 6,000 vessels were operating in the Arctic, with half travelling the North Pacific's Great Circle route between Asia and North America. Outside the Great Circle route, fishing vessels constituted a significant proportion of vessels operating (~50%) and bulk carriers made ~20% of vessels observed in the Arctic in the 2004 study (Arctic Council 2009). Remote communities in the Arctic (as well as mining and other operations) with no land transportation infrastructure, and who may be ice-locked for much of the year, rely upon re-supply vessels for dry foods, fuel, building materials and other products. It is also a far more cost-effective way of transportation than air transportation (Arctic Council 2009; Guy and Lasserre 2016; Peletz-Bohbot 2019).

A range of vessel types are involved in re-supply shipping: tankers, cargo vessels, container vessels, and tug and barge combinations. Tug/barge types are commonly used as re-supply vessels in western Canadian Arctic for communities as well as mining and construction project re-supply. These vessels are made up of a tug towing 1-3 barges and can extend more than one kilometre. This type of shipping is anticipated to increase as regional populations get larger and there is more development in this region (Arctic Council 2009). The bulk transport of ore, oil and gas is needed to ship out extracted materials from ore producing Arctic mines (such as nickel and zinc mines) as well as from oil and gas producing areas in non-Canadian Arctic areas. In some mining areas, cargo is stored until the ice melts, leading into a substantial shipping effort during the ice-free season, so that many of the bulk carriers operate mostly in the ice-free seasons and are not ice-strengthened (Arctic Council 2009). This shipping type is also likely to increase the most with growing interest in exploiting the natural resources of the Arctic (Arctic Council 2009).

Resupply vessels stop at numerous communities in the Canadian Arctic; many of these communities are also visited by other types of vessels. There are no ferries operating in the Canadian Arctic, however vessels carrying passengers for tourism operate during the ice-free season. Vessels touring the Canadian Arctic areas are relatively few in comparison to more heavily frequented areas around Norway, Greenland, Iceland and Svalbard. Tour vessels can range from small to large capacity, and the industry is expanding as more, and larger vessels become involved. Fishing vessels make up a notable portion of the commercial vessel traffic in the Arctic. Fishing vessels are generally opportunistic in nature and only present when there are ice-free, or limited ice conditions. Icebreaker, government, and research vessel types are relatively few in comparison to the number of other vessel types in Arctic waters.

With the expansion of vessel traffic and development (e.g., mining, emerging fisheries) in the Canadian Arctic. infrastructure for vessels is a necessity. There is a recently developed (2019) refueling station for CCG and Royal Canadian Navy vessels at Nanisivik, near Arctic Bay, Nunavut, the site of a former lead-zinc mine. As well, the prospect of a deep-water port in Iqaluit, and a number of small craft harbours in the Eastern Arctic are being pursued.

1.3.3 Atlantic Ocean

The Canadian Atlantic region includes the coast and waters of the Estuary and Gulf of St. Lawrence, the Atlantic Ocean, and the Bay of Fundy. Quebec City is recognized as the upper limit of brackish water and the point of transition between the St. Lawrence Estuary and River (El-Sabh 1979).

Vessels travelling through the Canadian Atlantic region include those inbound and outbound between international ports and Atlantic Canadian ports, including both coastal voyages from the USA and transoceanic voyages, coastal or transoceanic voyages transiting through the Canadian Atlantic on the way to the St. Lawrence Seaway and Great Lakes, voyages between Atlantic Canada and the St. Lawrence Seaway/Great Lakes, movements between ports located within Atlantic Canada, and coastal voyages between the Canadian Atlantic and the Canadian Arctic.

There are 77 commercial ports that receive merchant vessels in the Canadian Atlantic (Adams et al. 2012). Eight main commercial shipping ports occur in Newfoundland and Labrador (NL) and the Maritime provinces of Nova Scotia (NS) and New Brunswick (NB): Halifax, NS, Sydney, NS, Strait of Canso, NS, Saint John, NB, St. John's, NL, Botwood, NL, Come-by-Chance, NL, and Corner Brook, NL. The Port of Halifax is Canada's third busiest container port (New Brunswick Department of Transportation 2005). There are four main commercial shipping ports in Quebec in the St. Lawrence Estuary: Bécancour, Quebec City, Sept-Îles, and Trois-Rivières. The Port of Montreal, located in fresh water in the St. Lawrence River, is one of Canada's main container ports. Above Montreal lies the St. Lawrence Seaway locks and the entrance to the Great Lakes.

Commercial shipping is generally in the form of tankers and general, bulk and containerised cargo carriers. There are also a range of fishing vessels, petroleum exploration and production ships (seismic vessels, tugs, service ships, mobile oil platforms), cruise ships, and government vessels. The primary commodities being transported include crude oil, gas, coal, coke, minerals, chemicals, paper and forest products, and various containerised goods (Breeze et al. 2005).

The Atlantic cruise ship ports, Halifax and Saint John, are the second and third busiest in Canada, after Vancouver, with close to 250 vessels arriving annually (Figure 3). International, inter-provincial, and regional ferries operate in the Canadian Atlantic. Halifax is also the Atlantic headquarters of the Canadian Armed Forces fleet, and the home port of Canadian government research and Coast Guard vessels.

A unique aspect of commercial shipping in the Atlantic region is transshipment associated with offshore oil and gas platforms. Floating production storage and offloading (FPSO) is part of the oil and gas extraction and refinement process at sea in NL waters. An FPSO is a floating vessel for offshore production and storage. These vessels are equipped with dynamic positioning thrusters to remain in place without the deployment of anchors. Large gravity-based (GBS) platforms which rest on the seafloor in the relatively shallow waters of the Grand Banks of NL also offload their petroleum products to transhipment tankers. This type of transshipment has not been included in the current Pathways of Effects development.

There are areas of narrower passage in the Atlantic region (Bay of Fundy, Cabot Strait, Strait of Belle Isle, Placentia Bay) where there may be different types and magnitudes of potential effects than open-ocean shipping. In addition, winter ice cover is common in many areas of the Canadian Atlantic, including the Estuary and Gulf of St. Lawrence, northern Newfoundland, Labrador, and the upper Bay of Fundy.

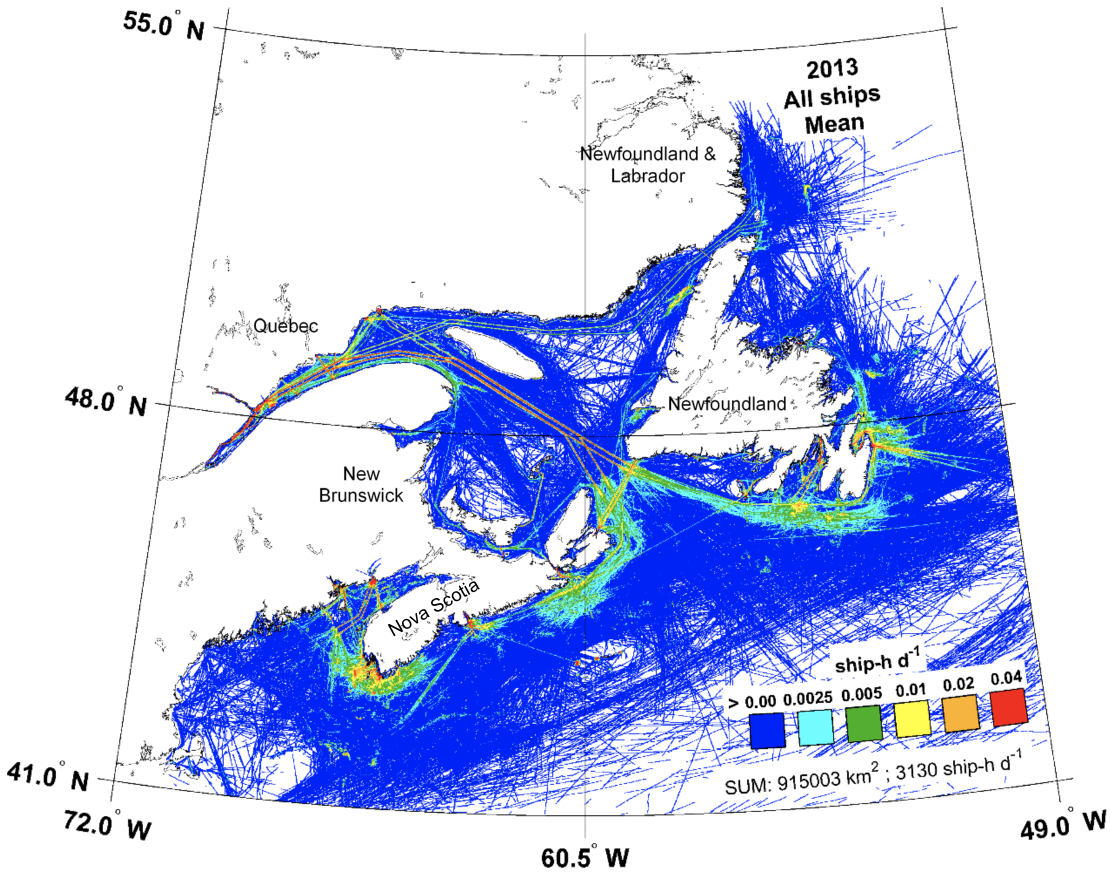

Figure 3. Mean traffic density of all ship movements in Atlantic Canada, as tracked using vessel Automated Information System, in 2013 with corresponding cumulative histogram and sums (daily ship-h km-2) (Adapted from Figure 3 in Simard et al. 2014).

1.4 OBJECTIVES

This systematic review of the effects of shipping-associated activities on Canadian marine ecosystems describes PoE models representing five sub-activities (anchoring and mooring, vessel at rest, grounding and sinking, movement underway, and discharge) and linked stressors. Each PoE conceptual model is supported by text describing each pathway linkage based on available scientific literature or expert opinion. The objective of this work is to develop PoE models that are useful tools for the scoping phase of environmental assessments, such as ecological risk assessment, environmental impact assessment, and cumulative effects assessment, and that clearly outline activities and stressors and clarify connections between human activities and potential effects on ecological endpoints. As they are scoping tools, they do not express the probability, magnitude, or risks of effects. An evaluation of the relative or absolute impact of the activities would occur in a subsequent assessment step and is not the goal of the current work.

1.5 SCOPE

- The scope of this work includes domestic and international marine shipping that occurs in the marine and coastal waters (including estuarine and intertidal environments) of the Arctic, Atlantic, and Pacific oceans of Canada. Each of these oceans comprise three bioregions related to biogeographic differences in ocean conditions and depth. Ice cover is only experienced in the Atlantic (seasonally) and the Arctic (both seasonally and year-round). Canada's large freshwater shipping industry is considered only to the extent that it interacts with the marine environment, for example, vessels travelling to and from freshwater ports may need to pass through marine waters.

- Activities considered in this document are limited to those involved in the movement of goods or people by commercial vessels and do not include, for example, activities such as fishing, seismic surveying, dredging, and port operations (e.g., when at-berth and while berthing). Non-commercial vessels (e.g., recreational vessels) are also not specifically included in these models. This work does not examine the effects of shipping activities and stressors on elements of human well-being, but is restricted to potential effects on marine biota and habitats in coastal environments. However, the PoE models are designed to be broad enough to be extended to vessels of different size classes and cover a range of vessel uses at a national scale across Canada.
- Cumulative effects from multiple stressors, stressor interactions, and indirect effects (such as those associated with climate change) were not included in this work; however, these undoubtedly occur and are important considerations when using the PoE models in an assessment, or when implementing an ecosystem-based approach to management.
- The effects of shipping activities and stressors are described using Canadian examples where possible and international examples where appropriate. Impacts specifically linked to shipping activities are the focus, but general stressor-based impact information is included where specific evidence is not available.
- Stressors and their broad-scale effects are the focus of this advice, rather than the endpoint examples provided. Endpoint examples are not comprehensive, and were chosen to illustrate how stressors may interact with features of the marine environment, and caution is advised when interpreting the outlined endpoints. In an assessment, users choose from many candidate endpoints, which can be specific to the region or area of interest. The goal in developing these endpoints was that they adequately describe the effects of a stressor while remaining generic enough to be applicable across Canadian regions.
- PoE models do not include any evaluation of the relative or absolute impact from these activities on specific endpoints; this would occur in a subsequent assessment step, such as risk assessment.
- The conditions against which change is measured (baseline) has not been defined in the PoE models but should be clearly specified and defined during an assessment phase.
- The supporting evidence provided herein does not include indigenous, traditional, or local knowledge, as this was not within the scope of the request for this work. These knowledge sources will provide important evidence and/or understanding of conditions, including environmental baseline(s) for subsequent assessments.
- While some endpoints have been identified for illustrative purposes here, the assessor is responsible for comprehensively scoping the specific endpoints (e.g., valued components) and stressors to be included in the assessment.
- The PoE models for marine shipping were developed as a tool to examine ecological endpoints, but the tool may be adapted for social, cultural, and economic endpoints.

2 PATHWAYS OF EFFECTS CONCEPTUAL MODELS

2.1 BACKGROUND

As described in Section 1.1.1, a PoE model consists of a visual representation of the model supported with text and available scientific literature describing each pathway linkage. Linkages are the connections between components in a PoE model and are numbered to allow users to locate accompanying justification text. The structure of the model, and the shape and colours of components used were based on Government of Canada national guidelines (Government of Canada 2012). The guidelines outline four main levels of components for an activity-based PoE conceptual model: (i) activity and sub-activity of interest; (ii) stressor(s) associated with the sub-activity; (iii) effect(s) of the stressor on the marine environment; and (iv) linkages to endpoints. Definitions for these terms are provided in Table 2.

Table 2. Definition of Pathways of Effects components used in the study.

Component	Definition	Source
Activity / Sub-activity	“an action that may impose one or more stressors on the ecosystem being assessed”	O et al. 2015
Stressor	“any physical, chemical, or biological means that, at some given level of intensity, has the potential to change an ecosystem or one or more of its components”	O et al. 2015
Effects	“the broad range of potentially measureable changes that may be observed”	Boehlert and Gill 2010
Endpoint	“valued attribute of ecological entities”	EPA 1998
Impacts	“effects that, with some certainty, rise to the level of deleterious ecological significance”	Boehlert and Gill 2010

The structure of an example generic PoE model outlined in Figure 4, shows the numbered linkages between the activity, associated stressors, and effects on endpoints.

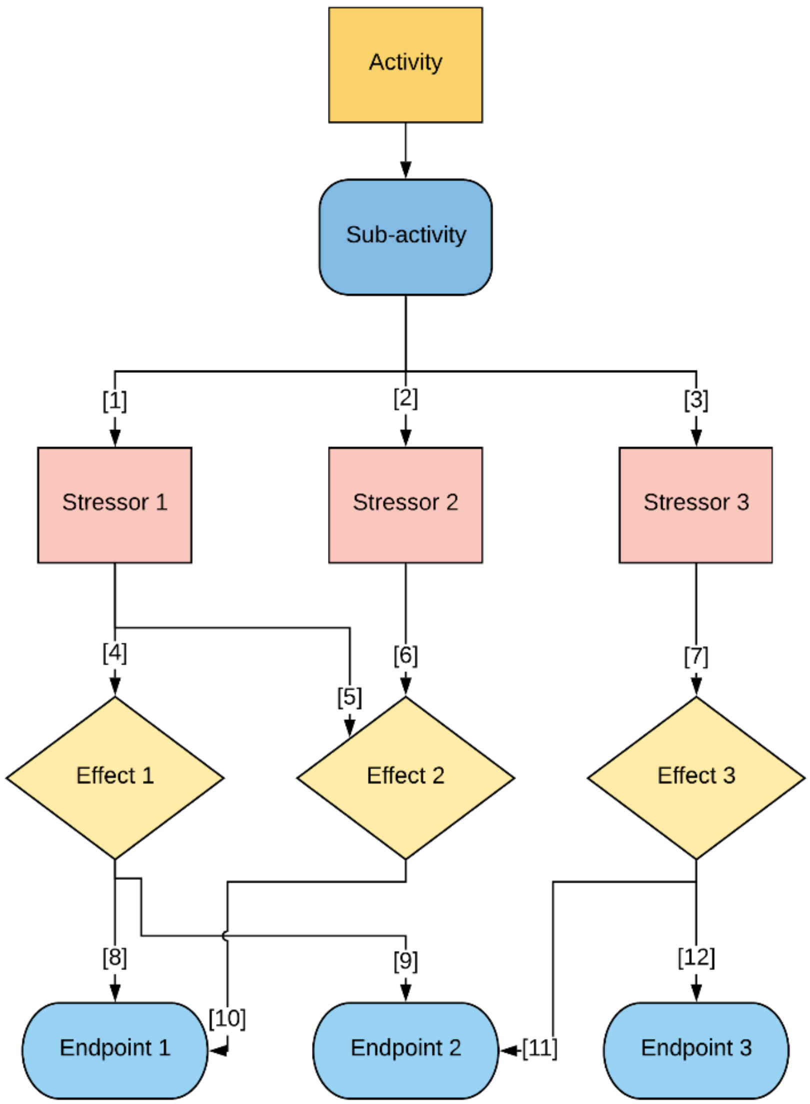

Figure 4. Structure of an example generic Pathway of Effects (PoE) model diagram. Arrows indicate the linkages between components, numbering links to supporting text.

The approach used to develop PoE models was to include all potential effect pathways first, and then systematically search scientific literature for evidence of measurable effect. If evidence to support the pathway was not available, the link was retained in the diagram and the lack of evidence noted in the evidence table.

2.2 ACTIVITIES ASSOCIATED WITH SHIPPING

Activities were identified by assembling activity terms developed in DFO risk assessment processes (Clarke Murray et al. 2016a; Hannah et al. 2019; Rubidge et al. 2018; Thornborough et al. 2016). Terms were cross-referenced for consistency and completeness with the outcomes of Transport Canada's engagement process (see Appendix A for a summary of how engagement outcomes were incorporated).

PoE models were developed for the following five sub-activities associated with commercial vessel shipping in Canadian waters: 1) anchoring and mooring, 2) vessel at rest, 3) grounding and sinking, 4) movement underway, and 5) discharge (divided into discharge (debris) and discharge (other)). Each sub-activity is briefly described in Table 3. The individual sub-activities described in the PoE models are all components of marine shipping, and are separated into individual PoE models to enhance manageability and understanding of the different components. Despite this, many of the models are inter-related and have overlap and so should be considered together, not in isolation.

Table 3. Definitions of identified sub-activities associated with commercial vessel shipping within the study scope.

Sub-activity	Description and scope
Anchoring and Mooring	The act of deploying and retrieving anchors, or attaching to a mooring buoy system during commercial vessel operations, including the subsequent movement of the anchoring or mooring buoy system while deployed. This includes commercial vessels at anchor or attached to a mooring buoy, both with, and without, the engine running. Note that it does not include tying alongside to a wharf or when in berth.
Vessel at rest	Stationary commercial vessels that are at anchor, or attached to a mooring buoy system. Vessel lights and engines are usually running, but may not be in some instances. Focus is on the vessel itself and excludes effects from anchor and mooring systems.
Grounding and sinking	Includes: (i) Vessel grounding - when a vessel impacts the seabed or underwater objects; and (ii) Sinking – when a vessel sinks and reaches the seabed to become a shipwreck.
Movement underway	Movement underway refers to the action of a commercial vessel in transit from one port of call to another. While underway, the vessel is under power and travelling through the water (includes icebreaking). A vessel is considered underway until it is anchored, moored or docked/at-berth.
Discharge	The release of any substance or object from commercial vessels (liquid/solid) both accidental and operational. Accidental discharges include oil spills (both small scale fuel spills and large-scale tanker spills), runoff from washing down decks, lost cargo, litter, and discarded/lost deck debris. Operational discharges include releases such as black water discharges (sewage), grey water (wastewater), ballast water, and bilge water.
- Discharge (debris)	Discharges of debris from commercial vessels engaged in marine shipping. Debris includes discarded food products, mismanaged garbage, and lost cargo of varying types. The specific source of marine debris is difficult to assign, so it relates to general marine debris, rather than debris specifically ascribed to shipping.
- Discharge (other)	Discharges (other than debris) from commercial vessels engaged in marine shopping including discharges of petroleum products and other contaminants such as in ballast water, engine exhaust, antifouling paint, and wastewater (which consists of black water (sewage) and grey water (non-sewage wastewater)).

2.3 STRESSORS

The list of stressors and nomenclature used was developed by assembling stressor terms already established and peer-reviewed in previous work by DFO (Clarke Murray et al. 2016a; Hannah et al. 2019; O et al. 2015; Rubidge et al. 2018; Thornborough et al. 2016) and cross-referenced for consistency and completeness with the outcomes of Transport Canada's engagement process (see Appendix A). The stressors included in this work are defined in Table 4.

Table 4. Names and descriptions of stressors used and which activities they are linked to

Stressor	Linked to activity	Stressor description
Substrate disturbance (sediment resuspension)	Anchoring and mooring Grounding and sinking Movement underway Discharge (debris)	The resuspension of sediment particles into the water column following disturbance of benthic substrates.
Substrate disturbance (crushing)	Anchoring and mooring Grounding and sinking Movement underway Discharge (debris)	Crushing of benthic substrata and communities from anchoring and mooring buoy systems, a grounded or sunken vessel, or discharged debris.
Foreign object / Obstacle	Anchoring and mooring Vessel at Rest Grounding and sinking Discharge (debris)	An object or obstacle affecting or altering habitat due to its presence, such as a vessel, anchor, or discharged material.
Light disturbance	Vessel at rest Movement underway	Temporary artificial light associated with the presence of commercial vessels; or conversely, a reduction in light caused by shading from a vessel.
Noise disturbance	Anchoring and mooring Vessel at rest Grounding and sinking Movement underway	Artificial noise associated with commercial vessels. Noise can range from pervasive, low frequency sound from vessel engines or ice breaking to short-term noise from anchor deployment and retrieval.
Vessel strikes	Movement underway	Strikes to mobile organisms by vessels (including propellers) while underway.
Entrapment/ entanglement/ smothering	Anchoring and mooring Discharge (debris)	The entrapment, entanglement or smothering of organisms in anchor or mooring gear and discharged material and debris such as plastics, containers, etc.
Prey imitation	Discharge (debris)	Manufactured materials and debris that could be mistaken for prey by marine organisms and ingested. This may include types of plastic debris, including microplastics.
Biological material	Discharge (other)	Discharges of biological material, primarily nutrient-rich sewage, from commercial vessels.
Disturbance (wake, turbulence, water displacement, hydrodynamic pressure field, breaking of ice)	Movement underway	Disturbance from the waves produced by displacement of water due to the movement of vessels (wake); turbulence created by the propellers of moving vessels ('propeller wash'). Includes the breaking and fragmentation of sea ice as the result of direct contact with icebreaking vessels.

Stressor	Linked to activity	Stressor description
Introductions of species and pathogens	Anchoring and Mooring Vessel at rest Discharge (other) Grounding and sinking Movement underway	Comprised of two components: introductions of species (i.e., Aquatic Invasive Species, AIS) and the introduction of pathogens, such as viruses, from shipping. AIS are organisms introduced to an area outside the natural range that can become established and have a negative impact on the new environment. Pathogens, such as disease-causing bacteria, viruses, fungi, and some parasites, can also be introduced via shipping.
Petroleum products	Discharge (other)	Petroleum products discharged from vessels through significant spills as well as through smaller scale, though still significant, operational discharges, such as bilge water releases.
Air emissions	Discharge (other)	Release of air-borne pollutants from the burning of hydrocarbons for fuel. Includes nitrogen oxides, sulphur oxides and particulate matter.
Other contaminants	Discharge (other)	Release of various contaminants from commercial vessels as part of regular operations

While the same stressor can result from multiple sub-activities, the magnitude, scale, and intensity of the stressor and its resulting effects are specific to each individual sub-activity. For example, the noise disturbance stressor might vary in its amplitude, duty cycle, and frequency depending on whether the noise originates from engines of a vessel underway or a generator from a vessel at rest. The resulting effects will differ depending on the characteristics of the noise (e.g., chronic versus acute noise disturbance).

2.4 EFFECTS

There is an important distinction between effect and impact; this work uses the definitions provided by Boehlert and Gill (2010). Effects include “the broad range of potentially measurable changes that may be observed” while impacts are “effects that, with some certainty, rise to the level of deleterious ecological significance”. Consequently, the presence of an effect in the PoE model does not necessarily indicate a significant impact. Pathways of effects models are used to elucidate the way that potential effects can manifest from stressors, but whether these effects become impacts should be assessed in a subsequent step (e.g., risk assessment, impact assessment). In these models, evidence for potential effects of stressors on generic endpoints is included for illustrative purposes.

To ensure consistency in structure and applicability across regions, three effect categories were used in each model to portray the broad-scale effects that stressors can have: change in fitness, mortality, and a change in habitat (Table 5).

Table 5. Definitions of direct effect categories

Effect	Description
Mortality	Death of an organism or group of organisms. Mortality can be an immediate response from interaction with a stressor or a delayed effect after exposure. This effect applies only to biotic components.
Change in fitness	Change to the physiological condition of an organism that reduces the ability to grow, survive to reproductive age, and/or produce or rear offspring. Change in fitness is complex, encompassing a broad range of different aspects, including changes to organism behaviour (such as communication, migration patterns, group cohesion, foraging patterns, avoidance, predation), changes to organism health (such as stress, disease, foraging efficiency, physiology, immunosuppression, changes to nervous system or endocrine system, mutagenic effects, spawning potential), organism injury, and organism displacement, among others. The disruption of physiological processes and temporary behavioural responses to a stressor may expend energy, distract from feeding, or increase the risk of injury or predation. These changes may be referred to as non-lethal effects. This effect applies only to biotic components.
Change in habitat	Change in the physical habitat of the marine environment. Habitat includes abiotic environmental factors (e.g., substrate, water column, soundscape, and sea ice).

Only direct effects were considered, as indirect effects were beyond the scope of the current work. While all of these effects can result from direct interaction with a stressor, a stressor may induce indirect (or secondary) effects on the marine environment and one or more of its components (Figure 5). For example, substrate disturbance (sediment resuspension) from anchoring may result in reduced growth rate (a change in fitness) of habitat-forming seagrass in the area surrounding the anchor – a direct effect. This change in fitness may result in the mortality of a juvenile fish dependent on that seagrass bed for protection from predation – an indirect effect. While potentially important in any subsequent assessment, the consideration of indirect effects in this generalised PoE structure would be almost limitless. Therefore, only direct effects resulting from interaction with a stressor are included in the PoE models and detailed in this document.

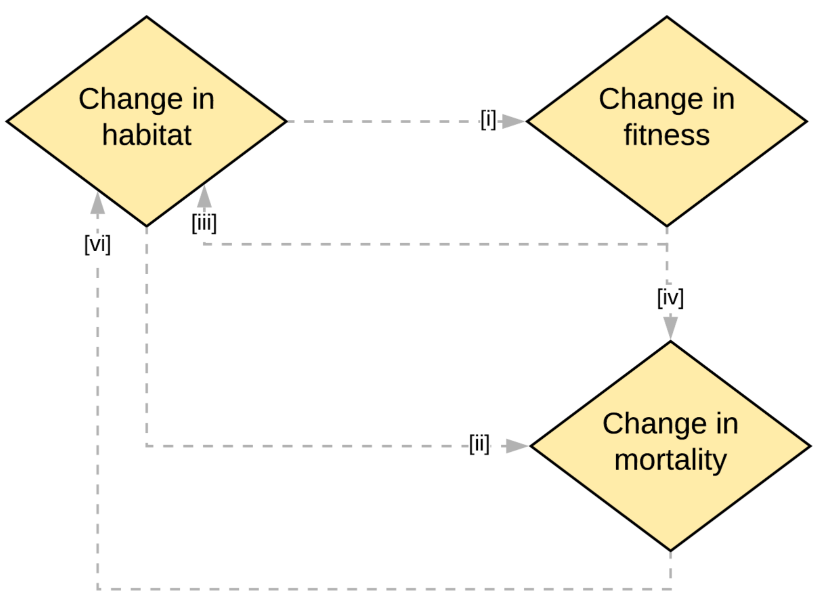

Figure 5. Generic direct effects and the indirect linkages ([i] through [vi]) between them

2.5 ENDPOINTS

An endpoint in the context of this work is defined as a valued attribute of ecological entities (EPA 1998). As not all organisms or ecosystem features can be studied, regulatory agencies and other risk managers must choose from among many candidate endpoints, which can be specific to the region of interest or identified for smaller areas such as Marine Protected Areas. Generic endpoints were chosen for illustration and substantiation purposes in the current PoE models in order to show how stressors may interact with features of the marine environment. The goal in developing these endpoints was that they be generic enough to be applicable across Canadian regions and be able to adequately describe the effects of a stressor. Generic ecological assessment endpoints are used in a wide range of risk and impact assessments because they are applicable to a wide array of environmental issues, and they may be assessed using existing assessment tools.

Endpoint examples selected (Table 6) were based on broad-scale categories of endpoints used in DFO Pacific Region's vulnerability assessment groupings developed for oil spill planning and response (Hannah et al. 2017). The detailed evidence for the pathways between effects and endpoints are presented in Appendix B1-B6, grouped by activity and stressor.

Table 6. Description of ecological endpoints used in the PoE models.

Generic endpoint	Description
Marine plants and algae	Marine vegetation across Canada (including micro- and macroalgae, phytoplankton, coralline algae and rhodoliths, sea grasses, and kelp).
Marine Invertebrates	Marine invertebrates and assemblages in Canadian waters, including those found throughout the water column and the seafloor.
Marine Fishes	Marine fishes in Canadian waters (i.e., pelagic, groundfish, diadromous, sharks, skates, and rays).
Marine mammals	Marine mammals in Canadian waters (i.e., cetaceans, pinnipeds, ursids, and mustelids).
Marine Reptiles	Sea turtles are the only representative of marine reptiles in Canadian waters. Species found in Canada include Loggerhead, Kemp's Ridley, Green sea turtle, Pacific leatherback, and Atlantic leatherback.
Marine Birds	Marine birds, e.g., seabirds, shorebirds, wading birds in Canadian waters.
Physical habitat (substrate)	Physical benthic substrates in Canadian marine waters provide habitat within substrates for infauna and habitat on top of the substrate for epifauna. Includes physical, chemical and biological characteristics and habitat-forming biogenic habitats such as coral and sponge.
Physical habitat (water column)	Physical water column habitat in Canadian marine waters includes the water column habitat for species (e.g., plankton and microbes), as well as its physical, chemical, and biological characteristics. Factors, such as temperature, salinity, dissolved oxygen depth, pH, water velocity and movement, and water clarity can affect the distribution of aquatic organisms in the water column (Deaton et al. 2010).
Physical habitat (sea ice)	Physical sea ice habitat in Canadian marine waters provides habitat for infauna and epifauna and consists of the habitat on the top of the ice (e.g., for polar bears), within the ice and ice channels (e.g., algae, polar cod) and under the ice (e.g., for ice amphipods).
Physical habitat (acoustic)	Acoustic habitat in Canadian marine waters.

3 ANCHORING AND MOORING

3.1 BACKGROUND AND SCOPE

Anchoring and mooring are considered together in this PoE model as they both act in a similar ways on the environment and have the same suite of associated stressors, despite differences that may exist. Differences would manifest in terms of intensity and temporal extent of effects, which are relevant at an assessment level, but not in the current work. Canadian commercial vessels use anchoring more often than mooring.

3.1.1 Anchoring

An anchorage is defined by Transport Canada as “a suitable area in which to anchor a vessel” and the right to anchor a vessel is part of the common law right of navigation (Transport Canada 2018). Many of Canada’s ports, harbours, estuaries, and bays provide shelter and safe anchorage for vessels. The duration of anchoring can depend on the purpose for which a vessel needs an anchorage and can range from a few hours, several days to a number of weeks (Transport Canada 2018). For example, the average length of stay for a vessel in the Gulf Islands, British Columbia is 8.6 days, but usually does not exceed 45 days (M. Kim, Transport Canada, Pers. Comm.). Commercial vessels use anchorages when waiting for clearance to enter a port, when waiting for berth or cargo availability, to maintain safety and security, due to inclement weather, during maintenance when preparing holds before taking cargo, making repairs, or making crew changes (Transport Canada 2018). Cruise ships utilise anchorage areas for one or more days when visiting smaller communities lacking docking facilities, or where berths are unavailable (e.g., Nanaimo BC, Charlottetown PEI, Iqaluit NU). Where designated anchorages are unavailable, anchoring locations are selected by large vessel operators (e.g., see Arctic Sailing Directions).

In southern BC, large commercial vessels intending to enter port often have to anchor due to the regular waits to enter the Port of Vancouver related to capacity, and anchorage areas are used very frequently. Anchorages utilised by waiting vessels are distributed in allocated areas that have been reviewed as suitable, for both safety and environmental reasons. Figure 6 shows the location of commercial shipping anchorages in the south coast of British Columbia. In the Atlantic region, commercial shipping vessels generally transit directly to ports, and waiting periods are unusual. There are assigned anchorage zones available which are used in some cases, but much less than in the Pacific region. In the Canadian Arctic, there are few designated anchorages, mostly in the Eastern Arctic. Waits by ships to enter the Port of Churchill, when it is open in the summer, are usually related to weather, rather than capacity issues. For example, the first cargo vessel visiting the recently reopened Port of Churchill had to wait at anchor for two weeks until there was suitable weather for loading and departing with a grain cargo (Franz-Warkentin 2019).

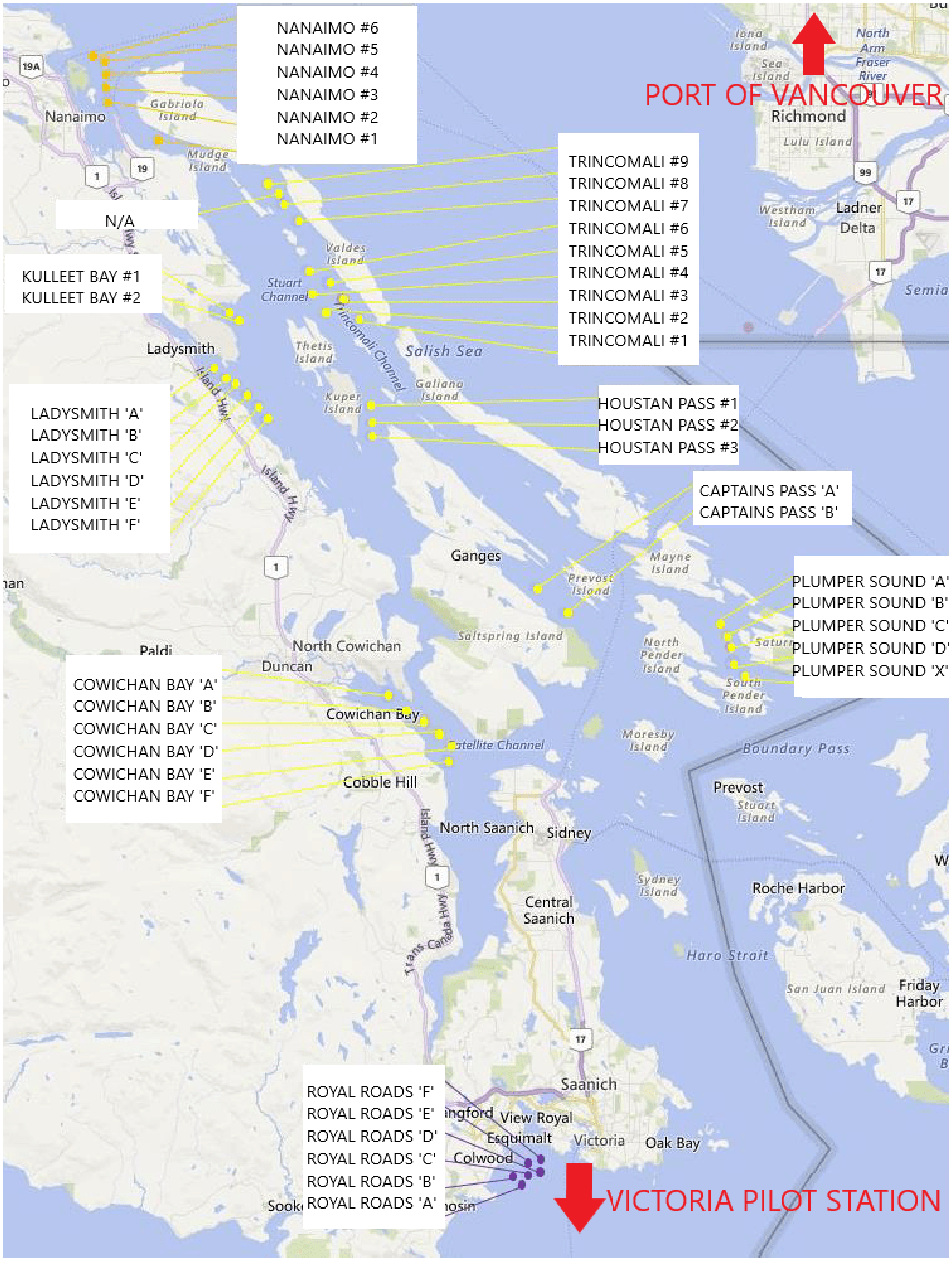

Figure 6. Location of anchorages in the southeast Vancouver Island region of British Columbia. Chart extract shows all anchorages, including six locations managed by Nanaimo Port and five at Esquimalt (Royal Roads), which are not part of the Pacific Region Interim Anchorages Protocol (Courtesy of M. Kim, Transport Canada).

Anchors used by the largest commercial vessels may weigh in excess of 25 tonnes (Davis et al. 2016) and are generally stockless anchors (a heavy set of flukes connected by a pivot or ball and socket joint to a shank). There are three stages of anchoring: dropping the anchor, dragging to lay out anchor chain and setting the anchor, then recovering the anchor and chain (Collins et al. 2010). While the anchor itself can impact the seabed, the most significant impacts result from the action of anchor chains dragging across the seabed as the anchored vessel swings around and moves in response to currents and wind, potentially affecting a large area of the benthos within the swing radius (Collins et al. 2010; Panigada et al. 2008) (Figure 7). The area impacted and magnitude of the impact is a function of the frequency of anchoring, dimensions and type of anchor used, anchor chain length (dependent on the size of the vessel, but usually 3 to 5 times water depth), currents and weather conditions, water depth, seabed type and the character of the biota present (Airoldi 2003; Milazzo et al. 2004; Montefalcone et al. 2006).

The impact of anchoring can be evident on the seabed for an extended timeframe. For example, it is estimated that almost 80% of marks on the seabed in the Bedford Basin of Halifax Harbour are attributable to anchoring dating back to the mid-1700s (Fader and Buckley 1995). An important component when considering anchoring effects in an assessment would be to take into consideration areas of historic anchoring in comparison to relatively pristine, or newer anchoring areas.

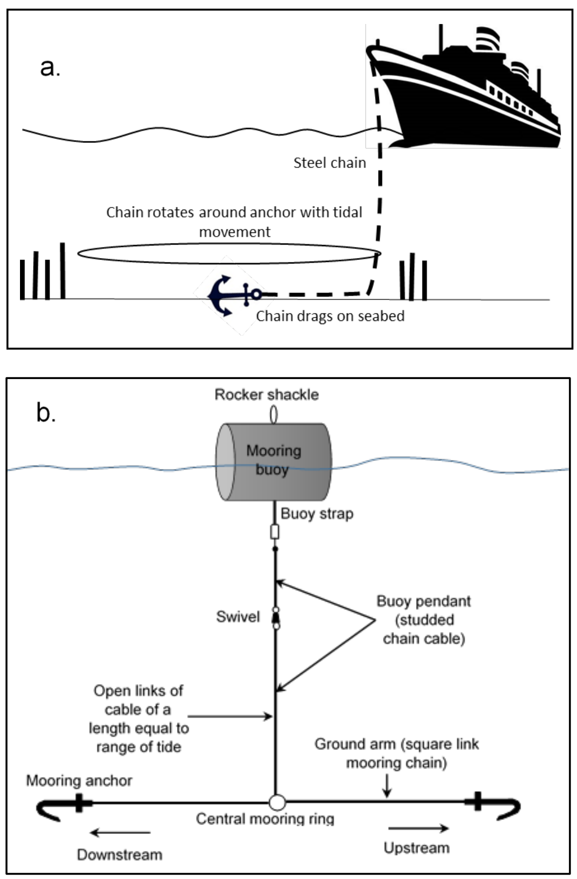

Figure 7. Examples of anchoring and mooring: a) An anchor is used to fix a vessel to a point on the bottom of the seafloor without connecting it to land (NOAA 2015); b) An example of a 2-arm commercial vessel mooring buoy system (adapted from Admiralty 1964); other variations on this general setup are used with different arrangements of cable and ground tackle depending on requirements of different vessel types/sizes.

3.1.2 Mooring

Vessel mooring, in this analysis, considers vessels secured to mooring buoy systems (not to other infrastructure such as wharves), the impacts of which can be somewhat similar to anchoring. Commercial vessel mooring buoys are not commonly used by vessels engaged in Canadian commercial shipping, as moorings are expensive to install and maintain, vessels have to make complex manoeuvres to be able to tie up to them, and bulk carriers generally need a tug to enable them to be attached to a mooring buoy (D. Kyle and M. Kim, Transport Canada, Pers. Comm.). They are generally used only for specific purposes, such as for naval vessels (e.g., in Halifax, NS, and Esquimalt, BC), and for dangerous goods and quarantine (D. Kyle, Transport Canada, Pers. Comm.). However, private commercial shipping companies do use commercial moorings for storing vessels such as scows and barges.

Commercial vessel moorings consist of multiple anchors arranged in a triangle on the seabed, and joined to another clump or anchor immediately below the buoy and connected vertically by a chain to the buoy structure. Variations in the exact type of ground tackle and system used depend on vessel size (D. Kyle, Transport Canada, Pers. Comm.) (Figure 7).

3.1.3 Scope

Not considered in the Anchoring and Mooring PoE:

- Impacts and effects from the presence of the anchored vessel itself are considered in the Vessel at rest PoE (Section 4).
- Impacts from the infrastructure associated with mooring buoy systems is out of scope, only the effects from the infrastructure that occur when vessels are tied to the mooring are considered (e.g., mooring chain scour).
- Effects related to mooring to other infrastructure, (e.g., tying alongside a wharf)
- Discharge, both operational and accidental, are associated with the ship while anchoring but are addressed as a separate activity in the (Discharge (debris) and Discharge (other) PoE models.
- Impacts from Dynamic Positioning Systems (DPS) are out of scope as they are not a part of regular marine shipping.

3.2 PATHWAYS OF EFFECTS DIAGRAM

Six stressors have been identified in association with the anchoring and mooring sub-activity: substrate disturbance (sediment resuspension); substrate disturbance (crushing); foreign object/obstacle; noise disturbance; entrapment/entanglement/smothering; and introductions of species and pathogens (Figure 8). Direct impacts from stressors associated with anchoring and mooring include a change in fitness, mortality and a change in habitat. Ecological components that may be disturbed by anchoring and mooring include marine plants and algae, marine invertebrates, marine fishes, marine mammals, marine reptiles, marine birds, and physical habitats (substrate, water column, acoustic, and sea ice). Evidence tables are available in Appendix B1.

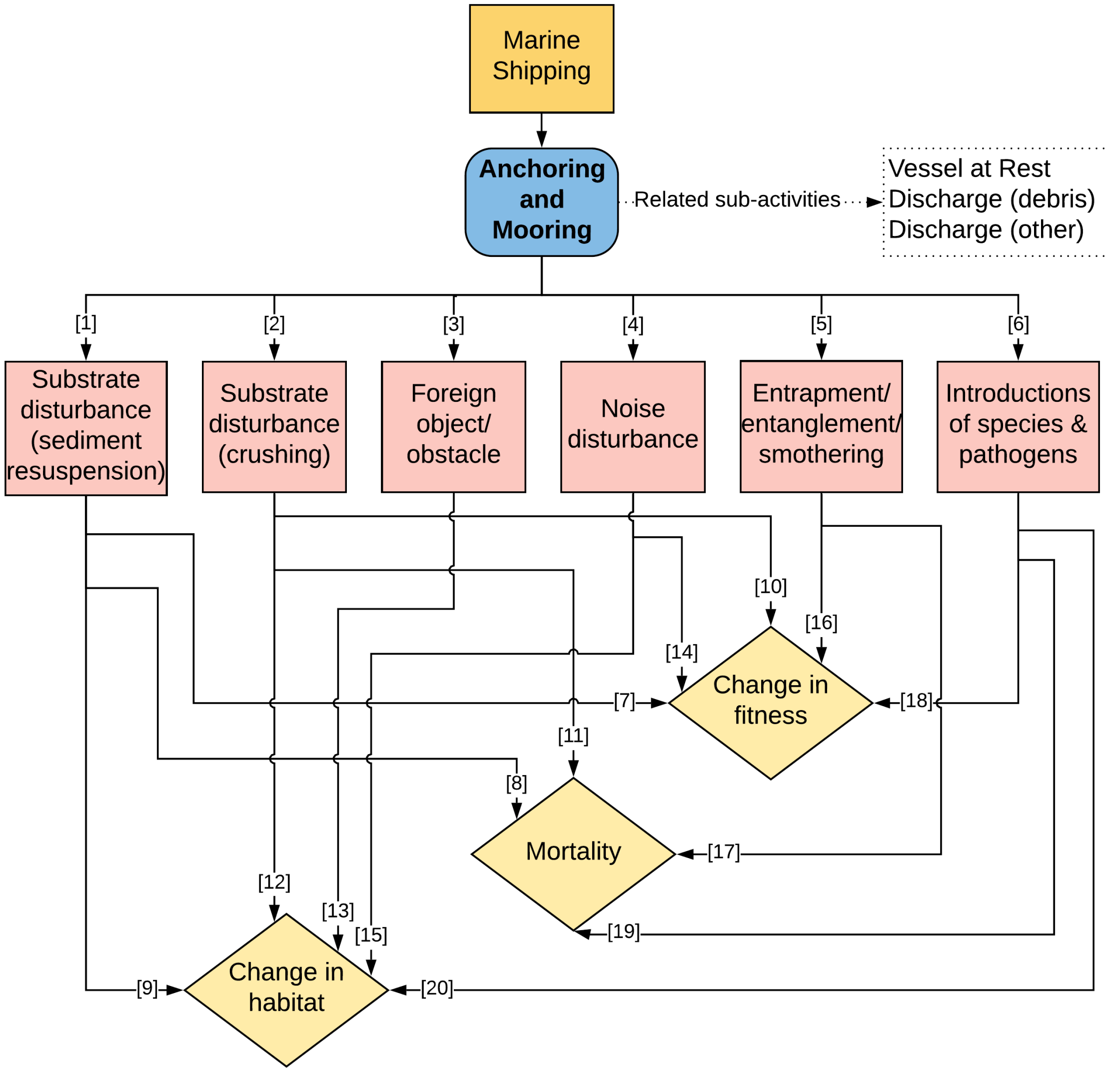

Figure 8. Diagram representing the pathways of effects conceptual model for Anchoring and Mooring.

3.3 STRESSOR DESCRIPTIONS

3.3.1 Substrate disturbance (sediment resuspension) [1]

Vessel positioning, dropping and retrieving of the anchor, and the movement of anchor/mooring chains, can disturb seafloor substrate which can lead to sediment becoming resuspended, and subsequent re-sedimentation (Collins et al. 2010). Substrate disturbance (sediment resuspension) from anchoring can result in direct impacts: change in fitness [7], mortality [8], and change in habitat [9]. Ecosystem components affected by this stressor include physical habitats (sediments, water quality), marine plants, fish, and invertebrates.

3.3.2 Substrate disturbance (crushing) [2]

Crushing of the seabed can occur as a ship's anchor is lowered and retrieved and even more so from movement of anchor/mooring chains while anchored/moored (Collins et al. 2010; Hastings et al. 1995; Herbert et al. 2009; Montefalcone et al. 2008; Walker et al. 1989). Substrate disturbance (crushing) from anchoring can result in direct impacts: change in fitness [10], mortality [11], and change in habitat [12]. Ecosystem components affected by this stressor include physical habitats (substrate), marine plants and algae, and invertebrates. These effects can be multiplied through either repeated swinging of the vessel in currents or winds, or through the presence of multiple vessels utilising a common anchoring ground in space and time.

3.3.3 Foreign object/obstacle [3]

The introduction of a foreign object (the anchor or mooring system) causes an obstacle on the seabed, a type of substrate disturbance which could result in a change in habitat [13]. All biological components are potentially affected by this stressor.

3.3.4 Noise disturbance [4]

Noise disturbance produced by dropping and retrieving anchors, and the movement of anchors and chains on the seabed and in the water column could result in a change in fitness of marine organisms by inducing temporary behavioural responses. Given that the loudest sounds produced by anchoring are of short duration and of much lower amplitude than when the vessels are underway, effects will be transitory startle reactions by nearby marine animals that are nearby with sensitive hearing (e.g., fish, marine mammals). Repetitive noise from an aggregation of anchored vessels may induce some animals to abandon areas otherwise beneficial to them, or to deviate from their usual migration routes. However, the biology of disturbance and the effect of noise on the survival and fecundity of marine mammals and their prey are not well understood, for a review see (Gomez et al. 2016). There is in general a lack of knowledge of the effects of noise from anchoring on marine biota. This stressor has the potential to result in a change in fitness [14] and/or a change in habitat [15].

See Movement Underway PoE (Section 6.3.4) for a more detailed description of shipping noise disturbance.

3.3.5 Entrapment/Entanglement/Smothering [5]

The deployment and retrieval of an anchor and chain has the potential to entrap or entangle marine biota in the chains or lines. In Atlantic Canada, there are also more complex anchoring systems with multiple lines potentially increasing the potential for this stressor to occur. This stressor could result in a change in fitness [16] and mortality [17].

3.3.6 Introductions of species and pathogens [6]

This stressor is comprised of two components: introductions of species and introductions of pathogens. In the context of this PoE model, this stressor primarily relates to the effects of aquatic invasive species (AIS) and pathogens introduced through biofouling of equipment used for anchoring.

Introductions of species (aquatic invasive species (AIS))

Species introduced to areas outside of their natural range can establish populations that can significantly impact the native environment. In order for these aquatic invasive species (AIS) to become established, founding individuals transferred to a new environment must be able to survive and establish a reproductive population. This population can also then act as a source for further (secondary) introduction of AIS (Floerl et al. 2009) in the local area.

Anchors and anchor chains have been identified as a potential source of aquatic invasive species introduction (West et al. 2007). Anchor chains, which are submerged in water at port and relatively protected during transit, are a potentially important mechanism of ship-mediated introductions (Chan et al. 2011; West et al. 2007). However, anchor chains are understudied as a vector of introductions (Chan et al. 2011).

The potential effects of AIS on an invaded ecosystem are difficult to predict (Olenin et al. 2011), but they can affect the marine environment at one or more levels: individual (e.g., internal biological pollution by parasites or pathogens), population (by genetic change, e.g., hybridisation), community (by a structural shift), habitat (by modification of physical–chemical conditions), or/and ecosystem (by alteration of energy and organic material flow) (Elliott 2003; Olenin et al. 2010a; Olenin et al. 2010b). The resulting effects are dependent on the invasive species introduced and can include change in fitness [18], mortality [19], and change in habitat [20].

Introduction of pathogens

Pathogens, defined as biological agents that cause disease, fall into five groups: viruses, bacteria, fungi, protozoa, and helminths (parasitic worms) (Janeway et al. 2001). Organisms from each of these groups have the potential to cause disease to marine organisms and may be transported by shipping activities. Biofouling communities of commercial vessels can harbour pathogens that affect humans (Revilla-Castellanos et al. 2015), which could be transported and introduced to new areas through fouled anchors and anchor chains. Though it is not known if pathogens that affect marine species are also present in biofouling and transported in this way, it is a possibility. Pathogens that affect marine species introduced by fouled anchors and anchor chains could cause a change in fitness [18] and mortality [19].

3.4 STRESSOR EFFECTS SUMMARY

The evidence for effects on an endpoint group by the stressors associated with Anchoring and Mooring are summarised in Table 7.

Table 7. Summary of potential linkages to effects to endpoint groups from anchoring and mooring stressors, further detailed description and supporting literature are provided in Appendix B1. A check mark (✓) indicates a potential effect. Shaded cells indicate a cell where a link to an endpoint is not possible. Abbreviations: Substrate (SU), Water column (WC), Acoustic (AC), Sea ice (SI), Marine plants and algae (MP/A), Marine invertebrates (MI), Marine fishes (MF), Marine mammals (MM) Marine reptiles (MR), Marine birds (MB).

Stressors	Effects	Endpoints									
		Physical habitat				Biological					
		SU	WC	AC	SI	MP/A	MI	MF	MM	MR	MB
Substrate disturbance (sediment re-suspension) [1]	Fitness					✓	✓	✓			
	Mortality					✓	✓	✓			
	Habitat	✓	✓								
Substrate disturbance (crushing) [2]	Fitness					✓	✓	✓			
	Mortality					✓	✓	✓			
	Habitat	✓									
Foreign object/ obstacle [3]	Fitness										
	Mortality										
	Habitat	✓	✓								
Noise disturbance [4]	Fitness						✓	✓	✓	✓	✓
	Mortality										
	Habitat			✓							
Entrapment/ Entanglement /Smothering [5]	Fitness								✓	✓	
	Mortality								✓	✓	
	Habitat										
Introductions of species and pathogens [6]	Fitness					✓	✓	✓			
	Mortality					✓	✓	✓			
	Habitat	✓									

3.5 KNOWLEDGE GAPS

Published studies on the impacts of anchoring deal almost exclusively with the effects of recreational boat anchoring on seagrass (*Posidonia*) meadows (Davis et al. 2016; Panigada et al. 2008). There are studies from Canadian waters, but these also focus on impacts from recreational anchoring (Leatherbarrow 2003; Oates et al. 2012). Conversely, 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; Panigada et al. 2008). Anchoring by commercial vessels is assumed to have a much larger adverse impact on benthic habitats and species, given the relatively larger anchors and heavier chains used by these vessels (Panigada et al. 2008). Furthermore, the magnitude of adverse impact will be greater in areas that are designated as anchoring grounds, such as bunkering areas, and ports and harbours (Abdulla and Linden 2008). There is a lack of knowledge of how effects of anchoring in historic and well-used anchorage areas compare to anchoring in more pristine areas (e.g., cruise ships at smaller communities). There is a need for data to understand the magnitude and extent of adverse impacts resulting from direct physical effects beyond the effects of anchoring on seagrass beds, and from multiple, repeated anchoring events on mobile species such as fish and marine mammals. Studies on the differences in effects, if there are any, between a vessel anchored at a single point (and swinging about that point) and anchored at multiple points are lacking.

4 VESSEL AT REST

4.1 BACKGROUND AND SCOPE

The vessel at rest sub-activity considers the direct effects of commercial shipping vessels at rest while anchored or attached to a mooring buoy system. The effects of vessel presence itself are considered separately from the effects of anchoring and mooring gear (see Anchoring and Mooring PoE) as they are distinctly different.

4.1.1 Scope

Not considered in the Vessel at Rest PoE:

- Disturbance from anchoring/mooring gear (refer to Anchoring and Mooring PoE) (section 3)
- Interaction of vessel with seabed (refer to Grounding and Sinking PoE) (section 5)
- Vessel discharges, such as debris (refer to Discharge (debris) PoE), oils (refer to Discharge (other) PoE), or air emissions (refer to Discharge (other) PoE) (Sections 7-9)
- Vessel at rest does not include the intentional ramming of vessels into ice to maintain a fixed location relative to ice (‘drifting with ice’), as federal regulations state that unless a vessel is made fast to shore, at anchor, or aground, it is considered underway (Collision Regulations (C.R.C., c. 1416)).

4.2 PATHWAYS OF EFFECTS DIAGRAM

Four stressors have been identified in association with the vessel at rest sub-activity: foreign object/obstacle, light disturbance, noise disturbance, and introductions of species and pathogens. Direct impacts from stressors associated with this sub-activity include a change in fitness, mortality, and a change in habitat (Figure 9).

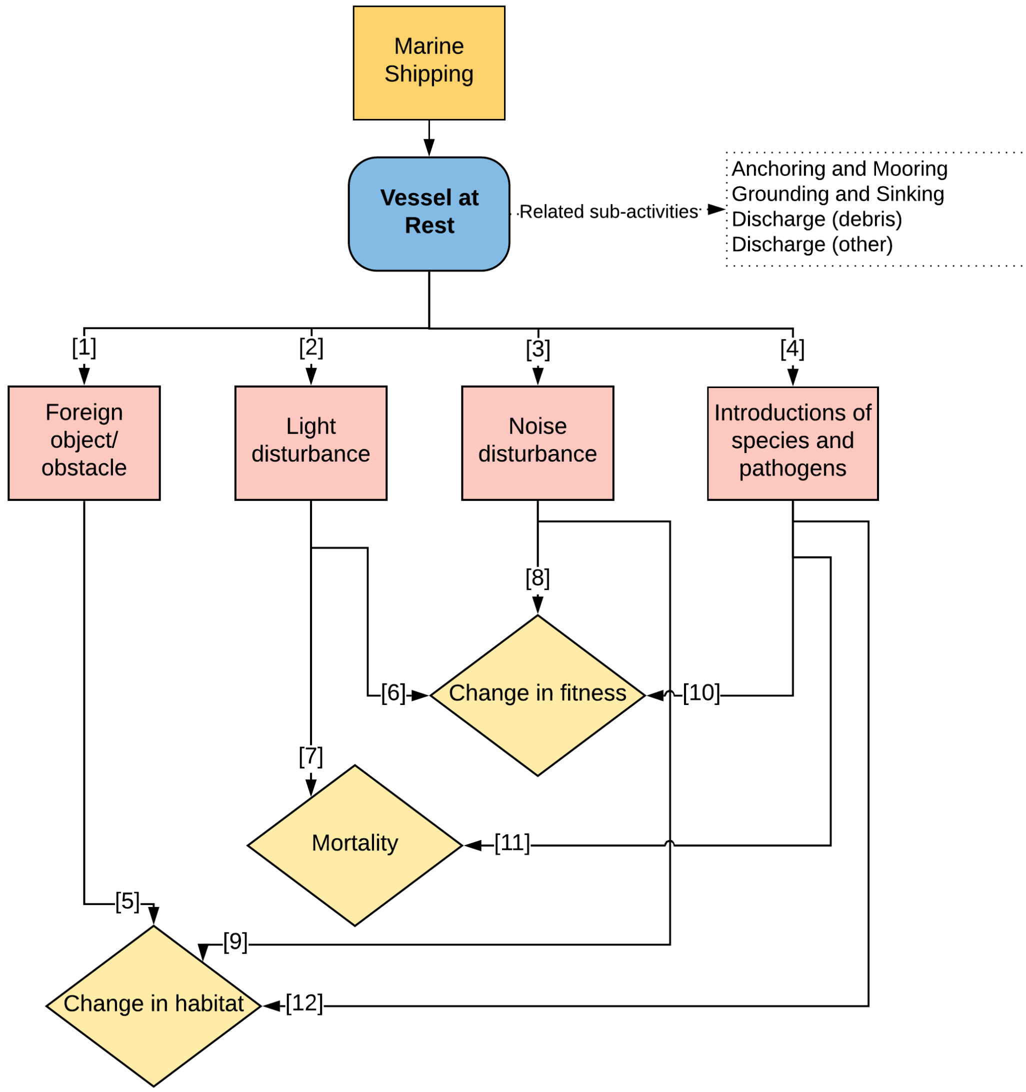

Figure 9. Diagram representing the pathways of effects conceptual model for Vessel at Rest.

Ecological components that may be disturbed by vessels at rest include marine plants and algae, marine invertebrates, marine fishes, marine mammals, marine reptiles, marine birds, and physical habitats (substrate, water column, acoustic, sea ice). Evidence tables are available in Appendix B2.

4.3 STRESSOR DESCRIPTIONS

4.3.1 Foreign object/obstacle [1]

Vessels at rest can act as a foreign object or obstacle in the water column, changing the water column habitat [5] and potentially hindering the movement and feeding of mobile biota, which may also accidentally collide with a vessel of which they are not aware.

4.3.2 Light disturbance [2]

Light disturbance by vessels at rest can affect the marine environment in two ways, by shading (the absence of light) and by continuous artificial light (the unnatural presence of light). Long-term shading of the seabed by stationary ships can result in adverse effects on the benthic biota underneath the vessels (Abdulla and Linden 2008). Light from commercial shipping vessels can both attract and repel marine organisms, resulting in behavioural responses that lead to collisions with the vessel and may result in injury [6] or mortality [7] (Longcore and Rich 2004). Effects of artificial lighting impact a wide range of ecological components, including marine mammals, birds, fish, invertebrates, and plants (Montevecchi 2006). Birds in particular are at risk of collision with lighted structures as they are attracted to light (Arctic Council 2009; Hodgson et al. 2013; Huntington et al. 2015).

4.3.3 Noise disturbance [3]

Noise associated with stationary vessels occurs when the engines are kept running while the vessel is at rest to provide electrical and hydraulic power for vessel operations. Many vessels anchor in designated locations, which can mean year-round exposure to vessel noise in some areas.

An anchored vessel is also a source of continuous sound from its pumps and auxiliary engines, generators, compressors, and other machinery. Such low-intensity sounds could cause masking of hearing (e.g., Hildebrand 2005; Payne and Webb 1971) and behavioural disruptions (e.g., Aguilar Soto et al. 2006) for marine mammals. Though there is limited information for marine invertebrates, exposure to ship noise disrupts feeding and respiration, and increases DNA breakage in mussels (Weilgart 2018). It is likely that if such disruptions occur for extended periods of time or in biologically important areas, they may affect longevity, growth, and reproduction [8]. Noise from an aggregation of anchored vessels may cause a change in habitat [9] inducing some animals to abandon areas otherwise beneficial to them, or to deviate from their usual migration routes. For example, shipping noise alters the movements and behaviour of Arctic cod (*Boreogadus saida*) (Ivanova et al. 2019). However, the biology of disturbance and the effect of noise on the survival and fecundity of marine mammals and their prey are not well understood (for a review see Gomez et al. 2016). A special case of higher-intensity vessel noise disturbance from vessels at rest is the use of dynamic positioning systems (DPS). These systems use auxiliary engines and propellers, often shrouded within tunnels in the ships' hulls, to maintain their position when anchors are not used, or where there is a risk that the anchors alone cannot maintain vessel position. With larger thrusters, even those within shrouds or tunnels which can reduce noise output, the blade tips cavitate at typical operating speeds and result in large, broadband sound outputs (Coney 2001; Lawson et al. 2001); large thrusters operating at speeds below those resulting in cavitation still produce broadband sounds of almost 180 dB re 1 μPa at 1 m. Large thrusters, thrusters that are cavitating, or multiple thruster systems can produce higher total sound energy (e.g., Breit and Dickinson 1990). This large underwater sound output is usually exacerbated by the changing aspect of the sound source as the vessel moves in position, and by the unpredictable power and direction settings of the thruster(s) as the vessel is kept in position. Vessels using DPS are not considered further in this document as transshipping (moving cargo between vessels) is not part of the scope of the current work.

4.3.4 Introductions of species and pathogens [4]

This stressor is comprised of two components: introductions of species and introductions of pathogens. In the context of this PoE model, this stressor primarily relates to the effects of aquatic invasive species (AIS) and pathogens introduced through biofouling of vessel hulls.

Introductions of species (aquatic invasive species (AIS))

The externally exposed vessel surfaces of vessels at rest can become fouled by encrusting or fouling biota, and such species can be transported out of their natural ranges as a vessel travels between ports. The spread of species by vessels between ports can occur through dislodgment and fragmentation of biota, but also by larval release as a vessel is at rest, which could result in the establishment of AIS in ports-of-call (Davenport and Davenport 2006; Sylvester and MacIsaac 2010; Sylvester et al. 2011; Ware et al. 2014). Hull-fouling increases with ship size, due to increased surface area for biota to attach (Carlton 1985; Chan et al. 2016; Coutts et al. 2003; Gollasch 2002). Other factors that can influence species introductions include season, mooring time, elapsed time since antifouling application, and vessel route (Coutts 1999; Ruiz and Smith 2005; Sylvester and MacIsaac 2010). The accumulation of fouling organisms also increases with mooring time (Coutts 1999; Sylvester and MacIsaac 2010). In the case of hull fouling, the shipping route influences the conditions to which organisms are exposed during transit, influencing survival rates.

A general description of how AIS can affect the marine environment is provided in the Anchoring and Mooring sub-activity stressor description (Section 3.3.6).

AIS attached to vessels at rest have the potential to be introduced to, establish and spread in through fragmentation and reproduction potentially resulting in a change of fitness [10] and mortality [11] of native organisms, and a change in habitat [12].

Introductions of pathogens

Pathogens, defined as biological agents that cause disease, fall into five groups: viruses, bacteria, fungi, protozoa, and helminths (parasitic worms) (Janeway et al. 2001). Organisms from each of these groups have the potential to cause disease to marine organisms and may be transported by shipping activities. Pathogens can be associated with the biofouling on ship's hulls (Revilla-Castellanos et al. 2015). It is possible, but not known if pathogens that affect marine species are also present in biofouling and transported in this way on vessels at rest. Pathogens that can affect marine species and were introduced via the biofouling present on the hulls of vessels at rest could cause a change in fitness [10] and mortality [11].

4.4 STRESSOR EFFECTS SUMMARY

The evidence for effects on an endpoint group by the stressors associated with Vessel at Rest are summarised in Table *8*.

Table 8. Summary of potential linkages to effects to endpoint groups from vessel at rest stressors, further detailed description and supporting literature are provided in Appendix B2. A check mark (✓) indicates a potential effect. Shaded cells indicate a cell where a link to an endpoint is not possible. Abbreviations: Substrate (SU), Water column (WC), Acoustic (AC), Sea ice (SI), Marine plants and algae (MP/A), Marine invertebrates (MI), Marine fishes (MF), Marine mammals (MM) Marine reptiles (MR), Marine birds (MB).

Stressors	Effects	Endpoints									
		Physical habitat				Biological					
		SU	WC	AC	SI	MP/A	MI	MF	MM	MR	MB
Foreign object/ obstacle [1]	Fitness										
	Mortality										
	Habitat		✓								
Light disturbance [2]	Fitness					✓	✓	✓	✓	✓	✓
	Mortality										✓
	Habitat										
Noise disturbance [3]	Fitness						✓	✓	✓		✓
	Mortality										
	Habitat			✓							
Introductions of species and pathogens [4]	Fitness					✓	✓	✓			
	Mortality					✓	✓	✓			
	Habitat	✓									

4.5 KNOWLEDGE GAPS

Although impacts on biota have been observed from vessel shading, data and studies examining these impacts long-term are lacking (Abdulla and Linden 2008). Studies are needed to quantify such aspects as the reduction in light to the seabed, the proportion of time the seabed is shaded by vessels at rest (which could be based on the duration that vessels are present over the year and hours of daylight), and comparisons between heavily used and lightly used anchoring areas.

Recent studies and a large-scale review have increased our understanding of the effects of vessel-related underwater noise (Gomez et al. 2016) but important knowledge gaps remain. In particular, long-term effects of chronic noise exposure, such as from vessels at an established anchoring location, deserves study. For some populations that are at risk from other factors, the addition of noise stressors may become more important.

5 GROUNDING AND SINKING

5.1 BACKGROUND AND SCOPE

Vessel grounding refers to the impact of a vessel with the seabed or underwater objects, usually while under power. The damage to a vessel can depend on the type of grounding that occurs, the seabed substrate encountered, and the nature of the grounding (e.g., weather conditions, impact speed). Soft groundings result in minor damage and may occur in areas with soft sediment, whereas a grounding in an area of hard substrate could have more serious impacts to the vessel and may lead to its sinking. A grounded vessel that cannot refloat without help is referred to as a stranded vessel, and a foundering vessel is one taking on water that could lead to capsizing or sinking. Sinking is used in this work as it solely refers to the impacts from a vessel that sinks, and reaches the seabed to become a shipwreck. The reasons why vessels ground or sink are not described in detail as it is the effects of the stressors that are the focus here.

There are an estimated three million shipwrecks on the seafloor around the globe, of which only a fraction have been discovered (UNESCO 2008). The vast majority of vessel groundings and sinking are accidental and may occur as the result of a collision, rough weather, storms and rogue waves, equipment breakdown, incompetent personnel, piracy, or flooding. Accidental groundings occur more frequently than sinking (Dimitrakakis et al. 2014) and are more likely to occur near shore when approaching ports (O'Brien 2001). Groundings can also occur wherever seamounts and shoals occur (Davies et al. 2011).

Some vessels are intentionally run aground (beached) to transfer cargo, as in some Arctic settlements where docking facilities are not available (e.g., Resolute). In those situations, sealift (supply) vessels anchor near shore and the supplies are ferried to shore or shallow water using smaller vessels and barges, often unloaded by forklift trucks operating in the nearshore. Intentional vessel scuttling also occurs, such as derelict ship disposal (including shipbreaking), or the creation of artificial reefs. Intentional grounding or sinking by the military may be for weapons training, or in wartime scuttling of vessels to act as a blockship (e.g., to close a harbour, river mouth), or to prevent the ship falling into enemy hands.

Canada does not hold an inventory of sunken vessels in waters under Canadian jurisdiction (Szeto and Rowney 2016). However, an independent analysis of shipwreck data from the beginning of the 20th century, identified hundreds of sunken ships (over 100 gross tonnes) in Canadian waters; 716 of these were capable of affecting the environment, though this was primarily based on an assessment of the contaminants associated with them (Szeto and Rowney 2016). Oils and other contaminants can be released at the time of wrecking and can continue to be released for decades afterwards. Vessels containing a large quantity of liquid contaminants would have a large spatial and temporal scale of potential effects (effects of spilled oil are discussed in the Discharge (other) PoE, Section 7).

The spatial extent of substrate disturbance stressors is usually confined to the footprint of the vessel and extends to a zone of influence around the site for other stressors. These stressors have the potential to impact the following endpoints: marine plants and algae, marine invertebrates, marine fish, marine mammals, marine reptiles, and physical habitats (substrate).

5.1.1 Scope

Not considered in the Grounding and Sinking PoE:

- Light disturbance – refer to Vessel at Rest PoE
- Debris released on grounding/sinking – refer to Discharge (debris) PoE
- Petroleum products released on grounding/sinking – refer to Discharge (other) PoE
- Contaminants released on grounding/sinking – refer to Discharge (other) PoE
- The recovery of sunken vessels is out of scope for this work, which assumes the wreck stays in place. The component of the permanence of a shipwrecks would be addressed in an assessment, and may be an important factor to consider given Canada's recent ratification of the Nairobi International Convention, the Wrecked, Abandoned or Hazardous Vessels Act (S.C. 2019, c. 1) that now requires that vessels over 300 gross tonnage have wreck removal insurance.

5.2 PATHWAYS OF EFFECTS DIAGRAM

Five stressors have been identified in association with the grounding and sinking sub-activity: substrate disturbance (sediment resuspension), substrate disturbance (crushing); foreign object/obstacle; noise disturbance and introductions of species and pathogens. Direct impacts from stressors associated with this sub-activity include a change in fitness, mortality and a change in habitat (Figure 10). Ecological components that may be disturbed by grounding and sinking include marine plants and algae, marine invertebrates, marine fishes, marine mammals, marine reptiles, marine birds, and physical habitats (substrate, water column, acoustic, sea ice). Evidence tables are available in Appendix B3.

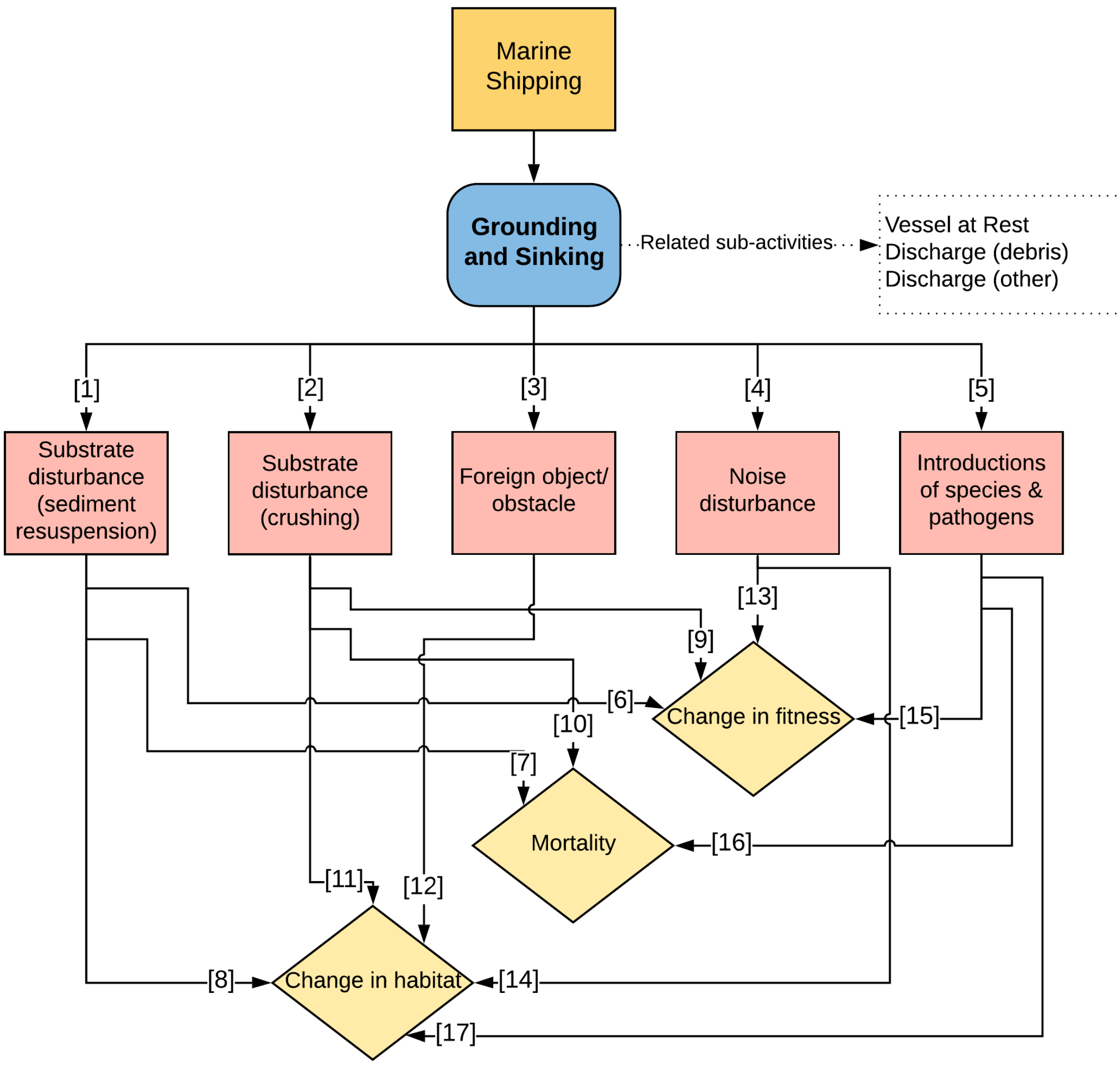

Figure 10. Diagram representing the pathways of effects conceptual model for Grounding and Sinking

5.3 STRESSOR DESCRIPTIONS

5.3.1 Substrate disturbance (sediment resuspension) [1]

Short-term sediment resuspension can occur at the time of the grounding or sinking when the vessel comes into contact with the seabed (Airoldi 2003) and potentially results in a change in fitness [6], mortality [7], and habitat [8].

5.3.2 Substrate disturbance (crushing) [2]

Crushing can occur as the vessel makes contact with the seafloor at the time of grounding or sinking and can continue if the vessel breaks apart and is shifted on the seafloor by currents and high-energy events. The weight of a vessel grounding on the seabed will result in the localised scraping of hard seabed substrate types and localised compression and movement of soft sediment seabed substrate types. This could lead to a change in fitness [9], mortality [10], and a change in habitat [11].

5.3.3 Foreign object/obstacle [3]

The sunken vessel or debris from a grounded or sunken vessel can act as a foreign object/obstacle in the water column and seabed, that otherwise would not be present in the area. This could cause a change in habitat [12].

5.3.4 Noise disturbance [4]

Some noise disturbance is expected to result from the initial impact of the vessel on the seabed when a vessel grounds or sinks. While no information is available on this specific stressor, it is expected to be a short-term single-event stressor that would result in, at most, minor changes in fitness of nearby organisms [13], however, there is the potential for extended noise disturbance if the vessel is not recovered and moves with waves or currents which could affect acoustic habitat [14].

5.3.5 Introductions of species and pathogens [5]

This stressor is comprised of two components: introductions of species and introductions of pathogens. In the context of this PoE model, this stressor primarily relates to the effects of aquatic invasive species (AIS) and pathogens introduced through release of biofouling from grounded or sunken vessels. Although AIS and pathogens can also be introduced through ballast water releases from the vessel when grounding or sinking, this aspect is considered under the Discharge (other) PoE.

Introductions of species (aquatic invasive species (AIS))

A vessel grounding or sinking could introduce hull fouling species to a new environment outside of their natural range, where they could become invasive if the environment is favourable for survival and establishment. A general description of how AIS can affect the marine environment has been described in the Anchoring and Mooring sub-activity stressor description.

AIS fouling the hulls of grounded or sunken vessels could lead to a change in fitness [15], and mortality [16] of native organisms, and a change in habitat [17].

Introduction of pathogens

Pathogens, defined as biological agents that cause disease, fall into five groups: viruses, bacteria, fungi, protozoa, and helminths (parasitic worms) (Janeway et al. 2001). Organisms from each of these groups have the potential to cause disease to marine organisms and may be transported by shipping activities. Pathogens can be associated with the biofouling on ship's hulls (Revilla-Castellanos et al. 2015). It is possible, but not known if pathogens that affect marine species are also present in biofouling and can be transported and introduced by grounded or sunken vessels. Pathogens introduced through association with biofouling on grounded or sunken vessel hulls and that can affect marine species could cause a change in fitness [10] and mortality [11].

5.4 STRESSOR EFFECTS SUMMARY

Potential linkages to effects on an endpoint group by the stressors associated with Grounding and sinking are summarised in Table 9.

Table 9. Summary of potential linkages to effects to endpoint groups from grounding and sinking stressors, further detailed description and supporting literature are provided in Appendix B3. A check mark (✓) indicates a potential effect. Shaded cells indicate a cell where a link to an endpoint is not possible. Abbreviations: Substrate (SU), Water column (WC), Acoustic (AC), Sea ice (SI), Marine plants and algae (MP/A), Marine invertebrates (MI), Marine fishes (MF), Marine mammals (MM), Marine reptiles (MR), Marine birds (MB).

Stressors	Effects	Endpoints									
		Physical habitat				Biological					
		SU	WC	AC	SI	MP/A	MI	MF	MM	MR	MB
Substrate disturbance (sediment resuspension) [1]	Fitness					✓	✓	✓			
	Mortality					✓	✓	✓			
	Habitat	✓	✓								
Substrate disturbance (crushing) [2]	Fitness					✓	✓				
	Mortality					✓	✓	✓			
	Habitat	✓			✓						
Foreign object/ obstacle [3]	Fitness										
	Mortality										
	Habitat	✓	✓								
Noise disturbance [4]	Fitness						✓	✓	✓	✓	✓
	Mortality										
	Habitat			✓							
Introductions of species and pathogens [5]	Fitness					✓	✓	✓			
	Mortality					✓	✓	✓			
	Habitat	✓									

5.5 KNOWLEDGE GAPS

The majority of stressors resulting from vessel grounding and sinking have effects that are localised in the area surrounding the vessel, with the exception of discharges of oils and contaminants, which could have far-ranging and severe impacts depending on the vessel type and scenario. Although many studies have examined the environmental effects following a vessel sinking event, especially of oil, fuels, contaminants, and cargo, few have concentrated on the chemical pollution introduced into seawater and sediments by the release of heavy metals (Dimitrakakis et al. 2014; Jones 2007). Similarly, very few studies have examined the effects of the physical disturbance to the substrate (particularly sediment resuspension).

6 MOVEMENT UNDERWAY

6.1 BACKGROUND AND SCOPE

Unless a vessel is made fast to shore, berthed, at anchor, or aground, it is considered underway (Collision Regulations (C.R.C., c. 1416)). The movement underway sub-activity incorporates the stressors of relevance to commercial vessels while underway, and is comprised primarily of surface acting stressors, meaning that the direct effects from this activity primarily act on organisms and habitats in shallow or surface waters. In shallow waters, turbulence from propellers and the hydrodynamic effects of the passing hull can re-suspend benthic sediments and the hydrodynamic pressure field caused by a ship sailing near a coast can result in higher wakes and pressure effects on shallow habitats and marine structures and plants (Deng et al. 2016). Vessels navigating shallow waters might also touch bottom with their hulls or propellers, crushing the substrate. If effects such as these occur often in frequently navigated routes, they could lead to changes in habitat.

In areas that experience ice cover, the effects of ice-breaking are an important consideration. Ice-breaking causes dramatic changes in the sea ice habitat, which has implications for organisms associated with ice. Icebreaking also creates artificial leads (ice fractures defining an area of open water or thin layer of new ice) that can result in short-term increases in biological productivity (Stirling 1998). Another aspect of vessel movement in the Arctic is that vessels will intentionally ram into the ice in order to hold position relative to the ice, a practice known as 'drifting with ice', and these vessels are still considered underway. The lights and noise associated ice breaking vessels and with drifting vessels can affect surrounding biota, such as attracting polar bears.

For many marine mammals, the vessel noise stressor can cause changes to acoustic habitat. Vessel noise can cause behavioural changes (avoidance, diving pattern changes), displacement from habitats, and masking or interfering with vocalisations produced for communication and sensation (which can disrupt feeding) in marine mammals (Jasny et al. 2005; Lacy et al. 2015; National Research Council 2005). For marine birds, light disturbance causes fitness or mortality effects as a result of their attraction to artificial light. Some stressor effects are felt differently by region, and the Disturbance (wake, turbulence, and water/ice displacement) stressor is particularly relevant for the Arctic region, where effects to ice resulting from vessel movement can result in a range of effects, such as habitat changes.

Impacts from movement underway depend on the vessel type, location, and frequency of vessel activity.

6.1.1 Scope

Not considered in the Movement Underway PoE:

- Discharges of debris from vessels underway – refer to Discharge (debris) PoE
- Discharges of petroleum products from vessels underway – refer to Discharge (other) PoE
- Discharges of air emissions and contaminants – refer to Discharge (other) PoE

6.2 PATHWAYS OF EFFECTS DIAGRAM

Seven stressors have been identified in association with the movement underway sub-activity: substrate disturbance (sediment resuspension) [1]; substrate disturbance (crushing) [2]; light disturbance [3], noise disturbance [4]; vessel strikes [5]; disturbance (wake, turbulence, water/ice displacement) [6]; and introductions of species and pathogens [7] (Figure 11). Two of the stressors associated with this sub-activity are unique to movement underway – vessel strikes and disturbance (wake, turbulence, water/ice displacement). Direct impacts from stressors associated with this sub-activity include a change in fitness, mortality, and a change in habitat. Ecological components that may be disturbed by movement underway include marine plants and algae, marine invertebrates, marine fishes, marine mammals, marine reptiles, marine birds, and physical habitats (substrate, water column, acoustic, and sea ice). Evidence tables are available in Appendix B4.

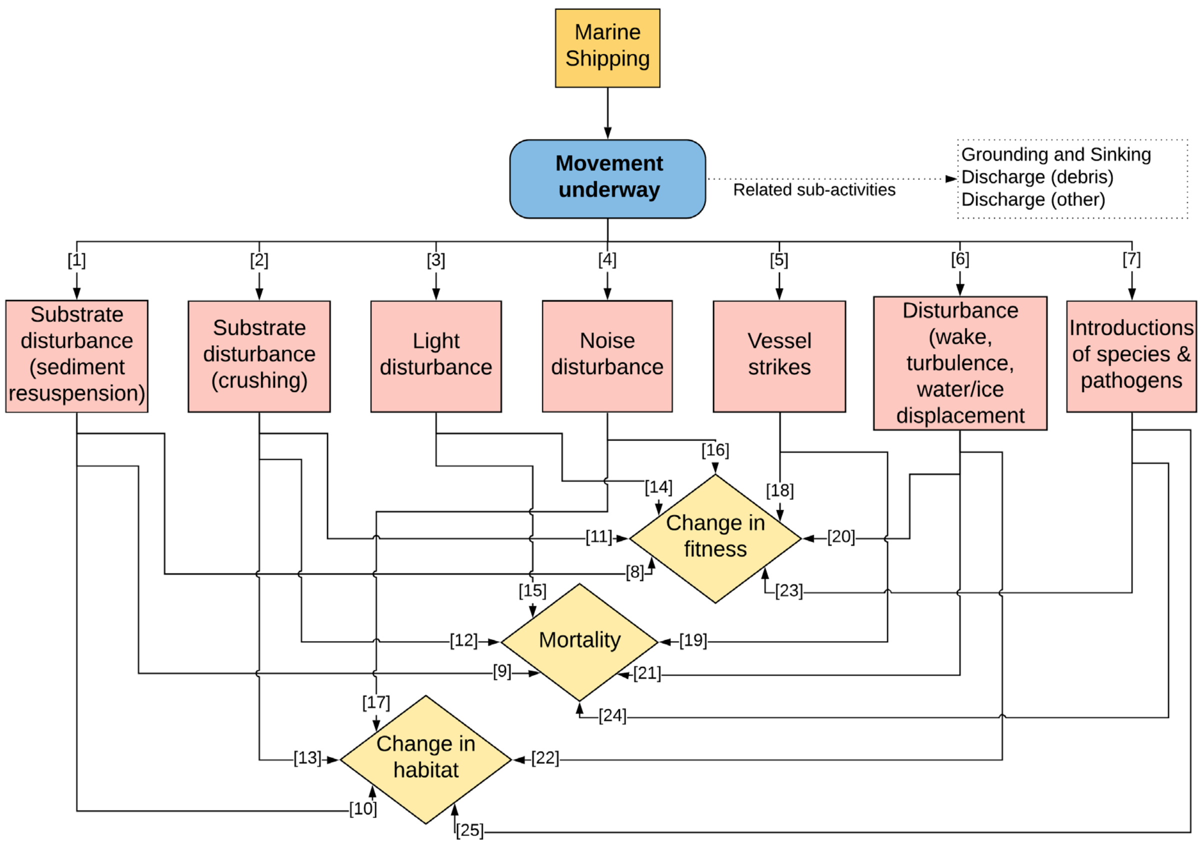

Figure 11. Diagram representing the pathways of effects conceptual model for Movement Underway

6.3 STRESSOR DESCRIPTIONS

6.3.1 Substrate disturbance (sediment resuspension) [1]

In shallow waters turbulence from propellers can stir up benthic sediments, increasing suspended sediments in the water (Beachler and Hill 2003) which could result in a change in fitness [8], mortality [9], and a change in habitat [10]. This stressor is of particular relevance to the Atlantic region where the continental shelf is extensive and shallow, it also of relevance in the Arctic where there is an extensive continental shelf with many uncharted waters.

6.3.2 Substrate disturbance (crushing) [2]

Ship movement has the potential to crush the substrate it encounters when moving through shallow areas. Crushing can cause change in fitness [11], mortality [12], and a change in habitat [13].

6.3.3 Light disturbance [3]

Light disturbance by moving vessels can both attract and repel marine organisms, resulting in behavioural responses that lead to a reduction in fitness, and collisions with the vessel resulting in injury or mortality (Longcore and Rich 2004). Light disturbance from moving vessels is expected to have similar, but less significant impacts on marine organisms, than light disturbance from vessels at rest (see Section 4.3.2) limited to a change in fitness [14], and mortality [15]. This is largely due to the reduced temporal exposure and potential for attraction by less mobile organisms (e.g., marine invertebrates). Additionally, shading is not a potential stressor from moving vessels. Effects of artificial lighting impact a wide range of ecological components, including marine mammals, birds, fish, and invertebrates (Montevecchi 2006).

6.3.4 Noise disturbance [4]

Over the past 50 years, anthropogenic activities, in particular shipping traffic, have contributed to increasing underwater noise pollution (Hildebrand 2009; Ross 2005). Commercial shipping is estimated to have raised the average ambient noise levels in the 20-200 Hz frequency band by about 10 dB in the past century[3] (Abdulla and Linden 2008). The potential effects of noise disturbance from shipping is expected to increase with the growth in the commercial shipping industry, both in terms of the number and size of vessels (Hatch et al. 2008). Ship propulsion noise accounts for more than 90% of anthropogenic acoustic disturbance in the ocean, making vessels underway one of the main anthropogenic sources of noise disturbance in marine environments, along with underwater explosions and seismic testing (Green et al. 1994; Slabbekoorn et al. 2010; Walker et al. 2019; Wright 2008). The low-frequency components of underwater sound usually attenuate slowly with distance and can travel hundreds of kilometres (CPCS Transcom Limited 2012; Rogers and Cox 1988).

Ship noise expresses different acoustic features and is usually a product of multiple radiating sources (engine noise, propeller cavitation, water moving over the hull, etc.). Noise can be impulsive, such as that produced by cavitation of near-surface or surface-piercing propellers (such as can occur when cargo vessels are lightly loaded), or it can be of a continuous broadband nature with most energy in tonal components at frequencies between 1 Hz and 1 kHz (Abdulla and Linden 2008; McCauley 1994). Low frequencies (<1,000 Hz) may be generated by engines, higher frequencies (>1,000 Hz) by rotating gears and mechanical resonances, and even higher tonal (1-2 kHz) by turbine engines and hydro-jets (such as fast ferries) (Abdulla and Linden 2008). Other vessel sound sources can be pumps and auxiliary engines, generators, compressors and other machinery. From a distance, vessels emit continuous, low frequency noise ranging from 1 to 500 Hz at 70±5 dB (dB re 1 $\mu Pa^2/Hz$ over stated frequency range) (McCauley 1994; Weilgart 2007). Ships contribute to ambient underwater noise levels over large geographic areas, and sounds of individual vessels are often spatially and temporally indistinguishable (Walker et al. 2019).

Sound levels and frequency characteristics of underwater noise from vessel propulsion are related to vessel size and speed (Heitmeyer et al. 2003; Simard et al. 2016; Veirs et al. 2016)

[3] Since dB are expressed on a logarithmic scale, an increase of 3 dB represents a doubling of acoustic energy.

Large ships create louder, lower frequency sounds with greater potential for long-range propagation because of their greater power, more slowly rotating engines and propellers, and larger surface areas for efficiently transmitting vibrations to water.

In the Arctic and coastal Labrador, the breaking of ice by icebreaker vessels can produce noise disturbance as areas of open water or channels through the ice are created and maintained. Noise produced by icebreaking ships is louder and more variable in comparison to other ships due to the backing up and ramming technique used to break ice (Arctic Council 2009; Hodgson et al. 2013; Wilson et al. 2017; WWF 2017). There are three noise types associated with icebreaking: ice ramming (primarily propeller cavitation), natural ice cracking, and an icebreaker vessel's bubbler system (high-pressure air blown into the water near the hull to push floating ice away from the ship) (Erbe 1997; Erbe and Farmer 1998, 2000; Erbe et al. 1999).

Marine noise is recognized as a significant and pervasive global scale issue with a broad range of negative effects in a variety of taxa (Clark et al. 2009; Merchant et al. 2014; National Research Council 2005; Williams et al. 2015). Hearing ranges and sensitivities vary between marine species (Erbe et al. 2012), and the impacts can depend on the duration and intensity of the noise (Slabbekoorn et al. 2010) and can impact marine organisms over long distances (Walker et al. 2019). Effects from noise disturbance can result in a change in fitness [16] and change in acoustic habitat [17].

6.3.5 Vessel strikes [5]

The occurrence and severity of vessel strikes on marine organisms in a number of regions around the world has become an important conservation issue, particularly in those places where extensive vessel traffic and high whale density co-occur (Silber et al. 2012; Van Waerebeek et al. 2007; Vanderlaan and Taggart 2007; Wiley et al. 2011). Vessel strikes are defined as collisions between vessels (and/or propellers) and marine organisms, most commonly marine mammals. This stressor may be on the rise with increases in shipping traffic and average travel speeds of vessels (Ritter and Panigada 2019). Vessel speed is an important factor contributing to the severity of a vessel strike (Conn and Silber 2013; Laist et al. 2001; Vanderlaan and Taggart 2007). Greater rates of serious injury and mortality occur at vessel speeds of ≥26 km h^{-1} (Abgrall et al. 2009; Jensen and Silber 2003). Strikes can cause a change in fitness [20] and mortality [21] and can impact a range of ecological endpoints. Marine mammals (specifically cetaceans) are the most commonly impacted organisms, however other surface interacting organisms such as sea turtles and basking sharks can also be impacted (COSEWIC 2009; Silber et al. 2010; Wilson et al. 2017).

The risk of vessel strikes can be seasonal, depending if aggregations of organisms occur at times when vessel traffic is high, and where aggregations or migration routes cross shipping corridors (Quakenbush et al. 2013; Silber et al. 2010). Areas with the highest interaction are associated with geographic bottlenecks, such as narrow straits and passageways.

In the Pacific Region, there are high densities of cetaceans (Williams and Thomas 2007) and a high intensity of maritime traffic but there has been little effort towards estimating cetacean mortality due to vessel strikes (Williams and O'Hara 2010). Rates of mortality and injury associated with vessel strikes are difficult to quantify as collisions with even large cetacean species are frequently unnoticed, and consequently go unreported (Félix and Van Waerebeek 2005; Laist et al. 2001; Panigada et al. 2008; Vanderlaan and Taggart 2007; Walker et al. 2019). In the Arctic, there are relatively few known incidents of vessel strikes on marine mammals, largely due to low levels of vessel traffic and little surveillance effort of struck animals in high latitudes (Arctic Council 2009, 2013). However, as shipping activity increases in the Arctic, the frequency of strikes is likely to rise (AMAP/CFF/SDWG 2013; Arctic Council 2009;

Hodgson et al. 2013) though such changes may be difficult to detect as vessels strikes are under reported, and the animals killed from strikes are less likely to be found in this area. In the Atlantic, the risk of vessel strike has been identified as a threat for a number of cetacean species listed as Species at Risk, including the endangered North Atlantic Right Whale (*Eubalaena glacialis*).

Vessel strikes can result in change in fitness [18] and mortality [19].

6.3.6 Disturbance (Wake, Turbulence, Water/Ice Displacement) [6]

The most pronounced physical impact of vessel movement underway is the alteration of the local hydrodynamic regime by the generation of ship-induced wake, turbulence and currents, and water and ice displacement (Gabel et al. 2017). As a vessel moves through the water, it displaces water and pushes the water forward, leading to increased pressure, drag and acceleration, and the generation of wake/waves and turbulence (Lindholm et al. 2001; Oebius 2000). Vessel characteristics (e.g., hullform, length, draft, speed, etc.) combined with the morphology of the waterway, dictate the properties of vessel-generated waves (e.g., wave height, length, celerity, etc.) (Gabel et al. 2017; Maynord 2005). The hydrodynamic pressure field caused by a ship sailing near a coast or island can result in higher wakes and pressure effects on shallow habitats and marine structures and organisms living there (Deng et al. 2016).

Vessel-induced waves are distinct from wind-driven waves and are capable of reaching shorelines otherwise protected from natural waves (Gabel et al. 2017; Stoll and Fischer 2011). Vessel-induced waves can reach larger wave heights, wave velocities, and occur more frequently than wind-driven waves in areas with restricted fetch (such as narrow channels, embayments, etc.) (Gabel et al. 2017; Hofmann et al. 2008, 2011). As a result, vessel-generated waves can have a greater impact on marine ecosystems than wind-driven waves, with impacts including vertical mixing, artificial upwelling, turbidity, sediment resuspension, temporary currents that result in a change in habitat, and disturbance of marine organisms that can result in a change in fitness (Gabel et al. 2017; Hofmann et al. 2011; Lindholm et al. 2001).

Physical habitats are primarily impacted by vessel wake and turbulence through sediment resuspension and shoreline/bank erosion (Gabel et al. 2017), resulting in changes in seabed and beach morphology, sediment grain sizes, and bank collapses (Gabel et al. 2017; Osborne and Boak 1999; Parnell et al. 2007). Impacts to shorelines from erosion is greatest in sheltered channels, embayments, and estuaries where the height of the vessel wake is equal to or exceeds the natural wind-driven wave heights (Bishop 2004). Vessel-generated waves impacting beaches and coastline can result in alongshore transport, increased weathering, and in some cases can overtop beach ridges (Parnell et al. 2007). Waves may also transport finer sediments to deeper areas as they erode the shore around the waterline (Soomere 2005).

Though non ice-strengthened vessels do travel in icy waters, their ability to move through ice-bound waters often requires specially reinforced icebreaking vessels that clear and maintain channels through ice. In the Arctic and winter coastal Labrador, ice-strengthened vessels are used to move cargo between ice-covered ports. Conventional ice-breaking vessels break ice by plowing and by backing up and ramming. Bow plowing uses a specialised bow structure that runs over the ice sheet and plows through the ice using a downward force. Backing up and ramming utilises the smooth bow of the vessel which glides over the ice, then comes down and crushes the ice sheet using the weight of the vessel, pushing broken ice out of the way; this is most often used to break thick ice (Arctic Council 2009; Canadian Ice Service). High pressure air blown into the water is also used to push floating ice away from the ship (bubbler systems).

Breaking new ice results in artificially formed channels of brash (churned/broken) ice, partially frozen water, or open water. Ice-breaking can directly alter and fragment key habitats and create artificial open channels through the sea ice, it can disturb and displace ice-dependent marine mammals such as pinnipeds, whose resting and birth lairs can be destroyed. The disturbance induces a flight response which can lead to the separation of mothers and pups, displacement from critical habitat, increased stress, and increased vulnerability to predation (Wilson et al. 2017; Yurkowski et al. 2018). Pinniped pups also have difficulty navigating brash ice due to the uneven surface and patches of water (Wilson et al. 2017). Fragmented habitat can result in pinniped pup disorientation, stress, increased energetic demands, and risk of hypothermia (Wilson et al. 2017). The effects of ice-breaking can be felt a much larger distance than might be anticipated, and the wakes of ships travelling through ice-covered waters can flood seal dens and wet baby seals potentially having fitness effects (Arctic Council 2009). Icebreaking activity displaces migrating narwhale and beluga (Cosens and Dueck 1988).

The effects from this stressor can result in a change in fitness [20], mortality [21], and change in habitat [22].

6.3.7 Introductions of species and pathogens [7]

This stressor is comprised of two components: introductions of species and introductions of pathogens. In the context of this PoE model, this stressor primarily relates to the effects of aquatic invasive species (AIS) and pathogens introduced through the biofouling of the hulls of vessels underway.

Introductions of species (aquatic invasive species (AIS))

Exposed vessel surfaces may become fouled by encrusting or fouling biota that can either become dislodged from the hull or can release reproductive propagules at any time along a vessel transit, thereby potentially introducing species to any location through which the vessel travels (Chan et al. 2011). These species have the potential to become AIS if they are introduced to an area outside of their native range where they could become established (Davenport and Davenport 2006; Sylvester and MacIsaac 2010; Sylvester et al. 2011; Ware et al. 2014). Hull-fouling species introductions can increase with ship size due to the larger surface area to which propagules can attach (Carlton 1985; Chan et al. 2016; Coutts et al. 2003; Gollasch 2002). The speed of underway vessels determines the shearing forces attached biota experience and affect their ability to remain attached and intact. To protect against these forces, sessile hull fouling organisms such as algae, hydroids, tunicates, bryozoans, barnacles and bivalves live in dense colonies, which also offer structural habitat and protection for motile organisms against the shearing forces experienced during ship movement (Davidson et al. 2009; Gollasch 2002; Herborg et al. 2009; Lewis et al. 2004; Therriault and Herborg 2008). The route taken can influence the survival rates of fouling biota, as this determines the conditions fouling biota are exposed to during transit (Coutts 1999; Ruiz and Smith 2005; Sylvester and MacIsaac 2010). The general way AIS can affect the marine environment has been described in the Anchoring and Mooring sub-activity stressor description. The introduction of species from this sub-activity could lead to a change in fitness [23], mortality [24], and a change in habitat [25].

Introduction of Pathogens

Pathogens, defined as biological agents that cause disease, fall into five groups: viruses, bacteria, fungi, protozoa, and helminths (parasitic worms) (Janeway et al. 2001). Organisms from each of these groups have the potential to cause disease to marine organisms and may be transported by shipping activities.

Pathogens can be associated with the biofouling on ship's hulls (Revilla-Castellanos et al. 2015) and could be transported and released by association with biofouling on the hulls of vessels underway. It is possible, but not known if pathogens that affect marine species are also present in biofouling and can be transported and introduced by vessels underway. Pathogens introduced through association with biofouling on vessels underway and that can affect marine species could cause a change in fitness [10] and mortality [11].

6.4 STRESSOR EFFECTS SUMMARY

Potential linkages to effects on endpoint groups by the stressors associated with Movement Underway are summarised in Table 10.

Table 10. Summary of potential linkages to effects to endpoint groups from movement underway stressors, further detailed description and supporting literature are provided in Appendix B4. A check mark (✓) indicates a potential effect. Shaded cells indicate a cell where a link to an endpoint is not possible. Abbreviations: Substrate (SU), Water column (WC), Acoustic (AC), Sea ice (SI), Marine plants and algae (MP/A), Marine invertebrates (MI), Marine fishes (MF), Marine mammals (MM), Marine reptiles (MR), Marine birds (MB).

Stressors	Effects	Endpoints									
		Physical habitat				Biological					
		SU	WC	AC	SI	MP/A	MI	MF	MM	MR	MB
Substrate disturbance (sediment resuspension)[1]	Fitness					✓	✓	✓			
	Mortality					✓	✓	✓			
	Habitat	✓	✓								
Substrate disturbance (crushing) [2]	Fitness					✓	✓	✓			
	Mortality					✓	✓	✓			
	Habitat	✓									
Light disturbance [3]	Fitness						✓	✓	✓		✓
	Mortality										✓
	Habitat										
Noise disturbance [4]	Fitness						✓	✓	✓	✓	✓
	Mortality										
	Habitat			✓							
Vessel strikes [5]	Fitness							✓	✓	✓	
	Mortality							✓	✓	✓	
	Habitat										
Disturbance (wake, turbulence, water/ ice displacement) [6]	Fitness					✓	✓	✓	✓		✓
	Mortality							✓	✓		✓
	Habitat	✓	✓		✓						
Introductions of species and pathogens [7]	Fitness					✓	✓	✓			
	Mortality					✓	✓	✓			
	Habitat	✓			✓						
Substrate disturbance (sediment resuspension)[1]	Fitness					✓	✓	✓			
	Mortality					✓	✓	✓			
	Habitat	✓	✓								

6.5 KNOWLEDGE GAPS

Many of the physical disturbance effects resulting from vessels underway are well-documented, although more research needs to be done to understand the effects of icebreaking when vessel operations are conducted in the context of climate-change-related ice conditions and with the introduction of new technologies. Similarly, studies are needed on the passage of cargo vessels of increasing size through narrow or shallow waters as these may cause substrate changes that can have impacts on marine animals' fitness and mortality over time.

In addition to the lack of baseline research to support impact studies, one of the biggest challenges in regulating the effects of noise is the lack of knowledge of the characteristics and levels of exposure that may pose risks to marine mammals and fishes, particularly in the long term and when multiple exposures act together. A large-scale literature review illustrated the individual- and species-level differences in response to anthropogenic sounds (Gomez et al. 2016), so many previous studies need to be revisited to account for exposure factors and context. For instance, attempts to assess the masking effects of a particular type of underwater noise for marine mammals have been hindered by a poor understanding of how animals make use of the many acoustic cues in their environment (Wartzok et al. 2003). Further, almost all the studies conducted so far have looked at short-term (minutes to hours) effects of anthropogenic noise on marine mammals (Wartzok et al. 2003). It is difficult to determine long-term impacts on individual animals or on populations, and no evidence exists of population-level effects from ocean noise (Wartzok et al. 2003). Finally, the long-term effects of ambient noise on individual marine organisms are even less well understood. Potential effects include changes in hearing sensitivity and behavioural patterns, as well as acoustically-induced stress. Because these effects may occur in species ranging from invertebrates to marine mammals, there is the potential for impacts on marine ecosystems at many levels.

While there has been much research in recent years on the effects of vessel noise on marine mammals, there has been much less on fish and invertebrates (including crustaceans) (Di Stefano et al. 2016; Weilgart 2018). There is increasing concern regarding the effects of such noise on fishes, other marine vertebrates such as aquatic and diving birds, and marine invertebrates (including crabs and lobsters). Potential effects of increased sound from shipping on fish and invertebrates are difficult to assess due to a lack of direct information (McCauley 1994; Popper and Hastings 2009). There is little evidence to suggest that ship noise has an immediate acute or lethal effect on fishes, and the impact of repeated disturbance and increased noise levels is generally unknown but may potentially be significant over the long term at the population or stock level (Abdulla and Linden 2008).

Many knowledge gaps still exist for vessel strikes and it is not known how many marine mammals are hit annually, or how any animals die after a strike. An increasing number of geographic hot spots have been identified for vessel strikes, and knowledge about how to tackle the issue is growing, with increasing national and international efforts to develop and implement mitigation measures (Ritter and Panigada 2019).

Invasiveness has mainly been studied from the perspective of human pathogens or organisms causing economic losses, with less attention paid to the broader effects of introduced species on the ecosystems (Hess-Erga et al. 2019).

7 DISCHARGE

7.1 OVERVIEW

The overall PoE conceptual model diagram for Discharge (Figure 12) contains ten stressors and is fairly complex.

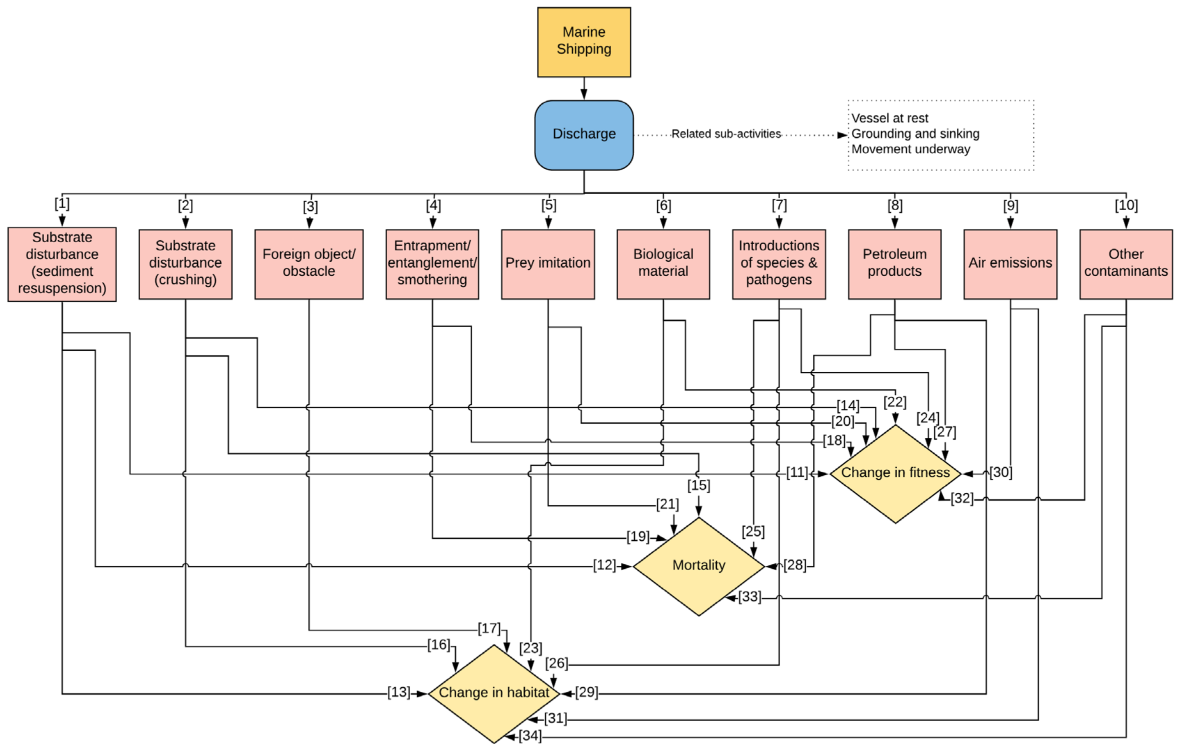

Figure 12. Diagram representing all linkages in the conceptual model for the Discharge sub-activity.

In order to enhance the understanding of the PoE, and to illustrate linkages more clearly, the Discharge PoE was divided into two PoE models, Discharge (debris) and Discharge (other), based on a natural division between the first five stressors specific to marine debris and the remaining five stressors. There are no stressors repeated between these two PoE models.

8 DISCHARGE (DEBRIS)

8.1 BACKGROUND AND SCOPE

Discharge (debris) considers the impacts of the release of solid materials from commercial vessels, both accidentally and operationally, that can occur when the vessel is at rest, moving underway or when a grounding or sinking occurs. This may include cargo and debris on deck.

The legal and accidental disposal of marine debris is defined as "any persistent, manufactured or processed solid material discarded, disposed or abandoned in the marine and coastal environment" (UNEP 2009). There are three types of marine cargo: liquid (petroleum products are addressed under the Discharge (other) activity), shipping containers (with varying contents), and dry bulk cargo (e.g., coal, iron ore, and grain) (Grote et al. 2016; Walker et al. 2019). In a global context, ~675 shipping containers are lost annually (World Shipping Council 2011). Dry bulk represents ~54% of shipping volumes worldwide (UNCTAD 2014; Walker et al. 2019). Approximately 10-15% of marine cargo is considered hazardous (Häkkinen and Posti 2013; Walker et al. 2019) and may include radioactive materials, pesticides/herbicides, fertilizers, and other chemicals (Omori et al. 1994).

Discharges of dry bulk cargo as the result of marine accidents (e.g., sinking, discharging of cargo residues after washing cargo holds, etc.) are more frequent than oil spills, but are generally undocumented (Grote et al. 2016; Omori et al. 1994; Walker et al. 2019). Spills of dry bulk and containers as cargo are relatively benign; however, the impacts are dependent on the type of cargo (CCA 2016). Even substances considered innocuous can be hazardous; for example, 2,600 tonnes of wheat lost during the grounding of a cargo ship in French waters (CCA 2016) resulted in the production of hydrogen sulphide through the decomposition of the wheat and the increase in sulphate reducing microbes (Mamaca et al. 2009).

The most common debris types found in the ocean are plastic, glass, and metal objects, in addition to fishing gear dumped mostly during the last 50 years. Plastics account for 60-80% of total marine litter (Derraik 2002; García-Rivera et al. 2017; Gregory and Ryan 1997). Marine debris has been identified as one of the five major marine pollutants by the International Oceanographic Commission. The main marine-based sources of deliberately discarded debris include vessels transiting shipping routes, fishing fleets, and tourism (cruise ships and other small commercial vessels) (Puig et al. 2012; Rehn et al. 2018; Tubau et al. 2015). Recyclables are often disposed of at port or are treated onboard (Butt 2007). Organic solid waste (e.g., paper, cardboard, and food waste) is incinerated at sea (Zuin et al. 2009). This release is restricted to offshore areas under MARPOL 73/78. Plastic waste is generally stored on ships and disposed of at on-shore facilities (disposal is prohibited at sea, but does occur).

There is no location in the ocean unaffected by anthropogenic debris (Galgani et al. 2015; Jeftic et al. 2009; Miyake et al. 2011; UNEP 2009). It is estimated that 15% of marine debris is floating at the sea surface, 15% remains in the water column, and 70% lies on the sea floor (UNEP 2005), wherein some areas it is equal to or greater than the biomass of megafauna (Ramirez-Llodra et al. 2013). Certain areas of the seafloor are more prone to capture and accumulate debris into depressions, crevasses and amidst rocks due to the geomorphology and hydrodynamic processes (Galgani et al. 1996; García-Rivera et al. 2017; Mordecai et al. 2011; Pham et al. 2014; Schlining et al. 2013; Tubau et al. 2015; Watters et al. 2010; Wei et al. 2012) and into areas of low hydrodynamics, such as bays and lagoons (Galgani et al. 1996; Pham et al. 2014; Schlining et al. 2013). These areas are referred to as "hotspots" of debris and tend to include a mixture of both land-based and marine-based litter. Light litter, particularly plastics and fishing gear (e.g., nets, wire tangles, and nylon line) tend to be susceptible to physical forces, forming the nuclei of debris hotspots on the seabed (Tubau et al. 2015). A literature review of studies focusing on seafloor debris (Tubau et al. 2015) found that in general, the highest reported concentrations occur on submarine canyons and seamounts, banks, mounts, and ocean ridges. The highest mean concentration of litter ever recorded on the seafloor was in two submarine canyons in the North Mediterranean Sea (La Fonera and Cap de Creus canyons), with 15,057 and 8,090 items per km^2, respectively (Tubau et al. 2015).

It is expected that light debris items, such as plastics, are likely to be transported variable distances by currents until they settle on the seafloor (Engler 2012; Ioakeimidis et al. 2014; Ramirez-Llodra et al. 2013). Additionally, studies indicate that debris already on the seafloor can be remobilised and transported to deeper waters (Canals et al. 2006; Durrieu de Madron et al. 2013; Puig et al. 2008; Tubau et al. 2015). Conversely, heavy debris (e.g., coal clinker, metal debris, etc.) is expected to predominantly consist of dumped shipping cargo or fishing gear, as these items will sink almost directly to the seafloor under shipping routes (Carlson et al. 2017; Tubau et al. 2015).

The ecological impact of shipping waste is dependent on the waste type. Heavy waste, such as coal clinker and metal waste, is associated with substrate disturbance stressors when the waste impacts with the seafloor, as well as having the potential to entrap deep-sea benthic organisms, release contaminants, and provide a hard substratum for settlement of aquatic invasive species. Lighter waste, such as plastics, can be transported over long distances and are more likely to entangle and/or entrap sessile deep-sea species (e.g., cold water corals and sponges) and habitats and result in the release of contaminants (Madurell et al. 2012; Orejas et al. 2009). Once in the ocean, plastic can become degraded into micro-sized or potentially even nano-sized particles (Cole et al. 2011; Galgani et al. 2010) through biological, photo, thermal, mechanical, thermo-oxidative, and hydrolysis processes (Anderson et al. 2016; Andrady 2011; Browne et al. 2007). Unless the shipping cargo consists of pre-production plastic pellets (known as nurdles) or some other type of small plastics, the breakdown of plastic debris into microplastics would be considered a secondary effect of debris discharge.

8.1.1 Scope

The Discharge (debris) PoE model is linked to three other PoEs, as it considers debris discharged from vessels at rest (Vessel at Rest PoE); vessels underway (Vessel Underway PoE) and during grounding/sinking (Grounding and Sinking PoE).

Not considered in the Discharge (debris) PoE:

- Debris associated with activities outside of commercial shipping, such as fishing and fishing gear (out of scope)
- Discharge of petroleum products (refer to Discharge (other) PoE)
- Discharge of non-solid components such as sewage, and ballast water (refer to Discharge (other) PoE)

8.2 PATHWAYS OF EFFECTS DIAGRAM

Five stressors have been identified in association with Discharge (debris): substrate disturbance (sediment resuspension) [1], substrate disturbance (crushing) [2], foreign object/obstacle [3], entanglement/entrapment/smothering [4], and prey imitation [5]. The prey imitation stressor is unique to this PoE. Direct impacts from stressors associated with this sub-activity include a change in fitness, mortality and a change in habitat (Figure 13). Ecological components that may be disturbed by discharged debris include marine plants and algae, marine invertebrates, marine fishes, marine mammals, marine reptiles. marine birds, and physical habitats (substrate, water column, sea ice). Evidence tables are available in Appendix B5.

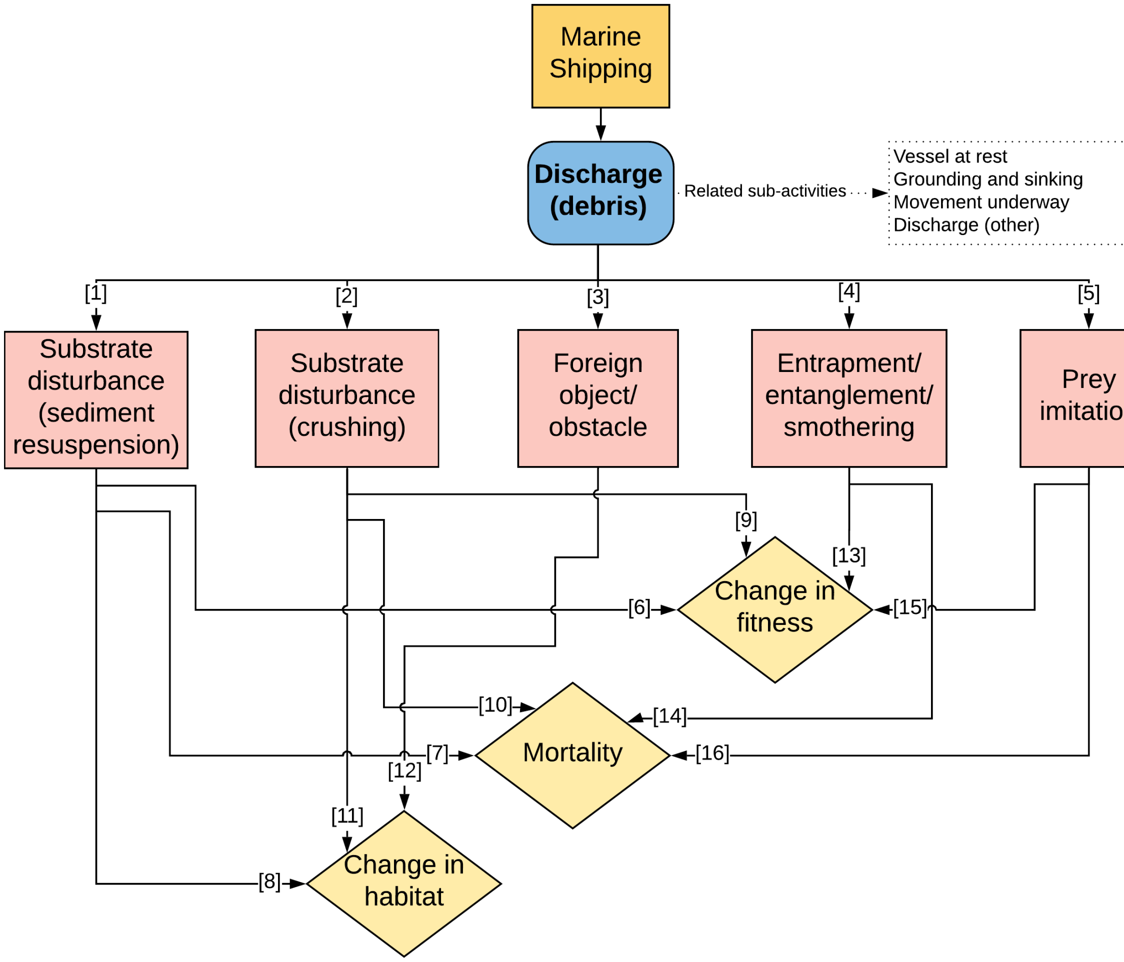

Figure 13. Diagram representing the pathways of effects conceptual model for Discharge (debris)

8.3 STRESSOR DESCRIPTIONS

8.3.1 Substrate disturbance (sediment resuspension) [1]

Debris that sinks to the seafloor following discharge from vessels would be expected to create a sediment plume which may continue with further movement of debris due to currents or waves, depending on the nature of the debris. While evidence is lacking for this linkage, impacts would be expected to be limited to benthic biota and habitats. Sediment resuspension potentially causes a change in fitness [6], mortality [7], and change in habitat [8].

8.3.2 Substrate disturbance (crushing) [2]

Substrate disturbance (crushing) refers to the benthic impacts of marine debris crushing the substrate, such as from lost shipping containers and their contents settling to the seabed (NOAA 2014). While evidence is lacking for this linkage, this crushing stressor may cause change in fitness [9], mortality [10], and change in habitat [11].

8.3.3 Foreign object/obstacle [3]

Debris such as cargo and deck debris lost overboard while vessels are underway or at rest can introduce foreign objects/obstacles to the seafloor or water column which, if not retrieved, can result in a change in habitat [12]. The same is true for debris discharged from grounded or sinking vessels that can break apart and release debris over a wide area when subjected to waves and destructive hydrodynamic forces. Foreign objects in this context include the vessel itself and any cargo and debris that sank with the vessel.

8.3.4 Entanglement/entrapment/smothering [4]

Introduced debris may cause mobile organisms to become entangled or entrapped in the debris, limiting movement or causing stress. Debris may also cover benthic organisms, causing smothering, reducing their access to light, food, or hindering the ability to reproduce. This stressor may cause change in fitness [13] and mortality [14].

8.3.5 Prey imitation [5]

Prey imitation refers to the accidental ingestion of debris by organisms during feeding or respiration. The debris types most commonly linked to prey imitation are plastics and microplastics. Microplastics can be ingested by marine organisms by filter feeding, suspension feeding, inhalation at air-water surface, consumption of prey exposed to microplastics, or via direct ingestion (Baulch and Perry 2014; Depledge et al. 2013). The ingestion or inhalation of plastic debris can block feeding and breathing apparatuses leading to a change in fitness [15] and/or mortality [16] (Laist 1997). Marine invertebrates, marine fishes, marine mammals, marine reptiles (sea turtles) and marine birds can be affected by prey imitation. Plastic particles often contain or adsorb contaminants and heavy metals on their surfaces, which can cause additional impacts. The prey imitation stressor can cause change in fitness [15] and mortality [16].

8.4 STRESSOR EFFECTS SUMMARY

Potential linkages to effects on endpoint groups by the stressors associated with Discharge (debris) are summarised in Table 11.

Table 11. Summary of potential linkages to effects to endpoint groups from Discharge (debris) stressors, further detailed description and supporting literature are provided in Appendix B5. A check mark (✓) indicates a potential effect. Shaded cells indicate a cell where a link to an endpoint is not possible. Abbreviations: Substrate (SU), Water column (WC), Acoustic (AC), Sea ice (SI), Marine plants and algae (MP/A), Marine invertebrates (MI), Marine fishes (MF), Marine mammals (MM), Marine reptiles (MR), Marine birds (MB).

Stressors	**Effects**	**Endpoints**									
		Physical habitat				**Biological**					
		SU	WC	AC	SI	MP/A	MI	MF	MM	MR	MB
Substrate disturbance (sediment resuspension)[1]	Fitness					✓	✓				
	Mortality					✓	✓				
	Habitat	✓									
Substrate disturbance (crushing) [2]	Fitness					✓	✓				
	Mortality					✓	✓				
	Habitat	✓									
Foreign object / obstacle [3]	Fitness										
	Mortality										
	Habitat	✓	✓		✓						
Entrapment/ Entanglement/ Smothering [4]	Fitness						✓		✓	✓	✓
	Mortality					✓	✓		✓	✓	✓
	Habitat										
Prey Imitation [5]	Fitness						✓	✓	✓	✓	✓
	Mortality								✓	✓	✓
	Habitat										

8.5 KNOWLEDGE GAPS

While theoretically likely, there is a lack of any evidence in the literature for impacts from sediment resuspension and crushing directly from discharged debris. There is expected to be limited sediment resuspension from marine debris, with the exception of large shipping containers.

While there are increasing descriptions of vertebrates, including fish, reptiles, birds and mammals, found dead with plastic or other debris in their guts, few studies have demonstrated that mortality was caused by the material ingested (Browne et al. 2015). Debris ingestion by marine mammals and reptiles is well described but little is known about potential impacts on marine invertebrates and fish, especially for microplastic ingestion, which can have sub-lethal impacts that are more difficult to link to debris ingestion.

9 DISCHARGE (OTHER)

9.1 BACKGROUND AND SCOPE

Discharge (other) incorporates the discharge of non-solid materials, which can occur both operationally and accidentally from vessels at rest, moving underway, or grounding / sinking.

Operational discharges include planned legal releases such as air emissions, black water (sewage), grey water (wastewater), ballast water (sea water pumped out of ballast tanks to control the trim and stability of the ship), recirculated seawater for cooling, and treated bilge water (full treatment required prior to discharge under the *Vessel Pollution and Dangerous Chemicals Regulations* (SOR/2012-69)).

Accidental releases of petroleum products and other contaminants from vessels engaged in commercial shipping can occur in a range of scenarios when vessels are underway, grounded or sunken, or at rest and releases can range in size, from small, such as leaks from vessels at rest, to large spills that result from underway vessel accidents. As at least 2000 different chemicals are transported by sea (Tornero and Hanke 2016), the types of substances that could be discharged accidentally from vessels can be diverse, with many likely to be harmful to marine life if introduced to the marine environment (defined as Hazardous Noxious Substances (HNS). Spills of petroleum products are a prominent type of accidental discharge given the obvious effects that petroleum spills have had in the past. Smaller amounts of petroleum products are also accidentally discharged from vessels often as a mixture with many other substances, such as in accidental releases of bilge water, which can contain an array of contaminants including oils, detergents, cleaners, lubricants, refrigeration and fire-extinguishing chemicals (Tornero and Hanke 2016).

9.1.1 Scope

The Discharge (other) PoE model is linked to three other PoE models, as it considers discharges from vessels at rest (Vessel at Rest PoE), during grounding/sinking (Grounding and Sinking PoE), and when underway (Movement Underway PoE).

Not considered in the Discharge (other) PoE:

- Discharges of debris (refer to Discharge (debris) PoE)
- Contaminants other than hull contaminants (the contaminants stressor focuses solely on hull contaminants as an example, and does not describe the complex impacts from the diverse contaminants that could be discharged (such as in bilge water, and grey water). Illegal discharges are also not considered.
- The air emissions stressor in this analysis is scoped to only consider black carbon, and does not include the diverse array of other components present in air emissions, as they result in indirect effects.
- The global effects of the release of greenhouse gases in air emissions is out of scope for this work.
- The complexities of toxic and physical effects resulting from different mixtures and types of petroleum products are out of scope as are effects resulting from the cleanup of spilled petroleum products as it is also often not possible to separate the toxic impacts of petroleum products from those of chemicals used to disperse and clean oil spills in impact studies.

9.2 PATHWAYS OF EFFECTS DIAGRAM

Five stressors have been identified in association with the discharge (other) sub-activity: biological material [1]; introductions of species and pathogens [2]; petroleum products [3]; air emissions [4]; and other contaminants [5]. With the exception of 'Introductions of species and pathogens', these stressors are unique to this PoE. Direct impacts from the stressors associated with Discharge (other) include a change in fitness, mortality and a change in habitat (Figure 14). Ecological components that may be disturbed include marine plants and algae, marine invertebrates, marine fishes, marine mammals, marine reptiles, marine birds, and physical habitats (substrate, water column, sea ice). Evidence tables are available in Appendix B6.

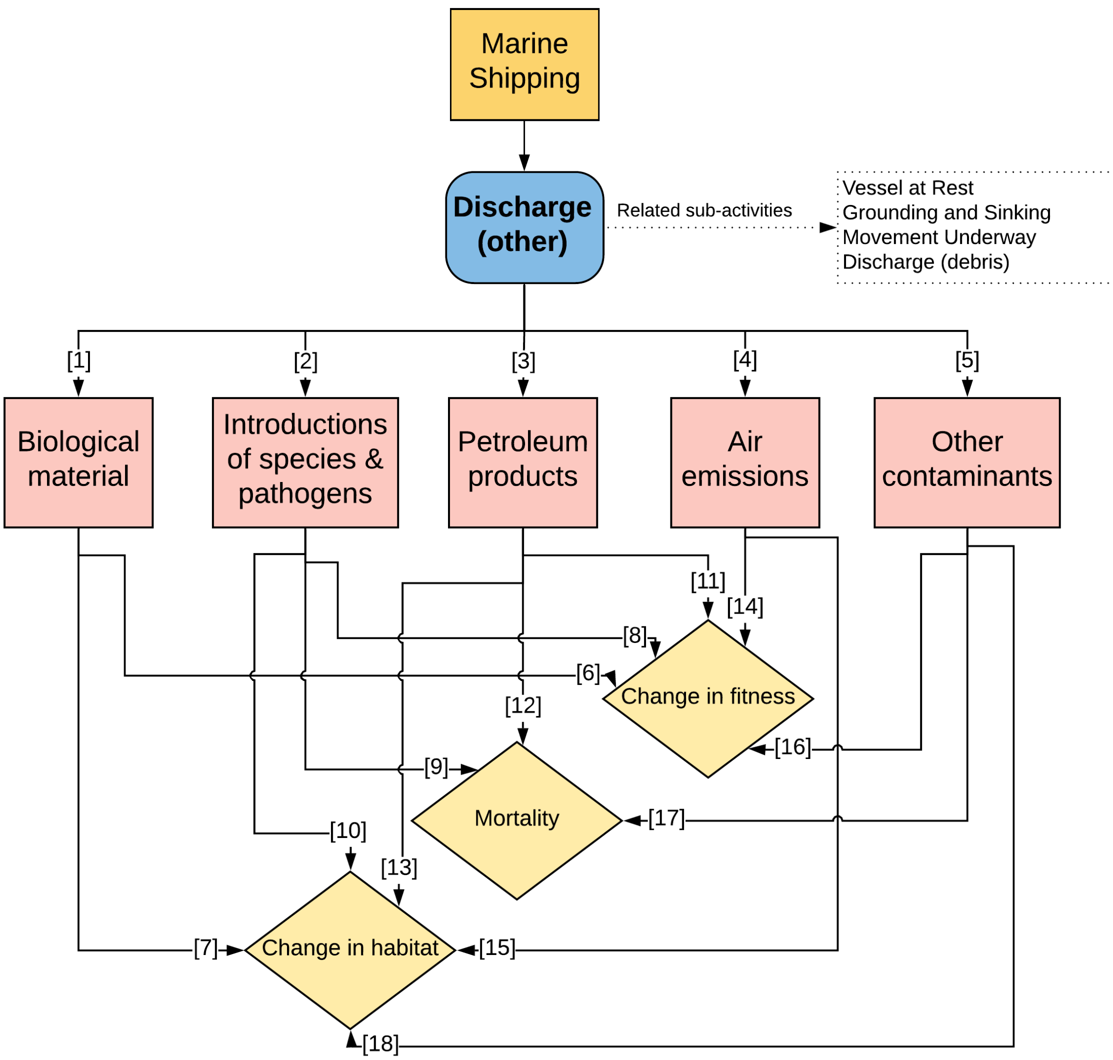

Figure 14. Diagram representing the pathways of effects conceptual model for Discharge (other).

9.3 STRESSOR DESCRIPTIONS

9.3.1 Biological material [1]

Biological material can be introduced into the marine environment operationally and also accidentally from vessels, primarily through black water (sewage) and grey water (waste water) discharges (Davenport and Davenport 2006). Ships produce on average 20 litres of black water and 120 litres of greywater per person per day (Walker et al. 2019). Cruise ships are the most significant source of operational discharges of black water and grey water of any commercial vessel, with an estimated weekly average discharge of 1 million litres (Davenport and Davenport 2006). Though there are no limits to the release of greywater at sea, untreated black water (sewage) must be discharged ≥3 nm from shore while travelling ≥7.4 km h^{-1}, treated black water can be discharged at <3 nm (Chen 2018). Other types of biological material that can be discharged include food, ground food can be discharged >3 nm from shore if a vessel is underway, and unground food if at least 12 nm from shore or above 60°N in the Arctic (Chen 2018).

The effects of an introduction of biological material and excess nutrients on the marine environment include oxygen depletion of coastal waters, an increased risk of harmful algal blooms (Sellner et al. 2003), and reductions in community biodiversity (O'Brien 2001). Nutrient inputs increase primary production and decrease oxygen concentrations due to increased production of dead organic matter; offshore areas (>30 km offshore) are disproportionately affected due to nitrogen limitation and absence of land input (Troost et al. 2013). This stressor can result in a change in fitness [6], or a change in habitat [7].

9.3.2 Introductions of species and pathogens [2]

This stressor is comprised of two components: introductions of species and introductions of pathogens. In the context of this PoE model, this stressor primarily relates to the effects of aquatic invasive species (AIS) and pathogens introduced through ballast water discharges, which are major vectors of AIS into Canadian waters (Casas-Monroy et al. 2013) and also can contain and transport pathogens.

Introductions of species (aquatic invasive species (AIS))

When a vessel takes on ballast water, including re-suspended sediments, a diverse range of biota can be introduced into the ballast tanks, many with the potential to be introduced to new areas through ballast water discharges later in the voyage (Carlton 1985; Carlton and Geller 1993; Casas-Monroy et al. 2013; Ware et al. 2014). Ballast water can contain phytoplankton, zooplankton, protozoa, algae, invertebrates and fish (CIESM 2002; David et al. 2007; Ghosh and Rubly 2015) and sediment in ballast water can contain worms, crustaceans, molluscs, protozoa, and the resting stages of dinoflagellates that find habitat in ballast tank sediments (Minchin 2009).

Ballast water is regulated in Canada by the *Ballast Water Control and Management Regulations*[4]. Vessels entering Canada from international marine waters, other than vessels that operate only north of Cape Cod on the Atlantic coast or Cape Blanco on the Pacific coast, must manage ballast water by one of the following methods: discharge ballast water in an approved area, treat ballast water to standards based on viable organism and indicator microbe content, , or pump ballast water to a reception facility. Vessels that use ballast water exchange

[4] Ballast Water Control and Management Regulations.

must complete the exchange ≥200 nm from land in water depth ≥2,000 m. Vessels that were unable to complete a mid-ocean ballast water exchange due to exceptional circumstances (e.g., weather), or those completing coastal voyages within 200 nm of land, may be permitted to use alternative exchange zones in the Atlantic (eastern end of Laurentian Channel, Atlantic Ocean south of Nova Scotia), Pacific (50 nm west of Vancouver Island and the Queen Charlotte Islands), and Arctic (eastern Hudson Strait and eastern Lancaster Sound).

Vessels reliant on frequent ballast exchange for cargo operations, such as bulk carriers and tankers, are considered high risk for the introduction of AIS (Casas-Monroy et al. 2013). The ballast water carried is greater on average for vessels entering Atlantic ports (39,842 m^3) compared to those entering Pacific (13,915 m^3) and Arctic ports (Port of Churchill:13,400 m^3) (Humphrey 2008; Stewart and Howland 2009). Few ballast water exchanges occur in the Canadian Arctic, and Arctic ports are considered to be unlikely sources of AIS for other regions (Casas-Monroy et al. 2014; Ruiz and Hewitt 2009). However, though there are no recorded ship-mediated AIS established in the Canadian Arctic (Chan et al. 2011), projections taking into account increasing shipping and climate change indicate this may change (Goldsmit et al. 2018).

Species introduced to new areas can have different effects that can result in impacts to marine organisms at an individual, population, community, and/or ecosystem level (Elliott 2003; Olenin et al. 2010) and not all AIS result in negative effects on the invaded ecosystem (Olenin et al. 2011). Introductions of species can result in a change in fitness [8], mortality [9], and a change in habitat [10].

Introduction of Pathogens

Pathogens, defined as biological agents that cause disease, fall into five groups: viruses, bacteria, fungi, protozoa, and helminths (parasitic worms) (Janeway et al. 2001). Organisms from each of these groups have the potential to cause disease to marine organisms and may be transported by shipping activities. Transport in ballast tanks is most commonly identified as the means by which shipping can relocate these organisms. The survival of microbes during ballast transport depends on the species or strain, the length of the journey, the water temperature, etc. (Gerba 2007; Sinclair et al. 2008). The ballast tank can act as an incubator for pathogens, where the decomposition of dead organisms within the tank promotes bacterial growth and viral replication (Saccà 2015). There is overlap between the categories ‘pathogens’ and ‘aquatic invasive species’ although pathogens transported by shipping may be either domestic or non-indigenous in origin.

Viral and bacterial pathogens can be transported in ballast tanks in the water and sediments or in biofilms covering the tank’s walls (Saccà 2015). Ballast tanks of vessels arriving in Vancouver contained 2.5 x 10^8 to 2.1 x 10^9 bacterial cells/L (Sun et al. 2010). Studies of vessels arriving in Chesapeake Bay and the Great Lakes reported mean concentrations in ballast water of 8 x 10^8 to 3 x 10^9 bacteria/L and 7 x 10^9 to 3 x 10^{11} virus-like particles/L (summarised in Cohen 2010). Antibiotic-resistant strains of bacteria have been commonly documented to occur in ballast tanks (Goodrich 2006; Thomson 2009; Thomson et al. 2003). Furthermore, the mixing of bacteria from the world’s harbours via ballast transport increases the risk that bacteria with plasmids promoting antibiotic resistance will come into contact with and transfer these plasmids to pathogenic bacteria (Cohen 2010). In a review of emerging cetacean diseases, Van Bressem et al. (2008) have expressed concern about “the world-wide dissemination of...antibiotics-resistant marine bacteria through water ballast.”

While the majority of research on pathogens transported by shipping has focused on human pathogens, e.g., transport of bacteria that cause cholera and shellfish poisoning (Bax et al. 2003), there is increasing scientific interest in microorganisms in ballast water and the introduction of organisms smaller than 10 µm, which can have a significant impact on the marine environment (Drillet 2016; Endresen et al. 2004; Litchman 2010; Lymperopoulou and Dobbs 2017; van der Star et al. 2011). It has been suggested that heterotrophic bacteria should be acknowledged and incorporated into ballast standards (Cohen and Dobbs 2015; Cohen et al. 2017; Ojaveer et al. 2014). Recent work has identified more than 60 pathogens in ballast water that had not been detected previously (Brinkmeyer 2016).

Other pathogens of interest may include species of fungi, protozoans, and worms. A study of vessels arriving in Vladivostok, Russia identified 24 species of fungi in the ballast tanks, including pathogenic and toxinogenic mycelial fungi, which are able to induce mycoses and mycotoxicoses in invertebrates and fishes (Zvyagintsev et al. 2009). At least 182 species of living protozoans, including some known to be parasitic, have been detected in ballast water tanks (Galil and Hulsmann 1997). The haplosporidian (protozoan) *Haplosporidium nelson* (also known as MSX), a pathogen of oysters, is hypothesised to have been carried in ballast water to the Bras d'Or Lakes, a marine water body in Nova Scotia (Stephenson et al. 2003). Parasitic worms may also be carried by ballast water although direct evidence is limited. The Eurasian monogenean gill parasite *Dactylogyrus amphibothrium* is thought to have been transported to the Great Lakes with fish discharged in ballast water in the mid-1980s (Cone et al. 1994).

Introductions of pathogens can result in a change in fitness [8] and mortality [9]

9.3.3 Petroleum products [3]

This stressor considers petroleum products (gasoline, diesel, bunker fuel, and unrefined crude oil) that can enter the marine environment through operational discharges, or from accidental spills of vessel fuel or from cargo (e.g., oil tankers) from vessels at rest, moving underway, or from grounding/sinking.

Operational releases of petroleum products

Large commercial vessels generate three main types of oily waste during routine operations: bilge water, sludge waste and oil cargo residues (for tanker vessels), vessels generate oily waste up to 8 t/day (Butt 2007; Walker et al. 2019). Legal discharges of oily water cannot exceed 15 ppm of oil in discharged water, exceeding this concentration results in oil being visible on the sea surface (ICPO-OIPC Interpol 2007); (MARPOL(73/78)).

Bilge water is a mixture of liquids that have drained from upper decks and interior spaces and collected in the bilge, an area on the lowest inner part of the ship hull. The liquid originates from areas such as the engine room, machine room, refrigeration, air conditioning and pump rooms and can contain, among other substances, hydraulic fluids, hydrocarbons, grease, solvents, metals and detergents (EPA 2011; Karakulski et al. 1998; Lindgren et al. 2016). Bilge water can accumulate up to 20 cubic metres a day (ICPO-OIPC Interpol 2007) and must be treated onboard using a separator that separates water from oil (Walker et al. 2019) before discharge. Cleaned water is discharged overboard and oil is stored for later disposal onshore (Walker et al. 2019). Accidental spills from the pumping of oily bilge water do occur (Encheva 2015).

Sludge waste is produced from on-board purification of the low quality fuel and lubricating oils generally used in the shipping industry; purification is required to remove contaminates from the fuel before it can enter the engines, as it would otherwise cause damage. The waste drains to a sludge tank. Oil cargo residues are wastes are produced from the cleaning of cargo tanks.

Accidental releases of petroleum products from vessels underway and at rest

Each year, approximately 80 million tonnes of oil are shipped from Pacific and Atlantic Canada, including ultra-light condensates and light oils, to heavy oils and bitumens (John 2015; Lee et al.

2015). Because each type of oil can be a complex mixture of compounds, the chemical composition of any oil discharge is critical for understanding its physical properties, behaviour and impacts to biota (Lee et al. 2015; Marty and Potter 2014). Accidental releases can vary in size from small frequent spills to larger less frequent spills.

Most oil floats on the water surface, where it is spread out by wind and currents. This layer of oil adds a new barrier that plants and animals pass through going between water and air, and may lead to oiling or inhalation of fumes. Some oil disperses into the water column below the surface, and may affect animals and plankton there (NOAA 2019). As the lighter fractions of crude oil evaporate or dissolve, clumps of sticky oil form, collecting bacteria and other single-celled organisms, and these may take years to degrade. As water mixes, particles of oil that sank from the surface may continue to float or may be deposited on the seafloor are resuspended (Rodenberg 2010).

The chemical properties of the initial surface slick of spilled oil can change due to physical, chemical and biological processes (weathering) that can result in components of the oil dissolving in the water, evaporating, or sinking (Lee et al. 2015). Condensates and light oils (e.g., gasoline and light crude oils) contain more volatile compounds that are acutely toxic to marine organisms, but they typically break down quickly and disappear. Heavier oils (e.g., bitumen and heavy fuel oils) contain more polycyclic aromatic hydrocarbons (PAHs), which persist in the environment, and cause chronic health effects (Lee et al. 2015).

Approximately 200 marine pollution incidents involving commercial vessels occur in Canada each year, with petroleum products accounting for ~90% of reported incidents (CPCS Transcom Limited 2012). There were no oil spills larger than one million litres in Canadian waters between 2003 and 2012 (CCA 2016). Over three-quarters of oil spills greater than 10,000 L involved fuel oil rather than oil carried as cargo, i.e., oil tankers were not the source of the majority of these spills (CCA 2016).

The effects of spilled oil on the marine environment vary depending on the volume and type of oil, the location of the oil spill, the exposure pathway (e.g., ingestion, inhalation, adhesion), the degree of weathering, and the vulnerability of the biological components in the spill area (Kirby and Law 2010; Rocha et al. 2016; Walker et al. 2019; Williams et al. 1994). In general, refined petroleum products tend to be more toxic but less persistent in the marine environment, while crude oils and heavy fuels tend to be less toxic but more persistent in the environment (AMSA 2003). Environmental impacts tend to be higher near shore than in open water (Patin 1999; USFWS 2010). Oil spills are a concern due to acute and chronic toxicity to marine organisms, fouling of fur and feathers, adhesion to skin, ingestion of oil directly or through predation on organisms that have taken up oil compounds, and inhalation of volatile fractions of the oil (AMAP 2007). Direct impacts from petroleum products include a change in fitness [11], mortality [12], and a change in habitat [13]. A change in habitat can result from large-scale releases of petroleum products, through the smothering and contamination of physical habitat. Spilled oil can persist in habitats for long periods, particularly in areas sheltered from weathering e.g., subsurface sediments, under gravel shorelines, and soft sediments) (McCay and Rowe 2004; USFWS 2010). Ecological components that may be affected by discharges of petroleum products include marine plants and algae, marine invertebrates, marine fishes, marine mammals, marine reptiles and marine birds. Physical habitats potentially affected include substrate, water column and sea ice.

Releases from grounding/sinking of vessels

The grounding or sinking of commercial vessels can result in the release of petroleum products as well as other contaminants related to fuel, cargo, antifouling paint, and corrosion (Schiel et al. 2016); these other contaminants are considered within the ‘Other contaminants’ stressor.

Petroleum products released vessels from the grounding/sinking stressor can be released over a short period of time as fuel or cargo spills, or as chronic releases over years or decades, such as from shipwrecks. While the petroleum products released over a short period at the time of sinking are generally more conspicuous and quantifiable, chronic spills (also referred to as "slow spills") are difficult to detect but can cause major environmental problems (Rogowska and Namieśnik 2009; Rogowska et al. 2010). It has been suggested that the long-term chronic spills from corroded sunken ships are potentially more harmful than if a single major oil event like an Exxon Valdez were to occur (Henkel et al. 2014).

Chronic oiling from sunken ships can occur over long periods (Henkel et al. 2014). Substantial chronic oiling via bunker fuel leakage from sunken vessels has been recorded occurring nearly 80 years after the sinking event (Hampton et al. 2003; Henkel et al. 2014) with the chemical effects still evident in some species (Ross et al. 2016). For example, the wreck of the cargo ship SS Jacob Luckenbach off the coast of San Francisco resulted in chronic oiling over a period of approximately 50 years via release of bunker fuel (Hampton et al. 2003; Luckenbach Trustee Council 2006). Another example is the SS Palo Alto, which was intentionally run aground in central California in 1929 to create a pier, and was found to have oiled 69 birds between 2004-2006 (Henkel et al. 2014).

Direct effects from petroleum products could cause a change in fitness [11], mortality [12], and a change in habitat [13].

9.3.4 Air emissions [4]

Fuel combustion associated with marine transportation results in the release of an array of air pollutants including sulphur oxide, nitrogen oxides, particulate matter, volatile organic compounds, carbon monoxide, and black carbon (CCA 2016; Endres et al. 2018; Eyring et al. 2010; Walker et al. 2019). Emissions released depend on the type of fuel used, engine, and engine efficiency (Bouman et al. 2017; Johansson et al. 2017; Pham and Nguyen 2015). The introduction of the Automatic Identification System in recent years, whereby ships larger than 300 t report their global position every few seconds has increased evaluation of ships emissions as it monitors ships speeds (Johansson et al. 2017). While difficult to quantify, marine shipping emissions have increased over the last 50 years (Smith et al. 2015).

Marine transportation produces significant atmospheric emissions of greenhouse gases and other pollutants (Arctic Council 2009; Walker et al. 2019), accounting for 33% of all trade-related emissions and 3.3% of global carbon dioxide (CO_2) (Crist 2009; Cristea et al. 2013; Dalsøren et al. 2007). Within Canadian jurisdiction, marine shipping produced 4 million tonnes (0.6%) of total greenhouse gas emissions in 2015 (Government of Canada 2017). Greenhouse gases contribute towards ocean warming and acidification, which can have effects on a wide range of biota, however the consideration of the effects of greenhouse gases are indirect and out of scope for the current work.

The pathways by which air emissions from commercial vessels affect the marine environment occur both directly through the deposition and dissolution of gases, and indirectly via radioactive forcing effects on the climate (Endres et al. 2018). The scope of the current work is limited to direct effects: the effects of the inhalation of exhaust gases and the effects of direct contact between particulate matter (including black carbon) and endpoints which can cause a change of fitness [14] and a change in habitat [15].

9.3.5 Other contaminants [5]

This stressor considers the discharge of contaminants other than petroleum products (as these are captured in the 'petroleum products' stressor). Vessels engaged in marine shipping can discharge a diverse range of chemical contaminants into the marine environment, and these can originate from grounded or sunken vessels (e.g., from cargo on board), from vessels underway (e.g., ballast water releases), and anchored/moored vessels (e.g., hull contaminants). Release of contaminants can occur both chronically (slow releases over time, such as from a shipwreck) or acutely (large releases, such as from an accidental spill from a vessel collision between vessels underway).

Contaminants can be discharged to the marine environment through ballast water exchange or bilge pumping. Ballast water exchange or bilge pumping contaminant releases occur in volumes significantly less than those involved in accidental spills associated with grounding or maritime accidents (Rømer et al. 1996).

Heavy metals are present nearly everywhere on commercial vessels: in the antifouling paints, the electric and electronic equipment, in its hull, and in the sacrificed anodes, as well as in cargo (Dimitrakakis et al. 2014; Jones 2007). The corrosion of the ship and cargo if wrecked can release a variety of heavy metals (Dimitrakakis et al. 2014). Toxic substances carried in containers as cargo can also become a source of chronic contaminants (Bu-Olayan et al. 1998; Lin and Hu 2007; Mirlean et al. 2001; Schiel et al. 2016). For example, the site of the MV Rena wreck (off the coast of New Zealand) remained heavily contaminated by trace metals, polycyclic aromatic hydrocarbons (PAHs), and organotins five years later, with substantial remnants of the ship and cargo still present (Schiel et al. 2016).

The current work focuses on antifouling paints as an example contaminant. Antifouling paints are applied as a protective coating to the hulls of vessels to avoid settlement on the vessel by marine organisms, act as a barrier against corrosion, and avoid navigational issues (Soroldoni et al. 2017). Tributyltin (TBT)-based antifouling paints were first introduced in the 1960s as an effective antifouling method, but were found to have serious, toxic effects on marine organisms (Abdulla and Linden 2008; Alzieu 2000; Bryan and Gibbs 1991; Evans et al. 2000; Gibbs 2009; Gibbs et al. 1990; Mee and Fowler 1991). As a result, the use of TBT was banned by the International Maritime Organisation in 2008 (IMO 2009) and replaced by the use of antifouling paints containing cuprous oxide (or other copper compounds) or zinc, combined with other "booster" biocides used since the 1980s (Bellas 2006; Thomas 2009). However, the legacy impacts of the use of TBT still affect the marine environment, for example, the linkage between TBT and imposex (reproductive impairment) in marine gastropods (Axiak et al. 1995; Ellis and Pattisina 1990; Gibbs et al. 1990; Heller 2015; Lahbib et al. 2018; Smith 1981; Straw and Rittschof 2004). In addition to metal-based biocides, the non-metallic biocides (e.g., diuron, DCOIT, irgarol 1051) may be present in antifouling paints and have been demonstrated to be toxic to marine invertebrates, seagrass and algae (Lindgren et al. 2016).

Antifouling paint can prevent biofouling in several different ways: (1) a multi-layered coating system using ablative paints that slough off over time, releasing copper or zinc-based biocide, (2) non-sloughing paints that slowly leaches biocides, and (3) slick coatings (e.g., Teflon, silicone) coatings that prevent marine organism growth on the hull. The antifouling paints with the greatest environmental impact include those containing biocides that can be released into the marine environment as antifouling paint particles or biocidal chemicals. Antifouling paint particles (APPs) are generated during boat hull repair, cleaning, and painting or as the vessel is moving and released into the marine environment (Soroldoni et al. 2017). APPs are typically generated in boatyards, shipyards, and marinas (Turner 2010) and end up in benthic sediments, particularly in semi-enclosed water bodies with a high density of vessels (Takahashi et al. 2012). APPs deposited in sediment may become toxic due to leaching of hazardous substances (i.e., metals, organic and organometallic biocides) into pore water, which may be partially reabsorbed to sediment particles (Singh and Turner 2009). The current work is limited to focusing on potential effects of anti-fouling paints only.

Ecological endpoints can be affected by this stressor through a change in fitness [16], mortality [17], and a change in habitat [18].

9.4 STRESSOR EFFECTS SUMMARY

Potential linkages to effects on endpoint groups by the stressors associated with Discharge (other) are summarised in Table 12.

Table 12. Summary of potential linkages to effects to endpoint groups from Discharge (other) stressors, further detailed description and supporting literature are provided in Appendix B6. A check mark (✓) indicates a potential effect. Shaded cells indicate a cell where a link to an endpoint is not possible. Abbreviations: Substrate (SU), Water column (WC), Acoustic (AC), Sea ice (SI), Marine plants and algae (MP/A), Marine invertebrates (MI), Marine Fishes (MF), Marine mammals (MM), Marine reptiles (MR), Marine birds (MB).

Stressors	**Effects**	**Endpoints**									
		Physical habitat				**Biological**					
		SU	WC	AC	SI	MP/A	MI	MF	MM	MR	MB
Biological material [1]	Fitness					✓	✓	✓	✓		
	Mortality										
	Habitat		✓								
Introductions of species & pathogens [2]	Fitness					✓	✓	✓	✓		
	Mortality					✓	✓	✓			
	Habitat	✓	✓								
Petroleum products [3]	Fitness					✓	✓	✓	✓	✓	✓
	Mortality					✓	✓	✓	✓	✓	✓
	Habitat	✓	✓		✓						
Air emissions [4]	Fitness					✓			✓	✓	✓
	Mortality										
	Habitat		✓		✓						
Other contaminants [5]	Fitness					✓	✓	✓	✓	✓	✓
	Mortality					✓	✓	✓			
	Habitat	✓	✓								

9.5 KNOWLEDGE GAPS

The effects of discharge stressors are highly dependent on the type and volume released and the nature of the receiving environment. There are many knowledge gaps around the behaviour of contaminants in seawater and effects on marine biota and habitats.

The effects of air emissions are primarily indirect, and only direct effects were included in the current work (i.e., effects from black carbon releases). Future iterations could potentially consider the indirect effects of air emissions and attempt to capture the breadth of information and studies on air emissions (e.g., Corbett and Fischbeck 1997; Dolphin and Melcer 2008; Tichavska et al. 2019). Research is needed to better understand the long-standing effects of air emissions produced by vessels, for example, in areas with long-term anchoring activities, toxin bioaccumulation and habitat compromise may occur (such as loss of Arctic sea ice through soot deposits). Petroleum products discharged from vessels are usually part of a complex chemical mixture, and caution is needed when attempting any generalisation of effects or impacts from specific examples. In particular, the impact of oil spills in Arctic ecosystems is poorly understood. In addition, the impacts of spilled oil isolated from the influence of dispersant and cleanup chemicals is lacking in many studies. There is a significant amount of evidence available for the other contaminants and petroleum products stressors, the specific objective and situation would determine which contaminants would be the focus of an assessment. If petroleum products were the focus of an assessment, a suite of PoE models addressing different mixtures of petroleum products, and in different conditions, such as the effects of toxic mixtures of chemicals used in oil spill dispersal and cleanup, would be required.

10 DISCUSSION

10.1 THE UTILITY AND APPLICABILITY OF POE MODELS

Pathways of Effects (PoE) models are primarily used in the scoping phase of environmental assessment to ensure that all activities and stressors have been identified and described, and that all possible effect pathways are captured. PoE models are also of stand-alone relevance to managers and fishery protection biologists and practitioners. The shipping PoE models detailed here were designed so that the user can identify the stressors produced by the sub-activity/activities relevant to the scope and scale of their assessment and quickly identify the stressors and general effects the stressors produce. Endpoints will be specific to the assessment area, and in this work, were designed to be generic enough to be applicable across regions. All identified pathways will not necessarily be applicable to each assessment type. More information should be gathered specific to the activity type, the region and the specific endpoints of interest to refine PoE models specific to the assessment.

Once assessment-specific endpoints (which may consist of a single species or multiple valued ecosystem components) are identified, the user can identify the types of effects that may be applicable to that specific endpoint. The creation of PoE models has been recommended as a first step in risk assessment (O et al. 2015) and used explicitly in cumulative effects assessments (Clarke Murray et al. 2019). PoE models allow the user to clearly articulate and define the system of interest in a structured way utilising graphical display with corresponding literature review (Government of Canada 2012).

PoE models describe a system of interest and do not include an assessment of relative importance, magnitude of change, or risk. The magnitude of impact is not evaluated as part of the definition of PoE models, but the threshold to be included in any model has not been defined. For this work, we included potential impact pathways first and then systematically searched for evidence of measurable impact. If evidence of the impact pathway was not available, we identified the lack of evidence in the tables but did not remove the link in the associated diagram. A small number of possible effects described in the PoE model did not have published scientific evidence to confirm the effect on an endpoint, however it is emphasised that an absence of evidence does not mean that there is no effect present. A precautionary approach is advised, where linkages are retained in the PoE model where an effect is possible. The reverse method of PoE definition could also be applied, where evidence of impact to a specific endpoint could be compiled and the PoE diagram constructed based on the available evidence only.

10.2 SHIPPING POE MODELS

The current work aims to describe possible impacts associated with commercial marine shipping in Canada. This contributes to an expanding body of work detailing the pathways of effects for a number of activities, including aquaculture (DFO 2009), offshore renewable energy (Isaacman and Daborn 2011), fisheries (e.g., Baer et al. 2010), activities in the Yukon North Slope pilot project (Stephenson and Hartwig 2009), activities affecting resident killer whales (Clarke Murray et al. 2019) and capelin (Giguère et al. 2011), and multiple activities impacting areas of interest for Marine Protected Area designation, such as Darnley Bay (DFO 2014).

Although the PoE models for this work have been developed specifically to examine the impacts of commercial shipping on the marine environment, they could be adapted for use for examining the effects of shipping in freshwater environments and for stressors associated with other vessel types, including recreational and fishing vessels. In addition, though the current models were developed for ecological endpoints a similar process could also be conducted for social, cultural and economic endpoints of interest.

The PoE models for marine shipping were limited to direct effects. Indirect effects can be important pathways to consider but were too extensive to compile for all the generic endpoints outlined in this work. However, for an assessment that considers only specific endpoints, indirect effects should be explored and included in the PoE models where possible (Clarke Murray et al. 2016b). Indirect effects can become particularly important in systems where multiple stressors may interact in varying ways to produce cumulative effects (Clarke Murray et al. 2019; Crain et al. 2008; Darling and Côté 2008).

Historical and current shipping intensity varies widely by region. The relatively recent increase in shipping activity in the Arctic may allow the establishment of shipping impact baselines for comparison, while shipping in the Atlantic has been occurring for centuries and pre-impact comparisons are likely not possible. Our knowledge of the ecosystems in each ocean varies, with less known about the Arctic marine ecosystem compared to Atlantic or Pacific ecosystems. For example, there is a smaller body of literature on oil effects in Arctic marine ecosystems compared to other marine ecosystems and oil behaves differently in ice-covered areas, due to the complex nature of the ice environment (Hänninen and Sassi 2010). The body of evidence examined for impacts was not limited to Canadian studies, and some information was only available in the global literature. Consideration should be given to the origin of studies and their applicability to the region of interest as regional context will be important in any subsequent impact assessment.

This work captures a snapshot of the pathways of effects of marine shipping, and synthesises evidence for effects based on current levels of understanding and current regulations. Understanding of effects and impacts will change, as well as factors that influence them, such as legislation and regulations. For example, due to changing international emission standards, commercial vessels are adopting new technologies. The International Maritime Organisation IMO2020 requires that the sulphur content of burned fuel burned is reduced from 3.5% to 0.5% sulphur by 2020 (IMO 2019). Vessels are approaching this regulation by installing scrubbers rather than using cleaner fuel, and in many cases as the scrubber systems are open loop so that the chemicals normally found in exhaust gases will be discharged into the water instead (European Commission Directorate-General for Moblity and Transport 2017). Deposition of these compounds, many of which may have long lifetimes in seawater, may lead to their long-term accumulation and may decrease pH, increase temperature and increase turbidity in the marine environment (Lange et al. 2015). Though Canadian vessels are already required to burn 0.1% sulphur fuel, many vessels in Canadian waters are not Canadian, and will be affected by this regulation. In particular, the cruise ships that travel the Pacific coast of Canada are expected to be using scrubbers (M. Kim, Transport Canada, Pers. Comm.). In the current PoEs, sulphur is included under the air emissions stressor, while in future iterations sulphur discharge may need to be added as an aquatic contaminant.

The individual sub-activities described in the PoE models are all components of marine shipping, and are separated into individual PoE models to enhance manageability and understanding of the different components. Despite this, many of the models are inter-related and have overlap and so should be considered together, not in isolation.

10.3 FUTURE WORK

Knowledge gaps and areas for future research have been identified in each of the PoE activity sections above. Major areas of knowledge gaps that will be important in an assessment of the impacts of shipping include the effects of commercial vessel anchoring in Canada, the long-term effects of underwater noise especially to fish and marine invertebrates, the incidence and severity of ship strikes on biota, direct and indirect effects of ice breaking on sea ice habitats, and the effects of increasing vessel traffic in the Arctic. The cumulative nature of stressors co-occurring in space and time may change relatively minor stressors to stressors worthy of further consideration, for example, the threshold of impact for multiple anchored or moored vessels.

This review has identified a number of linkages with almost no scientific studies conducted. The stressor effect summary tables provided for each sub-activity can be useful to highlight this information, as they not only show where evidence has been identified for a linkage, but also where evidence is lacking. These tables may be useful to identify where knowledge gaps exist for future work to address.

- The supporting evidence provided herein does not include indigenous, traditional or local knowledge, as this was not within the scope of the request for this work. These knowledge sources will provide important evidence and/or understanding of conditions, including environmental baseline(s) for subsequent assessments. In addition, this work does not include examples of cultural endpoints such as archaeological resources (e.g., fish weirs) which could be important to include in future work.
- As these PoE models represent a snapshot of current information, it is recommended that over time they are updated regularly with new evidence and linkages, and that new PoE models are developed where necessary. The suite of PoE models developed for this work has the potential to be a valuable resource that can be utilised by a range of users. The PoE models will ideally be maintained and updated by users to ensure that information is current and comprehensive as possible. Region specific PoE models could be developed and maintained, and could include more specific information on biota and habitats of interest in subsequent assessments.

10.4 NEXT STEPS

Pathways of effects (PoE) models are intended to be used as part of the scoping phase of assessments, such as Transport Canada’s Cumulative Effects Assessment of Marine Shipping. PoE models are one component of a scoping phase. Using the example of DFO’s Ecological Risk Assessment Framework (ERAF) (e.g., Clarke Murray et al. 2016a; O et al. 2015), occurring in parallel with PoE model development, is the identification and screening of environmental elements with particular ecological, social, or cultural importance to an ecosystem (Valued Ecosystem Components, VECs). A list of VECs is reduced to a manageable number for the assessment, potentially using screening criteria (e.g., Hannah et al. 2019). In the last scoping step, stressors identified for each sub-activity in the PoE models are tabulated against the selected VECs in an interaction matrix, and each VEC-stressor pair is assessed for a potential interaction, being scored as either (1) to indicate a potential negative interaction, or (0) no negative interaction based on biological expertise. This allows the user to screen out stressor-VEC combinations that are not expected to interact for each sub-activity. The outputs of the scoping phase should be a manageable number of interactions that can be explored in greater detail in a subsequent assessment.

A specific environmental assessment following the scoping phase evaluates the impact of the activity and its stressors on components of interest. The assessment phase can be qualitative (Clarke Murray et al. 2016a), semi-quantitative (DFO 2017; Rubidge et al. 2018), or fully quantitative (Clarke Murray et al. 2019) and aims to assess the impact of the stressors on VECs, singly and/or in combination. The stressors are evaluated for characteristics such as intensity, frequency and spatial scale and can be ranked, estimated or modelled for the region of interest. The magnitude of the effect and consequences on the VEC is evaluated using variables such as degree of effect on fitness, scale of mortality events, duration of effect, and level of impact (individual, population, species). Indirect effects could be brought into the assessment phase, in order to fully consider the effects of an activity on the valued components of interest (Clarke Murray et al. 2016a). The impact may be measured on a scale from negligible to highly significant, as often done in environmental impact assessment, or as a magnitude of impact, such as population consequence of disturbance, probability of extinction, or other metrics, depending on the goal of the assessment.

When applying the PoE models in a specific context, clearly defining the baseline conditions against which to measure change is important. The definitions of environmental baselines as historical, based on a temporal reference point, or ecological, based on a ‘pristine’ or ‘altered’ system, can create uncertainty for both the PoE model and its application in assessments. For example, conclusions on the impacts of anchoring in well-used anchorage areas with a long history of use compared to more recent, and lesser-used areas may be different. By defining an appropriate baseline, an assessment can avoid the danger of “shifting baseline” syndromes that can underestimate the impacts on valued components.

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APPENDIX A: INTEGRATION OF OUTCOMES OF TRANSPORT CANADA'S PUBLIC ENGAGEMENT CAMPAIGN INTO CURRENT WORK

Transport Canada's (TC) engagement campaign in 2018 asked people across Canada key questions to help guide a national assessment framework for the cumulative effects of marine shipping. The key question of relevance for the current work was: "in what ways do you think maritime activities affect the environment?". Responses were organised by TC into seven broad categories, each encompassing a list of specific stressors. These are presented in Table A1 together with a description of if and how these were captured in the Pathways of Effects (PoE) models described in the current work. Not all activities/stressors identified through the TC process have been included in the PoE models presented in the current work, as they were outside the scope of the work (e.g., activities that relate to vessel use, rather than the vessel itself such as in-water works).

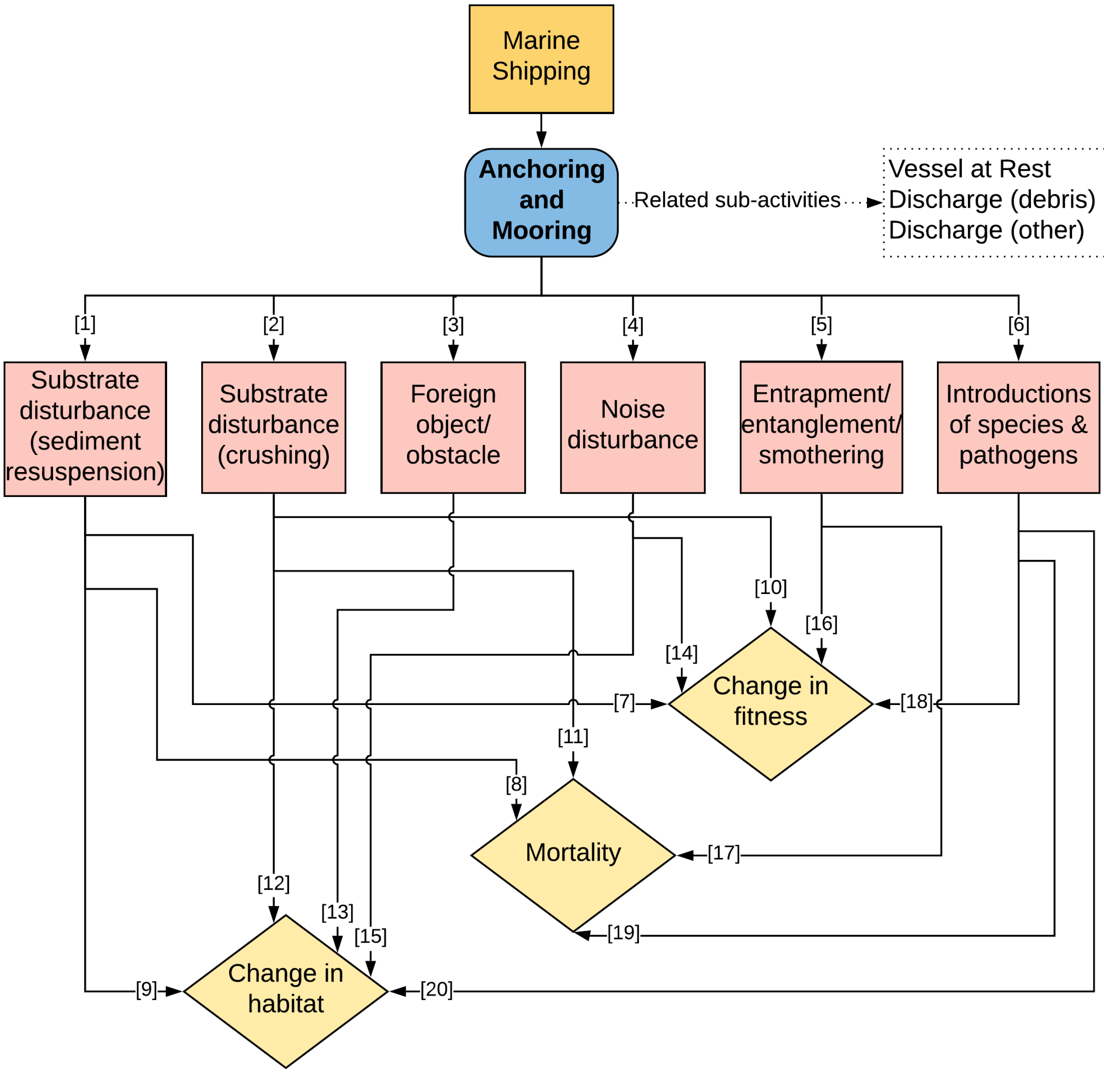
Table A1. Activities and stressors identified through the Transport Canada engagement process and how and whether each have been addressed in this document. Components that were out of scope for the current work are coloured in grey.

Sub-activity ('stressor category')	Stressor (linked to sub-activity)	Description of how captured in current work/ or if out of scope
In-water works: Log-booming, Dredging, Disposal at sea	Changes in animal behaviour	Activity and linked stressors are out of scope for the current work
	Erosion	
	Hydrology	
	Sediment accretion/Release	
	Landscape changes	
	Wood debris	
	Contaminants	
Anchoring	Substrate disturbance	Captured under the *substrate disturbance (crushing)* and *substrate disturbance (sediment resuspension)* stressors in the Anchoring and Mooring PoE
	Light	Captured under the *light disturbance* stressor in the Vessel at Rest PoE
	Noise	Captured under the *noise disturbance* in the Anchoring and Mooring PoE and the Vessel at Rest PoE
	Vibration	Unclear if this refers to vibration from the vessel, the impact, or motion of the anchor dropping. Captured under the *noise disturbance* stressor in the Anchoring and Mooring PoE and in the Vessel at Rest PoE
	Aquatic invasive species	Captured under the *introductions of species and pathogens* stressor in in the Anchoring and Mooring PoE and in the Vessel at Rest PoE
	Pathogens	Captured under the *introductions of species and pathogens* stressor in the Discharge (other) PoE
	Entanglement	Captured under the *entrapment/ entanglement/smothering* stressor in the Anchoring and Mooring PoE
	Contaminants	*Other contaminants* stressor in the Discharge (other) PoE model

Sub-activity ('stressor category')	Stressor (linked to sub-activity)	Description of how captured in current work/ or if out of scope
Grounding, Wrecking	Substrate disturbance	*Substrate disturbance (crushing)* and *substrate disturbance (sediment resuspension)* stressors in the Grounding and Sinking PoE model
	Light	*Light disturbance* stressor in the Vessel at Rest PoE model
	Noise	*Noise disturbance* stressor in the Grounding and Sinking PoE model
	Aquatic invasive species	*Introductions of species and pathogens* stressor in in the Grounding and Sinking PoE model
	Debris	Captured under the *substrate disturbance (crushing), substrate disturbance (sediment resuspension), foreign object/obstacle, entrapment/ entanglement/smothering* and *prey imitation s*tressors in Discharge (debris) PoE model
	Cargo release	A type of debris - see Discharge (debris) PoE model
	Contaminants	Contaminants other than petroleum products are considered in the *other contaminants* stressor in the Discharge (other) PoE model
Discharge: Operational	Aquatic invasive species	Captured under the *introductions of species and pathogens* stressor in the Discharge (other) PoE model
	Pathogens	Captured under the *introductions of species and pathogens* stressor in the Discharge (other) PoE model
	Debris	Captured in the Discharge (debris) PoE model, which consists of five stressors: *substrate disturbance (sediment resuspension)*, *substrate disturbance (crushing), foreign object/obstacle, entrapment/ entanglement/smothering,* and *prey imitation*
	Oils	Captured under the *petroleum products* stressor under the Discharge (other) PoE model
	Grey water and sewage	Sewage and some parts of grey water are captured under the *biological material* and *other contaminants* stressors in the Discharge (other) PoE model
	Chemicals	*Other contaminants* stressor in the Discharge (other) PoE model
	Contaminants	*Other contaminants* stressor in the Discharge (other) PoE model
	Air emissions	*Air emissions* stressor in the Discharge (other) PoE model
	Nutrient enrichment	*Biological material* stressor in the Discharge (other) PoE model
	Salinity	Out of scope
	Climate change	Out of scope
	Biotoxins	*Introductions of species and pathogens* stressor in the Discharge (other) PoE model
Discharge: Accidental	Oil spill/contaminants	Petroleum oils are captured under the *petroleum products* stressor in the Discharge (other) PoE model. Contaminants other than petroleum products are captured under the *other contaminants* stressor in the Discharge (other) PoE model
	Cargo release	A type of debris - see Discharge (debris) PoE model
	Substrate disturbance	*Substrate disturbance (crushing)* and *substrate disturbance (sediment resuspension)* and *foreign object/obstacle* stressors in the Discharge (debris) PoE model
	Air emissions	*Air emissions* stressor in the Discharge (other) PoE model
	Bioaccumulation	An indirect effect from the *other contaminants* stressor (out of scope)
	Garbage	A type of debris - see Discharge (debris) PoE model
	Plastics release	A type of debris - see Discharge (debris) PoE model

Sub-activity ('stressor category')	Stressor (linked to sub-activity)	Description of how captured in current work/ or if out of scope
Movement Underway	Substrate disturbance	*Substrate disturbance (sediment resuspension), substrate disturbance (crushing)* and *foreign object/obstacle* stressors in the Movement Underway PoE model
	Light	*Light disturbance* stressor in the Movement underway PoE model
	Noise	*Noise disturbance* stressor in the Movement underway PoE model
	Vibration	*Noise disturbance* stressor in the Movement underway PoE model
	Aquatic invasive species	*Introductions of species and pathogens* stressor in the Movement underway PoE model
	Pathogens	*Introductions of species and pathogens* stressor in the Movement underway PoE model
	Wake/wash	*Disturbance (wake, turbulence, water/ice displacement)* stressor in the Movement underway PoE model
	Erosion	*Disturbance (wake, turbulence, water/ice displacement)* stressor in the Movement underway PoE model
	Strikes	*Strikes* stressor in the Movement Underway PoE model
	Ice-breaking	*Disturbance (wake, turbulence, water/ice displacement)* stressor in the Movement underway PoE model
	Entanglement/ Entrapment	Not included in the Movement underway PoE model, but present as the *entrapment/ entanglement/smothering* stressor in the Anchoring and Mooring, and Discharge (debris) PoE models
	Disruption to migration routes/ nesting	Captured as an effect from stressors such as light and noise disturbance in the Movement underway PoE model
	Military activities	Out of scope
Harvesting	Wake/wash	This sub-activity and linked stressors are out of scope for the current work
	Loss of gear	
	Loss of resources/ habitat	
	Entanglement	
	Sediment disturbance	

APPENDIX B1: ANCHORING AND MOORING TABLES OF EVIDENCE



Definition: The Anchoring and Mooring sub-activity considers the act of deploying and retrieving anchors, or attaching to a mooring buoy system during commercial vessel operations, including movement of the anchoring or mooring system while deployed. This sub-activity has six associated stressors: substrate disturbance (sediment resuspension) (Table B1-1); substrate disturbance (crushing) (Table B1-2); foreign object/obstacle (Table B1-3); noise disturbance (Table B1-4); entrapment/ entanglement/ smothering (Table B1-5); and introductions of species and pathogens (Table B1-6).

Tables of evidence are provided for each stressor in the following pages, based on the order outlined in the diagram above. Specific evidence refers to information specific to the sub-activity (commercial vessel anchoring and mooring), whereas generic evidence is broader evidence that can provide insight where specific evidence may not be available. Not applicable generic evidence indicates this is the sole linkage and that specific evidence is available. Not available indicates that no evidence was found for that linkage.

Table B1-1 - Evidence for the **Substrate disturbance (sediment resuspension) [1]** stressor

<table>
<tr><th colspan="2">Anchoring and Mooring - Substrate disturbance (sediment resuspension) [1]</th></tr>
<tr><td colspan="2">Anchoring and mooring can cause the repeated resuspension of sediments through the physical action of the components of the anchoring or mooring system (e.g., anchors and chains) being deployed/retrieved and particularly the chains moving across the seabed as the anchored/moored vessel moves and disturbs sediments (Collins et al. 2010).</td></tr>
<tr><th colspan="2">Anchoring and Mooring – Substrate disturbance (sediment resuspension) [1] - Change in fitness [7]</th></tr>
<tr><td>Marine plants and algae</td><td>Anchoring and Mooring - Substrate disturbance (sediment resuspension) [1] - Change in fitness [7] B11FP

<u>Specific evidence</u> – Not available. There is a lack of specific evidence on the effects of sediment resuspension from anchoring to this endpoint.

<u>Generic evidence</u> – Increased suspended sediment can smother benthic habitats, including seagrass beds, and reduce the availability of light, oxygen, nutrients or increase levels of hydrogen sulphide and metabolic waste products (Airoldi 2003). Resuspended sediment reduces the light reaching marine plants impacting fitness through reduced photosynthesis (Buzzelli et al. 1998; Silberstein et al. 1986). Impacts to photosynthetic capacity can result in impaired growth and ultimately mortality (den Hartog and Phillips 2001; Hemminga 1998) and has been linked to changes in species composition in macrophytes (Murphy and Eaton 1983). Frequent episodes of resuspended sediment and nutrients in the water column can result in further reductions in light availability, increased phytoplankton populations and excessive epiphyte loading on marine plant leaves (Buzzelli et al. 1998; Gordon et al. 1994; Onuf 1996; Silberstein et al. 1986). Fine sediments that settle onto seagrass leaves significantly impair photosynthetic performance (Brodersen et al. 2017) and the same is likely true to other plants and algae. Resuspended sediment may scour the fronds of algae, and depths of 5cm of resettled sediment may smother macroalgae (Tyler-Walters et al. 2005).</td></tr>
<tr><td>Marine invertebrates</td><td>Anchoring and Mooring - Substrate disturbance (sediment resuspension) [1] - Change in fitness [7] B11FI

<u>Specific evidence</u> – Benthic communities of invertebrates in areas of high anchoring activity were in poorer health (lower fitness) than those in low anchoring intensity areas (recreation vessel study) (Backhurst and Cole 2000; Leatherbarrow 2003) to which sediment resuspension has likely contributed.

<u>Generic evidence</u> – Suspended sediment may clog the feeding apparatus of filter and suspension feeders, such as sponges and corals, and reduce their ability to feed and respire.

Resettled sediment may smother small epifaunal species, such as sponges, bryozoans, and ascidians, and could exclude grazing littorinids (Tyler-Walters et al. 2005). Sponges have been documented to temporarily cease feeding when suspended sediment enters the water column (Grant et al. 2019; Tompkins-MacDonald and Leys 2008). Reduction in feeding rate can decrease food intake and potentially compromise growth and reproductive ability (Leys 2013; Leys et al. 2011). Increased sediment loads decreases Eastern Oyster (Crassostrea virginica) fitness (Wall et al. 2005). Suspended sediment can reduce egg and larval development of some marine invertebrates, which could increase the amount of time larvae spend in the plankton, resulting in increased time at risk of predation. Crustacean juveniles and adults may be tolerant of high levels of suspended sediment (Wilber and Clarke 2001). Increased sediment may positively impact sponge and polychaete abundance (Magris and Ban 2019).</td></tr>
<tr><td>Marine fishes</td><td>Anchoring and Mooring – Substrate disturbance (sediment resuspension) [1] - Change in fitness [7] B11FF

<u>Specific evidence</u> – Not available. There is a lack of evidence as to whether the increased suspended sediments specifically from anchoring or mooring could produce behavioural changes in fish leading to reduced fitness.

<u>Generic evidence</u> – Fish have been documented to avoid and/or flee from suspended sediment, reducing feeding duration and increasing the chance of injury or mortality while fleeing their preferred habitat. Sedimentation can smother sessile eggs of species such as skates (egg purses attached to marine plants), herring spawn on macroalgae, or of bottom-nesting species such as Atlantic lumpfish (Griffin et al. 2009). Juvenile Coho salmon avoid suspended sediment</td></tr>
</table>

	(Bisson and Bilby 1982). Resuspended sediment may disrupt feeding behaviour of fish, resulting in reduced foraging rates (Johnston and Wildish 1982), but feeding success may be dependent on prey behaviour. Visual acuity may be reduced, however the increased turbidity could also increase the visual contrast of prey and increase feeding rates, as was found for larval Pacific herring. When persistent, survival, year-class strength, recruitment, and condition of juvenile fish can be reduced by decreased feeding. The increased sediment can also cause alarm reactions, including increased swimming and disruption of schooling (Wilber and Clarke 2001). Localised displaced sediment may affect marine fish (Wenger et al. 2017) and impacts from increased suspended sediment can impact feeding behaviour, avoidance behaviour and displacement, as well as impact egg and juvenile development (DFO 2000).
Anchoring and Mooring – Substrate disturbance (sediment resuspension) [1] - Mortality [8]	
Marine plants and algae	Anchoring and Mooring - Substrate disturbance (sediment resuspension) [1] - Mortality [8] B11MP Specific evidence – Not available. Evidence is lacking as to whether the increased suspended sediments specifically from anchoring or mooring could result in mortality to this endpoint. Generic evidence – Long periods of increased turbidity from sediment suspension can cause eventual death of plants (Gordon et al. 1994; Onuf 1996). Scouring and/or abrasion by moving sediments may damage or remove whole organisms or their parts. Impacts to photosynthetic capacity can result in impaired growth and ultimately mortality (den Hartog and Phillips 2001; Hemminga 1998).
Marine invertebrates	Anchoring and Mooring - Substrate disturbance (sediment resuspension) [1] - Mortality [8] B11MI Specific evidence – Not available. Evidence is lacking as to whether the increased suspended sediments specifically from anchoring or mooring could result in mortality to this endpoint. Generic evidence – Resettled sediment may smother small epifaunal species, such as sponges, bryozoans, and ascidians (Tyler-Walters et al. 2005). High levels of resuspended sediment may also have lethal effects on invertebrate larvae (Wilber and Clarke 2001). Increased sediment mobility increases the risk of mortality for corals, sponges, and other benthic organisms through smothering (Airoldi 2003). Moving sediments may damage or remove entire invertebrate communities or cause injury (Airoldi 2003). Sedimentation can smother sessile eggs of species such as squid, or of bottom-nesting invertebrate species such as octopus. Localised displaced sediment may inundate or smother fixed and sedentary benthic species, such as corals and anemones (and possibly clams) with possible resultant mortality (Jones et al. 2019).
Marine fishes	Anchoring and Mooring - Substrate disturbance (sediment resuspension) [1] - Mortality [8] B11MF Specific evidence – Not available. Evidence is lacking as to whether the increased suspended sediments specifically from anchoring or mooring could result in mortality to this endpoint. Generic evidence – Increased sediment resulting from sediment resuspension could result in mortality by asphyxiation due to the coating of respiratory epithelia by fine sediment particles, cutting off gas exchange, larger particles can be trapped by gill lamellae and cause asphyxiation at high concentrations (Wilber and Clarke 2001). The avoidance response of fish to bird and fish predators may also be reduced for some fish species in increased turbidity, potentially resulting in mortality.
Anchoring and Mooring – Substrate disturbance (sediment resuspension) [1] - Change in habitat [9]	
Physical habitat (substrate)	Anchoring and Mooring - Substrate disturbance (sediment resuspension) [1] - Change in habitat [9] B11HS Specific evidence – Anchors and anchor chains can re-suspend sediment as they move with the vessel, resulting in areas of scarred seagrass beds that are less cohesive, contain less organic material, and have a lower silt fraction (Collins et al. 2010). The repeated resuspension of benthic sediments can result in the separation of coarse and fine sediment fractions, altering the grain size in areas of the seafloor. Sediment burial and scouring may occur together (Airoldi 2003). Generic evidence – The deposition of suspended sediments can cause a physical habitat change by altering substrates (DFO 2000).

Physical habitat (water column)	Anchoring and Mooring - Substrate disturbance (sediment resuspension)[1]—change in habitat [9] B11HW Specific evidence – Not available. It is posited that resuspended sediment caused by anchors could have a temporary impact on water quality, which, depending on the movement of the anchor, can persist throughout the duration the anchor is deployed. The agitating of the seafloor by anchors and chains may increase turbidity and nutrient loading in the water column. Supporting evidence not available. Generic evidence – The increased turbidity from suspended sediment in the water column can change habitat characteristics by reducing light penetration (DFO 2000). Sediment resuspension allow toxins that were previously buried to become bioavailable (Ross et al. 2016).

Table B1-2 - Evidence for the **Substrate disturbance (crushing) [2]** stressor

Anchoring and Mooring - Substrate disturbance (crushing) [2]	
The anchor or mooring, and associated equipment, has the potential to crush the substrate it encounters while deployed, and also when retrieved.	
Anchoring and Mooring – Substrate disturbance (crushing) [2] - Change in fitness [10]	
Marine plants and algae	Anchoring and Mooring - Substrate disturbance (crushing) [2] - Change in fitness [10] B12FP Specific evidence – When a temporary anchoring system is deployed (both the anchor and chain), seagrass can be bent and crushed, disrupting the growth and reproduction processes and reducing fitness (Ceccherelli et al. 2007; Montefalcone et al. 2008). When a temporary anchor is pulled up it can cut into the seagrass rhizome mat, tearing a hole in its fabric and fragmenting the seagrass bed (Collins et al. 2010). Damage caused by the movement of the components of anchor and mooring systems while deployed can undermine the rhizome structure of seagrasses impeding their recovery (Collins et al. 2010; Montefalcone et al. 2008). Scarring and fragmentation of seagrass beds can increase sediment erosion, leading to declines in seagrass growth rate and reproductive fitness (Collins et al. 2010). Primary production of coastal seagrass meadows may be affected through reduced leaf lengths and leaf areas in affected areas (García-Charton et al. 2000). Given these types of effects, (Leatherbarrow 2003) concluded that eelgrass beds in anchorage sites were in poorer health than at comparable non-anchorage sites. In addition to eelgrass, rhodoliths (unattached coralline algal reefs) have been identified as having the potential to be affected by anchoring when substrate has been altered (Steller et al. 2003). The same would be true for larger kelp forests which must anchor to a stable substrate so as not to be swept away by currents or storms. Generic evidence – If physical impacts to seagrass meadows reach deep enough into the substrate (such as with deep propeller damage), the roots and rhizomes of the seagrass can be injured and removing some of the sediment they are rooted in and depend on as a primary nutrient source for the plants (Kenworthy et al. 2002). Scarring and fragmentation of seagrass beds can increase sediment erosion, leading to declines in seagrass growth rate and reproductive fitness (Collins et al. 2010). At the smaller scale of recreational vessel anchoring, such dragging and scouring activity can lead to reduced shoot density and bed cover in *Posidonia* seagrasses (Francour et al. 1999). The extent of habitat change due to anchoring will depend to some extent on the type of substrate and the organisms living there. Soft-bottom habitats may suffer relatively more damage from anchoring than rocky substrates with crevices providing refugia from anchoring activity.
Marine invertebrates	Anchoring and Mooring - Substrate disturbance (crushing) [2] - Change in fitness [10] B12FI Specific evidence – Anchoring on infralittoral and circalittoral habitats affects the associated fauna, particularly sessile (attached) species. Impacts to fitness of marine invertebrates can occur through alteration of habitat structure, reduced primary production and changes to trophic relationships (García-Charton et al. 2000). Evidence from seagrass meadows show that anchoring may cause loss of structural complexity through reduced density and coverage (García-Charton et al. 2000). Physical disturbance, such as anchoring, may increase the vulnerability of benthic invertebrate communities to subsequent disturbances of the same or differing type (Ceccherelli et al. 2007; Hastings et al. 1995). Crabs are documented to be drawn to foreign objects, such as derelict fishing pots, on the seafloor (Bullimore et al. 2001).

	Generic evidence – Activities that drag heavy items on the seabed have the potential to cause lethal and sub-lethal impacts to benthic fauna. Scallop dredging has been shown to cause in-situ damage to large benthic invertebrates on the seabed (Jenkins et al. 2001). Permanent changes in invertebrate communities have been recorded in areas of trawling activities, with changes more likely to become permanent with increasing frequency of dragging activities (Jones 1992). In calmer or deeper areas, where communities are less adapted to disturbance, invertebrates take longer to recover after crushing activities (Jones 1992).
Marine fishes	Anchoring and Mooring - Substrate disturbance (crushing) [2] - Change in fitness [11] B12FF Specific evidence - Evidence of direct effects from crushing of marine fishes from anchoring and mooring equipment were not available. However, it is expected that moving anchors and chains have the potential to crush benthic fish in the area resulting in fitness effects, particularly types that bury themselves in soft sediments (e.g., flat fish). Generic evidence – Marine biota including marine fishes are crushed by dredges and towed nets (Thrush and Dayton 2002; Watling and Norse 1998 - In: (Davis et al. 2016)).
Anchoring and Mooring – Substrate disturbance (crushing) [2] - Mortality [11]	
Marine plants and algae	Anchoring and Mooring - Substrate disturbance (crushing) [2] - Mortality [11] B12MP Specific evidence – Marine plants and algae can be crushed and detached/uprooted when anchors encounter the benthic environment. Areas of seagrass can be removed by the scouring of anchors and chains, forming gaps in the beds (Walker et al. 1989). Several studies have specifically examined the effects of recreational boat anchoring on seagrass (*Posidonia*) beds (Francour et al. 1999; Ganteaume et al. 2005; Milazzo et al. 2004; Montefalcone et al. 2006; Pasqualini et al. 1999). However, there is a paucity of studies examining the impact of commercial vessel anchoring on vegetation and habitats (Davis et al. 2016; Panigada et al. 2008). Dragging anchor chains have adverse effects on seagrass beds, exposing root-rhizomes and producing circular scars on seagrass meadows (Collins et al. 2010; Francour et al. 1999; Hastings et al. 1995; La Manna et al. 2015; Milazzo et al. 2004; Montefalcone et al. 2006; Walker et al. 1989). Seagrasses completely detached from a seagrass bed by anchoring often end up washed ashore or transported by currents and water movement to deeper areas where they can die if environmental conditions are not suitable for survival (Panigada et al. 2008). This can result in masses of decomposing seagrass root-rhizome material when the detached seagrasses die. Anchoring on rocky bottoms can affect assemblages of infralittoral algae (Panigada et al. 2008), which can be crushed or detached from rocky substrate. Generic evidence – Crushing of the substrate resulting from dredging can physically remove vegetation and bury seagrasses causing mortality (Erftemeijer and Lewis 2007).
Marine invertebrates	Anchoring and Mooring - Substrate disturbance (crushing) [2] - Mortality [11] B12MI Specific evidence – Anchoring on rocky bottoms can affect sensitive invertebrates associated with benthic habitats (Abdulla and Linden 2008). In deeper waters, anchoring may have an adverse impact on sensitive circalittoral benthic habitats, including coralligenous assemblages and rhodolith (coralline red algae) beds. Similar to seagrass beds, marine invertebrates can experience mortality through direct physical damage (Abdulla and Linden 2008). The abundance of benthic organisms in anchoring scars has been documented to be much lower than in the surrounding seagrass beds, particularly polychaetes, oligochaetes, bivalves and amphipods (Collins et al. 2010). Shelled species such as bivalves, abalone, and subsurface clams in flocculent sea bottoms may be particularly at risk of mortality from the crushing impacts of anchoring and mooring gear as they are relatively sessile species with fragile shells would be more easily crushed and killed (Tyler-Walters et al. 2005). Generic evidence – Substrate disturbance (crushing) from bottom trawling causes mortality of damaged invertebrates and changes in faunal composition, the degree of impact is related to the type of gear, nature of bottom substrate, speed of towing, and frequency of impact. Impacts are stronger in deeper water where recovery is slower (Jones 1992). Scallop dredging causes in-situ damage, including mortality, to benthic invertebrates on the seabed (Jenkins et al. 2001). Abrasion from trawling or dredging gear may scrape off patches of hydroids, bryozoans, ascidians, sponges, and other encrusting fauna, and the shells of mussels, limpets, periwinkles, and the tubes of tubeworms may be crushed (Tyler-Walters et al. 2005).

Marine fishes	Anchoring and Mooring - Substrate disturbance (crushing) [2] - Mortality [11] B12MF Specific evidence – Evidence of direct effects from crushing of marine fishes from anchoring and mooring equipment were not available. However, it is expected that moving anchors and chains have the potential to crush and kill benthic fish in the area, particularly types that bury themselves in soft sediments (e.g., flat fish). Generic evidence – Marine biota including marine fishes are crushed and killed by dredges and towed nets (Thrush and Dayton 2002; Watling and Norse 1998 - In:(Davis et al. 2016)).
Anchoring and Mooring – Substrate disturbance (crushing) [2] – Change in habitat [12]	
Physical habitat (substrate)	Anchoring and Mooring - Substrate disturbance (crushing) [2] - Change in habitat [12] B12HS Specific evidence – The movement of dropped temporary anchors as well as the chain components of anchoring and mooring systems can drag across the substrate, overturning rocks and digging trenches or holes in soft sediments, altering physical habitats (Montefalcone et al. 2006; Walker et al. 1989). Sediments in temporary anchor scars have been observed to be less cohesive and more mobile, with average shear vane stress significantly lower in anchor scars than surrounding seagrass beds, resulting in a depression in the seabed (Collins et al. 2010; Hastings et al. 1995; Herbert et al. 2009; Walker et al. 1989). Similarly, the silt fraction and organic content has been found to be lower in the scars than adjacent seagrass (Collins et al. 2010). Changes to sediment quality, including overturned rocks, ruts, and/or holes in soft substrates caused by anchors and anchor chains can cause gaps in continuous substrate on the seafloor (Collins et al. 2010). This can result in secondary habitat loss and fragmentation of associated communities and biogenic habitats (such as seagrass beds, glass sponges, and corals) (Airoldi 2003; La Manna et al. 2015). Physical habitats can be crushed by the impact and subsequent scour of anchoring and mooring equipment (Abdulla and Linden 2008). The crushing and compacting of physical habitats can result in a reduction in the complexity of the substrate (Dennis and Bright 1988). Seagrasses and some of the underlying sediments can be excavated by anchors, making these areas vulnerable to further damage (Whitfield et al. 2002). Seagrass rhizomes and roots may be crushed or excavated. The removal of the stabilizing plant structures may cause the sediment to become unstable and difficult to restore (Kenworthy et al. 2002). The extent of habitat change due to anchoring will depend on the type of substrate and the organisms living there. Soft-bottom habitats may suffer relatively more damage from anchoring than rocky substrates with crevices providing refugia from anchor activity. The impact of anchoring on the seabed is evident in major ports and harbours around the world. For example, it is estimated that almost 80% of marks on the seabed in the Bedford Basin (Halifax Harbour) are attributable to anchor marks dating back to the mid-1700s. Anchor marks were estimated to be up to 2.5m deep, can span an area of 5m, with linear drag marks of up to several kilometres in length. Anchor chain marks can form radial pattern of linear depressions. The footprint of the disturbance in Halifax Harbour was exacerbated by the release of gas-charged sediments (Fader and Buckley 1995). Generic evidence – Frequent disturbance to benthic substrates reduces habitat structure and complexity (Handley et al. 2014).

Table B1-3 - Evidence for the **Foreign object/obstacle) [3]** stressor

Anchoring and Mooring - Foreign object/obstacle [3]	
Anchoring and mooring systems introduce a foreign object in the water column (lines/chains) and seabed (anchor), that otherwise would not be present in the area. The way that this stressor manifests may differ between anchoring and mooring systems.	
Anchoring and Mooring – Foreign object/obstacle [3] – Change in habitat [13]	
Physical habitat (substrate)	Anchoring and Mooring - Foreign object/obstacle [3] - Change in habitat [13] B13HS Specific evidence – The presence of the anchoring or mooring system results in a temporary change in habitat. It is possible that anchors could have similar effects to artificial reef installations, where communities colonise and develop over time, but impacts would depend on duration of anchoring. A change in habitat can result in short-term behavioural responses in mobile species. Some fish may avoid the anchor altogether, while others are attracted to foreign objects for protection or predation, as seen in artificial reefs and fish-aggregating devices (Rountree 1990). Generic evidence – The introduction of a foreign object has the potential to alter the existing habitat structure (Smiley 2006). The effect of this stressor on physical habitats is likely to be particularly notable in areas dominated by soft sediments, with the sudden introduction of suitable hard settlement substrates resulting in an increase in biogenic habitats (e.g., corals, sponges, marine plants, etc.). Extensive colonization by mussels can be expected for shallow subtidal apparatus and floating mooring equipment (e.g., mooring buoys) (Joschko et al. 2008).
Physical habitat (water column)	Anchoring and Mooring - Foreign object/obstacle [3] - Change in habitat [13] B13HW Specific evidence – The presence of anchor lines or chains in the water column may cause a change in the physical habitat of the water column, especially for larger fauna such as cetaceans, turtles, and sharks. Marine mammals and turtles lacking echolocation can collide with anchor chains or be forced to navigate around them. There is at least one report of killer whales in the NE Pacific exhibiting potentially dangerous playful behaviour around anchored boats; such as dragging a sailboat by its anchor chain (CBC 2006; Rudisueula 2018). Colonisation of anchor chains and buoys by mussels and other fouling species can cause a localised change in habitat to the water column (Joschko et al. 2008), creating a different habitat that would be present without the chain in the water column. Generic evidence – A non-natural foreign object can cause an obstacle in the water column, which can affect water column habitat, and alter the movement and feeding of biota.

Table B1-4 - Evidence for the **Noise disturbance [4]** stressor

Anchoring and Mooring - Noise disturbance [4]	
Noise may be produced by deploying and retrieving of anchors, movement of anchor and chain while anchored, and by the anchoring or mooring system moving as waves, current, and winds move the vessel potentially creating an acoustic disturbance. Specific evidence is rare for this linkage as impacts of noise from anchoring/mooring noise are little studied.	
Anchoring and Mooring – Noise disturbance [4] - Change in fitness [14]	
Marine invertebrates	Anchoring and Mooring - Noise disturbance [4] - Change in fitness [14] B14FI Specific evidence – Evidence for fitness effects to marine invertebrates from noise from anchoring and mooring was not available. It is expected that anchoring and mooring noise could induce temporary behavioural responses in marine invertebrates. The noise produced by deploying and retrieving anchors is a sudden, acute noise that could temporarily disturb feeding and breeding behaviours of marine invertebrates. Generic evidence – Acute noise disturbance can cause startle responses and changes in behaviour that have the potential to affect growth and reproduction, especially if feeding

	behaviour is disturbed or foraging habitat is frequently subjected to noise. The hearing capability of marine invertebrates is largely unknown (McCauley 1994). However, studies have shown behavioural and physiological responses to auditory stimuli (Bejder et al. 2009; McCauley 1994; Wale et al. 2013b; Williams et al. 2015). Exposure of crustaceans to anthropogenic marine noise can result in behavioural and physiological changes. Noise has been found to have a negative impact on antipredator and feeding behaviours; affected individuals spent more time in exposed conditions before reaching shelter (Wale et al. 2013b). A study examining the responses of crustaceans to exposure to both very high (air gun) and low sound levels found no effect on delayed mortality or damage to the mechanosensory system associated with animal equilibrium and posture (Payne et al. 2007). Other studies have found that crustaceans can exhibit a stress response that includes altered aggressive behavioural patterns and changes in the components of the haematoimmunological system (e.g., serum glucose and protein concentrations) when exposed to an acoustic stimulus (0.1-25 kHz) (Celi et al. 2013). Exposure, both singular and repeated, of crustaceans to playback of ship noise has resulted in higher oxygen consumption (indicating a higher metabolic rate and potentially increased stress) providing no obvious evidence of habituation or tolerance (Williams et al. 2015). Noise disturbance is documented to delay or disrupt the development of scallop, sea hare, and barnacle larvae (Weilgart 2018).
Marine fishes	Anchoring and Mooring - Noise disturbance [4] - Change in fitness [14] B14FF Specific evidence – Evidence for fitness effects to marine fishes from noise from anchoring and mooring was not available but it is expected that anchoring and mooring noise could induce temporary behavioural responses in marine fishes. Generic evidence – More than 50 families of fish use sound (usually below 2-3 kHz) for communication, aggression, territoriality, defence and reproduction (Panigada et al. 2008). Underwater sounds can mask communication, increase stress, cause habitat abandonment, cause loss of hearing, and damage eggs (Mitson and Knudsen 2003; Panigada et al. 2008; Popper et al. 2003; Wahlberg and Westerberg 2005; Wysocki et al. 2006). The reaction of fish to noise has only been studied in a small number of species and types of sound (Panigada et al. 2008). Fish use sound to communicate and to perceive information from the environment in a wide variety of behaviours including aggression, protection of territory, defense and reproduction (Dufour 1980; OSPAR 2009). Not all fish can detect the same range, amplitudes, or frequencies of sound and not all environments are suitable for transmitting the same sound frequencies (Fay 1988; Rogers and Cox 1988). The gas-filled swim bladder in fish may be a receiver for sound energy, even at frequencies not used for communication, and may even act as a sound amplifier (Panigada et al. 2008). Anthropogenic sound can mask fish communication (Norman 2011; Wahlberg and Westerberg 2005), generate stress that negatively affects the fish's welfare (e.g., increased cortisol levels recorded in freshwater fish; (Wysocki et al. 2006), cause a startle or escape response (Anderson 1988; Blaxter et al. 1981; Eaton and Popper 1995; Eaton et al. 1991; Engås et al. 1998; Hawkins and Popper 2012; Mitson and Knudsen 2003; Schwarz and Greer 1984), alter movements, speed, and patterns of swimming (e.g., in Atlantic cod and Atlantic and Pacific herring); (Olsen et al. 1983; Slabbekoorn et al. 2010; Suzuki et al. 1980), destroy the sensory cells in fish ears, and in the long term cause temporary and possibility permanent loss of hearing (Hastings et al. 1996; McCauley et al. 2003; Popper et al. 2003; Popper et al. 2005; Samuel et al. 2005; Smith et al. 2004). Documented responses of fish to noise include physiological effects such as elevated heart rate, secretion of stress hormones, and increased metabolism and motility (Slabbekoorn et al. 2010). Each of these effects can have varying degrees of impact on fish, varying from short-term to chronic consequences (Abdulla and Linden 2008). High noise levels may damage to ears or swim bladders, which has the potential to impact buoyancy control and orientation (Weilgart 2018).
Marine mammals	Anchoring and Mooring - Noise disturbance [4] - Change in fitness [14] B14FM Specific evidence – Evidence for fitness effects to marine mammals from noise from anchoring and mooring was not available but it is expected that anchoring and mooring noise could induce temporary behavioural responses in marine mammals. Repetitive noise from an aggregation of anchored vessels may induce some animals to abandon areas otherwise beneficial to them, or to deviate from their usual migration routes. However, the biology of disturbance and the effect of noise on the survival and fecundity of marine mammals and their prey are not well understood (for a review see (Gomez et al. 2016). Generic evidence – Increased human activity, including noise disturbance, has been identified as causing multi-year abandonment of a portion of marine mammal habitat (Bryant et al. 1984).

	Many natural noises in the marine environment give biological cues for marine organisms, acting as navigational guides and allowing detection of conspecifics and other species. Noise emissions which interfere with natural sounds in the marine environment may affect the timing of social and reproductive behaviour (McCauley 1994), particularly if the disturbance to vulnerable or endangered animals coincides with very short breeding or spawning periods. Physical harm and stress are recognised as an impact caused by underwater noise (Slabbekoorn et al. 2010). Frequent or chronic exposure to low intensity sounds may cause hearing loss and make animals that rely on hearing to locate and capture prey and to detect and avoid predators less able to do so (Abdulla and Linden 2008). Hearing loss of marine mammals can be characterized as a permanent threshold shift in hearing sensitivity that is unrecoverable over time or as a temporary threshold shift where hearing recovers completely over a specified time (Jones et al. 2017). For pinnipeds, the non-pulse underwater sound exposure level (a metric proposed by (Southall et al. 2007) was predicted as 203 dB re 1 μPa2 s for a permanent threshold shift, and 183 dB re 1 μPa2 s for a temporary threshold shift (Jones et al. 2017). As a secondary effect pathway, behavioural changes due to vessel noise can result in physical harm to marine mammals, including lesions, stranding, and even death (Walker et al. 2019; Wright et al. 2011). Furthermore, if mating and breeding activities are disrupted by chronic stress from vessel noise, there may be greater population-scale impacts (Erbe 2012). Noise pollution cause marine mammals to abandon their habitat (Borsani et al. 2008). Low intensity sounds may cause masking and behavioural disruptions, and may cause animals to abandon areas or change their usual migration routes if present frequently or for extended periods of time, or if present during key periods such as mating, feeding, birth, or mother-young bonding (Panigada et al. 2008).
Marine reptiles	Anchoring and Mooring - Noise disturbance [4] - Change in fitness [14] B14FR Specific evidence – Evidence for fitness effects to marine reptiles from noise from anchoring and mooring was not available but it is expected that anchoring and mooring noise could induce temporary behavioural responses in sea turtles. Generic evidence – The ability of marine turtles to hear underwater sound has been confirmed by measuring their auditory brainstem responses (Ketten and Bartol 2006) and by observations of their behavioural responses to sound (Hazel and Gyuris 2006; Lenhardt et al. 1996; Moein et al. 1993; O'Hara and Wilcox 1990). Behavioural responses to auditory stimuli include a startle response (Lenhardt et al. 1996; Lenhardt et al. 1983) and changes in swimming pattern and orientation (O'Hara and Wilcox 1990).
Marine birds	Anchoring and Mooring - Noise disturbance [4] - Change in fitness [14] B14FB Specific evidence – Evidence for fitness effects to marine birds from noise from anchoring and mooring was not available but it is possible that anchoring and mooring noise could induce temporary behavioural responses in marine birds. Generic evidence – Depending on the noise type, frequency, volume, or duration, noise may cause physical damage to birds' ears, cause responses including stress, fright-flight, or avoidance, alter behaviours such as foraging, reproduction, or predator avoidance, may mask communication or alter song characteristics, and may result in population-level changes (Ortega 2012). When played aircraft noise, any level of noise above background levels resulted in scanning and alert responses in sea birds, with increased proportions of the colony reacting with higher noise levels. When played 90 dB and 95 dB noise, startle and escape behaviours were observed by a portion of the colony (Brown 1990).
Anchoring and Mooring – Noise disturbance – Change in habitat [15]	
Physical habitat (acoustic)	Anchoring and Mooring - Noise disturbance [4] - Change in habitat [15] B14HA Specific evidence – The noise produced by deploying and retrieving anchors is a sudden, acute noise, different than that of travelling vessels. Evidence for the effects of this type of noise from anchoring and mooring on acoustic habitat was not available. Generic evidence – Noise travels long distances underwater and therefore the disturbance affects the entire water column (seabed to surface). The acoustic environment provides important information about the locations of predators and prey species, and is used for navigation, communication, and for habitat selection (McWilliam and Hawkins 2013). Noise can reduce or otherwise impact the acoustic habitat of marine mammals and mask echolocation signals essential for locating food, navigating and finding mates (Williams et al. 2013). Acoustic

	features of marine habitat have been listed for protection for some species in Canada. For instance, southern resident killer whales require areas to rest or forage in which the level of ambient noise is low enough to allow the functions of the habitat to continue (DFO 2011). Loud and/or continuous sounds, such as produced by large-scale vessel movements, could compromise the ecological value of certain cetacean habitats.

Table B1-5 - Evidence for the **Entrapment / Entanglement / Smothering [5]**

Anchoring and Mooring - Entrapment / Entanglement / Smothering [5]	
Mooring systems, and the deployment and retrieval, and presence of anchors and chains have the potential to entrap, entangle or smother marine biota.	
Anchoring and Mooring - Entrapment/ Entanglement/ Smothering [5] - Change in fitness [16]	
Marine mammals	Anchoring and Mooring - Entrapment/entanglement/smothering [5] - Change in fitness [16] B15FM Specific evidence – Anchor lines and chains present in the water to stabilise vessels at rest could potentially entangle or entrap marine mammals and can result in physical damage and time lost for foraging and other activities. Anchor lines (not chains) have been implicated in entanglement of marine mammals, notably sirenians (Reinert et al. 2017). The risk of entanglement has been linked to the tension on the deployed line, with taut lines less likely to entangle marine mammals than slack (Benjamins et al. 2014). Whales may accidentally swim into anchor lines whilst moving amongst boats anchored close to breeding or feeding grounds. There are reports of large cetaceans (including humpback, right and fin whales) interacting with anchoring gear and towing small yachts from their moorings or becoming entangled (Benjamins et al. 2014). In 2017 a bubble-net feeding humpback became entangled in a cruise ship anchor in Alaska for 12 hours before being freed (Bohrer 2017). The damage received during entanglement could result in fitness effects, although this has not been documented. Vessel anchoring systems have not been implicated in entanglements of North Atlantic right whales (Johnson et al. 2005). Generic evidence – Entanglement in fishing gear is an important stressor for cetaceans, with associated fitness impacts (Johnson et al. 2005; Knowlton and Kraus 2001). Marine mammals can become entangled in most gear types, though especially pot and line gear, with documented fitness impacts (Johnson et al. 2005; Johnson 2005). Minke whales are capable of visually detecting ropes and ultimately avoiding anchor chains and ropes (Kot et al. 2012). Other marine mammals may also be able to detect and subsequently avoid obstacles. However, avoidance, can cause an animal to self-exclude from an area and this displacement may have fitness impacts (e.g., disrupted feeding).
Marine reptiles	Anchoring and Mooring - Entrapment/entanglement/smothering [5] - Change in fitness [16] B15FR Specific evidence – Anchor and mooring lines present in the water could potentially entangle or entrap marine reptiles. Entanglement has been identified as the principal threat to leatherback sea turtles by DFO Species at Risk (DFO 2018b). Although there is a lack of evidence or reports of sea turtles entangled in anchor chains, they are known to become entangled in fishing gear and lines and they bear scars or other physical damage which could have fitness effects (DFO 2018b). The incidence of entanglement in vessel anchor lines or chains compared to fishing related entanglements is not known. Generic evidence – Sea turtles can become entangled in fishing gear with associated fitness impacts (Bugoni et al. 2001). An experimental study found that capturing sea turtles by entanglement netting causes significant physiological impacts (Hoopes et al. 2000).
Anchoring and Mooring – Entrapment/ Entanglement/ Smothering [5] - Mortality [17]	
Marine mammals	Anchoring and Mooring - Entrapment/entanglement/smothering [5] - Mortality [17] B15MM Specific evidence – A whale has been documented to be entangled in an anchor chain on the Pacific coast in 2017 when a bubble-net feeding humpback became entangled in a cruise ship anchor chain in Alaska for 12 hours before being freed (Bohrer 2017). If entangled whales are

	not freed, mortality is an expected result if the animal is unable to breathe, or if injuries received are severe. <u>Generic evidence</u> – Entanglement in fishing gear is an important stressor for several large cetaceans, with lethal outcomes reported (Johnson et al. 2005; Knowlton and Kraus 2001). Marine mammals can become entangled in most fishing gear types, with pot and line gear common. Impacts from entanglement in fishing gear include mortality (Johnson et al. 2005; Johnson 2005).
Marine reptiles	Anchoring and Mooring - Entrapment/entanglement/smothering [5] - Mortality [17] B15MR <u>Specific evidence</u> – There is a lack of evidence or reports of entanglement of marine reptiles in anchor chains. Entanglement is the principal threat to leatherback sea turtles identified by DFO Species at Risk (DFO 2018a). <u>Generic evidence</u> – Sea turtles can become entangled in fishing gear and marine debris with associated mortality (Bugoni et al. 2001). Sea turtles have been reported to become entangled in mooring lines (associated with fishing gear) and die from drowning (DFO 2018a).

Table B1-6 - Evidence for the **Introductions of species and pathogens [6]** stressor

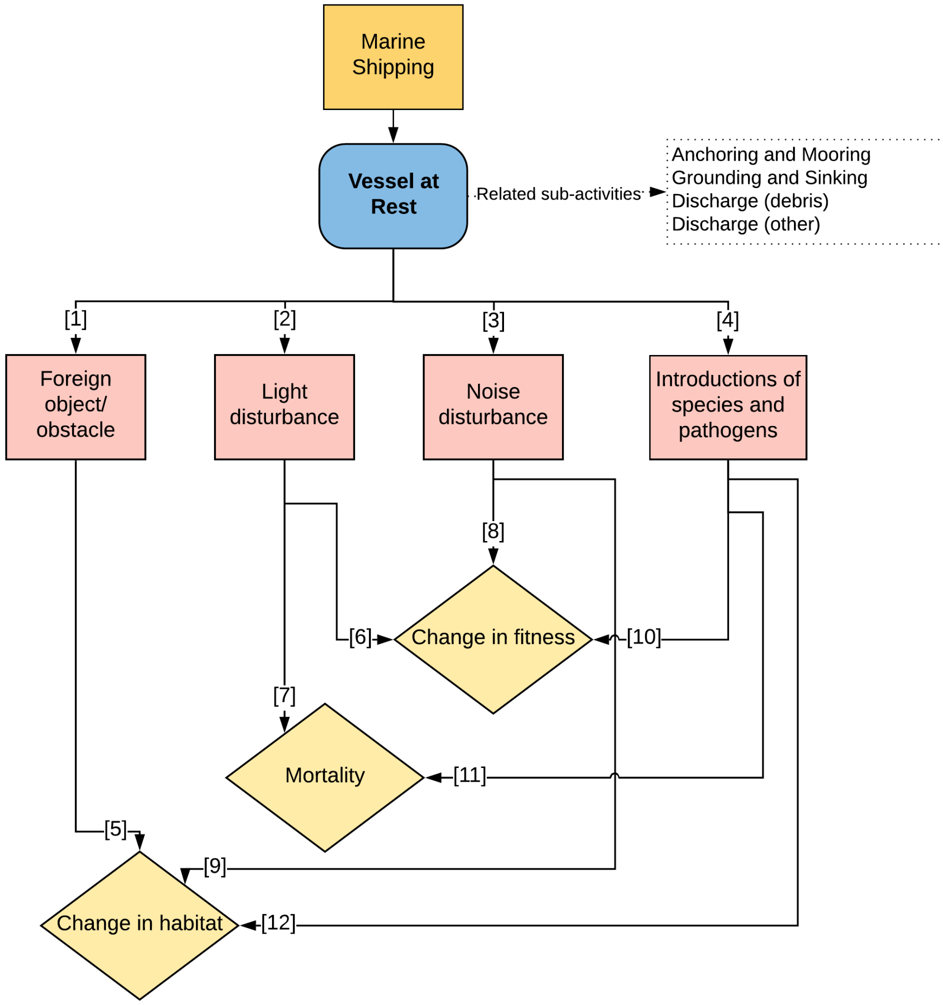
Anchoring and Mooring - Introductions of species and pathogens [6]	
Introductions of species - Temporary anchoring equipment and areas such as anchor lockers (where anchors and chains are stored) can harbour aquatic invasive species (AIS) as biofouling. When equipment is deployed and retrieved, AIS may be introduced to new areas. *Introductions of pathogens* - Examines the effects of pathogens introduced through anchoring and mooring equipment.	
Anchoring and Mooring - Introductions of species and pathogens [6] - Change in fitness [18]	
Marine plants and algae	Anchoring and Mooring - Introductions of species and pathogens [6] - change in fitness [18] B16FP **Introductions of species** <u>Specific evidence</u> – Anchoring in beds of invasive plants or algae can cause fragmentation and transport of the invasive fragments to new locations and habitats (West et al. 2007). Depending on the species transported, the introduction and spread of invasive plants and algae cause loss of native flora due to competition. Introduced species may also attach to native species, and may cause them to be uprooted or dislodged. For example, *Codium fragile* var. *tomentosoides* has been observed to attach to and overgrow eelgrass (Locke et al. 2002), with the increased buoyancy resulting from the production and trapping of gases by *Codium* pulling the eelgrass plant from the substrate. <u>Generic evidence</u> – Introduced algal species may be able to exclude native species by dominating substrata needed for recruitment. In addition, some introduced bryozoans, such as *Membranipora* spp., can cause defoliation of kelps, which reduce growth and survival of the native species (Levin et al. 2002). Several introduced algal and invertebrate species grow epiphytically on seagrass, which can reduce its ability photosynthesize and grow (Williams 2007). Some introduced species that may be spread by shipping, such as *Didemnum* sp., are able to spread rapidly and smother algae (Daniel and Therriault 2007). **Introductions of pathogens** <u>Specific evidence</u> – Evidence of fitness effects on marine plants and algae from pathogens originating from anchoring and mooring was not available but is possible as pathogens have been found in biofouling (Revilla-Castellanos et al. 2015) and so may also be present in biofouling associated with anchoring and mooring gear. Pathogens could potentially cause fitness effects in marine plants and algae. <u>Generic evidence</u> – Pathogens are found in biofouling (Revilla-Castellanos et al. 2015), and it is possible that pathogens present in biofouling associated with anchoring and mooring gear could have a fitness effect on marine plants and algae. Some seagrasses face population declines from a wasting disease caused by opportunistic pathogens in the genus *Labyrinthula* (Groner et

	al. 2016) though the evidence indicates these pathogens were already present, and not transported.
Marine invertebrates	Anchoring and Mooring - Introductions of species and pathogens [6] - Change in fitness [18] B16FI **Introductions of species** Specific evidence – Invasive marine invertebrates can colonise anchors and anchor chains when left in the water for longer periods of time. When retrieved and transported, some species can survive and be introduced to new locations when the anchor is redeployed. Invasive club tunicate and zebra mussel have been found on anchors (Bourque et al. 2007; Johnson et al. 2001) and hypothesised to be transported with anchors to new locations (Darbyson et al. 2009). Species of invasive marine invertebrates can reduce, remove or alter native communities through competition and predation. Generic evidence – Fouling species can be transported on vessel hulls, and may dislodge by peeling off or fragmenting while in transit (Clarke Murray et al. 2012; Coutts 1999). Once present, non-native filter feeders may change the plankton composition or reduce the amount available to other consumers (Daniel and Therriault 2007). Fast-growing colonial species may smother invertebrates or prevent benthic settlement as they spread over large areas of substrate (Daniel and Therriault 2007). **Introductions of pathogens** Specific evidence – Evidence of fitness effects on marine invertebrates from pathogens originating from anchoring and mooring was not available. However, as hull biofouling can contain pathogens (Revilla-Castellanos et al. 2015) biofouling associated with anchoring and mooring may also harbour pathogens which could potentially cause fitness effects in marine invertebrates exposed to pathogens. Generic evidence – Oysters and mussels are known fouling organisms that can be contaminated by disease-causing pathogens, however, there is not currently research showing disease transport through their fouling (Goulletquer et al. 2002; Minchin 2007). Pathogens have the potential to cause disease in marine invertebrates, as demonstrated when fitness effects were observed in Pacific and American oysters infected with *Haplosporidium nelsoni,* a pathogen found in Nova Scotia and British Columbia (Canada Food Inspection Agency 2018).
Marine Fishes	Anchoring and Mooring - Introductions of species and pathogens [6] - Change in fitness [18] B16FF **Introductions of species** Specific evidence – Invasive marine species can colonise anchors and anchor chains when left in the water for longer periods of time. When retrieved and transported, some species can survive and be introduced to new locations when the anchor is redeployed. Species that may be introduced via fouling, such as the colonial ascidian *Didemnum* sp., may impact fish populations by smothering food organisms which may result in fish leaving the area, and may prevent successful reproduction through damage of fish eggs and larvae as they settle onto its acidic tunic (Daniel and Therriault 2007). Increased mooring time is associated with increased invasion risk because it allows more time for species to accumulate (Chan et al. 2011). Generic evidence – Introduced species may reduce recruitment success of some fish species through the consumption of their eggs (Haslob et al. 2007). Ingestion of some introduced algae has also been known to harm herbivorous fish (Maggi et al. 2015). There is also concern that introduced species may smother native food sources while offering little nutritional value as replacement, or that native fish could be displaced from refuge habitat (Daniel and Therriault 2007). **Introductions of pathogens** Specific evidence – Evidence of fitness effects on marine fishes from pathogens originating from anchoring and mooring was not available. However, as biofouling can contain pathogens (Revilla-Castellanos et al. 2015) biofouling associated with anchoring and mooring gear may also harbour pathogens which could potentially cause fitness effects in marine fishes. Generic evidence – Pathogens can be found in biofouling samples, and has been asserted be an overlooked vector of pathogens (Revilla-Castellanos et al. 2015). A virus in the family *Rhabdoviridae* can cause infectious haematopoietic necrosis, which affects many finfish including species of salmon, trout, herring, and sturgeon (Canada Food Inspection Agency

	2018). Infectious pancreatic necrosis, caused by a virus in the family Birnaviridae, affects a wide variety of marine and freshwater fishes (Canada Food Inspection Agency 2018).
Anchoring and Mooring - Introductions of species and pathogens [6] - Mortality [19]	
Marine plants and algae	Anchoring and mooring - Introductions of species and pathogens [6] - Mortality [19] B16MP **Introductions of species** Specific evidence – Evidence of mortality effects to this endpoint from species introduced from anchoring and mooring was not available, though it is known that anchors and chains left in the water for longer periods of time can be colonised by invasive marine species. When retrieved and transported, some species can survive and be introduced to new locations when the anchor is redeployed. Increased mooring time is associated with increased invasion risk because it allows more time for species to accumulate (Chan et al. 2011). Generic evidence – Some introduced species that are spread by shipping, such as the colonial ascidian *Didemnum* sp., are able to spread rapidly and can smother algae (Daniel and Therriault 2007). Introduced mobile species may harm native plants as they forage. For example, the European Green Crab damages the rhizomes and shoots of the eelgrass *Zostera marina* while digging for prey and burrowing for shelter, which has reduced the eelgrass biomass (Matheson et al. 2016). Introduced species may also attach to native species, and may cause them to be uprooted or dislodged. For example, *Codium fragile* var. *tomentosoides* has been observed to attach to and overgrow eelgrass (Locke et al. 2002), with the increased buoyancy resulting from the production and trapping of gases by *Codium* pulling the eelgrass plant from the substrate. **Introductions of pathogens** Specific evidence – Evidence of mortality of marine plants and algae from pathogens originating from anchoring and mooring was not available. However, as hull biofouling can contain pathogens (Revilla-Castellanos et al. 2015) biofouling associated with anchoring and mooring gear may also can harbour pathogens which could potentially cause fitness effects in marine plants and algae. Generic evidence – Seagrasses such as *Zostera marina* face population declines due to wasting disease caused by pathogens in the genus *Labyrintula* (Groner et al. 2016).
Marine invertebrates	Anchoring and mooring - Introductions of species and pathogens [6] - Mortality [19] B16MI **Introductions of species** Specific evidence – Invasive marine species can colonise anchors and anchor chains when left in the water for longer periods of time. When retrieved and transported, some species can survive and be introduced to new locations when the anchor is redeployed. Species that may be introduced via ship hulls, such as the colonial ascidian *Didemnum* sp., are able to spread rapidly and smother native invertebrate species (Daniel and Therriault 2007). Increased mooring time is associated with increased invasion risk because it allows more time for species to accumulate (Chan et al. 2011). Generic evidence – Introduced species may consume native invertebrates. For example, the European Green Crab reduced the abundance of three native clam species and a native shore crab in a California Bay through predation (Grosholz et al. 2000). **Introductions of pathogens** Specific evidence – Evidence of mortality of marine invertebrates from pathogens originating from anchoring and mooring was not available. However, as biofouling can contain pathogens (Revilla-Castellanos et al. 2015) biofouling associated with anchoring and mooring may also can harbour pathogens which could potentially cause mortality in marine invertebrates. Generic evidence – Viruses can cause mortality in invertebrates (Kim et al. 2016; Kim et al. 2019). Pacific and American oysters infected with the pathogenic protozoan *Haplosporidium nelsoni* can result in juvenile and adult mortality (Canada Food Inspection Agency 2018).
Marine fishes	Anchoring and mooring - Introductions of species and pathogens [6] - Mortality [19] B16MF **Introductions of species** Specific evidence – Invasive marine species can colonise anchors and anchor chains when left in the water for longer periods of time. When retrieved and transported, some species can survive and be introduced to new locations when the anchor is redeployed. Species that may be

	introduced via ship hulls, such as the colonial ascidian *Didemnum* sp., may have defense strategies, such as an acidic tunic, that could kill fish eggs or larval fish settling on its surface (Daniel and Therriault 2007). Increased mooring time is associated with increased invasion risk because it allows more time for species to accumulate (Chan et al. 2011). Generic evidence – Introduced species may consume native fish species. For example, the invasive lionfish in the Bahamas prey on over 40 species of native fish and was demonstrated to reduce prey fish abundance by 90% (Albins and Hixon 2013). **Introductions of pathogens** Specific evidence – Evidence of mortality of marine fishes from pathogens originating from anchoring and mooring biofouling was not available. However, as hull biofouling can contain pathogens (Revilla-Castellanos et al. 2015) biofouling associated with anchoring and mooring may also harbour pathogens which could potentially cause mortality in marine fishes. Generic evidence – A pathogen known to cause gill disease in fish has ben found in the biofouling associated with aquaculture nets (Tan et al. 2002). There are many pathogens that affect fish, including some with death rates up to 95% (Batts et al. 1993; Canada Food Inspection Agency 2018; Gagné et al. 2007; Walker and Winton 2010).
Anchoring and Mooring - Introductions of species and pathogens [6] - Change in habitat [20]	
Physical habitat (substrate)	Anchoring and Mooring - Introductions of species and pathogens [6] - Change in habitat [20] B16HS **Introductions of species** Specific evidence - Introduction of rapidly spreading non-native benthic species can cause a change to the benthic habitat. In the Mediterranean, the invasive alga, *Caulerpa taxifolia*, transported on ships' anchors (Cevik et al. 2007; West et al. 2007), is adept at sprouting in the furrows created by anchor chains on loose sediments. *C. taxifolia* can rapidly colonise a variety of substrates, displacing native species and causing a change in habitat (Byers et al. 2010; Langar et al. 2002) that is detrimental to a native species (Byers et al. 2010) and can cause an alteration of physical and chemical properties of the surrounding water and sediment. Generic evidence – The colonisation of substrates by introduced invasive species can modify substrate conditions, altering habitat (Olenin et al. 2011). For example, the dense colonisation of substrate by invasive zebra mussels in the Great Lakes has caused a change in benthic habitats (Ricciardi and MacIsaac 2000; Ricciardi et al. 1997; Strayer 2009). **Introductions of pathogens** Specific evidence – Evidence of effects to physical habitat (substrate) from introduction of pathogens from biofouling of anchoring and mooring gear was not available. Generic evidence – Ecosystem engineering seagrasses such as *Zostera marina*, which provide habitat to many species, face population declines due to wasting disease caused by pathogens in the genus *Labyrintula* (Groner et al. 2016).

APPENDIX B2: VESSEL AT REST TABLES OF EVIDENCE



Definition: The Vessel at Rest sub-activity considers effects from commercial vessels that are anchored, or attached to a mooring buoy system. The vessel is the focus, and this PoE excludes effects from anchor and mooring systems (refer to Anchoring and Mooring PoE model). This sub-activity has four associated stressors: foreign object/obstacle (Table B2-1); light disturbance (Table B2-2); noise disturbance (Table B2-3); and introductions of species and pathogens (Table B2-4).

Tables of evidence are provided for each stressor in the following pages, based on the order outlined in the PoE diagram above. *Specific* evidence refers to information specific to that linkage, whereas *generic* evidence is more broad but still relevant and can provide insight where specific evidence is not available. *Not applicable* generic evidence indicates this is the sole linkage and that specific evidence is available. *Not available* indicates that no evidence was found for that linkage.

Table B2-1 - Evidence for the **Foreign object/obstacle [1]** stressor

Vessel at Rest - Disturbance (foreign object/obstacle) [1]	
Vessels at rest can act as a foreign object/obstacle in the upper water column that can hinder the movement and feeding of mobile biota. Mobile organisms may also accidentally collide with a vessel if they are not aware of it (in contrast to the stressor Strikes, which represents a strike from a vessel under power). Refer to Anchoring and Mooring PoE for consideration of foreign object/obstacle effects from anchor/mooring systems (Appendix B1)	
Vessel at Rest – Foreign object/obstacle [1] – Change in habitat [5]	
Change in habitat (water column)	Vessel at rest - Foreign object/obstacle [1] - Change in habitat [5] B21HW Specific evidence – Marine mammals lacking echolocation can collide with vessels at rest they are not aware of, particularly such as when engaged in feeding. Humpback lunge feeding behaviour has been notable in these incidents. There were 15 reported cases of humpback whales colliding with anchored or drifting vessels in Alaska in a 2012 study (Neilson et al. 2012). In one case a humpback whale made a 1.5m hole through the hull of an anchored 22m wooden sailboat, sinking the vessel and leaving behind six plates of baleen held together by torn flesh. A second vessel (a 10m fiberglass sailboat) was rammed by a humpback whale while drifting with engine off and sank, and was expected to have caused damage to the whale (Neilson et al. 2012) (note that these examples are recreational vessels). There is at least one report of killer whales in the NE Pacific exhibiting potentially dangerous playful behaviour around anchored boats, including dragging a sailboat by its anchor chain (CBC 2006; Rudisueula 2018). Vessel presence may disturb and prevent pinnipeds from hauling out. Sea turtles are likely able to detect vessels at anchor (with engine off) and avoid them, as one study found green sea turtles did not pass close to or under anchored vessels, altering course when 15-20m away to avoid the anchored vessels (Hazel et al. 2007). Generic evidence – Refer to Anchoring and Mooring PoE for generic evidence of this stressor to this endpoint (Table B1-3, cell reference B13HW).

Table B2-2 – Evidence for the **Light disturbance [2]** stressor

Vessel at Rest - Light disturbance [2]	
Vessels at rest for extended periods or at fixed locations such as moorings or anchorages can manifest this stressor in two ways, firstly by shading – the reduction of light underneath the vessel, and secondly by increasing light through the use of artificial lighting, used on vessels at all times, including at night.	
Vessel at Rest - Light disturbance [2] - Change in fitness [6]	
Marine plants and algae	Vessel at rest - Light disturbance [2] - Change in fitness [6] B22FP Specific evidence – Shading can reduce energy produced by photosynthetic biota. In the Mediterranean, long-term shading by stationary recreational vessels results in adverse effects on the benthic biota present underneath the vessels (Abdulla and Linden 2008). Fitness impacts from increased artificial light are expected to be negligible for marine plants and algae but this is cannot be verified due to a lack of studies focusing on this. Generic evidence – Diminished macrophyte biomass effects have been reported resulting from shading from low bridges (Struck et al. 2004), and there are observations from shaded areas under docks of depressed shoot density affecting the canopy structure of eelgrass due to not getting sufficient light for normal photosynthesis (Burdick and Short 1999).
Marine inverte-brates	Vessel at rest - Light disturbance [2] - Change in fitness [6] B22FI Specific evidence – Artificial light from commercial vessels can negatively affect the feeding, reproduction, orientation and predator avoidance behaviour of marine invertebrates (Underwood et al. 2017). Artificial light can reduce the settlement of filter feeding invertebrates, but attract

	crustaceans and annelids (Davies et al. 2015). Artificial lights from vessels can impact the diel vertical migration of zooplankton, triggering an escape response, zooplankton might be particularly affected in Arctic areas where zooplankton migrations are closely tied to small changes in light (Ludvigsen et al. 2018). There is no specific evidence on the effects of shading from the vessel. <u>Generic evidence</u> – Shading from low bridges results in lower abundances and diversity of macroinvertebrate communities, the reason for this is connected to reduced macrophyte biomass resulting in fewer resources and refuge from predators for the benthic invertebrates (Struck et al. 2004).
Marine fishes	Vessel at rest - Light disturbance [2] - Change in fitness [6] B22FF <u>Specific evidence</u> – Though evidence is lacking, shading is not expected to impact marine fish. There is a lack of specific evidence from effects of artificial light specifically from vessels at rest. <u>Generic evidence</u> – Artificial light can provoking behavioural responses in marine fish and increase their risk of predation. Fish may be either attracted or repelled by artificial light, depending on the species, wavelength of the light, and the amount of natural ambient light present (Ben-Yami 1976; Greer et al. 2010; Marchesan et al. 2005). The response to artificial light depends on environmental conditions, habitat, and feeding strategies (Greer et al. 2010). However, Artificial light at night attracts some fish species, and can result in increased predation by other species attracted by the light (Nightingale and Simenstad 2002; Yurk and Trites 2000). Conversely, some predatory marine fish have been documented as being averse to light, resulting in fish moving to greater depths and inhibiting foraging and spawning (Juell et al. 2003; Marchesan et al. 2005; Rich and Longcore 2006). Impacts on marine fish in the Arctic may be greater in the winter than the summer, due to the nearly constant use of vessel lights in extended hours of darkness (if vessels are present at that time of year). In the Arctic, many fish have unique sensory and behavioural adaptations for living in darkness (Hammerschlag et al. 2017) which could increase impacts of artificial light.
Marine mammals	Vessel at rest - Light disturbance [2] - Change in fitness [6] B22FM <u>Specific evidence</u> – Specific evidence on fitness effects to marine mammals from light disturbance from vessels at rest was not available. <u>Generic evidence</u> – Shading is not expected to impact marine mammals, and many would be expected to not be notably impacted by artificial lights from commercial shipping vessels at rest. In particular, cetaceans rely more on echolocation for feeding and are less inclined to be impacted by artificial light than other marine mammals, such as pinnipeds (Greer et al. 2010). Pinnipeds may be disturbed by the presence of artificial light, and have been documented to be attracted to areas of artificial light at night to feed on other organisms attracted by the light (Greer et al. 2010). Marine mammal species in the Arctic are adapted to foraging in dim light and darkness (Greer et al. 2010) which could make impacts from artificial light more significant than in other regions.
Marine reptiles	Vessel at rest - Light disturbance [2] - Change in fitness [6] B22FR <u>Specific evidence</u> – Specific evidence on fitness effects to marine reptiles from light disturbance from vessels at rest was not available. <u>Generic evidence</u> – Shading is not expected to impact marine reptiles. Though sea turtles are vulnerable to disorientation from artificial light adjacent to nesting areas (Kamrowski et al. 2012), they do not nest in Canadian waters. There is a lack of evidence of attraction or disorientation to ships lights in foraging sea turtles.
Marine birds	Vessel at rest [2] – Light disturbance - change in fitness [6] B22FB <u>Specific evidence</u> – The 24-hour high intensity lights of commercial shipping vessels at rest can disorientate and/or attract birds, which can result in birds colliding with ship structures during darkness or heavy fog, or may cause birds to fly around the light until they hit the object or collapse due to exhaustion which would result in injury or death (Arctic Council 2009; Black 2005; Bruderer et al. 1999; Hodgson et al. 2013; Huntington et al. 2015; Merkel and Johansen 2011; Schwemmer et al. 2011). <u>Generic evidence</u> – Marine birds are attracted to artificially lighted structures, such as ship lights, especially in foggy conditions when moisture droplets increase the area of light refraction (Black 2005; Merkel and Johansen 2011; Rojek 2001). In the Arctic, light attraction depends on the

	weather, season, and age of the bird but most light disturbance issues occur during fall migration (Arctic Council 2009). Light disturbance in the Arctic is not considered a high risk for bird species because most birds only reside in the Arctic in summer months; however, this risk is increased during non-breeding and ice-free periods (Arctic Council 2009).
Vessel at Rest - Light disturbance [2] - Mortality [7]	
Marine birds	Vessel at rest - Light disturbance [2] - Mortality [7] B22MB <u>Specific evidence</u> – Marine birds attracted to artificial ship lights can become disoriented and can die as a result of collisions with ship structures, and also from exhaustion following disorientation. Impacts are worse when the area of light refracted is increased due to moisture in the air (fog, low cloud) (Rojek 2001). Fast flying bird species and those that fly in large flocks are especially at risk (Schwemmer et al. 2011). The attraction of breeding populations and young seabirds to artificial light could impact reproductive fitness of endangered populations in particular (Rojek 2001). <u>Generic evidence</u> – It is well known that marine birds suffer mortalities as a result of impacts of artificial light. Marine birds are strongly attracted to artificial light and will fly around the light source for extended periods and may die due to exhaustion or collisions with lights or lighted structures (Montevecchi 2006). Impacts are particularly notable in migrating birds, nocturnal birds, and when moisture in the air increases light refraction enhancing illumination (Black 2005; Merkel and Johansen 2011; Rojek 2001). Different birds species and life stages are also impact differently.

Table B2-3 - Evidence for the **Noise disturbance [3]** stressor

Vessel at Rest - Noise disturbance [3]	
Vessels at rest generate noise due to the continuous running of ships engines, day-to-day deck activities, and the use of thrusters.	
Vessel at Rest - Noise disturbance [3] - Change in fitness [8]	
Marine inverte-brates	Vessel at rest - Noise disturbance [3] - Change in fitness [8] B23FI <u>Specific evidence</u> – Physiological responses have been observed in crabs exposed to ship noise, manifesting as increased oxygen consumption, indicating increased metabolic rate from this potential stress response (Wale et al. 2013a). Marine invertebrates in general are probably susceptible to shipping noise as they are sensitive to low frequencies (UNEP 2012). Noise disturbance may cause developmental delays or body malformations in some invertebrate larvae, as documented for scallop, sea hare, and barnacle larvae. However, one study found that tunicate larvae settled and metamorphosed faster when exposed to generator noise compared to control larvae, increasing the risk of these species fouling ships (Weilgart 2018). Blue mussels exposed to ship noise playbacks for up to six hours were found to have increased DNA breaks, lower oxygen-consumption rates, and lower algal clearance rates (Wale et al. 2019; Weilgart 2018). <u>Generic evidence</u> – In crustaceans, general impacts from noise include stress responses, foraging changes, increased locomotion and slower predator response (Tidau and Briffa 2016). Noise exposure during marine invertebrate larval development results in body malformations (De Soto et al. 2013). In shrimp, moderate noise exposure can reduce growth and reproductive rates (Lagardère 1982), and high noise levels have been reported to cause acoustic trauma in cephalopods (André et al. 2011). Noise disturbance may delay or disrupt development of larvae some invertebrate species, and has been documented for scallop, sea hare, and barnacle larvae (Weilgart 2018).
Marine fishes	Vessel at rest - Noise disturbance [3] - Change in fitness [8] B23FF <u>Specific evidence</u> – Engine and deck noise could potentially disrupt fish feeding or communication behaviour due to noise masking or displace fish from preferred feeding locations, which may lead to reduced fitness of fish species. This may have a larger effect on territorial species or those with particular habitat preferences (e.g., rockfish species). However,

	there is evidence that fish can be attracted to vessels at rest at different noise levels (Røstad et al. 2006). Boat noise may confuse the settlement process of fish onto a reef, with some individuals becoming attracted to the noise while others are repelled, and may result changes to population dynamics, predation risk, and energetic costs (Weilgart 2018). Noise disturbance can also have physical impacts. Even in only two hours, noise from an idling outboard motor was able to cause significant hearing sensitivity loss in fathead minnows (Weilgart 2018). Generic evidence – Anthropogenic noise in general has an adverse effect on fish behaviour and physiology, with some more sensitive that others (Cox et al. 2016). Vessel noise can change Tuna schooling behaviour with potential fitness implications due to impacts to migration and feeding (Sarà et al. 2007). High noise levels have been shown to affect auditory systems in fish (McCauley et al. 2003), with damage to ears or swim bladders also having the potential to impact buoyancy control and orientation (Weilgart 2018). Noise disturbance may also affect reproduction, with studies documenting impacts to parental behaviour, inappropriate agression and defensive behaviour, offspring survival, acoustic courtship, visual courtship, likelihood of spawning, and choice of nesting site (Weilgart 2018).
Marine mammals	Vessel at rest - Noise disturbance [3] - Change in fitness [8] B23FM Specific evidence – Though evidence for fitness impacts from vessels underway is available, evidence of fitness impacts to marine mammals specific to noise from vessels at rest is lacking. An anchored vessel is potentially a source of continuous sound from its pumps and auxiliary engines, generators, compressors, and other machinery. Since such low-intensity sounds could cause masking of hearing and behavioural disruption effects for marine mammals (such as displacement), this may reduce the animals' individual or population-level fitness through effects on longevity, growth, and reproduction. Generic evidence – The impact of noise disturbance on cetaceans at both the individual and population level is not well understood (DFO 2011; Nowacek et al. 2007). There has been substantial research on impacts of vessel noise on Pacific killer whales (DFO 2011, 2018c). Killer whale fitness can be affected by vessel noise through (1) Behavioural changes (e.g., switching of behavioural modes and avoidance behaviour) that can lead to reduced foraging; (2) Auditory masking – as vessel noise overlaps with the sound frequency range used by killer whales (Berchok et al. 2006; Hatch et al. 2012; Mouy et al. 2009; Tervo et al. 2011; Watkins et al. 1987), it can mask the receiving of acoustic signals used for foraging, navigation, communication and social interaction (Castellote et al. 2012; Clark et al. 2009; Erbe 1997; Erbe et al. 2016; Weilgart 2007). Masking can interfere with echolocation of prey and the effectiveness of foraging activities; and (3) Stress – being unable to avoid disturbance can cause stress, the impacts of which can be manifested through reduced reproductive success (Lusseau and Bejder 2007).
Marine birds	Vessel at rest - Noise disturbance [3] - Change in fitness [8] B23MB Specific evidence – Specific evidence of fitness effects of noise from vessels at rest to marine birds was not available, however it is expected that there is a potential effect. Generic evidence – Depending on the noise type, frequency, volume, or duration, noise may cause physical damage to birds' ears, cause responses including stress, fright-flight, or avoidance, alter behaviours such as foraging, reproduction, or predator avoidance, may mask communication or alter song characteristics, and may result in population-level changes (Ortega 2012). When played aircraft noise, any level of noise above background levels resulted in scanning and alert responses in sea birds, with increased proportions of the colony reacting with higher noise levels. When played 90 dB and 95 dB noise, startle and escape behaviours were observed by a portion of the colony (Brown 1990). Vessels with loud engines were found to cause stress responses in seabird at nesting sites from 800 m away, while quieter vessels were usually able to get within 100 m before causing disturbance (Rojek et al. 2007). Vessels passing within 500 m of seabird colonies caused behavioural responses and even when remaining for more than six hours near the nesting sites, some seabird species remained stressed with behavioural responses continuing which resulted in increased predation on eggs and chicks (Rojek et al. 2007).
Vessel at Rest - Noise disturbance [3] - Change in habitat [9]	
	Vessel at rest - Noise disturbance [3] - Change in habitat [9] B23HA

Physical habitat (acoustic)	<u>Specific evidence</u> – Though specific evidence is lacking, the continual noise produced by vessels at rest may contribute to the anthropogenic noise footprint that can impact the acoustic habitat of marine mammals, and have other impacts as described in the generic evidence. <u>Generic evidence</u> – Refer to Anchoring and Mooring PoE evidence tables for further background generic evidence of effects of this stressor to this endpoint (Table B1-4, reference B14HA).

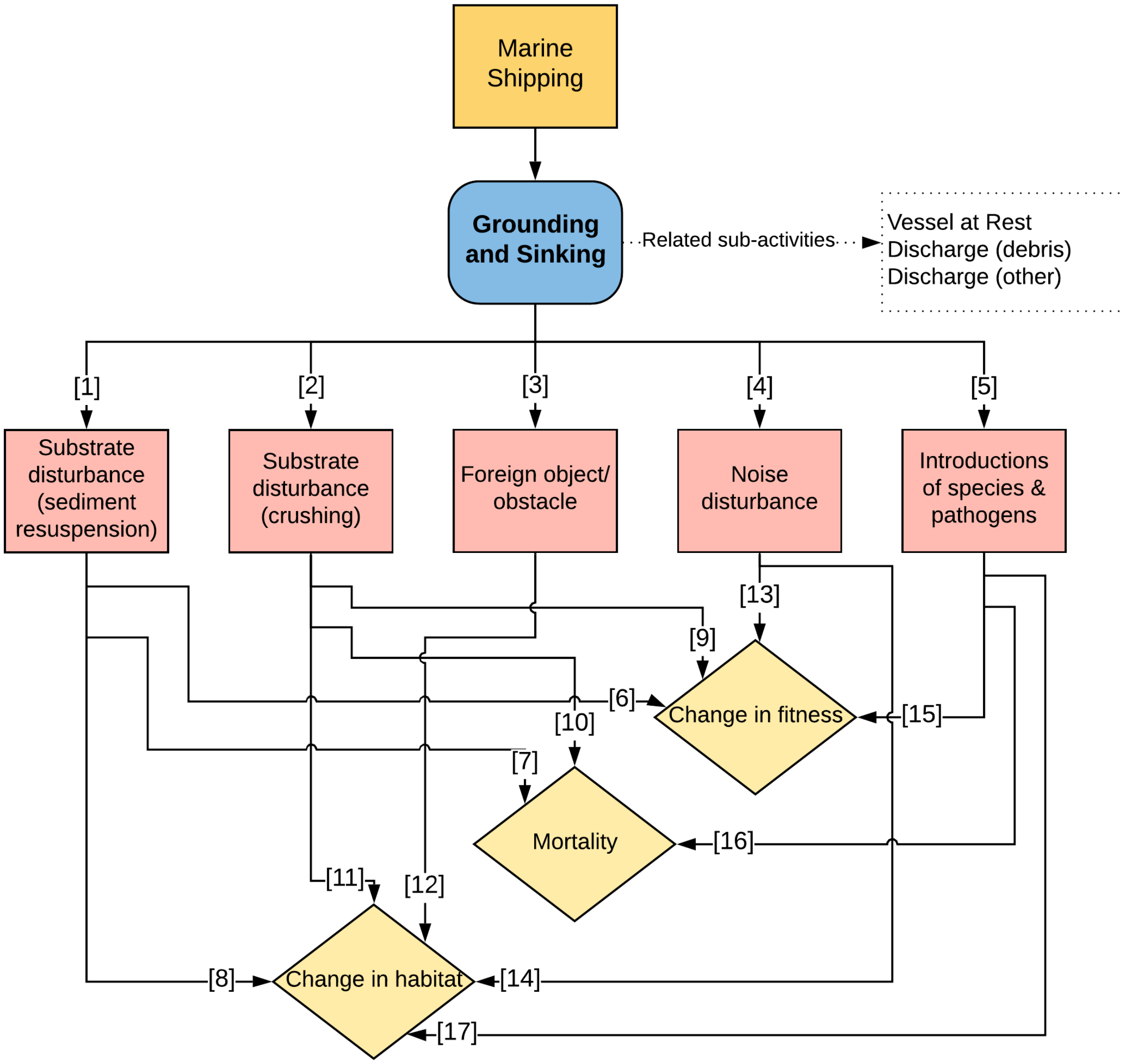
Table B2-4 - Evidence for the **Introductions of species and pathogens [4]** stressor (Vessel at Rest PoE model)

Vessel at Rest - Introductions of species and pathogens [4]	
Introductions of species **-** Non-native aquatic invasive species (AIS) fouling the hulls of vessels at rest have the potential to spread to the area around the vessel. *Introductions of pathogens* - Examines the impacts of pathogens introduced through vessels at rest.	
Vessel at Rest - Introductions of species and pathogens [4] - Change in fitness [10]	
Marine plants and algae	Vessel at rest - Introductions of species and pathogens [4] - Change in fitness [10] B24FP **Introductions of species** <u>Specific evidence</u> – Some introduced species that are spread by shipping, and can be found in the biofouling of vessels at rest, such as the colonial ascidian *Didemnum* sp., are able to spread rapidly and smother algae (Daniel and Therriault 2007). Increased mooring time is associated with increased invasion risk because it allows more time for species to accumulate (Chan et al. 2011). One of the primary vectors of the invasive alga *Codium* is ship hulls (Ansell et al. 1998) and *Codium fragile* var. *tomentosoides* has been observed to attach to and overgrow eelgrass (Locke et al. 2002). Buoyancy resulting from the production and trapping of gases by *Codium* can pull up the whole eelgrass plant, which is then cast up on the shore and may die. *Codium* has spread rapidly to become a dominant and persistent component of seaweed assemblages in the rocky low intertidal to subtidal zones of the Atlantic coast of Nova Scotia (Scheibling and Anthony 2001). In this area, *Codium* can form continuous meadows, often replacing entire kelp beds and occurring to a depth of 15 m (Chapman 1998). <u>Generic evidence</u> – Refer to Anchoring and Mooring PoE for generic evidence from this stressor to this endpoint (Table B1-6, reference B16FP). **Introductions of pathogens** <u>Specific evidence</u> – Though there is evidence of pathogens present in hull fouling biota (Revilla-Castellanos et al. 2015), the species identified are not known to impact marine biota. Evidence is lacking to describe whether pathogens affecting marine biota are present in hull fouling biota of vessels at rest and how these can affect marine plants and algae. <u>Generic evidence</u> – Refer to Anchoring and Mooring PoE for generic evidence from this stressor to this endpoint (Table B1-6, reference B16FP).
Marine invertebrates	Vessel at rest - aquatic invasive species [4] - Change in fitness [10] B24FI **Introductions of species** <u>Specific evidence</u> – Some introduced species are spread by shipping and can be found on hulls of vessels at rest, such as the colonial ascidian *Didemnum* sp., are able to spread rapidly and smother marine invertebrates such as sponges, hydroids, anemones, limpets, oysters, mussels, scallops, barnacles, bryozoans, corals, ascidians, and other invertebrates, may change the plankton composition or amount available to other species, and prevent invertebrate larval settlement onto substrata (Daniel and Therriault 2007). Increased mooring time is associated with increased invasion risk because it allows more time for species to accumulate (Chan et al. 2011). <u>Generic evidence</u> – Refer to Anchoring and Mooring PoE for generic evidence from this stressor to this endpoint (Table B1-6, reference B15FI). **Introductions of pathogens**

	Specific evidence – No evidence specific to this sub-activity was available. Generic evidence – Refer to Anchoring and Mooring PoE for generic evidence from this stressor to this endpoint (Table B1-6, reference B15FI).
Marine fishes	Vessel at rest - Introductions of species and pathogens [4] - Change in fitness [10] B24FF **Introductions of species** Specific evidence – Species that may be introduced via ship hulls, such as the colonial ascidian *Didemnum* sp., may impact fish populations by smothering food organisms which may result in fish leaving the area, and may prevent successful reproduction through damage of fish eggs and larvae as they settle onto its acidic tunic (Daniel and Therriault 2007). Increased mooring time is associated with increased invasion risk because it allows more time for species to accumulate (Chan et al. 2011). Generic evidence – Refer to Anchoring and Mooring PoE for generic evidence from this stressor to this endpoint (Table B1-6, reference B16FF). **Introductions of pathogens** Specific evidence – No evidence specific to this sub-activity could be found at this time, however as hull biofouling can contain pathogens (Revilla-Castellanos et al. 2015), biofouling associated with vessels at rest may also can harbour pathogens which could potentially cause fitness effects in marine fishes. Generic evidence – Refer to Anchoring and Mooring PoE for generic evidence from this stressor to this endpoint (Table B1-6, reference B16FF).
Vessel at Rest - Introductions of species and pathogens [4] - Mortality [11]	
Marine plants and algae	Vessel at rest - Introductions of species and pathogens [4] - Mortality [11] B24MP **Introductions of species** Specific evidence – Some of the AIS known to be introduced through shipping (including from fouled hulls of vessels at rest) such as colonial tunicates, can cause mortality in native marine plants and algae by overgrowing and smothering these species (Daniel and Therriault 2007). Increased mooring time is associated with increased invasion risk because it allows more time for species to accumulate (Chan et al. 2011). *Codium fragile* var. *tomentosoides*, introduced through multiple vectors including hulls (Ansell et al. 1998), has been observed to attach to and overgrow eelgrass (Locke et al. 2002). *Codium* attached to eelgrass can pull up the whole plant due to the increased buoyancy resulting from the production and trapping of gases (Scheibling and Anthony 2001). Generic evidence – Refer to Anchoring and Mooring PoE for generic evidence from this stressor to this endpoint (Table B1-6, reference B16MP). **Introductions of pathogens** Specific evidence – No evidence specific to this sub-activity could be found at this time. Generic evidence – Refer to Anchoring and Mooring PoE for generic evidence from this stressor to this endpoint (Table B1-6, reference B16MP).
Marine invertebrates	Vessel at rest - Introductions of species and pathogens [4] - Mortality [11] B24MI **Introductions of species** Specific evidence – Some species introduced through shipping are able to overgrow and smother native invertebrate species and may also prevent benthic larval settlement (Daniel and Therriault 2007). Increased mooring time is associated with increased invasion risk because it allows more time for species to accumulate (Chan et al. 2011). Generic evidence – Refer to Anchoring and Mooring PoE for generic evidence from this stressor to this endpoint (Table B1-6, reference B16MI). **Introductions of pathogens** Specific evidence – No evidence specific to this sub-activity could be found at this time.

	Generic evidence – Refer to Anchoring and Mooring PoE for generic evidence from this stressor to this endpoint (Table B1-6, reference B16MI).
Marine fishes	Vessel at rest - Introductions of species and pathogens [4] - Mortality [11] B24MF **Introductions of species** Specific evidence – Some species introduced through hull fouling have defense strategies, such as an acidic tunic, that could kill fish eggs or larval fish settling on its surface (Daniel and Therriault 2007). Increased mooring time is associated with increased invasion risk because it allows more time for species to accumulate (Chan et al. 2011). Generic evidence – Refer to Anchoring and Mooring PoE for generic evidence from this stressor to this endpoint (Table B1-6, reference B16MF). **Introductions of pathogens** Specific evidence – No evidence specific to this sub-activity could be found at this time. Generic evidence – Refer to Anchoring and Mooring PoE for generic evidence from this stressor to this endpoint (Table B1-6, reference B16MF).
Vessel at Rest - Introductions of species and pathogens [4] - Change in habitat [12]	
Physical habitat (substrate)	Vessel at rest - Introductions of species and pathogens [4] - Change in habitat [12] B24HS **Introductions of species** Specific evidence – Some introduced species, such as the colonial ascidian *Didemnum* sp., are able to spread rapidly and smother habitat-forming species such as algae, sponges, oysters, mussels, barnacles, and corals, and may change the plankton composition or amount available to other species, and prevent larval settlement onto substrata (Daniel and Therriault 2007). *Acrothamnion preissii* and *Womersleyella setacea*, algae probably introduced via ship transport to the Mediterranean Sea, now form dense turfs in some areas that cover rock, macrophytes, and seagrasses, and also trap sediment, which changes the substratum and prevents other macrophyte species from settling (CIESM 2002). Increased mooring time is associated with increased invasion risk because it allows more time for species to accumulate (Chan et al. 2011). Generic evidence – Refer to Anchoring and Mooring PoE for generic evidence from this stressor to this endpoint (Table B1-6, reference B16HS). **Introductions of pathogens** Specific evidence – No evidence specific to this sub-activity could be found at this time. Generic evidence – Refer to Anchoring and Mooring PoE for generic evidence from this stressor to this endpoint (Table B1-6, reference B16HS).

APPENDIX B3: GROUNDING AND SINKING TABLES OF EVIDENCE



Definition: The Grounding and Sinking sub-activity considers the grounding (a vessel impacting the seabed or underwater objects), and sinking (when a commercial vessel sinks and reaches the seabed to become a shipwreck) of commercial vessels. This sub-activity has five associated stressors: substrate disturbance (sediment resuspension) (Table B3-1); substrate disturbance (crushing) (Table B3-2); foreign object/obstacle (Table B3-3); noise disturbance (Table B3-4); and introductions of species & pathogens (Table B3-5).

Tables of evidence are provided for each stressor in the following pages, based on the order outlined in the PoE diagram above. *Specific* evidence refers to information specific to that linkage, whereas *generic* evidence is broader evidence that can provide insight where specific evidence is not available. *Not applicable* generic evidence indicates this is the sole linkage and that specific evidence is available. *Not available* indicates that no evidence was found for that linkage.

Table B3-1 - Evidence for the **Substrate disturbance (sediment resuspension) [1]** stressor

Grounding and Sinking - Substrate disturbance (sediment resuspension) [1]	
The physical interaction between a vessel and the seabed during a grounding or sinking event can cause sediments to become resuspended. Sediment produced from grounding and sinking events are expected to be a large influx in a short period of time.	
Grounding and Sinking - Substrate disturbance (sediment resuspension) [1] - Change in fitness [6]	
Marine plants and algae	Grounding and Sinking - Substrate disturbance (sediment resuspension) [1] - Change in fitness [6] B31FP Specific evidence – The settling of suspended sediments can result in reduced fitness of biogenic habitat species, such as seagrass (Airoldi 2003). Resuspended sediment reduces the availability of light and reduces photosynthetic capacity, resulting in impaired growth (den Hartog and Phillips 2001; Hemminga 1998). The magnitude and area of effect will depend on the amount and coarseness of the sediment and the velocity of currents in the vicinity of the grounding. Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Table B1-1, reference B11FP).
Marine invertebrates	Grounding and Sinking - Substrate disturbance (sediment resuspension) [1] - Change in fitness [6] B31FI Specific evidence – Subsequent settling of suspended sediments can result in reduced fitness of biogenic habitat species, such as corals and sponges (Airoldi 2003). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Table B1-1, reference B11FI).
Marine fishes	Grounding and Sinking - Substrate disturbance (sediment resuspension) [1] - Change in fitness [6] B31FF Specific evidence – Not available. There may be a short term avoidance of the sediment plume produced by fish in the area. Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Table B1-1, reference B11FF).
Grounding and Sinking – Substrate disturbance (sediment resuspension) [1] – Mortality [7]	
Marine plants and algae	Grounding and Sinking - Substrate disturbance (sediment resuspension) [1] - Mortality [7] B31MP Specific evidence – Sediment displaced by grounding or propeller action can settle on nearby seagrass beds. When sediment is not removed by storms or currents, seagrasses covered by the resuspended sediment may suffer mortality (Whitfield et al. 2002). Continued reduction in light and photosynthetic capacity caused by resuspended sediment may ultimately result in mortality (den Hartog and Phillips 2001; Hemminga 1998). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Table B1-1, reference B11MP).
Marine invertebrates	Grounding and Sinking - Substrate disturbance (sediment resuspension) [1] - Mortality [7] B31MI Specific evidence – Not available. It is expected that sediment produced from grounding and sinking could be a significant amount generated within a short period of time in a localised area that could result in mortality of affected benthic invertebrates. Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Table B1-1, reference B11MI).
Marine fishes	Grounding and Sinking - Substrate disturbance (sediment resuspension) [1] - Mortality [7] B31MF Specific evidence – Not available. Evidence is lacking as to whether the increased suspended sediments specifically from grounding and sinking could result in mortality to this endpoint. Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Table B1-1, reference B11MF).

Grounding and Sinking - Substrate disturbance (sediment resuspension) [1] - Change in habitat [8]	
Physical habitat (substrate)	Grounding and Sinking - Substrate disturbance (sediment resuspension) [1] – Change in habitat [8] B31HS Specific evidence – The arrival of a shipwreck to the seabed increases flow velocity and turbulent intensity around the wreck (Quinn 2006). Sediments can be moved and resuspended due to these changes in the water flow (from a fully submerged shipwreck), potentially altering physical habitat. Shipwrecks can cause the creation of scour pits in mobile sediment, and scouring processes around shipwrecks can occur for decades (Quinn 2006). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Table B1-1, reference B11HS).
Physical habitat (Water column)	Grounding and Sinking - Substrate disturbance (sediment resuspension) [1] – Change in habitat [8] B31HW Specific evidence – Not available. It is posited that resuspended sediment caused by grounding or sinking ships could have a temporary impact on water quality, which depending on the movement of the vessel, could persist throughout the duration the ship is in contact with the substrate. The agitating of the seafloor by the vessel may increase turbidity and nutrient loading in the water column. Supporting evidence not available. Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Table B1-1, reference B11HW).

Table B3-2 - Evidence for the **Substrate disturbance (crushing) [2]** stressor

Grounding and Sinking - Substrate disturbance (crushing) [2]	
The physical interaction between a vessel and the seabed during a grounding or sinking event can crush the substrate it encounters.	
Grounding and Sinking - Substrate disturbance (crushing) [2] - Change in fitness [9]	
Marine plants and algae	Grounding and Sinking - Substrate disturbance (crushing) [2] - Change in fitness [9] B32FP Specific evidence – Fronds of algae, such as *Fucus serratus* and *Chondrus crispus*, could be torn off by the abrasion of ships grounding, reducing photosynthetic ability and affecting fitness (Tyler-Walters et al. 2005). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Table B1-2, reference B12FP).
Marine invertebrates	Grounding and Sinking - Substrate disturbance (crushing) [2] - Change in fitness [9] B32FI Specific evidence – Abrasion due to grounding is likely to scrape off patches of hydroids, bryozoans, ascidians, sponges, and other encrusting fauna (Tyler-Walters et al. 2005). It is expected that marine invertebrates and plants that have been crushed or partially crushed without resulting in mortality will have reduced growth rate or reproductive capacity. Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Table B1-2, reference B12FI).
Grounding and Sinking - Substrate disturbance (crushing) [2] - Mortality [10]	
Marine plants and algae	Grounding and Sinking - Substrate disturbance (crushing) [2] - Mortality [10] B32MP Specific evidence – Sinking can lead to the elimination of benthic biota, particularly marine plants present within the footprint occupied by the sunken vessel (Hudson and Goodwin 2001). (Oral and Öztürk 2006) emphasise that the impacts of grounding on seagrass are considerable. Benthic flora may be lost due to the abrasion of grounding and wreck movement (Ross et al. 2016). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Table B1-2, reference B12MP).

Marine invertebrates	Grounding and Sinking - Substrate disturbance (crushing) [2] - Mortality [10] B32MI Specific evidence – Benthic marine invertebrates present within the footprint occupied by the sunken vessel can be crushed and eliminated (Hudson and Goodwin 2001). The impacts of grounding on mussel beds can be substantial (Oral and Öztürk 2006). Abrasion due to grounding is likely to scrape off patches of hydroids, bryozoans, ascidians, sponges, and other encrusting fauna, and the shells of mussels, limpets, periwinkles, and the tubes of tubeworms may be crushed (Tyler-Walters et al. 2005). Benthic animals may be removed by the abrasion of grounding and subsequent wreck movement (Ross et al. 2016). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Table B1-2 reference B12MI).
Marine fishes	Grounding and Sinking - Substrate disturbance (crushing) [2] - Mortality [10] B32MF Specific evidence – Evidence of direct effects from crushing of marine fishes from grounding and sinking was not available. However, it is expected that vessels have the potential to crush benthic fish in the area, particularly types that bury themselves in soft sediments (e.g., flat fish). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Table B1-2 reference B12MF).
Grounding and Sinking - Substrate disturbance (crushing) [2] - Change in habitat [11]	
Physical habitat (substrate)	Grounding and Sinking - Substrate disturbance (crushing) [2] - Change in habitat [11] B32HS Specific evidence – Physical habitats can be crushed as the vessel makes contact with the seafloor at the time of the incident and can continue if the vessel breaks apart or if the wreck shifts on the seafloor due to currents and high-energy events. Effects on physical benthic habitats and species resulting from abrasion by ship hulls is mainly restricted to shallow-water areas, including shoals, the inner reaches of harbours, bays and inlets, and navigation canals (Abdulla and Linden 2008). The crushing and compacting of physical habitats can result in a reduction in the complexity of the substrate (Dennis and Bright 1988). When vessels run aground in a seagrass meadow, boat operators may attempt to dislodge by powering out of the shallow area. This can cause the propeller to excavate all of the seagrasses and some of the underlying sediments. The steep gradient caused by this may be unstable and vulnerable to further damage (Whitfield et al. 2002). Propellers may excavate the sediments of seagrass meadows if they reach deep enough, which may injure the seagrass rhizomes and roots. The removal of the stabilizing plant structures may cause the sediment to become unstable and difficult to restore (Kenworthy et al. 2002). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Table B1-2, reference B12HS)
Physical habitat (sea ice)	Grounding and Sinking - Substrate disturbance (crushing) [2] - Change in habitat [11] B32HI Specific evidence – Not available at this time. Generic evidence – The effects of grounding and sinking could have some similar, though smaller scale, effects as ice displacement from intentional icebreaking of vessels underway (Table B4-6, reference B46HI). However, in the case of grounding and sinking, the effect would be smaller scale and localised to the area of the grounded or sunk vessel.

Table B3-3 - Evidence for the **Foreign object/obstacle) [3]** stressor

Grounding and Sinking - Foreign object/obstacle [3]	
The grounded, damaged or sunken ship can act as a foreign object / obstacle in the water column and seabed, that otherwise would not be present to biota in the area.	
Grounding and Sinking - Foreign object/obstacle[3] - Change in habitat [12]	
Physical habitat (substrate)	Grounding and Sinking - Foreign object/obstacle [3] - Change in habitat [12] B33HS Specific evidence – The introduction of foreign material as the result of sunken vessels alters the existing habitat structure due to the materials introduced and physical stratification (Perkol-Finkel

	and Benayahu 2004; Smiley 2006; Walker et al. 2019). The effect of this stressor on physical habitats is particularly notable in areas dominated by soft sediments, with the sudden introduction of suitable settlement substrates resulting in an increase in biogenic habitats (e.g., corals, sponges, marine plants, etc.). The hard substrate of a shipwreck can provide habitat for algae and fish species, acting as an island on a muddy seafloor (Meyer et al. 2017). If the wrecked ship remains on the seafloor, it may act as new habitat for both motile and sessile fauna (Meyer et al. 2017). The new habitat created by the presence of the foreign object can increase local heterogeneity and biodiversity (Perkol-Finkel and Benayahu 2004; Ramirez-Llodra et al. 2011), but only if hazardous materials are not present (Walker et al. 2019). Colonization of sunken vessels is initially slow, but can have as many as four successional waves in the first decade (Hiscock et al. 2010; Walker et al. 2019). Fouling communities that form on wood or concrete are more likely to resemble natural reefs, while those on steel-based artificial reefs are restricted by the reduced encrustation caused of antifouling paint (Walker et al. 2019). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Table B1-3, reference B13HS).
Physical habitat (water column)	Grounding and Sinking - Foreign object/obstacle [3] - Change in habitat [12] B33HW Specific evidence – The presence of a grounded or sunken vessel in the water column may cause a change in the physical habitat of the water column, especially for larger fauna such as cetaceans, turtles, and sharks. Marine mammals and turtles lacking echolocation could collide with submerged ships or be forced to navigate around them. Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Table B1-3, reference B13HW).

Table B3-4 - Evidence for the **Noise disturbance [4]** stressor

Grounding and Sinking - Noise disturbance [4]	
Noise may be produced by the impact of vessels on the seabed when grounding or sinking, while no information is available on this specific linkage, it can potentially have a temporary disturbance effect on marine invertebrates, fishes, mammals and reptiles. Refer to Movement underway for consideration of the impacts from noise of a vessel underway, including when icebreaking (Table B4-4).	
Grounding and Sinking - Noise disturbance - Change in fitness [13]	
Marine invertebrates	Grounding and Sinking - Noise disturbance [4] - Change in fitness [13] B34FI Specific evidence – Not available. Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects of this stressor to this endpoint (Table B1-4, reference B14FI).
Marine fishes	Grounding and Sinking - Noise disturbance [4] - Change in fitness [13] B34FF Specific evidence – Not available. Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects of this stressor to this endpoint (Table B1-4, reference B14FF).
Marine mammals	Grounding and Sinking-Noise disturbance [4] - Change in fitness [13] B34FM Specific evidence – Not available. Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects of this stressor to this endpoint (Table B1-4, reference B14FM).
Marine reptiles	Grounding and Sinking-Noise disturbance [4] - Change in fitness [13] B34FR Specific evidence – Not available. Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects of this stressor to this endpoint (Table B1-4, reference B14FR).

Marine birds	Grounding and Sinking-Noise disturbance [4] - Change in fitness [13] B34FB Specific evidence – Not available. Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects of this stressor to this endpoint (Table B1-4, reference B14B).
Grounding and Sinking - Noise disturbance - Change in habitat [14]	
Physical habitat (acoustic)	Grounding and Sinking - Noise disturbance [4] - Change in habitat [14] B34FR Specific evidence – While no specific evidence could be found, grounded or sunken vessels rocking on the substrate in response to wave action may generate ongoing noise that could affect acoustic habitat. Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for further background generic evidence of effects of this stressor to this endpoint (Table B1-4, reference B14HA).

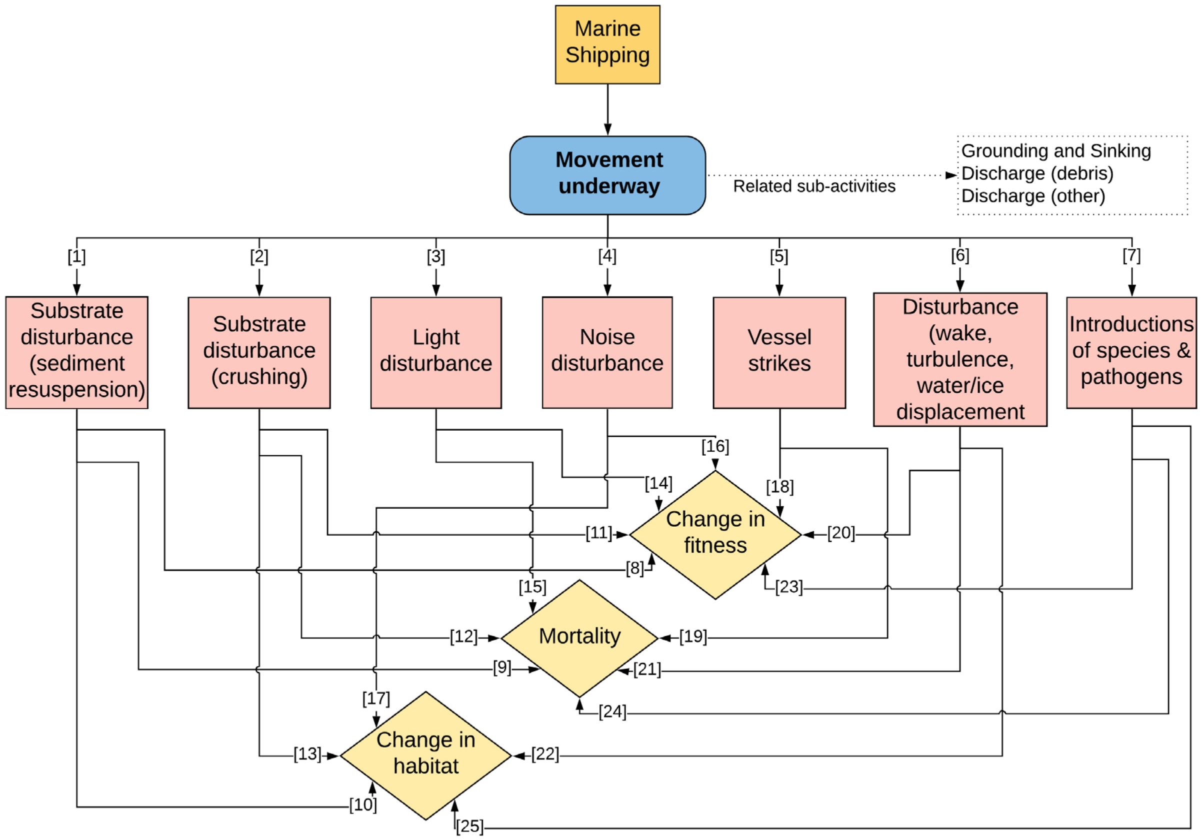
Table B3-5 - Evidence for the **Introductions of species and pathogens [5]** stressor

Grounding and Sinking – Introductions of species and pathogens [5]	
Introductions of species - Grounding of ships on the seafloor may dislodge aquatic invasive species from vessel hulls and leave them in other habitats, and sunken ships can provide habitat to aquatic invasive species. Refer to Discharge (other) PoE for discussion of AIS introduction by ballast water release. *Introductions of pathogens* - Examines the impacts of pathogens introduced to the environment through grounding and sinking ships.	
Grounding and Sinking - Introductions of species and pathogens [5] - Change in fitness [15]	
Marine plants and algae	Grounding and Sinking – Introductions of species and pathogens [5] - Change in fitness [15] B35FP **Introductions of species** Specific evidence – Non-indigenous species may use shipwrecks as stepping stones into new areas (Creed et al. 2017). Once present, some species introduced through shipping are able to overgrow and smother algae (Daniel and Therriault 2007). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects of this stressor to this endpoint (Table B1-6, reference B16FP). **Introductions of pathogens** Specific evidence – No evidence specific to this sub-activity could be found at this time. Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects of this stressor to this endpoint (Table B1-6, reference B16FP).
Marine invertebrates	Grounding and Sinking - Introductions of species and pathogens [5] - Change in fitness [15] B35FI **Introductions of species** Specific evidence – Shipwrecks can favour the emergence of invasive species, providing habitat for them and impacting the fitness of other marine life when the AIS competes for resources (Work et al. 2008). Shipwrecks may be colonised by a wide variety of marine invertebrate species, including non-native species (aquatic invasive species) that may out-compete native species (Bieler et al. 2017). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects of this stressor to this endpoint (Table B1-6, reference B16FI). **Introductions of pathogens** Specific evidence – No evidence specific to this sub-activity could be found at this time. Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects of this stressor to this endpoint (Table B1-6, reference B16FI).

Marine Fishes	Grounding and Sinking - Introductions of species and pathogens [5] - Change in fitness [15] B35FF **Introductions of species** Specific evidence – Non-indigenous species may use shipwrecks as stepping stones into new areas (Creed et al. 2017). Introduced species such as the colonial ascidian *Didemnum* sp. may impact fish populations by smothering food organisms, which may result in fish leaving the area, or may prevent successful reproduction through damage of fish eggs and larvae as they settle onto its acidic tunic (Daniel and Therriault 2007). Generic evidence – Refer to Anchoring and Mooring PoE for generic evidence from this stressor to this endpoint (Table B1-6, reference B16FF). **Introductions of pathogens** Specific evidence – No evidence specific to this sub-activity could be found at this time. Generic evidence – Refer to Anchoring and Mooring PoE for generic evidence from this stressor to this endpoint (Table B1-6, reference B16FF).
Grounding and Sinking - Introductions of species and pathogens [5] - Mortality [16]	
Marine plants and algae	Grounding and Sinking - Introductions of species and pathogens [5] - Mortality [16] B35MP **Introductions of species** Specific evidence – Non-indigenous species may use shipwrecks as stepping stones into new areas (Creed et al. 2017). Once present, some species introduced through shipping are able to overgrow and smother algae (Daniel and Therriault 2007). Generic evidence – Refer to Anchoring and Mooring PoE for generic evidence from this stressor to this endpoint (Table B1-6, reference B16MP). **Introductions of pathogens** Specific evidence – No evidence specific to this sub-activity could be found at this time. Generic evidence – Refer to Anchoring and Mooring PoE for generic evidence from this stressor to this endpoint (Table B1-6, reference B16MP).
Marine invertebrates	Grounding and Sinking - Introductions of species and pathogens [5] - Mortality [16] B35MI **Introductions of species** Specific evidence – Non-indigenous species may use shipwrecks as stepping stones into new areas (Creed et al. 2017). Once present, some species introduced through shipping are able to overgrow and smother native species and may also prevent benthic larval settlement (Daniel and Therriault 2007). Generic evidence – Refer to Anchoring and Mooring PoE for generic evidence from this stressor to this endpoint (Table B1-6, reference B16MI). **Introductions of pathogens** Specific evidence – No evidence specific to this sub-activity could be found at this time. Generic evidence – Refer to Anchoring and Mooring PoE for generic evidence from this stressor to this endpoint (Table B1-6, reference B16MI).
Marine fishes	Grounding and Sinking - Introductions of species and pathogens [5] - Mortality [16] B35MF **Introductions of species** Specific evidence – Non-indigenous species may use shipwrecks as stepping stones into new areas (Creed et al. 2017). Once present, some species introduced through shipping have defense strategies, such as an acidic tunic, that could kill fish eggs or larval fish settling on its surface (Daniel and Therriault 2007). Generic evidence – Refer to Anchoring and Mooring PoE for generic evidence from this stressor to this endpoint (Table B1-6, reference B16MF). **Introductions of pathogens** Specific evidence – No evidence specific to this sub-activity could be found at this time.

	Generic evidence – Refer to Anchoring and Mooring PoE for generic evidence from this stressor to this endpoint (Table B1-6, reference B16MF).
Grounding and Sinking - Introductions of species and pathogens [5] - Change in habitat [17]	
Physical habitat (substrate)	Grounding and Sinking - Introductions of species and pathogens [5] - Change in habitat [17] B35HS **Introductions of species** Specific evidence – Species that are attached to a ship when it grounds or sinks would then be able to access the surrounding environment. A ship that remains in the habitat rather than being recovered could also act as new habitat, which could also act as a stepping stone for those species into other environments (Creed et al. 2017). A sunken trawler off New Zealand was a potential source of the invasive alga *Undaria pinnatifida*, though it was successfully eradicated before it could spread (Wotton et al. 2004), but had management been unsuccessful, *U. pinnatifida* has the potential to alter reef habitat by obstructing refuges (Irigoyen et al. 2011). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects of this stressor to this endpoint (Table B1-6, reference B16HS). **Introductions of pathogens** Specific evidence – No evidence specific to this sub-activity could be found at this time. Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects of this stressor to this endpoint (Table B1-6, reference B16HS).

APPENDIX B4: MOVEMENT UNDERWAY TABLES OF EVIDENCE



Definition: The movement underway sub-activity considers the action of a commercial vessel in transit from one port of call to another. While underway, the vessel is under power and travelling through the water. This sub-activity has seven associated stressors: sediment disturbance (sediment resuspension) (Table B4-1), substrate disturbance (crushing) (Table B4-2), light disturbance (Table B4-3), noise disturbance (Table B4-4), vessel strikes (Table B4-5), disturbance (wake, turbulence, water/ice displacement) (Table B4-6), and introductions of species and pathogens (Table B4-7).

Tables of evidence are provided for each stressor in the following pages, based on the order outlined in the PoE diagram above. *Specific* evidence refers to information specific to that linkage, whereas *generic* evidence is broader evidence that can provide insight where specific evidence is not available. *Not applicable* generic evidence indicates this is the sole linkage and that specific evidence is available. *Not available* indicates that no evidence was found for that linkage.

Table B4-1 – Evidence for the **Substrate disturbance (sediment resuspension) [1]** stressor

Movement underway - Substrate disturbance (sediment resuspension) [1]	
Vessel movement can cause the resuspension of sediments through hull-generated waves and turbulence, and propeller wash. Refer to Grounding and Sinking PoE for sediment resuspended from contact with the seabed.	
Movement underway - Substrate disturbance (sediment resuspension) [1] - Change in fitness [8]	
Marine plants and algae	Movement underway - Substrate disturbance (sediment resuspension) [1] - Change in fitness [8] B41FP Specific evidence – Vessel-waves impact the fitness of algal species due to the increases in turbidity and nutrient loading they can produce (Demes et al. 2012). The movement of propellers can increase suspended sediments, decrease light penetration and thus impede photosynthesis (Beachler and Hill 2003). Frequent episodes of resuspended sediment and nutrients in the water column by vessel wake and turbulence can result in a reduction in light availability, increased phytoplankton populations and excessive epiphyte loading on marine plant leaves (Buzzelli et al. 1998; Gordon et al. 1994; Onuf 1996; Silberstein et al. 1986). This reduction in light and photosynthetic capacity result in impaired growth and mortality (den Hartog and Phillips 2001; Hemminga 1998) and has been linked to changes in species composition in macrophyte communities (Murphy and Eaton 1983). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Table B1-1, reference B11FP).
Marine invertebrates	Movement underway - Substrate disturbance (sediment resuspension) [1] - Change in fitness [8] B41FI Specific evidence – Disturbance from wakes decreased bivalve mollusc (*Crassostrea virginica*) fitness due to increased sediment loads, plus relative water motion, and percent silt/clay, and may also reduce its reproductive success through substrate disruption (Wall et al. 2005). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Table B1-1, reference B11FI).
Marine fishes	Movement underway - Substrate disturbance (sediment resuspension) [1] - Change in fitness [8] B41FF Specific evidence – Sublethal effects of suspended sediment has been documented for a range of fish species. Under varying concentrations of sediment, marine fish may exhibit reduction in growth rate, interruption of feeding behaviours, and decreased health (Newcombe and MacDonald 1991). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Table B1-1, reference B11FF).
Movement underway - Substrate disturbance (sediment resuspension) [1] - Mortality [9]	
Marine plants and algae	Movement underway - Substrate disturbance (sediment resuspension) [1] - Mortality [9] B41MP Specific evidence – Often, sediment displaced by grounding or propeller action will settle on nearby seagrass beds. When sediment is not removed by storms or currents, seagrasses covered by the resuspended sediment may die (Whitfield et al. 2002). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Table B1-1, reference B11MP).
Marine invertebrates	Movement underway - Substrate disturbance (sediment resuspension) [1] - Mortality [9] B41MI Specific evidence – Oyster reefs affected by boat wake have higher sediment loads and lower juvenile survival, producing dead margins at the edges of reefs most affected by water motion and sediment resuspension (Wall et al. 2005). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Table B1-1, reference B11MI).
	Movement underway - Substrate disturbance (sediment resuspension) [1] - Mortality [9] B41MF

Marine fishes	Specific evidence – The avoidance response to bird and fish predators may be reduced for some fish species in increased turbidity. Fine particles of resuspended sediment may coat respiratory epithelia, cutting off gas exchange, and larger particles can be trapped by gill lamellae and cause asphyxiation at high concentrations (Wilber and Clarke 2001). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Table B1-1, reference B11MF).
Movement underway - Substrate disturbance (sediment resuspension) [1] - Change in habitat [10]	
Physical habitat (substrate)	Movement underway - Substrate disturbance (sediment resuspension) [1] - Change in habitat [10] B41HS Specific evidence – In shallow water, turbulence from propellers and the hydrodynamic effects of the passing hull can re-suspend benthic sediments, increasing volume of suspended sediments in the water and decreasing light penetration to the substratum (Abdulla and Linden 2008; Beachler and Hill 2003). Ships navigating in shallow water areas, such as embayments, canals, straits and the inner reaches of harbours and ports, tend to stir up sediments from soft bottoms, washing out finer sediments, leaving coarser fractions *in situ* (Abdulla and Linden 2008; Ali et al. 1999; Fonseca and Bell 1998). This can result in nearshore sediments with low organic matter content (Ali et al. 1999) and changing the substrate composition towards coarser grain deposits, which may promote a change in habitat characteristics (Ali et al. 1999; Bishop 2003). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Table B1-1, reference B11HS).
Physical habitat (water column)	Movement underway - Substrate disturbance (sediment resuspension) [1] - Change in habitat [10] B41HW Specific evidence – Oyster reefs near major boating channels have higher total sediment loads, silt/clay fractions and relative water motion (Wall et al. 2005). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Table B1-1, reference B11HW)

Table B4-2 - Evidence for the **Substrate disturbance (crushing) [2]** stressor

Movement underway - Substrate disturbance (crushing) [2]	
Vessel movement has the potential to crush the substrate it encounters when moving through shallow areas. This stressor differs from grounding in that the vessel keeps moving, rather than coming to a complete stop.	
Movement underway - Substrate disturbance (crushing) [2] - Change in fitness [11]	
Marine plants and algae	Movement underway - Substrate disturbance (crushing) [2] - Change in fitness [11] B42FP Specific evidence – Aquatic plants, such as seagrass beds, are vulnerable to damage from propellers (Bell et al. 2002). Seagrass meadows may be sheared by propellers; the rhizomes and roots of seagrass plants could be injured if a propeller reaches deep enough to excavate the sediments. The excavated sediment is one of the primary nutrient sources for the plants (Kenworthy et al. 2002). Fronds of algae, such as *Fucus serratus* and *Chondrus crispus*, could be torn off by the abrasion by vessels, reducing their ability to photosynthesise (Tyler-Walters et al. 2005). Large kelps such as *Macrocystis pyrifera* may be susceptible to damage or destruction due to vessel or propeller impact. Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Table B1-2, reference B12FP).
Marine invertebrates	Movement underway - Substrate disturbance (crushing) [2] - Change in fitness [11] B42FI Specific evidence – Abrasion due to grounding is likely to scrape off patches of hydroids, bryozoans, ascidians, sponges, and other encrusting fauna (Tyler-Walters et al. 2005).

	Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Table B1-2, reference B12FI).
Marine Fishes	Movement underway - Substrate disturbance (crushing) [2] - Change in fitness [11] B42FF Specific evidence – Evidence of direct effects from crushing of marine fishes from vessels underway was not available. However, it is expected that vessels have the potential to crush benthic fish in the area, particularly types that bury themselves in soft sediments (e.g., flat fish). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Table B1-2 reference B12MF).
Movement underway - Substrate disturbance (crushing) [2] - Mortality [12]	
Marine plants and algae	Movement underway - Substrate disturbance (crushing) [2] - Mortality [12] B42MP Specific evidence – Seagrass meadows may be sheared by propellers and the rhizomes and roots of seagrass plants could be injured if a propeller reaches deep enough to excavate the sediment matrix (Kenworthy et al. 2002). When vessels run aground in a seagrass meadow, boat operators may attempt to dislodge by powering out of the shallow area. This can cause the propeller to excavate all of the seagrasses and some of the underlying sediments (Whitfield et al. 2002). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Table B1-2, reference B12MP).
Marine invertebrates	Movement underway - Substrate disturbance (crushing) [2] - Mortality [12] B42MI Specific evidence – Abrasion could scrape off patches of hydroids, bryozoans, ascidians, sponges, and other encrusting fauna, and the shells of mussels, limpets, periwinkles, and the tubes of tubeworms may be crushed (Tyler-Walters et al. 2005). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Table B1-2, reference B12MI).
Marine Fishes	Movement underway - Substrate disturbance (crushing) [2] - Mortality [12] B42MF Specific evidence – Evidence of direct effects from crushing of benthic marine fishes from vessels underway was not available. However, it is expected that vessels have the potential to crush benthic fish in the area, particularly types that bury themselves in soft sediments (e.g., flat fish). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Table B1-2 reference B12MF).
Movement underway - Substrate disturbance (crushing) [2] - Change in habitat [13]	
Physical habitat (substrate)	Movement underway - Substrate disturbance (crushing) [2] - Change in habitat [13] B42HS Specific evidence – Propellers may excavate the sediments of seagrass meadows if they reach deep enough, which may injure the seagrass rhizomes and roots. The removal of the stabilising plant structures may cause the sediment to become unstable and difficult to restore (Kenworthy et al. 2002). Excavation of seagrasses and some of the underlying sediments can result in steep and unstable gradients vulnerable to further damage (Whitfield et al. 2002). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Table B1-2, reference B12HS).

Table B4-3 - Evidence for the **Light disturbance [3]** stressor

Movement underway - Light disturbance [3]
Artificial lighting is used on vessels underway at all times, including at night, and may disturb biota as they travel through areas. Shading from vessels underway is assumed to be negligible, in contrast to vessels at rest.

Movement underway - Light disturbance [3] - Change in fitness [14]	
Marine invertebrates	Movement underway - Light disturbance [3] - Change in fitness [14] B43FI Specific evidence – The presence of artificial light from commercial vessels can negatively affect the behaviour of marine invertebrates, including feeding, reproduction, orientation and predator avoidance (Underwood et al. 2017). This can result in a reduction of fitness of marine invertebrates or increased risk of predation. Generic evidence – Refer to Vessel at Rest PoE evidence tables for background generic evidence of fitness effects to this endpoint (Table B2-2, reference B22FP).
Marine fishes	Movement underway - Light disturbance [3] - Change in fitness [14] B43FF Specific evidence – The presence of artificial light can affect marine fishes by provoking behavioural responses and increasing their risk of predation. Fishes may be either attracted or repelled by artificial light, depending on the species, wavelength of the light, and the amount of natural ambient light present (Ben-Yami 1976; Greer et al. 2010; Marchesan et al. 2005). Fish responses to artificial light is dependent on environmental conditions, habitat, and feeding strategies (Greer et al. 2010). Artificial light at night attracts some fish species, and can result in increased predation by larger species attracted by the same light (Nightingale and Simenstad 2002; Yurk and Trites 2000). Conversely, some predatory marine fishes have been documented as being averse to light, resulting in fish moving to greater depths thereby inhibiting their foraging and spawning (Juell et al. 2003; Marchesan et al. 2005). Impacts on marine fishes in the Arctic are likely to be greater in the winter than the summer, due to the nearly constant use of vessel lights (Davis et al. 1999). Generic evidence – Refer to Vessel at Rest PoE evidence tables for background generic evidence of fitness effects to this endpoint (Table B2-2, reference B22FF).
Marine mammals	Movement underway - Light disturbance [3] - Change in fitness [14] B43FM Specific evidence - Most marine mammals, such as cetaceans, are not expected to be impacted by light disturbance from commercial shipping vessels moving underway, as the disturbance is transitory and they rely more on echolocation for feeding. However, other marine mammals, such as pinnipeds and polar bears can be attracted to artificial light (Greer et al. 2010; Stirling 1998). Generic evidence – Refer to Vessel at Rest PoE evidence tables for background generic evidence of fitness effects to this endpoint (Table B2-2, reference B22FM).
Marine birds	Movement underway - Light disturbance [3] - Change in fitness [14] B43FB Specific evidence – The high-intensity lights of commercial shipping vessels can disorient and/or attract birds, resulting in birds colliding with ship structures during darkness or heavy fog (Arctic Council 2009; Black 2005; Bruderer et al. 1999; Hodgson et al. 2013; Huntington et al. 2015; Merkel and Johansen 2011; Schwemmer et al. 2011). Fast-flying bird species and those that fly in large flocks are especially at risk (Schwemmer et al. 2011). Light attraction in the Arctic depends on the weather, season, and age of the bird, but most light disturbance issues occur during fall migration (Arctic Council 2009). Light disturbance in the Arctic is not considered a high risk for bird species because most species reside in the Arctic in summer months; however, this risk is increased during non-breeding and ice-free periods (Arctic Council 2009). Generic evidence – Refer to Vessel at Rest PoE evidence tables for background generic evidence of fitness effects to this endpoint (Table B2-2, reference B22FB).
Movement underway - Light disturbance [3] - Mortality [15]	
Marine birds	Movement underway - Light disturbance [3] - Mortality [15] B43MB Specific evidence – Birds may become disoriented or attracted to high intensity lights of shipping vessels, and collisions result in injury and mortality (Arctic Council 2009; Black 2005; Bruderer et al. 1999; Hodgson et al. 2013; Huntington et al. 2015; Merkel and Johansen 2011; Schwemmer et al. 2011).

	Generic evidence – Refer to Vessel at Rest PoE evidence tables for background generic evidence of mortality for this endpoint (Table B2-2, reference B22MB).

Table B4-4 - Evidence for the **Noise disturbance [4]** stressor

Movement underway - Noise disturbance [4]	
Vessels underway generate noise from engines, propellers, wave action, and electronic equipment. Noise is expected to be more considerable from vessels underway compared to when at rest (Vessel at Rest PoE).	
Movement underway - Noise disturbance [4] - Change in fitness [16]	
Marine invertebrates	Movement underway - Noise disturbance [4] - Change in fitness [16] B44FI Specific evidence – Only a few studies have examined the effect of noise disturbance on marine invertebrates. Ship noise has been shown to affect the metabolic rate of shore crabs, increasing the demand for oxygen and potentially increasing stress (Wale et al. 2013a). Noise has been shown to affect visual display in cuttlefish (Kunc et al. 2014). Vessel noise playback affected embryonic development and increased larval mortality in sea hares (Nedelec et al. 2014). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of fitness effects from this stressor to this endpoint (Table B1-4, reference B14FI).
Marine fishes	Movement underway - Noise disturbance [4] - Change in fitness [16] B44FF Specific evidence – The varying anatomy of fishes and its relation to hearing suggests that fish may be sensitive to changes in particle motion and/or sound pressure (Hawkins and Popper 2017). Behavioural responses to noise disturbance are widely variable and depend on the particular circumstances, behaviours occurring, and context of the sound (Hawkins and Popper 2017; Popper 2003; Popper et al. 2003). Limited data suggests that sound may alter behaviour patterns but little is known on the effects on reproduction, growth, and fitness (Popper 2003; Popper et al. 2003). (Nichols et al. 2015) found that intermittent boat noise, as opposed to continuous boat noise, caused the greatest stress response in juvenile giant kelpfish, suggesting that the reduced predictability of anthropogenic noise causes greater stress. Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of fitness effects from this stressor to this endpoint (Table B1-4, reference B14FF).
Marine mammals	Movement underway - Noise disturbance [4] - Change in fitness [16] B44FM Specific evidence – For many marine mammals, the vessel noise stressor can affect acoustic habitat surrounding frequently travelled routes, as well as other areas of aggregation, such as due to foraging. Impacts of noise disturbance from vessels underway include behavioural changes (avoidance, diving pattern changes), displacement from habitats, and masking or interfering with vocalizations produced for communication and sensation (which can disrupt feeding) (Jasny et al. 2005; Lacy et al. 2015; National Research Council 2005). The biology of disturbance and the effect of noise on the fecundity of marine mammals are still not well understood. After detection of a sound, behavioural responses of marine mammals are highly variable and depend on internal and external factors, e.g., individual hearing sensitivity, past exposure to noise leading to habituation or sensitization, individual tolerance, demographic factors, presence of dependent offspring, etc. (Wartzok et al. 2003). Behavioural responses range from subtle changes in surfacing and breathing patterns, to cessation of vocalizations (Watkins 1986), to active avoidance or escape from the region of the highest sound levels (Richardson et al. 1995), to disruptions in breeding, nursing, and migration (Croll et al. 2001; Foote et al. 2004; Huntington et al. 2015; Walker et al. 2019). For example, marine mammals in the Canadian Arctic have been observed avoiding ice-breaking vessels and altering their behaviour for days following the event (Finley et al. 1990). The noise associated with icebreaking vessels underway can directly impact marine mammals by disturbing calving grounds, nursery, and moulting areas (Carter et al. 2017). The noise from icebreaker bubbler systems is the most effective at masking whale

calls, followed by the ramming noise/sound of the ice being crushed (Erbe et al. 1999; Wartzok et al. 2003). Some species of Arctic cetaceans have been recorded as being able to hear icebreaking from up to 75 km away and are known to avoid the area they experienced the noise disturbance for several days (Erbe and Farmer 2000). Additionally, female killer whales in British Columbia have been observed to increase their speed and increase the angle between successive dives as a result of vessel noise (Williams et al. 2002).

Shipping traffic has been documented to disturb pinniped haul out sites, which includes both the vessel noise and presence of the vessel itself (Jansen et al. 2015). The presence of vessels can alter the haulout patterns and behavioural activity budgets of pinnipeds by increasing the rate of flushing (vacating the haulout site and entering the water) and increasing vigilance behaviour (Young 2009). Flushing is energetically costly (Taylor and Knight 2003), although the cost is disproportionately greater for pups and adults that are pupping, nursing, and moulting (Brasseur et al. 1996; Suryan and Harvey 1999; Young 2009). Flushing can result in increased heart rate and metabolic rate (Tarlow and Blumstein 2007). Repeated exposure may induce the relocation of seals to other areas (Young 2009).

In general, resting animals are more likely to be disturbed by noise than animals engaged in social activities, foraging, or migrating (Richardson et al. 1995). Some age and sex classes are more sensitive to noise disturbance, and such disturbance may be more detrimental to young animals (Richardson et al. 1995). Marine mammals startled by vessel noise can enter the water (Young 2009) and leave calves stranded and vulnerable to predation (Fay et al. 1984). Additionally, groups of marine mammals containing calves are more responsive to vessel noise, altering respiration, diving, swimming, and aerial behaviour (Bauer et al. 1993; Blane and Jaakson 1994).

Noise pollution can cause marine mammals to alter their behaviour by directly disturbing them (Aguilar Soto et al. 2006; Burns and Seaman 1986; Cosens and Dueck 1988; Finley et al. 1990) or by masking their acoustic signals over large areas (Hildebrand 2005; Norman 2011; Payne and Webb 1971; Richardson et al. 1995; Scharf 1970; Weilgart 2007); loud sounds may directly affect their hearing abilities by producing either temporary or permanent hearing loss (Gordon and Tyack 2002; National Research Council 2000, 2003; Richardson et al. 1995; Simmonds and Lopez-Jurado 1991). All these effects may be critical for the survival of marine mammals. Little research has been conducted on the effect of shipping noise on the distribution, movement, and behaviour of pinnipeds (Jones et al. 2017).

Alternatively, marine mammals can exhibit habituation to repeated exposure to a signal that is not associated with physical discomfort or overt social stress (Richardson et al. 1995), even if they initially showed a behavioural response.

One of the most pervasive and significant effects of a general increase in background noise on marine mammals is the reduction in an animal’s ability to detect relevant sounds in the presence of other sounds, known as auditory masking (Abdulla and Linden 2008). Masking occurs when both the signal and masking sound have similar frequencies and either overlap or occur very close to each other in time. Noise is only effective in masking a signal if it is within a certain “critical band” around the signal’s frequency (Scharf 1970). The effects of masking depend on the function of the signal being masked (Richardson et al. 1995). Signal masking effects on marine mammals with depleted populations can inhibit the animal’s ability to attract a suitable mate (Myrberg Jr 1990; Payne and Webb 1971). The physiological costs to ameliorate masking effects, such as using more energy to increase the level of vocalizations, have not been determined. Marine mammals exhibit a range of strategies to deal with the effects of masking, including changes in vocalization patterns (Au and Perryman 1985; Jouventin et al. 1999). For example, belugas in the St. Lawrence River reduce their calling rate in response to ferries (Lesage et al. 1999).

Polar bears have been reported to be drawn to the noise of ice-breaking vessels due to curiosity (Stirling 1998).

There is little evidence to suggest that ship noise has an immediately acute or lethal effect on marine mammals or other marine organisms. Shipping noise in high traffic areas can be louder and more widespread than the levels that have caused whale strandings.

Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of fitness effects to this endpoint (Table B1-4, reference B14FM).

Movement underway - Noise disturbance [4] - Change in fitness [16] | B4FR

Marine reptiles	Specific evidence – Low-frequency noise has the potential to impact sea turtles, as their hearing lies within the broad frequency spectrum of noise produced by vessels, with the range of highest sensitivity between 200 and 700 Hz, and with a peak near 400 Hz (Bartol et al. 1999; Ketten and Bartol 2006; Richardson et al. 1995; Ridgway et al. 1969; Samuel 2004). Despite this, it has been hypothesised that sea turtles do not solely rely on sound cues to avoid danger such as vessel strikes and predators (Hazel and Gyuris 2006). However, continued exposure to high levels of pervasive anthropogenic noise in vital sea turtle habitats and any increase in noise levels could affect sea turtle behaviour and ecology (Samuel 2004). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of fitness effects to this endpoint (Table B1-4, reference B14FR).
Marine birds	Movement underway - Noise disturbance [4] - Change in fitness [16] B44FMB Specific evidence – Vessels with loud engines were found to cause stress responses in seabird at nesting sites from 800 m away, while quieter vessels were usually able to get within 100 m before causing disturbance (Rojek et al. 2007). Vessels passing within 500 m of seabird colonies caused behavioural responses and even when remaining for more than six hours near the nesting sites, some seabird species remained stressed with behavioural responses continuing which resulted in increased predation on eggs and chicks (Rojek et al. 2007). Generic evidence – Refer to Vessels at Rest PoE evidence tables for background generic evidence of fitness effects to this endpoint (Table B2-3, reference B23MB).
Movement underway - Noise disturbance [4] - Change in habitat [17]	
Physical habitat (acoustic)	Movement underway - Noise disturbance [4] - Change in habitat [17] B44HA Specific evidence – Many natural noises in the marine environment give biological cues for marine organisms, acting as navigational guides and allowing detection of other species, including prey. This natural noise pattern is a feature of a normal acoustic habitat. Anthropogenic underwater noise which interfere with natural sounds in the marine environment may affect the timing of social and reproductive behaviour (McCauley 1994), particularly if the disturbance to vulnerable or endangered animals coincides with very short breeding or spawning periods. Such noise can also interfere with natural life functions like communication in social species, foraging behaviour, and navigation. In effect, these anthropogenic sounds cause a loss of acoustic habitat for some or all the organisms that live there; i.e., the acoustic functions of the habitat are compromised. Documented responses of fish include: physiological effects such as elevated heart rate, secretion of stress hormones, and increased metabolism and motility (Popper 2003). For marine mammals, effects can include: physiological effects (such as elevated heart rate, secretion of stress hormones) (Reeves et al. 2012; Rolland et al. 2017), behavioural changes (avoidance, diving pattern changes), displacement from habitats (Tyack 2008), and masking or interfering with vocalizations made for communication and sensation (which can disrupt feeding) (Hildebrand 2005; Jasny et al. 2005; Lacy et al. 2015; National Research Council 2005). For animals exhibiting these responses, the effects of anthropogenic noise represent a loss of acoustic habitat. Low-intensity sounds can cause masking and behavioural disruptions for marine organisms: although there is little direct evidence, it is likely that if such disruptions occur frequently, for extended periods or time, or during biologically important activities such as mating, feeding, birth or mother-young bonding, they may affect longevity, growth, and reproduction. Noise may induce animals to abandon areas otherwise beneficial to them, or to deviate from their usual migration routes. Commercial shipping is estimated to have raised average ambient noise levels in the 20-200 Hz band, the dominant frequency band used by baleen whales for communication (Payne and Webb 1971). The masking effect of shipping noise has therefore reduced the potential for long-range communication in Mysticetes – limiting a key feature of their acoustic habitats (Payne and Webb 1971). Similar effects may be expected with fish since they use sounds to communicate and to perceive information from the environment; more than 50 families of fish use sound, generally below 2-3 kHz, in a wide variety of behaviours including aggression, protection of territory, defence and reproduction. Sounds can mask fish communication (Wahlberg and

	Westerberg 2005), generate stress that negatively affects the animals' welfare (Wysocki et al. 2006), induce fish to abandon noisy areas (Mitson and Knudsen 2003), destroy to sensory cells in fish ears and, in the long term, cause temporary and possibly permanent loss of hearing (McCauley et al. 2003; Popper 2003; Popper et al. 2005; Smith et al. 2004), and also damage eggs. Additionally, the gas-filled swim bladder may serve as a sound amplifier for both hearing and sound production, and can act as a potential receiver for sound energy even at frequencies not used for communication. Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Table B1-4, reference B14HA)

Table B4-5 - Evidence for the **Vessel Strikes [5]** stressor

Movement underway - Vessel Strikes [5]	
Mobile fauna, that are unable to avoid, or unaware of an oncoming vessel, can be struck. (For physical benthic impacts refer to the substrate disturbance (crushing) stressor).	
Movement underway - Vessel Strikes [5] - Change in fitness [18]	
Marine fishes	Movement underway - Vessel Strikes [5] - Change in fitness [18] B45FF Specific evidence – Not available Generic evidence - While evidence was not available, it is possible that vessels could strike fish causing injuries similar to what is found for other taxa, including disorientation, haemorrhaging, broken bones, and wounds.
Marine mammals	Movement underway - Vessel Strikes [5] - Change in fitness [18] B45FM Specific evidence – Large whale species and small cetaceans are affected by vessel strikes as these species can be found along the water surface (AMAP/CFF/SDWG 2013; Arctic Council 2009; Hodgson et al. 2013; Jensen and Silber 2003; Knowlton and Kraus 2001; Laist et al. 2001; Nelson et al. 2007; Reeves et al. 2012). Pinnipeds are also susceptible to vessel strikes, resulting in trauma that can lead to strandings and mortality (Goldstein et al. 1999; Swails 2005). Marine vessel strikes can result in serious injury, including massive trauma, haemorrhaging, broken bones, and wounds from propellers (Arctic Council 2009; Huntington et al. 2015). Studies have found that most sub-lethal and lethal injuries on large cetaceans are caused by vessels ≥80 m travelling ≥26 km h^{-1} (Laist et al. 2001). North Atlantic right whales, fin whales, and humpback whales (among other marine mammal species) have been observed with scar patterns and injuries consistent with a vessel strike – often with a propeller or rudder. It is not known how these injuries influence the long-term individual fitness of the struck animals. Particularly for endangered species such as North Atlantic right whales and northwest Atlantic blue whales, vessel strikes can lead to population-level effects on fitness. Toothed cetaceans, with the possible exception of sperm whales, are much less likely than large baleen whales to be victims of vessel strikes, so vessel strikes are not expected to cause individual or population-level fitness effects. Generic evidence – Not applicable.
Marine reptiles	Movement underway - Vessel Strikes [5] - Change in fitness [18] B45FR Specific evidence – Sea turtles are vulnerable to vessel strikes due to their frequent interaction with the sea surface and vessel strikes are a contributor to sea turtle injury (Hazel and Gyuris 2006; Lutcavage et al. 1997). Some sea turtles do not appear to be able to flee fast moving vessels (those travelling over 4 kmh^{-1} in open waters) (Hazel et al. 2007). Laboratory studies conclude that vessel speed is likely to significantly influence the likelihood of lethal injury to sea turtles (Work et al. 2010). Generic evidence – Not applicable.
Movement underway - Vessel strikes [5] - Mortality [19]	
	Movement underway - Vessel Strikes [5] - Mortality [19] B45MF

Marine fishes	Specific evidence – Not available. Generic evidence – In the tidal freshwater portion of the James River, Atlantic sturgeon face strike mortality from large ocean cargo ships with nearly 84% of recovered carcasses showing propeller damage, though it is suspected that less than one third of vessel strike mortalities are documented (Balazik et al. 2012).
Marine mammals	Movement underway - Vessel Strikes [5] - Mortality [19] B45MM Specific evidence – Mortality of marine mammals as the result of vessel strikes can occur either directly at the time of the incident, or as a result of injury or a reduction in fitness after the strike event. Direct collisions between vessels and marine mammals can result in mortality through massive trauma (Huntington et al. 2015; Nelson et al. 2007). Worldwide records of vessel strikes on whales show that all large whales are at risk (Abgrall et al. 2009; Jensen and Silber 2003; Laist et al. 2001). Juveniles and calves have higher interactions rates (in the order of 3:1) than adults, increasing their potential exposure to vessel strikes (Knowlton and Kraus 2001). A study in the United States between 1975-1996 and 1980-2006 suggested that vessel strikes are responsible for approximately 15% of observed mortalities (Douglas et al. 2008; Laist et al. 2001). The most frequently reported victims of vessel strikes are fin, humpback, right, and sperm whales, and the actual magnitude of this mortality may be much greater as many dead cetaceans are not detected. The detection rate varies with the size of the surrounding population, which affects the likelihood that an observer may be in the area. The death of a killer whale in British Columbia occurred when it exhibited playful behaviour around an idling tugboat, and was sucked into the propeller (CBC 2006). The tugboat was stationary but it was not anchored or moored so is considered underway. Generic evidence – Not applicable.
Marine reptiles	Movement underway - Vessel Strikes [5] - Mortality [19] B45MR Specific evidence – Sea turtles have shown to be most at risk of vessel strike in open waters when vessel speeds exceed 4 kmh^{-1}, with risk increasing with vessel speeds (Hazel et al. 2007). Higher vessel speeds increase the probability that a strike results in sea turtle mortality (Work et al. 2008). As of 2016 there had only been one officially reported vessel strike to a Leatherback sea turtle in Atlantic Canadian waters (CSTN 2016), and though these incidents are likely to go under reported, DFO Species at Risk has stated that this threat is negligible to this species when in Canadian waters (DFO 2018a). Generic evidence – Not applicable.

Table B4-6 - Evidence for the **Disturbance (wake, turbulence, water/ice displacement) [6]** stressor

Movement underway - Disturbance (wake, turbulence, water/ice displacement) [6]	
As a vessel moves through the water, it displaces water and pushes the water forward, leading to increased pressure, drag and acceleration, and the generation of wake/waves and turbulence (Lindholm et al. 2001; Oebius 2000). Icebreaking vessels displace ice during movement. This stressor excludes impacts from sediment resuspension from wake/turbulence (refer to substrate disturbance (sediment resuspension) stressor (Table B4-1).	
Movement underway - Disturbance (wake, turbulence, water/ice displacement) [6] - Change in fitness [20]	
Marine plants and algae	Movement underway - Disturbance (wake, turbulence, water/ice displacement) [6] - Change in fitness [20] B46FP Specific evidence – Vessel wake and turbulence can uproot marine macrophytes, reducing plant biomass, height and percentage cover (Asplund and Cook 1997), and results in shorter leaves and fewer offshoots(Doyle 2001; Fonseca and Kenworthy 1987; Fonseca and Bell 1998). Nutrients in sediment can be released when they are stirred up by turbulence, potentially resulting in phytoplankton blooms which can suppress macrophytes (Anthony and Downing 2003). Extremophile algae and bacteria living in pore spaces within sea ice, and which are

	fundamental to polar ecosystems (Thomas and Dieckmann 2002) may be affected by ice displacement. Generic evidence – Not applicable.
Marine invertebrates	Movement underway - Disturbance (wake, turbulence, water/ice displacement) [6] - Change in fitness [20] B46FI Specific evidence – Vessel wake and associated turbulence can dislodge marine invertebrates, particularly intertidal organisms and those inhabiting seagrass beds (Bishop 2008). Wave disturbance has also been linked to reduced growth rates in some benthic invertebrates, such as amphipods (Gabel et al. 2017). Vessel-waves impact the fitness of various species of marine invertebrates by increasing turbidity and nutrient loading (Aldridge et al. 1987) and altering the temperature profile (Lindholm et al. 2001). Disturbance from wakes decreased bivalve mollusc (*Crassostrea virginica*) fitness due to increased relative water motion, sediment loads, and percent silt/clay, and may also reduce its reproductive success through dislodgement of substrate (Wall et al. 2005). However, not all invertebrate communities appear to be affected by the increased wave action from vessel wake (Demes et al. 2012). Generic evidence – Not applicable.
Marine fishes	Movement underway - Disturbance (wake, turbulence, water/ice displacement) [6] - Change in fitness [20] B46FF Specific evidence – Disturbance from vessel wake, turbulence, and water displacement can decrease foraging efficiency and induce behavioural responses that make fish more vulnerable to predators. Turbidity decreases visibility of prey, increasing the fish's effective search volume for prey, and waves may suspend normally benthic prey in the water column (Gabel et al. 2017). Turbulence associated with moving vessels can entrain fish in flows leading to areas where they can be injured (Popper et al. 2003). Generic evidence – Not applicable.
Marine mammals	Movement underway - Disturbance (wake, turbulence, water/ice displacement) [6] - Change in fitness [20] B46FM Specific evidence – Icebreaking can impact marine mammal fitness by disturbing and displacing ice-dependent marine mammals such as pinnipeds. In pinniped pupping/nursery areas, icebreaking can destroy resting and birth lairs and cause the separation of mothers and pups due to the production of a flight response, the mother moving away from the vessel followed by her much slower pups (Wilson et al. 2017; Yurkowski et al. 2018). This results in mother-pup separation, displacement from critical habitat, increased stress, and increased vulnerability to predation. Icebreaking activity is highest in spring, coinciding with critical neonatal and nursing periods for pinnipeds, the separation of mother-pup pairs at this time can end the lactation period early and have significant fitness impacts as well as endangering pup survival (Huntington et al. 2015; Wilson et al. 2017). The wakes of ships travelling through ice-covered waters in seal pupping/nursery areas can flood seal dens and wet baby seals potentially having fitness effects (Arctic Council 2009). Breaking new ice results in artificially formed channels of brash (churned/broken) ice, partially frozen water, or open water. This artificial opening of channels in sea ice can alter the behaviour of marine mammals. The formation of artificial channels within 10 m of pinniped pups is considered to be breaking pupping habitat (Wilson et al. 2017). Pinniped pups have difficulty navigating brash ice due to the uneven surface and patches of water (Wilson et al. 2017). Fragmented habitat can result in pinniped pup disorientation, stress, increased energetic demands, and risk of hypothermia (Wilson et al. 2017). Icebreaking activity displaces migrating narwhale and beluga (Cosens and Dueck 1988), and it is possible that icebreaking - when combined with climate change related ice conditions - could result in predatory killer whales being able to hunt other marine mammal prey in places in the Arctic that were formerly refuges (Ferguson et al. 2010). Polar bears are reported to be drawn to icebreaking vessels from curiosity due to the noise and light but also because icebreaking creates artificial leads that can result in short-term increases in biological productivity including polar bear prey (Stirling 1998). Artificial open channels by icebreakers can be mistaken for polynyas by cetaceans, which are a core winter habitat for many Arctic marine mammals (Arctic Council 2009; DFO 2012; Laidre and Heide-Jørgensen 2005). Once the artificially opened channels refreeze, marine mammals (specifically cetaceans) can become trapped far from the sea ice edge and suffer reduced feeding opportunities (Arctic Council 2009).

	Generic evidence – Not applicable.
Marine birds	Movement underway - Disturbance (wake, turbulence, water/ice displacement) [6] - Change in fitness [20] B46FB Specific evidence – Marine birds may be directly impacted by vessel wake by the inundation of nests (Boyle and Samson 1985; Reichholf 1976; Tessler et al. 2014; Ward and Andrews 1993), decreasing breeding success. Alternatively, some birds may benefit from vessel waves and turbulence due to the enhanced feeding opportunities as benthic prey is disturbed (Gabel et al. 2017). Migratory birds that use sea ice as important feeding and staging areas in the spring and fall (Thomas and Dieckmann 2008) are susceptible to being disturbed by icebreaking through the destruction of habitat. Generic evidence – Not applicable.
Movement underway - Disturbance (wake, turbulence, water/ice displacement) [6] - Mortality [21]	
Marine fishes	Movement underway - Disturbance (wake, turbulence, water/ice displacement) [6] - Mortality [21] B46MF Specific evidence – Vessel wake can result in mortality of fish in the inshore zone due to the risk of being stranded (Ackerman 2002; Adams et al. 1999; Pearson and Skalski 2011). The effect may occur in higher numbers at night when many fish species move to shallow inshore areas (Gaudin 2001). Generic evidence – Not applicable.
Marine mammals	Movement underway - Disturbance (wake, turbulence, water/ice displacement) [6] - Mortality [21] B46MM Specific evidence – Displacement and breaking of ice during icebreaking can destroy critical habitat for ice-dependent pinnipeds, such as birthing and nursing areas, breathing holes, resting lairs, and haul-out platforms in the shore-fast ice. Potential effects include displacement, separation of mothers and pups, destruction of resting and birth lairs, and collisions with vessels (Yurkowski et al. 2018). Ice-breeding pinnipeds are the most susceptible to icebreaking during pupping (birthing and lactating) (Harkonen et al. 2008). All of these effects would increase the mortality rate for pups. During icebreaking there is risk of collisions with pinnipeds, with pups the most susceptible (Davis 1981; Stewart et al. 2014; Stirling and Calvert 1983; Wilson et al. 2017). Collisions occur, but are considered rare (Wilson et al. 2017). Collisions between pinnipeds during icebreaking are most frequent at vessel speeds ≥7.4 kmh^{-1} and at night, although this is possibly due to individuals being dazzled by ship lights (Wilson et al. 2017). Artificial open channels by icebreakers can be mistaken for polynyas by cetaceans, which are a core winter habitat for many Arctic marine mammals (Arctic Council 2009; DFO 2012; Laidre and Heide-Jørgensen 2005). Once the artificially opened channels refreeze, marine mammals (specifically cetaceans) can become trapped far from the sea ice edge suffer and reduced feeding opportunities or mortality through drowning (Arctic Council 2009). Generic evidence – Not applicable.
Marine birds	Movement underway - Disturbance (wake, turbulence, water/ice displacement) [6] - Mortality [21] B46MB Specific evidence – Marine birds may be directly impacted by vessel wake by the inundation of nests (Boyle and Samson 1985; Reichholf 1976; Tessler et al. 2014; Ward and Andrews 1993), decreasing breeding success. Migratory birds that use sea ice as important feeding and staging areas in the spring and fall (Thomas and Dieckmann 2008) are susceptible to being disturbed by icebreaking through the destruction of habitat. Generic evidence – Not applicable.
Movement underway - Disturbance (wake, turbulence, water/ice displacement) [6] - Change in habitat [22]	
Physical habitat (substrate)	Movement underway - Disturbance (wake, turbulence, water/ice displacement) [6] - Change in habitat [22] B46HS Specific evidence – Abiotic physical habitats are primarily impacted by vessel wake and turbulence through sediment resuspension and shoreline/bank erosion (Gabel et al. 2017), resulting in changes in seabed and beach morphology, sediment grain sizes, and bank collapses (Gabel et al. 2017; Osborne and Boak 1999; Parnell et al. 2007). Impacts to shorelines from

	erosion is greatest in sheltered channels, embayments, and estuaries where the height of the vessel wake is equal to or exceeds the natural wind-driven wave heights (Bishop 2004). Vessel-generated waves impacting beaches and coastline can result in alongshore transport, increased weathering, and in some cases can overtop beach ridges (Parnell et al. 2007). Waves may also transport finer sediments to deeper areas as they erode the shore around the waterline (Soomere 2005). For evidence of impacts relating to sediment resuspension from wake/turbulence, refer to substrate disturbance (sediment resuspension) stressor (Table B4-1). Generic evidence – Not applicable.
Physical habitat (water column)	Movement underway - Disturbance (wake, turbulence, water/ice displacement) [6] - Change in habitat [22] B44HW Specific evidence – Vessel wake and turbulence can result in increased mixing, turbidity, disturbed water temperature regimes and nutrient loading in the water column, resulting in a change in water quality in the disturbed area (Anthony and Downing 2003; Lindholm et al. 2001). Large ship (150-200 m long) traffic has been found to contribute to the eutrophication via increased recycling of nutrients due to elevated bottom temperature and increased mixing depth and artificial upwelling (Lindholm et al. 2001). Generic evidence – Not applicable.
Physical habitat (sea ice)	Movement underway - Disturbance (wake, turbulence, water/ice displacement) [6] - Change in habitat [22] B46HI Specific evidence - Icebreaking results in artificially formed channels of brash (churned/broken) ice, partially frozen water, or open water outside of areas where polynyas naturally occur (Wilson et al. 2017). This channel formation causes the alteration and fragmentation of key habitats for marine mammals. Due to the seasonal natural of both icebreaking vessels and sea ice, these effects are temporary, as artificial open channels eventually refreeze (Wilson et al. 2017). As they refreeze, marine mammals (specifically cetaceans) who had mistaken them for polynyas can become trapped far from the sea ice edge (Arctic Council 2009). However, as climate change reduces the thickness and extent of sea ice, it could become more susceptible to longer-term disruption such that icebreaker channels could remain open longer, and ice pan sizes smaller and thinner. The ice habitat of extremophile algae and bacteria living in pore spaces within sea ice, and are fundamental to polar ecosystems (Thomas and Dieckmann 2002) may be impacted by icebreaking. Generic evidence – Not applicable.

Table B4-7 - Evidence for the **Introductions of species and pathogens [7]** stressor

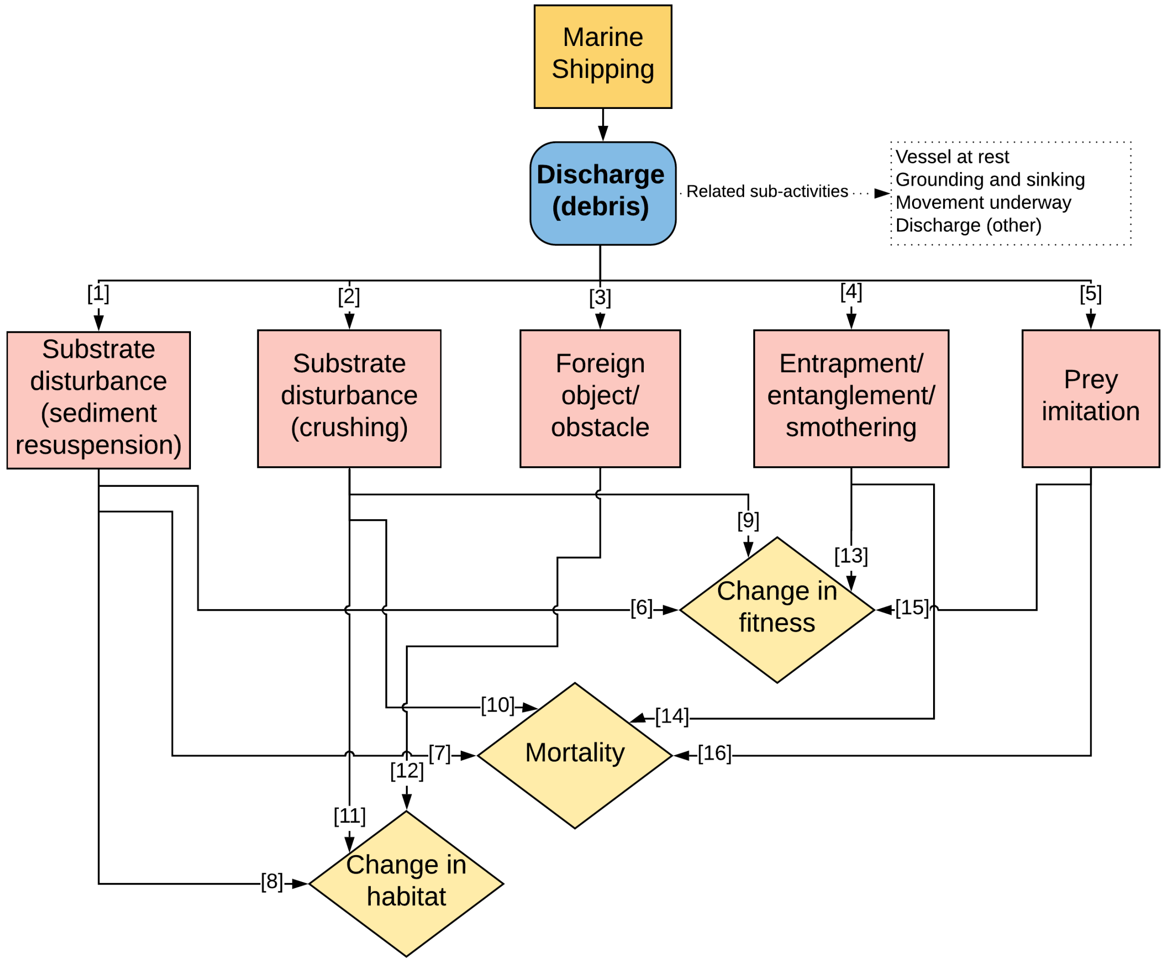
Movement underway - Introductions of species and pathogens [7]	
Introductions of species Non-native aquatic invasive species (AIS) fouling the hulls of vessels at rest have the potential to spread to the areas the vessel travels. **Introductions of pathogens** Examines the impacts of pathogens introduced through vessels that are underway.	
Movement underway - Introductions of species and pathogens [7] - Change in fitness [23]	
Marine plants and algae	Movement underway – Introductions of species and pathogens [7] - Change in fitness [23] B47FP **Introductions of species** Specific evidence – Introduced algal species may be able to exclude native species by dominating substrata needed for recruitment. In addition, some introduced bryozoans, such as *Membranipora*, can cause defoliation of kelps, which reduced growth and survival (Levin et al. 2002). Several introduced algal and invertebrate species grow epiphytically on seagrass, which can reduce its ability photosynthesize and grow (Williams 2007). Some introduced species that

	may be spread by shipping, such as *Didemnum* sp., are able to spread rapidly and smother algae (Daniel and Therriault 2007). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of fitness effects to this endpoint (Table B1-6, reference B16FP). **Introductions of pathogens** Specific evidence – No evidence specific to this sub-activity could be found at this time. Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of fitness effects to this endpoint (Table B1-6, reference B16FP).
Marine invertebrates	Movement underway - Introductions of species and pathogens [7] - Change in fitness [23] B47FI **Introductions of species** Specific evidence – Fouling species can be transported on ship hulls, and may dislodge by peeling off or fragmenting while in transit (Clarke Murray et al. 2012). Species that are not able to tolerate the water velocity experience on the hull may be transported in niche areas out of the flow, such as sea chests (recesses used for water intakes or outlets, in order to minimise drag and piping damage) (Coutts et al. 2003). These fouling species may include algae, hydroids, bryozoans, barnacles, bivalves, and ascidians, and can form colonies that are sufficiently dense to provide habitat for motile organisms (Chan et al. 2011). Once present, non-native filter feeders may change the plankton composition or reduce the amount available to other invertebrate consumers (Daniel and Therriault 2007). Fast-growing colonial species may smother invertebrates or prevent benthic settlement as they spread over large areas of substrate (Daniel and Therriault 2007). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of fitness effects to this endpoint (Table B1-6, reference B16FI). **Introductions of pathogens** Specific evidence – No evidence specific to this sub-activity could be found at this time. Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of fitness effects to this endpoint (Table B1-6, reference B16FI).
Marine fishes	Movement underway - Introductions of species and pathogens [7] - Change in fitness [23] B47FF Specific evidence – Species that may be introduced via ship hulls, such as the colonial ascidian *Didemnum* sp., may impact fish populations by smothering food organisms which may result in fish leaving the area, and may prevent successful reproduction through damage of fish eggs and larvae as they settle onto its acidic tunic (Daniel and Therriault 2007). Increased mooring time is associated with increased invasion risk because it allows more time for species to accumulate (Chan et al. 2011). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of fitness effects to this endpoint (Table B1-6, reference B16FF). **Introductions of pathogens** Specific evidence – No evidence specific to this sub-activity could be found at this time, however as hull biofouling can contain pathogens (Revilla-Castellanos et al. 2015), biofouling associated with vessels underway may also can harbour pathogens which could potentially cause fitness effects in marine fishes. Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of fitness effects to this endpoint (Table B1-6, reference B16FF).
Movement underway – Introductions of species and pathogens [7] - Mortality [24]	
Marine plants and algae	Movement underway - Introductions of species and pathogens [7] - Mortality [24] B47MP **Introductions of species** Specific evidence – Introduced algal species may be able to exclude native species by dominating substrata needed for recruitment. In addition, some introduced bryozoans, such as *Membranipora*, can cause defoliation of kelps, which reduced growth and survival (Levin et al.

	2002). Some introduced species that may be spread by shipping, such as *Didemnum* sp., are able to spread rapidly and smother algae (Daniel and Therriault 2007). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of fitness effects to this endpoint (Table B1-6, reference B16MP). **Introductions of pathogens** Specific evidence – No evidence specific to this sub-activity could be found at this time. Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of fitness effects to this endpoint (Table B1-6, reference B16MP).
Marine invertebrates	Movement underway - Introductions of species and pathogens [7] - Mortality [24] B47MI **Introductions of species** Specific evidence – Fouling species can be transported on ship hulls, and may dislodge by peeling off or fragmenting while in transit (Clarke Murray et al. 2012) (Clarke Murray et al. 2012) . Species that are not able to tolerate the water velocity experience on the hull may be transported in niche areas out of the flow, such as sea chests (recesses used for water intakes or outlets, in order to minimise drag and piping damage) (Coutts et al. 2003). These fouling species may include algae, hydroids, bryozoans, barnacles, bivalves, and ascidians, and can form colonies that are sufficiently dense to provide habitat for motile organisms (Chan et al. 2011). Once present, fast-growing colonial species may smother invertebrates or prevent benthic settlement as they spread over large areas of substrate (Daniel and Therriault 2007). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of fitness effects to this endpoint (Table B1-6, reference B16MI). **Introductions of pathogens** Specific evidence – No evidence specific to this sub-activity could be found at this time. Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of fitness effects to this endpoint (Table B1-6, reference B16MI).
Marine fishes	Movement underway - Introductions of species and pathogens [7] - Mortality [24] B47MF **Introductions of species** Specific evidence – Fouling species can be transported on ship hulls, and may dislodge by peeling off or fragmenting while in transit (Clarke Murray et al. 2012). Species that are not able to tolerate the water velocity experience on the hull, including sometimes fishes, may be transported in niche areas out of the flow, such as sea chests (recesses used for water intakes or outlets, in order to minimise drag and piping damage) (Coutts et al. 2003). These species may include fouling algal and marine invertebrate species, as well as fishes. The fouling species of algae, hydroids, bryozoans, barnacles, bivalves, and ascidians can form colonies that are sufficiently dense to provide habitat for motile organisms such as fishes (Chan et al. 2011). Some species introduced through shipping have defense strategies, such as an acidic tunic, that could kill fish eggs or larval fish settling on its surface (Daniel and Therriault 2007). Generic evidence – Refer to Anchoring and Mooring PoE for generic evidence from this stressor to this endpoint (Table B1-6, reference B16MF). **Introductions of pathogens** Specific evidence – No evidence specific to this sub-activity could be found at this time. Generic evidence – Refer to Anchoring and Mooring PoE for generic evidence from this stressor to this endpoint (Table B1-6, reference B16MF).
Movement underway – Introductions of species and pathogens [7] - Change in habitat [25]	
Physical habitat (substrate)	Movement underway - Introductions of species and pathogens [7] – Change in habitat [24] B47HS **Introductions of species** Specific evidence – Fouling species can be transported on ship hulls, and may dislodge by peeling off or fragmenting while in transit (Clarke Murray et al. 2012). Species that are not able to tolerate the water velocity experience on the hull may be transported in niche areas out of the flow, such as sea chests (recesses used for water intakes or outlets, in order to minimise drag

	and piping damage) (Coutts et al. 2003). These fouling species may include algae, hydroids, bryozoans, barnacles, bivalves, and ascidians, and can form colonies that are sufficiently dense to provide habitat for motile organisms (Chan et al. 2011). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects of this stressor to this endpoint (Table B1-6, reference B16HS). **Introductions of pathogens** Specific evidence – No evidence specific to this sub-activity could be found at this time. Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects of this stressor to this endpoint (Table B1-6, reference B16HS).
Physical habitat (sea ice)	Movement underway - Introductions of species and pathogens [7] – Change in habitat [24] B47HI Specific evidence – Species live on, under, and within the ice, so there is potential for species or pathogens to be introduced into these habitats. Generic evidence – Refer to Vessels at Rest PoE evidence tables for background generic evidence of effects of this stressor to this endpoint (Table B2-4, reference B24HI).

APPENDIX B5: DISCHARGE (DEBRIS) TABLES OF EVIDENCE



Definition – The Discharge (debris) sub-activity considers debris discharged from commercial vessels engaged in marine shipping. Examples of debris include discarded food products, mismanaged garbage and lost cargo of varying types. The specific source of marine debris is difficult to assign, as much of the evidence relates to general marine debris, rather than debris specifically ascribed to shipping. Microplastics are fragments and fibres of larger debris and because of their small size are especially difficult to assign to source. This sub-activity has five associated stressors: substrate disturbance (sediment resuspension) (Table B5-1); substrate disturbance (crushing) (Table B5-2); foreign object/obstacle (Table B5-3); entrapment/ entanglement/ obstacle (Table B5-4); and prey imitation (Table B5-5).

Tables of evidence are provided for each stressor in the following pages, based on the order outlined in the PoE diagram above. *Specific* evidence refers to information specific to that linkage, whereas *generic* evidence is broader evidence that can provide insight where specific evidence is not available. *Not applicable* generic evidence indicates this is the sole linkage and that specific evidence is available*. Not available* indicates that no evidence was found for that linkage.

Table B5-1 - Evidence for the **Substrate disturbance (sediment re suspension) [1]** stressor

Discharge (debris) - Substrate disturbance (sediment resuspension) [1]	
When debris discharged from vessels impacts the seafloor it would be expected to create a sediment plume which may continue with further movement of debris due to currents or waves, depending on the nature of the debris. Impacts would be expected to be limited to benthic biota and habitats. There is a lack of any evidence for this in the literature, so generic evidence of this stressor to endpoints can be consulted. For generic evidence on the impacts of sediment resuspension to endpoints refer to the Anchoring and Mooring PoE table of evidence for this stressor (Table B1). There is expected to be limited sediment re suspension from marine debris, with the exception of large shipping containers.	
Discharge (debris) - Substrate disturbance (sediment resuspension) [1] - Change in fitness [6]	
Marine plants and algae	Discharge (debris) - Substrate disturbance (sediment resuspension) [1] - Change in fitness [6] B51FP Specific evidence – Not available. Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Appendix Table B1-1, reference B11FP).
Marine invertebrates	Discharge (debris) - Substrate disturbance (sediment re suspension) [1] - Change in fitness [6] B51FI Specific evidence – Not available. Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Appendix Table B1-1, reference B11FI).
Discharge (debris) - Substrate disturbance (sediment resuspension) [1] - Mortality [7]	
Marine plants and algae	Discharge (debris) - Substrate disturbance (sediment resuspension) [1] - Mortality [7] B51MP Specific evidence – Not available. Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Appendix Table B1-1, reference B11MP).
Marine invertebrates	Discharge (debris) - Substrate disturbance (sediment resuspension) [1] - Mortality [7] B51MI Specific evidence – Not available. Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Appendix Table B1-1, reference B11MI).
Discharge (debris) - Substrate disturbance (sediment resuspension) [1] – Change in habitat [8]	
Physical habitat (substrate)	Discharge (debris) - Substrate disturbance (sediment resuspension) [1] – Change in habitat [8] B51HS Specific evidence – Not available. Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Appendix Table B1-1, reference B11HS).

Table B5-2 - Evidence for the **Substrate disturbance (crushing) [2]** stressor

Discharge (debris) - Substrate disturbance (crushing) [2]
This stressor includes the benthic impacts of marine debris crushing the substrate and benthic organisms. Crushing can occur when lost shipping containers and their contents settle to the seabed (NOAA 2014).

Discharge (debris) - Substrate disturbance (crushing) [2] - Change in fitness [9]	
Marine plants and algae	Discharge (debris) - Substrate disturbance (crushing) [2] - Change in fitness [9] B52FP Specific evidence – Debris can crush salt marsh vegetation (Uhrin and Schellinger 2011; Viehman et al. 2011) and abrade or crush seagrass blades reducing oxygen available to the plants and reducing photosynthesis (Uhrin et al. 2005). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Appendix Table B1-2, reference B12FP).
Marine invertebrates	Discharge (debris) - Substrate disturbance (crushing) [2] - Change in fitness [9] B52FI Specific evidence – Larger debris has been shown to cause direct mechanical injury to corals (Richards and Beger 2011). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Appendix Table B1-2, reference B12FI).
Discharge (debris) - Substrate disturbance (crushing) [2] - Mortality [10]	
Marine plants and algae	Discharge (debris) - Substrate disturbance (crushing) [2] - Mortality [10] B52MP Specific evidence – Not available. Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Appendix Table B1-2, reference B12MP).
Marine invertebrates	Discharge (debris) - Substrate disturbance (crushing) [2] - Mortality [10] B52MI Specific evidence – Not available. Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Appendix Table B1-2, reference B12MI).
Discharge (debris) - Substrate disturbance (crushing) [2] - Change in habitat [11]	
Physical habitat (substrate)	Discharge (debris) - Substrate disturbance (crushing) [2] – Change in habitat [11] B52HS Specific evidence – The arrival of marine debris at the seabed can result in habitat displacement in the immediate area, such as from a lost container (as reported in (Taylor et al. 2014). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Appendix Table B1-2, reference B12HS).

Table B5-3 - Evidence for the **Foreign object/obstacle [3]** stressor

Discharge (debris) - Foreign object /obstacle [3]	
The presence of discharged debris can create an obstacle to the movement of mobile biota and change the habitat available in an affected ecosystem.	
Discharge (debris) – Foreign object/obstacle [3]– Change in habitat [12]	
Physical habitat (substrate)	Discharge (debris) - Foreign object/obstacle [3] - Change in habitat [12] B53HS Specific evidence – Sunken marine debris can have a local impact to physical habitat (substrate) in a number of ways. Studies on a lost container indicate mild disturbance to the seabed due to three components: (i) alteration of flow patterns leading to changes in local grain size distribution; (ii) the addition of structure/hard substratum which can result in aggregation of megafauna, and (iii) promotion of indirect effects that can lead to changes in the sediment habitat and community (Taylor et al. 2014). Accumulation of plastic debris on benthic substrates can inhibit gas exchange between the overlying water and the pore water in sediments (Derraik 2002). Debris can provide hard substrate habitat for plants and algae in habitats where they would not otherwise be found, and can provide habitat and shelter for invertebrates, with some species showing increased abundances with increasing debris cover (Katsanevakis et al. 2007).

	Other species show decreased abundance or no effect of debris coverage (Katsanevakis et al. 2007). Debris can provide hard substratum for colonisation in soft sediment areas, impacting community structure. For example, the assemblage of fauna colonising the exterior and benthos 10m around a lost shipping container in the deep sea in California was significantly different to the seabed faunal assemblages up to 500m away (Taylor et al. 2014). In areas with numerous large marine debris such as shipping containers, these structures may act as stepping stones for the movement of hard substrate biota in the marine environment (Taylor et al. 2014). <u>Generic evidence</u> – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Appendix Table B1-3, reference B13HS).
Physical habitat (water column)	Discharge (debris) - Foreign object/obstacle [3] - Change in habitat [12] B53HW <u>Specific evidence</u> – The presence of floating debris changes the habitat of the water column, creating hard substrate in a habitat where it would be rare (Derraik 2002). Woody debris and pumice are natural sources of floating debris that degrade quickly in the water column, compared to anthropogenic debris such as plastics. <u>Generic evidence</u> – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Appendix Table B1-3, reference B13HW).
Physical habitat (sea ice)	Discharge (debris) - Foreign object/obstacle [3] - Change in habitat [12] B53HI <u>Specific evidence</u> – Not available. <u>Generic evidence</u> – The presence of microplastics in Arctic sea ice is an increasing concern, given that the concentration of microplastics in sea ice exceed that in the surrounding seawater. Though the mechanisms that microplastics are incorporated into sea ice are little known, microcosm experiments have determined that high concentrations of microplastics in the surface of sea ice can result in high salinity, affect ice albedo (light reflectance) and brine volume content, potentially affecting the structure and nature of this habitat (Geilfus et al. 2019).

Table B5-4 - Evidence for the **Entrapment/Entanglement/Smothering [4]** stressor

Discharge (debris) - Entrapment/Entanglement/Smothering [4]	
This stressor considers the impacts of biota becoming trapped, tangled or smothered by marine debris, including the ropes and lines associated with commercial ships.	
Discharge (debris) - Entrapment/Entanglement/Smothering [4] - Change in fitness [13]	
Marine invertebrates	Discharge (debris) - Entrapment/entanglement/smothering [4] - Change in fitness [13] B54FI <u>Specific evidence</u> – Not available. <u>Generic evidence</u> – Larger debris covering corals cause direct mechanical injury, reduce rates of photosynthesis through light limitation, and limit filter feeding by restricting water circulation and preventing food particles from reaching feeding structures (Richards and Beger 2011).
Marine mammals	Discharge (debris) - Entrapment/entanglement/smothering [4] - Change in fitness [13] B54FM <u>Specific evidence</u> – Entrapment or entanglement in debris may cause wounds that are likely to become infected (Byard and Machado 2018; Carretta et al. 2018). Entanglement impairs swimming and feeding behaviour (i.e., causes drag which results in inability to catch prey). Entangled animals spend less time ashore and more time foraging at sea (Laist 1997). Moreover, animals that are entangled in small debris and get to shore do so at an increased metabolic cost. This imposes added food requirements, resulting in more time spent feeding. It also increases the risk of predation because of decreased mobility. Seals become frequently entangled in loop-shaped items that encircle the neck at young age and cause increasing injury with growth (Allen et al. 2012; Byard and Machado 2018; Fowler 1987; Lucas 1992). Long-term survival is significantly reduced in grey seals (Allen et al. 2012). Baleen whales are vulnerable to plastic debris becoming entangled in their feeding structures (Lambertsen et al. 2005).

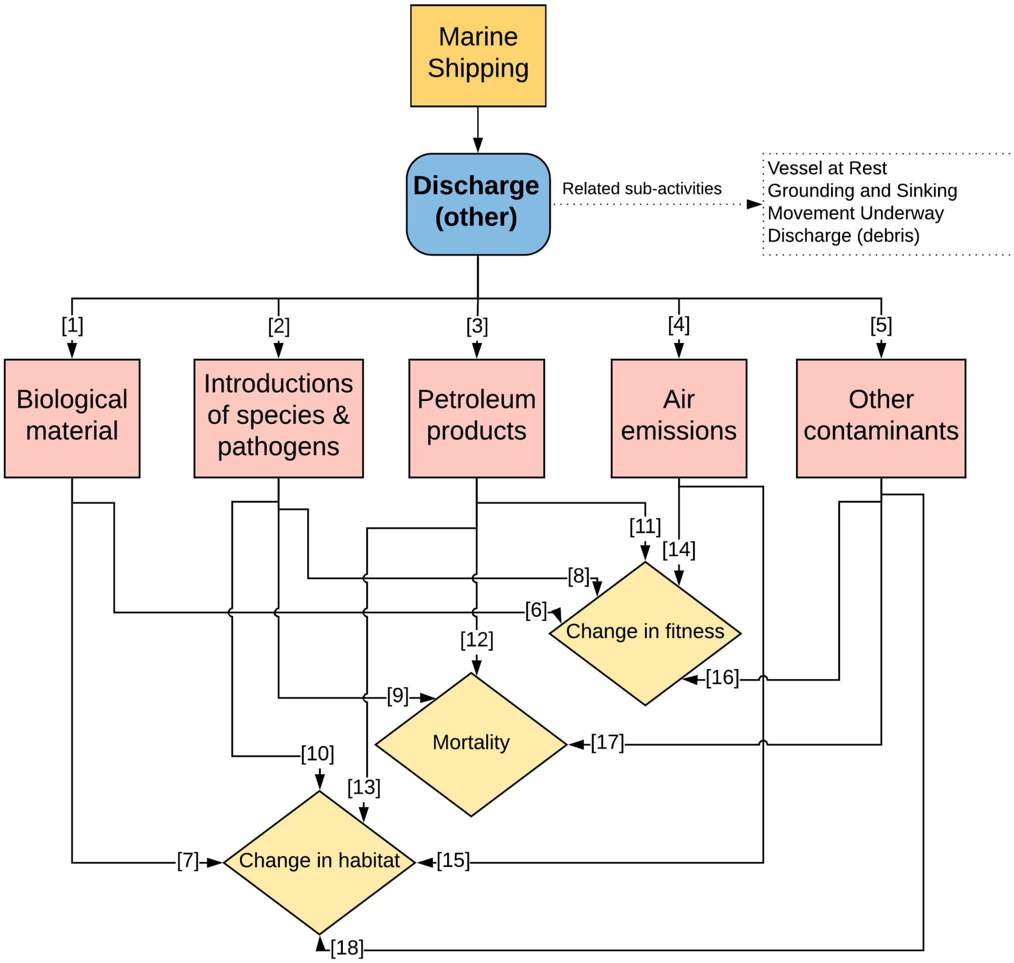
	Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects of this stressor to this endpoint (Table B1-5, reference B15FM).
Marine reptiles	Discharge (debris) - Entrapment/entanglement/smothering [4] - Change in fitness [13] B54FR Specific evidence – Entanglement in marine debris affects all seven sea turtle species (Kühn et al. 2015) and is known to result in fitness effects such as skin infections, leg amputations and sepsis in sea turtles (Barreiros and Raykov 2014; Orós et al. 2005). Entanglement may also cause complications in proper foraging or surfacing to breathe, increasing energy expenditure and reducing fitness (Wabnitz and Nichols 2010). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Table B1-5, reference B15FR).
Marine birds	Discharge (debris) - Entrapment/entanglement/smothering [4] - Change in fitness [13] B54FB Specific evidence – Seabirds can become entangled around the bill, wings and feet with rope-like debris materials, which affects their ability to fly or forage properly (Camphuysen 2001; Rodríguez et al. 2013). Seabirds have also used marine debris such as netting into nests which has the potential to entangle chicks (Kühn et al. 2015). Generic evidence – Not available
Discharge (debris) - Entrapment/Entanglement/Smothering [4] - Mortality [14]	
Marine plants and algae	Discharge (debris) - Entrapment/entanglement/smothering [4] - Mortality [14] B54MP Specific evidence – Not available. Generic evidence – Marine debris has been shown to hinder recovery of mangrove forests through the smothering of seedlings (Smith 2012).
Marine invertebrates	Discharge (debris) - Entrapment/entanglement/smothering [4] - Mortality [14] B54MI Specific evidence – Coral cover decreased significantly with increased macrodebris cover (Richards and Beger 2011). Debris covering corals cause direct mechanical damage and mortality (Richards and Beger 2011). A relationship between marine debris and coral diseases has been observed, which can cause death of the colony (Harrison et al. 2011). Generic evidence – Not applicable.
Marine mammals	Discharge (debris) - Entrapment/entanglement/smothering [4] - Mortality [14] B54MM Specific evidence – Many species of pinnipeds (22 of 33 species), and whales (25 of 80 species) have been recorded as entangled or entrapped in marine debris (Kühn et al. 2015). Most animals vulnerable to entanglement are highly migratory (e.g., sea turtles, and marine mammals) and tend to be scattered across wide ocean areas (Laist 1997). Direct mortality can often occur when marine animals become tangled in debris (Citta et al. 2014; Derraik 2002; Knowlton and Kraus 2001; Laist 1987; Reeves et al. 2012). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Table B1-5, reference B15MM).
Marine reptiles	Discharge (debris) - Entrapment/entanglement/smothering [4] - Mortality [14] B54MR Specific evidence – All species of marine turtles (7 of 7 species) have been recorded as entangled in marine debris which frequently results in mortality (Kühn et al. 2015; Laist 1997). Generic evidence – Refer to Anchoring and Mooring PoE evidence tables for background generic evidence of effects to this endpoint (Table B1-5, reference B15MR).
Marine birds	Discharge (debris) - Entrapment/entanglement/smothering [4] - Mortality [14] B54MB Specific evidence – Many seabird species have been reported as entangled in debris (103 of 406 species) and entanglement in marine debris can be a significant source of mortality for some species (Kühn et al. 2015). Adult birds have also used debris, such as ropes and nets, in nest construction, which could result in chick mortality through entanglement (Kühn et al. 2015). Generic evidence – Not applicable.

Table B5-5 - Evidence for the **Prey imitation [5]** stressor

Discharge (debris) - Prey imitation [5]	
This stressor considers the impacts of marine debris that is mistaken as food by marine biota (often plastic debris) and ingested.	
Discharge (debris) - Prey imitation [5] - Change in fitness [15]	
Marine invertebrates	Discharge (debris) - Prey imitation [5] - Change in fitness [15] B55FI Specific evidence – Not available. Generic evidence – Microplastics have most commonly been reported in plankton or neuston samples (Lopez Lozano and Mouat 2009). Additionally, microplastics are in the same size range as plankton, creating potential for the microplastics to be ingested by filter feeding organisms (Browne et al. 2007). Microplastics have been discovered in a the digestive tract of a range of filter feeding marine invertebrates (e.g., (Mathalon and Hill 2014)).
Marine fishes	Discharge (debris) - Prey imitation [5] - Change in fitness [15] B55FF Specific evidence – Not available. Generic evidence – Plastic and microplastics have been found in the tissue and stomach of a range of pelagic and demersal fish species (Lusher et al. 2013). Diet studies have shown that plastic debris is found in the stomachs of a range of fish species, potentially causing growth and reproductive effects (Browne et al. 2015).
Marine mammals	Discharge (debris) - Prey imitation [5] - Change in fitness [15] B55FM Specific evidence – Not available. Generic evidence – Marine mammals are well known to ingest marine debris, with over 26 species of toothed whales and multiple pinnipeds confirmed to ingest debris (NOAA 2014). Plastics have been identified in the stomach and scat of pinnipeds and cetaceans worldwide (Eriksson and Burton 2003). For pinnipeds, the pathway of ingestion is presumed to be from consumption of prey species that have consumed microplastics (Eriksson and Burton 2003), although many researchers have anecdotal accounts of marine mammals (and other taxa) playing with and directly consuming plastics of various sizes. The same is true for cetaceans (e.g., (Baird and Hooker 2000), with populations of both large and small cetaceans suffering fitness consequences from direct and indirect plastic consumption (Alexiadou et al. 2019; Baulch and Perry 2014; Besseling et al. 2015; De Stephanis et al. 2013; Fossi et al. 2018).
Marine reptiles	Discharge (debris) - Prey imitation [5] - Change in fitness [15] B55FR Specific evidence – Not available. Generic evidence – Sea turtles are particularly susceptible to the accidental ingestion of plastics. A primary food source of the sea turtle species that inhabit Canadian waters is jellyfish. All sea turtle species have been documented with debris ingestion (Kühn et al. 2015). Ingestion may lead to malnutrition, killing the consumer, and affecting the individual and population long-term (Bjorndal et al. 1994).
Marine birds	Discharge (debris) - Prey imitation [5] - Change in fitness [15] B55FB Specific evidence – Not available. Generic evidence – Ingestion of plastic debris has been documented for 164 out of 406 species of seabird (Kühn et al. 2015). Ingestion of plastics by seabirds produces a reduced feeding stimulus and/or reduced storage volume of the stomach, reduced meal size, reduced growth, increased levels of organochlorine assimilation, and intestinal blockage (Derraik 2002; Laist 1987; Provencher et al. 2009). Ingestion of plastic particles can also hinder formation of fat deposits in migratory sea birds, adversely affecting long-distance migration and possibly affecting their reproductive effort (Derraik 2002).
Discharge (debris) - Prey imitation [5] - Mortality [16]	

Marine mammals	Discharge (debris) - Prey imitation [5] - Mortality [16] B55MM <u>Specific evidence</u> – Not available. <u>Generic evidence</u> – Prey imitation can cause mortality of marine mammals and sea turtles through obstruction of the gut, throat, or digestive tract, causing starvation (Browne et al. 2015). The death of a sperm whale was caused by a large amount plastic debris in its stomach (De Stephanis et al. 2013). The ingestion of plastic debris in marine mammals may be underestimated, as dead or sick animals may go unnoticed and sink upon death (Baird and Hooker 2000; Williams et al. 2011a).
Marine reptiles	Discharge (debris) - Prey imitation [5] - Mortality [16] B55MR <u>Specific evidence</u> – Not available. <u>Generic evidence</u> – Prey imitation can cause mortality of sea turtles through gut impaction and perforation (Wilcox et al. 2018). Ingestion of debris has caused mortality in both adult and juvenile sea turtles (Bjorndal et al. 1994; Bugoni et al. 2001; Mrosovsky et al. 2009; Tourinho et al. 2010). Plastic ingestion has been linked to population effects for sea turtles; analysis of a large dataset found significant mortality predictions for sea turtles: probability of mortality reached 50% once a sea turtle had 14 pieces of plastic in the gut (Wilcox et al. 2018).
Marine birds	Discharge (debris) - Prey imitation [5] - Mortality [16] B55MB <u>Specific evidence</u> – Not available. <u>Generic evidence</u> – Ingestion of plastics by sea birds produces a false sense of fullness and/or reduced storage volume of the stomach, which causes the animal to stop eating and leads to malnutrition and ultimately, death (Derraik 2002; Laist 1987). Lethal impacts of debris ingestion have been documented in a number of seabird species (Avery-Gomm et al. 2013; Colabuono et al. 2009; Kenyon and Kridler 1969; Pettit et al. 1981).

APPENDIX B6: DISCHARGE (OTHER) TABLES OF EVIDENCE



Definition: The Discharge (other) sub-activity pathways of effects model considers discharges other than debris and has five associated stressors: *biological material* (Table B6-1); *introductions of species* and *pathogens* (Table B6-2); *petroleum products* (Table B6-3); *air emissions* (Table B6-4); and *other contaminants* (Table B6-5).

Tables of evidence are provided for each stressor in the following pages, based on the order outlined in the diagram above. *Specific* evidence refers to information specific to the sub-activity (commercial vessel discharges (other)), whereas *generic* evidence is broader evidence that can provide insight where specific evidence may not be available. *Not applicable* generic evidence indicates this is the sole linkage and that specific evidence is available*. Not available* indicates that no evidence was found for that linkage.

Table B6-1 – Evidence for the **Biological material [1]** stressor

Discharge (other) - Biological material [1]
Biological material can be discharged from vessels into the marine environment through routes such as waste disposal and lost cargo (Davenport and Davenport 2006; O'Brien and Dixon 1976). The introduction of biological material can result in nutrient enrichment, which can stimulate plant growth and algal blooms, and cause eutrophication. Where plant growth or algal blooms are significant enough to reduce oxygen, other biota can be affected, such as fish and seagrass.

Other substrates are released with sewage discharges including pollutants, the diverse effects of pollutants and contaminants is out of scope for this stressor. For an example, see the evidence for the *other contaminants* stressor.	
Discharge (other) - Biological material [1] - Change in fitness [6]	
Marine plants and algae	Discharge (other) - Biological material [1] - Change in fitness [6] B61FP Specific evidence – Studies in the Baltic sea indicate that nutrients discharged in vessel wastewater (of which sewage is a component), have only a relatively small contribution to eutrophication, but could have localised impacts along shipping routes (reviewed in (Jägerbrand et al. 2019). Additionally, vessel wastewater discharges may favour cyanobacteria blooms, which can have toxic impacts (potentially changing fitness to marine plants and algae), and contribute further to eutrophication through increasing bioavailable nitrogen (Larsson et al. 2001; Vahtera et al. 2007), cited in (Jägerbrand et al. 2019). Generic evidence – An excess of nutrients from biological material can cause eutrophication, with potential fitness impacts to coastal ecosystems (including marine plants and algae). For example, nutrient enrichment in shallow coastal waters can result in fitness effects to slow-growing algae, when fast-growing algae become stimulated to grow faster by increased nutrient availability and take space or shade the slow growing varieties (Pedersen and Borum 1996). Excess nutrients in nutrient-limited waters shift the composition and biomass of phytoplankton and macroalgal communities, which in turn can affect carbon sequestration and nutrient biogeochemistry (Raudsepp et al. 2019; Spilling et al. 2014). Increased nutrients from sewage outfalls changed the composition of phytoplankton communities (Pan and Subba Rao 1997). Gradients in sewage levels have been linked to differences in algal community structure, with different species present at polluted and pristine sites (Gorostiaga and Díez 1996). Algal species found near outfalls are characterised by smaller growth forms, shorter life histories and early colonisers (Littler and Murray 1975).
Marine invertebrates	Discharge (other) - Biological material [1] - Change in fitness [6] B71FI Specific evidence – The discharge of faecal bacteria in wastewater is a potential cause of contamination of shellfish such as bivalves (Herz and Davis 2002; Lindgren et al. 2016), although this contamination is a health concern for human consumption and not a specific impact on invertebrates. Generic evidence – A study of low-volume domestic sewage discharge by (Littler and Murray 1975) found that fewer invertebrate species were found near the outfall, and the community was less diverse than control sites. Sewage discharge causes significant reduction in both mussels and associated fauna, with both short and long-term effects (Elías et al. 2006; Vallarino and Elías 2006).
Marine fishes	Discharge (other) - Biological material [1] - Change in fitness [6] B61FF Specific evidence – Excess nutrients from releases of biological material from vessels can cause contamination in fish species (Larsson et al. 2001; Vahtera et al. 2007), although this contamination is a health concern for human consumption and not a specific impact on fishes. Generic evidence – Reproductive impairment and endocrine disruption has been observed in fish at downstream sites of sewage outfalls (Jessica et al. 2007) The effect of other chemicals and pollutants in sewage discharge is difficult to distinguish from the effect of biological material alone.
Marine mammals	Discharge (other) - Biological material [1] - Change in fitness [6] B61FM Specific evidence – Not available. Generic evidence – An excess of nutrients from biological material can cause eutrophication, which together with harmful algal blooms can affect marine mammal health and reproductive success (Van Dolah 2005). Harmful algal blooms (which are usually caused by agricultural runoff rather than vessel discharges) are a source of marine mammal mortality and injury worldwide (Van Dolah 2005).

Discharge (other) - Biological material [1] – Change in habitat [7]	
Physical habitat (water column)	Discharge (other) - Biological material [1] - Change in habitat [7] B61HW Specific evidence – In a cruise ship environmental impact model, nutrients, bacteria, viruses and other pathogens discharged by ships are suggested to result in habitat fragmentation and/or loss (Carić and Mackelworth 2014). Dissolved oxygen may be reduced due to the decomposition of biological materials discharged from vessels in greywater and wastewater. Generic evidence – The effects of the introduction of biological material and excess nutrients may cause oxygen depletion of coastal waters, an increased risk of harmful algal blooms (Sellner et al. 2003), and reductions in community biodiversity (O'Brien 2001). Large releases of nutrients can result in prolonged spring phytoplankton maxima and in turn cause toxic algal blooms (Sellner et al. 2003; Smayda 1997; Van Dolah 2005). Elevated nutrient loading has been proposed as the primary reason for the increasing frequency of harmful algal blooms (Sellner et al. 2003).

Table B6-2 – Evidence for the **Introductions of species and pathogens [2]** stressor

Discharge (other) - Introductions of species and pathogens [2]	
Introductions of species Ballast water is a vector for the transportation of Aquatic Invasive Species (AIS), which can be released during ballast water exchange. AIS can also be transported attached to the hull and other submerged surfaces of the ship (this vector is considered in the Vessel at Rest PoE model B2-4). **Introductions of pathogens** Examines the impacts of pathogens transported in ballast tanks or in sewage discharges, including viruses and bacteria amongst others.	
Discharge (other) – Introductions of species and pathogens [2] - Change in fitness [8]	
Marine plants and algae	Discharge (other) – Introductions of species and pathogens [2] - Change in fitness [8] B62FP **Introductions of species** Specific evidence – Marine plants can be impacted by introduced species as either prey of the introduced species, or from competition for resources from other benthic introduced species (both marine plants and invertebrates). *Codium fragile* is spread through ballast water, among other pathways (Fofonoff et al. 2018). *Codium fragile* var. *tomentosoides* has been observed to attach to and overgrow eelgrass (Locke et al. 2002). Buoyancy resulting from the production and trapping of gases by *Codium* can pull up the whole eelgrass plant, which is then cast up on the shore and may die. *Codium* has spread rapidly to become a dominant and persistent component of seaweed assemblages in the rocky low intertidal to subtidal zones of the Atlantic coast of Nova Scotia (Scheibling and Anthony 2001). In this area, *Codium* can form continuous meadows, often replacing entire kelp beds and occurring to a depth of 15 m (Chapman 1998). Generic evidence – Invasive algal species can cause a change in fitness to native algal species by affecting the ability of the native species to photosynthesis and stunting growth. In the NE Pacific, a study in Washington State found that the negative effects of *Sargassum muticum* on native algae appear to be a result of shading (Britton-Simmons 2004). For more information and generic evidence of effects of this stressor to this endpoint refer to Anchoring and Mooring PoE evidence tables (Table B1-6, reference B16FP). **Introductions of pathogens** Specific evidence – Ballast water can transport pathogens that may cause waterborne diseases that affect plants, and with the concentrations of bacteria and viruses in ballast water 6-8 orders of magnitude higher than for other taxonomic groups, the increased propagule pressure should lead to a higher likelihood of successful invasion (Ruiz et al. 2000).

	Generic evidence – Refer to Anchoring and Mooring PoE for generic evidence of this stressor to this endpoint (Table B1-6, reference B16FP).
Marine invertebrates	Discharge (other) – Introductions of species and pathogens [2] - Change in fitness [8] B62FI **Introductions of species** Specific evidence – Invertebrates are the most commonly transported AIS in both ballast, and attached to marine-sourced debris. Notable invasions of invertebrates that have been linked to ballast water transport include the comb jelly *Mnemiopsis leidyi* (from the eastern coast of North America to the Black Sea), the Asian sea star *Asterias amurensis* (from Japan to Tasmania), the shore crab *Carcinus maenas* (to Australia, the Pacific and Atlantic coasts of North America, South Africa, and the Patagonian coast from Europe), the European Green Crab (including into Canadian waters), and the Chinese mitten crab (Minchin 2009; Walker et al. 2019). Due to uptake of both sediments and water as ballast, invertebrates in various life stages and eggs (dormant eggs, resting eggs, statoblasts, and cysts) can be transported to other areas, resulting in competition with and predation of native invertebrate species (Bailey et al. 2005; Briski et al. 2011; Cáceres 1997; Duggan et al. 2006; Duggan et al. 2005; Klassen and Locke 2007; Locke et al. 1993; Minton et al. 2005; Shea and Chesson 2002; Sutherland et al. 2009). Sea urchins in NS derived less nutrition from feeding on *Codium* than from kelp, thus replacement of kelp beds by *Codium* is problematic to grazers (Scheibling and Anthony 2001). Generic evidence –(Wright 2008) found a change in fitness in a marine invertebrate due to AIS presence. They found that a bivalve species, *Anadara trapezia*, responded to invasion by the habitat-forming seaweed, *Caulerpa taxifolia*, with significantly lower adult growth, body condition, shell condition, female reproduction and survivorship in comparison to unvegetated sediment. Refer to Anchoring and Mooring PoE for generic evidence of this stressor to this endpoint (Table B1-6, reference B16FI). **Introductions of pathogens** Specific evidence – Many viral families are found in ballast tanks worldwide (Kim et al. 2016; Kim et al. 2019). Some bacterial and viral pathogens transported in ballast water occur on the outer surfaces of invertebrates (Saccà 2015). For example, bacteria have been observed attached to the chitinous surfaces of copepods and other crustaceans (Huq et al. 2001; Lipp et al. 2002), to larval stages of planktonic invertebrates (Martinelli Filho et al. 2010), and to the mucilaginous envelopes of some phytoplankton (Huq et al. 2001; Lipp et al. 2002). Exposure to pathogens can result in fitness impacts to marine invertebrates with some life stages more susceptible than others. For example, bivalve clam larvae are more susceptible to *Vibrio* pathogens (Dubert et al. 2016). Molluscs are known to become contaminated by pathogens, for example by haplosporidian protozoa (Goulletquer et al. 2002). Infection by *Haplosporidium nelsoni* can cause multinuclear sphere X (MSX) disease in Pacific and American oysters, resulting in slower valve closure response to disturbance, decreased growth, fouling inside of the left peripheral valve, receding mantle, and discolouration on internal valve surfaces and digestive glands (for juveniles). *H. nelsoni* has been found in Nova Scotia and British Columbia (Canada Food Inspection Agency 2018), and anecdotal evidence linked the appearance of MSX in oysters in the Bras d'Or Lakes, NS, to discharge of ballast water originating from the eastern USA. Generic evidence – Not applicable. Refer to Anchoring and Mooring PoE for generic evidence of this stressor to this endpoint (Table B1-6, reference B16FI).
Marine fishes	Discharge (other) - Introductions of species and pathogens [2] - Change in fitness [8] B62FF **Introductions of species** Specific evidence – Adult, juvenile and larval fishes are capable of being transported by ballast water. If invasive fish populations become established there can be a reduction in fitness of native populations of fish through increased competition for prey and/or predation by the aquatic invasive species. The introduction of aquatic invasive species through ballast exchange has been found to have a significant impact on commercial fisheries (e.g., introduction of the comb jelly to the Black and Azov Seas caused significant declines in the commercial anchovy fisheries (Bailey 2015; Daskalov and Mamedov 2007; Walker et al. 2019). In ballast water arriving to the east and west coast of Canada in 2007, (Klein et al. 2009) found that 52 out of 67 samples contained diatoms from the genus *Chaetoceros*, which are known to have harmed salmonids

	and other fish taxa. The invasive ctenophore, *Mnemiopsis leidyi*, in the Southern Caspian Sea (likely introduced from ballast water discharge) has affected fish through competition for food and also the displacement of other plankton species (Finenko et al. 2006). Phytoplanktonic invasive species may bloom with impacts on the health and mortality of fish species (Katsanevakis et al. 2014). Generic evidence – Refer to Anchoring and Mooring PoE for generic evidence of this stressor to this endpoint (Table B1-6, reference B16FF). **Introductions of pathogens** Specific evidence – Pathogens released in discharges from ships may result in a change in fitness in marine fishes. For example, cholera has been detected in vessels sampled and can be transported in ballast water. An epidemic strain of cholera from South America has been discovered in fish and shellfish in the Gulf Coast (Herz and Davis 2002). Cholera has the potential to cause a detrimental impact to fish health; however, fish may also benefit from the presence of cholera in their intestine (Halpern and Izhaki 2017). Generic evidence – A number of viral fish diseases that are known to be spread by contaminated water (water used in seafood processing and handling) in Canada (Canada Food Inspection Agency 2018). Infectious haematopoietic necrosis affects many finfish including species of salmon, trout, herring, and sturgeon, is caused by a virus in the family Rhabdoviridae (Canada Food Inspection Agency 2018). Infectious pancreatic necrosis is caused by a virus in the family Birnaviridae and affects a wide variety of marine and freshwater fishes (Canada Food Inspection Agency 2018). Refer to Anchoring and Mooring PoE for generic evidence of this stressor to this endpoint (Table B1-6, reference B16FF).
Marine mammals	Discharge (other) - Introductions of species and pathogens [2] - Change in fitness [8] B62FM **Introductions of species** No evidence available at this time. **Introductions of pathogens** Specific evidence – An increase in antibodies for *Taxoplasma gondii* in polar bears, ringed seals, and adult bearded seals in Svalbard has been linked to the discharge of ballast water, which is known to contain algae, viruses, and bacteria, from increased ship traffic (Jensen et al. 2010). Generic evidence – Not applicable.
Discharge (other) – Introductions of species and pathogens [2] - Mortality [9]	
Marine plants and algae	Discharge (other) – Introductions of species and pathogens [2] – Mortality [9] B62MP **Introductions of species** Specific evidence – Marine plants can become prey of the introduced species. Likely introduced through ballast water, the invasive Chinese Mitten crab feeds on algae and aquatic plants in addition to pulling up plant shoots due to aggressive interactions with other crabs (Fofonoff et al. 2018). Generic evidence – Refer to Anchoring and Mooring PoE for generic evidence of this stressor to this endpoint (Table B1-6, reference B16MP). **Introductions of pathogens** Specific evidence – Ballast water can transport pathogens that may cause waterborne diseases that affect plants, and with the concentrations of bacteria and viruses in ballast water 6-8 orders of magnitude higher than for other taxonomic groups, the increased propagule pressure should lead to a higher likelihood of successful invasion (Ruiz et al. 2000). Generic evidence – Refer to Anchoring and Mooring PoE for generic evidence of this stressor to this endpoint (Table B1-6, reference B16MP).
Marine invertebrates	Discharge (other) - Introductions of species and pathogens [2] - Mortality [9] B62MI **Introductions of species** Specific evidence – Possibly introduced through ballast water, the invasive European Green crab, Chinese Mitten crab, Harris Mud Crab, and Asian Shore Crab each predate on native invertebrates (Fofonoff et al. 2018).

	<u>Generic evidence</u> – Refer to Anchoring and Mooring PoE for generic evidence of this stressor to this endpoint (Table B1-6, reference B16MI). **Introductions of pathogens** <u>Specific evidence</u> – Viral families found in ballast tanks worldwide can cause mortality in invertebrates (Kim et al. 2016; Kim et al. 2019). Infection by *Haplosporidium nelsoni* can cause multinuclear sphere X (MSX) disease in Pacific and American oysters, resulting in juvenile and adult mortality. *H. nelsoni* has been found in Nova Scotia and British Columbia (Canada Food Inspection Agency 2018), and anecdotally linked to discharge of ballast water originating from the eastern USA. <u>Generic evidence</u> – Refer to Anchoring and Mooring PoE for generic evidence of this stressor to this endpoint (Table B1-6, reference B16MI).
Marine fishes	Discharge (other) - Introductions of species and pathogens [2] - Mortality [9] B62MF **Introductions of species** <u>Specific evidence</u> – Phytoplanktonic invasive species may bloom and impact the health and mortality of fish species (Katsanevakis et al. 2014). For example, dinoflagellate cysts can be transported in ballast water, some species of which are capable of harming fish if they cause a toxic bloom (Hallegraeff 2003). The Yellowfin Goby, possibly introduced through ballast water, has been suspected of consuming juvenile Tidewater Goby and Staghorn Sculpin. Also likely introduced through ballast water, the invasive Chinese Mitten crab feeds on trapped fish and fish eggs (Fofonoff et al. 2018). <u>Generic evidence</u> – Refer to Anchoring and Mooring PoE for generic evidence of this stressor to this endpoint (Table B1-6, reference B16MF). **Introductions of pathogens** <u>Specific evidence</u> – Pathogens released in discharges from ships may cause mortality in marine fishes. For example, cholera has been detected in vessels sampled and can be transported in ballast water. An epidemic strain of cholera from South America has been discovered in fish and shellfish in the Gulf Coast (Herz and Davis 2002). <u>Generic evidence</u> – Pathogens affecting fish, such as rhabdovirus, result in losses of cultured and wild fish, e.g., Pacific Salmon (Batts et al. 1993; Walker and Winton 2010). Rhabdovirus can result in mass mortality of both fresh and marine fish species (Gagné et al. 2007). Infectious salmon anaemia (ISA) caused by the ISA virus, is known to affect *Oncorhynchus mykiss* (rainbow trout), *Salmo salar* (Atlantic salmon), and *Salmo trutta* (brown trout), and may affect *Salvelinus alpinus* (Arctic char), and *Clupea harengus* (Atlantic herring). ISA can cause death at rates up to 90% in affected populations, and is spread by contact with contaminated water, equipment, or fish (Canada Food Inspection Agency 2018). White sturgeon iridoviral disease is caused by a virus in the family Iridovirus and affects sturgeons, causes death in 95% of infected fish under one year of age, and is spread by contaminated water, equipment, and fish (Canada Food Inspection Agency 2018). Refer to Anchoring and Mooring PoE for generic evidence of this stressor to this endpoint (Table B1-6, reference B16FM).
Discharge (other) – Introductions of species and pathogens [2] – Change in habitat [10]	
Physical habitats (substrate)	Discharge (other) - Introductions of species and pathogens [2] - Change in habitat [10] B62HS **Introductions of species** <u>Specific evidence</u> – Buoyancy resulting from the production and trapping of gases by introduced *Codium* can pull up whole eelgrass plants, which are then cast up on the shore and may die. *Codium* has spread rapidly to become a dominant and persistent component of seaweed assemblages in the rocky low intertidal to subtidal zones of the Atlantic coast of Nova Scotia (Scheibling and Anthony 2001). In this area, *Codium* can form continuous meadows, often replacing entire kelp beds and occurring to a depth of 15 m (Chapman 1998). Likely introduced through ballast water, invasive Chinese Mitten crabs create extensive burrows in tidal stream banks, which may lead to increased erosion, bank slumping (Fofonoff et al. 2018). <u>Generic evidence</u> – The introduction of AIS can result in a change in physical or chemical conditions of habitats (Elliott 2003; Olenin et al. 2010). Outbreaks can modify substratum conditions, including shore zones, smother benthic sediments, or result in the loss of biogenic habitat species (e.g., eelgrass). Zebra mussels have been introduced into the Great Lakes

	through ballast water discharges. The dense colonisation of substrate by these mussels has caused a change in benthic habitats characteristics (Ricciardi and MacIsaac 2000). **Introductions of pathogens** Specific evidence – No evidence specific to this sub-activity could be found at this time. Generic evidence – Some ecosystem engineering seagrasses, which provide habitat to many species, face population declines due to wasting disease caused by pathogens (Groner et al. 2016).
Physical habitats (water column)	Discharge (other) - Introductions of species and pathogens [2] - Change in habitat [10] B62HW **Introductions of species** Specific evidence – Ballast water exchanges are reported to not affect the diversity and abundance of diatoms and dinoflagellates in ballast tanks (Briski et al. 2013) which could lead to species introductions. A study by (Villac et al. 2013) found that if the diatoms in ballast sediments had been released, it could have led to 60 new species records on the Atlantic Coast and 70 on the Pacific Coast. Nine toxigenic species from the genus *Pseudo-nitzschia*, some non-native to Pacific and Atlantic Canada, have been found in ballast water *en route* to Canadian ports, and were not affected by ballast exchange (Kaczmarska and Ehrman 2015). The introduction of species via ballast water exchange can contribute to toxic algal bloom outbreaks (Bax et al. 2003; Doroff et al. 2011; Olenin et al. 2011; Terdalkar et al. 2005; Van Dolah 2000). Outbreaks can alter oxygen and nutrient concentrations, pH and transparency of the water, and the accumulation of synthetic pollutants (Olenin et al. 2011). Generic evidence – Following the invasion of the ctenophore, *Mnemiopsis leidyi*, in the Southern Caspian Sea (likely introduced from ballast water discharge) the water column is now a different habitat due to a changed community of plankton and fishes compared to the pre-invasion state (Roohi et al. 2010). **Introductions of pathogens** No evidence available

Table B6-3 – Evidence for the **Petroleum products [3]** stressor

Discharge (other) – Petroleum products [3]	
Exposure to the hydrocarbons in petroleum products, such as those discharged from vessels involved in marine shipping through accidental spills or operational discharges, can affect fitness and mortality of biota through toxic and physical impact pathways, and can also change physical habitats. Releases of petroleum products can often occur together with other substances (these are considered in the 'other contaminants' stressor).	
Discharge (other) – Petroleum products [3] - Change in fitness [11]	
Marine plants and algae	Discharge (other) – Petroleum products [3] - Change in fitness [11] B63FP Specific evidence - accidental release (grounding/collision/sinking) - Oil released after the grounding of the *Exxon Valdez* resulted in fitness effects to upper intertidal plant and algae populations due to the limited dispersal ability of some species and harsh upper intertidal conditions, making recovery slow (Stekoll et al. 1993). Decreases in percentage cover of populations of a range of species was observed in affected areas (e.g., *Cladophora, Myelophycus, Palmaria, Odonthalia, Polysiphonia*) , and an increase only for one (*Gloiopeltis*) (Stekoll et al. 1993). Damage to intertidal plants was documented following the *Nestucca* oil spill (caused by a collision) on Canada's Pacific west coast (Duval et al. 1989). Oil released from the grounding of the *Tampico Maru* in Baja California severely affected the kelp *Macrocystis* possibly due to toxic impacts inhibiting photosynthesis (Nelson-Smith 1972). Crude oil from the *Exxon Valdez* oil spill smothered kelp blades (Pearson et al. 1995, cited in (Roberts et al. 2008)). The *Deepwater Horizon* oil spill (a well blowout) caused large-scale seagrass bed damage (Beyer et al. 2016) and in salt marshes, coating and smothering of vegetation with oil caused a decrease in the standing crop of marsh vegetation (Hester et al. 2016).

	<u>Generic evidence</u> – Fitness impacts to marine plants and algae from petroleum products are primarily related to the inhibition of photosynthesis and gas exchange either through toxic or physical pathways. *Toxic pathways* – Soluble oil compounds can concentrate in the thylakoid membranes of aquatic plants and impair photosynthetic ability in seagrasses (Runcie et al. 2004). Oil can prevent germination and growth in marine plants (USFWS 2010). Studies on toxic impacts from oil to seagrasses indicate that while leaves and shoots show damage, roots and rhizomes can be less affected (Clark et al. 1978; Dean et al. 1998; Phillips and Watson 1984). Marine plants respond variably to oil (Patin 1999) and toxicity can manifest differently depending on factors such as the age of the plant and the season, for example in seagrasses, oil exposure in spring can impact flower production and viability (Phillips and Watson 1984). However, drawing broad conclusions from toxicity studies can be challenging, a review of 85 marine plant and algae toxicity studies from a range of oils and dispersants was unable to make clear conclusions due to variable responses and diverse methods and measurements (Lee et al. 2015; Lewis and Pryor 2013). Although oil can prevent the germination and growth of marine plants, most vegetation, including kelp, often recovers after clean up (USFWS 2010). Phytoplankton are able to metabolize hydrocarbons, with unknown fitness effects, other than facilitating toxin movement in the ecosystem (Beyer et al. 2016). *Physical / mechanical pathways* - Plants and algae types with morphology that can easily become coated and smothered with oil can experience photosynthetic impairment (e.g., marsh plants (Pezeshki et al. 2000), kelp (*Nereocystis)* (Antrim et al. 1995). In marine algae, the degree of photosynthetic impairment is related to oil thickness (O'Brien and Dixon 1976). Surfgrass (*Phyllospadix)* plants are reported to trap oil between their blades (Foster et al. 1971). Although some plants survive oil fouling by producing new leaves, even relatively non-toxic oils can stress or kill plants if gas-exchange is physically prevented (Pezeshki et al. 2000). Impacts to vascular plants depend on the severity of fouling, and long-term impacts will depend on whether below-ground roots and rhizomes are affected. Impacts from unrefined products tend to be short-term and recovery can occur within a few years (Hayes 1996; Hester et al. 2016; Rutherford 2013). Succulent marsh species, such as American glasswort, are particularly sensitive to oiling (Davy et al. 2001; Moody 1990; Morris and Harper 2006). March species with tall, reedy or stiff grassy stems may stand above oil, limiting impacts from photosynthetic impairment (Morris and Harper 2006). Oil can physically adhere to phytoplankton (Lee et al. 1985), and oil (and dispersants) are toxic to phytoplankton species (Garr et al. 2014; Lee et al. 2015) and inhibit growth (Hjorth et al. 2008; Ozhan et al. 2014). Findings for the effects of oil on phytoplankton in the literature are variable, with some studies reporting local short-term decreases in abundance and productivity of phytoplankton, while others report increases in primary productivity (Duval et al. 1989). Phytoplankton are expected to have high recovery regardless of their exposure or sensitivity, due to the mixing and dispersal of oil by water currents and the rapid growth rate of phytoplankton and recruitment from un-oiled areas (Lee et al. 2015).
Marine invertebrates	Discharge (other) - Petroleum products [3] - Change in fitness [11] B63FI <u>Specific evidence - accidental release (grounding/collision/sinking) -</u> Clam, mussel, and intertidal communities were still recovering from the *Exxon Valdez* oil spill 20 years later (EVOSTC 2009). Mussels (*Mytilus trossulus*) sampled in 1996 in areas affected by the 1989 *Exxon Valdez* oil spill were less tolerant to air exposure than reference groups (Thomas et al. 1999). Coral communities some distance (11 km) from the *Deep Water Horizon* well oil blowout surveyed 3-4 months after the spill showed widespread signs of stress (e.g., excess mucous production, covered with flocculent material, sclerite enlargement (White et al. 2012). The shallow water species most affected after the *Deepwater Horizon* spill included Cnidarians such as gorgonian corals (Etnoyer et al. 2016) and stony coral larvae (Goodbody-Gringley et al. 2013). Bivalves in Plumper Bay, Victoria, BC, took over three years to become suitable for human consumption after a Diesel spill in 2016 (pers. comm. M. Herborg, DFO). <u>Generic evidence</u> – Specific fitness impacts are related to the morphology and characteristics of each group of marine invertebrates, few of which are well studied. The main mechanism of impact in marine invertebrates is physical smothering, rather than toxicity (Suchanek 1993), which can impact respiration, movement, create excess weight on mobile organisms, or cause them to be carried away by waves and currents. *Toxic pathways* - Oil can impact benthic marine invertebrates by altering metabolic rate, feeding rate, and shell formation (Patin 1999; USFWS 2010) and can have long lasting impacts to

	physiological activities and reproduction (Adzigbli and Yuewen 2018). Sea stars exposed to crude oil exhibit reduced feeding, growth (O'Clair and Rice 1985), ability to locate prey (Temara et al. 1999), and problems with embryonic development (Davis et al. 1981; Spies and Davis 1982). The low mobility of bivalves such as clams and mussels limits movement away from contaminated waters, and they can consume suspended oil droplets when filter-feeding (Dupuis and Ucán-Marín 2015; Payne and Driskell 2003). Clams exposed to crude oil exhibit decreased burrowing, increased respiration rate, inhibited growth and high mortalities (Stekoll et al. 1980). Some bivalves bury themselves into oiled sediments less deeply than normal, increasing predation risk (Pearson et al. 1981). Corals exposed to oil have inhibited growth and altered nutrient dynamics and biochemical composition which can lead to bacterial infection (Gass 2003; Jamieson et al. 2006). *Physical/mechanical* - The feeding appendages of filter feeders, suspension feeders and lophophorates could become clogged by oil affecting their ability to feed (Pechenik 2005). There may be a greater impact on sessile marine invertebrates due to smothering that can impact respiration. Other appendages such as the fine tentacles of cnidarians could also be clumped together by oil. Larval marine invertebrates could also be affected as many feed using setae or cilia (Shanks 2001). Corals exposed to disturbances, whether physical or chemical, react defensively by retracting their polyps and producing a hypersecretion of mucus (Gass 2003). If this defence mechanism lasts for a prolonged period of time, effects can include decreased nutrient assimilation and production, altered biochemical composition, partial or complete inhibition of growth, and bacterial infection (Gass 2003; Jamieson et al. 2006). Intertidal marine invertebrates are often one of the most visibly affected biological resources following oil spills (Duval et al. 1989). Some infaunal bivalve species burrow more slowly and do not bury themselves as deeply in oiled sediment than in clean sand, making them more vulnerable to predation (Pearson et al. 1981). Atlantic rock crab (*Cancer irroratus*) larvae cultured in water contaminated with No. 2 fuel oil displayed altered behaviour in response to gravity or light (Bigford 1977). Fewer larvae were produced by female Dungeness crabs (*Metacarcinus magister*) exposed to oiled sediments for a reproductive cycle, though there was no effect on Tanner crabs (*Chionoecetes bairdi*) (Suchanek 1993). Studies also demonstrated that two types of crabs, *Pugettia* and *Cancer*, had suppressed chemoreception abilities after exposure to crude oil, which affected food searching (Suchanek 1993). The seastar *Evasterias trochelii* displayed inhibited growth and feeding in the presence of crude oil of at least 0.12ppm, and sublethal amounts of oil also reduced feeding rates in several bivalve species (Suchanek 1993).
Marine fishes	Discharge (other) - Petroleum products [3] – Change in fitness [11] B63FF Specific evidence - accidental release (grounding/collision/sinking) – Growth of Dolly Varden, cutthroat trout, and pink salmon was reduced in the years following the *Exxon Valdez* oil spill (Hepler et al. 1996; Wertheimer and Celewycz 1996). In the years after the *Exxon Valdez* oil spill, some salmon species were seen to recover, but this was not the case for herring that had not recovered after 20 years, although opinion is divided as to whether this can be solely attributed to the spill (EVOSTC 2009; Marty 2008). Herring were about to spawn when the *Exxon Valdez* oil spill occurred. Sub-lethal effects were documented and adult returns from this year class was low (Thorne and Thomas 2008, 2014). Exposure to weathered oil from the Exxon Valdez spill has been implicated in indirect effects on growth, deformities, and behaviour to marine fishes (e.g., herring, salmon) with the potential for long-term reproductive consequences (Peterson et al. 2003). Generic evidence – In marine fishes, fitness effects from exposure to oil occur primarily through toxic pathways, rather than physical and there is more research available on oil toxicity to fish than for other biological groups (Lee et al. 2015). Marine fishes can be affected directly through uptake by the gills, direct contact with droplets, maternal transfer, and ingestion of oil or oiled prey (Elmgren et al. 1983; Lee et al. 2015; Patin 1999). Exposure can affect reproduction, growth, disease and survival (Lee et al. 2015), impacts can be physiological, mutagenic, and behavioural (Patin 1999), and consequences range from subtle sub-lethal effects to large-scale mortality (Lee et al. 2015). *Toxic impact*- A change in fitness can result from chronic exposure, such as oil retained in sediments, or from delayed or ongoing effects of acute exposures. Oil also has the potential to affect spawning success, as eggs and larvae of many fish species, including salmon, are highly sensitive to oil chemicals. Sub-lethal impacts to early life stages include gill damage and

	impaired growth and development (Adzigbli and Yuewen 2018; Patin 1999; USFWS 2010). Adult fish may experience reduced growth, enlarged livers, changes in heart and respiration rates, fin erosion, and reproductive impairment when exposed to oil (USFWS 2010) . *Physical impact* - The characteristics of marine fishes can influence the severity of fitness effects experienced through physical routes of oil exposure. Species that filter feed, are benthic, or gather in large aggregations may be more affected (Hannah et al. 2017).
Marine mammals	Discharge (other) - Petroleum products [3] - Change in fitness [11] B63FM Specific evidence - accidental release (grounding/collision/sinking) - There is well documented evidence of the effects of oil spilled from a grounded vessel on marine mammals from the Pacific ocean. This comes from the aftermath of the *Exxon Valdez* oil tanker grounding in 1989 in Alaska, spilling 11 million gallons of crude oil. After this spill there were extensive sea otter deaths indicating population-level effects (Garshelis and Johnson 2013; Marty 2008) and severe impacts to resident killer whales, with 14 of the 36 killer whales in the resident Price William Sound pod disappearing post-spill (EVOSTC 2009). A sea otter death was also reported after the Nestucca collusion oil spill (a collision) (Waldichuk 1989). Harbour seals were highly affected by the *Exxon Valdez* oil spill, but appeared to have recovered 20 years later (EVOSTC 2009). Generic evidence – Over both short- and longer-term, exposure to petroleum products or other contaminants can cause effects ranging from surface fouling of fur and baleen, irritation of eyes and skin, irritation or destruction of intestinal linings, organ damage, neurological disorders, increased metabolism, and inhibited thermoregulation. Factors in marine mammals that can influence the severity of fitness effects they experience include exposure routes, behavioural ecology, and physiological characteristics (Jarvela-Rosenberger et al. 2017). Some of the characteristics of marine mammals make them vulnerable to impacts from an oil spill: they breathe at the surface where oil and oil vapour would be present, and they often aggregate, making more individuals exposed at once. Further, some species, such as humpback whales, have feeding structures that are vulnerable to being fouled, and others are bottom feeders (such as grey whales) that could be exposed to fouled sediments. The fur of fur seals and sea otters can be fouled by oil. *Toxic impact* - Even in low concentrations, oil can have severe effects on marine mammals including skin and eye lesions from external contact, and liver toxicity and lung congestion from ingestion or inhalation (Burrowes et al. 2003). Ingestion of oil, such as after fouling of baleen, may result in inflammation, ulcers, bleeding, diarrhea, maldigestion, liver or kidney damage (NOAA 2010). Hydrocarbons can produce physiological, metabolic, and behavioural disruption in marine mammals, leading to increased mortality (Patin 1999). This includes interference with the nervous system, enzyme activity, blood formation, or generation of gas emboli (Patin 1999; USFWS 2010). Some hydrocarbons can induce genetic damage and carcinogenic effects, leading to increased mortality (Patin 1999). Long-term chronic effects include immune system suppression, higher rates of infection, skin ulcerations, damage to adrenal and reproductive systems, and behavioural changes that may reduce an individual's ability to find food or avoid predators (Patin 1999; USFWS 2010). *Physical impact* - Filter feeding structures of baleen whales could become fouled with oil, reducing ability to feed (Wursig 1990). Oil may foul baleen, possibly decreasing feeding ability (NOAA 2010). Fouling of fur by oil can hinder thermoregulation by drastically reducing the insulative value of pelt, such as in fur seals and sea otters in the Pacific region (Geraci and St. Aubin 1990). In the Arctic, fur bearing animals such as ringed, harp, bearded and hooded seal pups, are particularly sensitive and can quickly die from hypothermia if affected (Skjoldal et al. 2009) .
Marine reptiles	Discharge (other) - Petroleum products [3] - Change in fitness [11] B63FR Specific evidence - accidental release (grounding/collision/sinking) - Oiled sea turtles (still living) have been documented following oil spills that resulted from a collision (between two tugs and the barge *Bouchard* B155 in Tampa Bay, Florida) and also a grounding (oil tanker *Alvenus* in 1984 in Texas) (Shigenaka et al. 2010). It is expected that many more individuals were affected that were not located. It is assumed that oiled sea turtles have encountered a spill, potentially ingested oil, and will experience fitness effects through physical and toxic impacts (if not rehabilitated). Generic evidence – Fitness impacts to adult sea turtles occur through both toxic and physical pathways. Population level impacts are uncertain since sea turtles in Canadian waters are transient foragers, and usually occur individually.

	Toxic impacts - Toxic impact is primarily due to the ingestion of oil or inhalation of oil vapours. Sea turtles do not avoid oil slicks and are indiscriminate ingesters, consuming any items of an appropriate size, including tarballs. Toxic impact from exposure and absorption of oil could irritate or burn the skin, reduce absorption or digestion of food, damage organs, affect the immune system, lower reproductive success and reduce survival (Milton et al. 2003; NOAA 2010). Sea turtles that forage within small particle sediment substrate (such as Green sea turtles) may also encounter and ingest contaminated sediments (Seminoff et al. 2006). Sea turtles inhale a large amount of air before diving and can potentially take in toxic vapours and oil droplets and then be exposed to them for an extended time, affecting fitness through impacts to the respiratory system (Milton et al. 2003; NOAA 2016). Chronic exposure to hydrocarbons can disrupt feeding in sea turtles, resulting in poor body condition (Hall et al. 1983). *Physical impacts* - The physical impacts of sea turtles becoming covered in oil are known to have severe fitness effects such as dehydration, overheating, decreased mobility and exhaustion, which impacts foraging and predator evasion (NOAA 2016). Ingested oil, such as in the form of tarballs can have physical impacts on the digestive system of sea turtles, including swelling and infection (Milton et al. 2003). The ingestion of tarballs by Loggerhead sea turtles resulted in severe oesophageal swelling, disrupting food ingestion and buoyancy, and causing bacterial infection (Milton et al. 2003). A conceptual framework capturing the complexities of effects of oil exposure to sea turtles has been developed by (Lutz et al. 1989) to capture the various routes of exposure of sea turtles to oil and the pathways of effects in detail.
Marine birds	Discharge (other) - Petroleum products [3] - Change in fitness [11] B63FB Specific evidence - accidental release (grounding/collision/sinking) - Oil from the Exxon Valdez spill (grounding) was implicated in the compromised health of exposed marine birds. The exposure occurred as a result of ingestion of contaminated prey and from foraging around areas contaminated with oil (Peterson et al. 2003). Specific evidence – operational release (movement underway, vessel at rest) – Impacts of chronic ship source oil pollution have been studied in seabirds, unlike most biotic groups (Wiese 2002b). Mortality of birds from chronic ship sourced oil pollution has been well documented but sub-lethal effects are less well quantified. Generic evidence – There is evidence of significant fitness effects to marine birds as a result of oil exposure. Toxic impact from ingestion has also been reported. *Toxic impact* - Even in low concentrations oil can have severe effects on marine birds, while ingestion may lead to death (Burrowes et al. 2003). *Physical impact* – The most significant physical impact from oil to birds is the fouling of feathers, which reduces their insulative value, increasing hypothermia risk and impacting buoyancy. The ingestion of oil as birds preen fouled feathers can result in damage to internal organs (Adzigbli and Yuewen 2018; Skjoldal et al. 2009).
Discharge (other) - Petroleum products [3] - Mortality [12]	
Marine plants and algae	Discharge (other) - Petroleum products [3] - Mortality [12] B63MP Specific evidence - accidental release (grounding/collision/sinking) - Oil released after the grounding of the *Exxon Valdez* resulted in the absence of larger size classes of subtidal kelps, with a higher relative abundance of smaller size classes, but cleanup efforts may have been a contributing factor to these impacts (Stekoll et al. 1993). Intertidal algal populations were affected, with a significant removal of many species, particularly *Fucus gardneri,* from mid to upper intertidal zones. The oil spilled from the *Nestucca* spill (a collision) impacted Canada's Pacific west coast, and resulted in mortality to intertidal plants, particularly in rocky and sandy habitats (Duval et al. 1989). The 1978 grounding of the AMOCO Cadiz and subsequent oil spill affected nearby eelgrass beds, but they were observed to begin recovering within a year or so (Suchanek 1993). Generic evidence – Marine plants and algae respond variably to oil and exposure can result in mortality for some species (Patin 1999; USFWS 2010). Mortality is caused through toxic and physical impacts. *Toxic impact* - Algae may die or become more abundant in response to oil spills, depending on the oil's composition. Refined hydrocarbon products cause the greatest acute toxicity to salt

	marsh vegetation, compared to unrefined products (Hayes 1996; Morris and Harper 2006). However, often vegetated areas, including kelp, recovers after clean up (USFWS 2010) . *Physical impact* - Even relatively non-toxic oils can stress or kill marine plants through physical means if they are smothered to a degree that photosynthesis and gas-exchange is prevented (Pezeshki et al. 2000). This happens in seagrasses, where low tides expose seagrass beds to smothering by surface oil (Dean et al. 1998; Howard et al. 1989; Runcie et al. 2004). The characteristics of marine plants and algae can influence the severity of acute physical impacts they can experience from oil exposure.
Marine invertebrates	Discharge (other) - Petroleum products [3] - Mortality [12] B63MI Specific evidence – accidental release (grounding/collision/sinking) - Oil released from the grounding of the Tampico Maru in Baja California resulted in the elimination of seastar (*Pisaster*) and sea urchin (*Strongylocentrotus*) populations in the area for multiple years as well as extensive deaths of shore crabs (Nelson-Smith 1972). After the 1989 Exxon Valdez spill, densities of subtidal crabs and seastars (e.g., *Telmessus* and *Dermasterias*, respectively) were significantly lower at oiled sites than non-oiled sites, though not all seastars were affected (Suchanek 1993). The oil spill following the grounding of the Torrey Canyon in Britain resulted in mass die offs of marine invertebrates (though the significant use of dispersants likely contributed) (Clark 1982). Coral communities beneath a documented oil plume from the Macondo well blowout (*DeepWater Horizon*) were damaged or dead (White et al. 2012). Generic evidence – Marine invertebrates experience acute impacts from oil by smothering (physical) and toxic pathways. *Toxic impacts* - In marine invertebrates, toxicity varies with oil type, species, life stage and habitat conditions (Lee et al. 2015). Dissolved oil is more bioavailable to marine invertebrates than oil in droplets (Dupuis and Ucán-Marín 2015). Marine invertebrates have varying levels of sensitivity to oil contamination (Elmgren et al. 1983). Populations of limpets are noted to be significantly reduced following major oil spills (Suchanek 1993). Clams exposed to crude oil exhibit high mortalities (Stekoll et al. 1980). *Physical impacts* - The smothering action of oil can cause significant mortality to sessile or low mobility marine invertebrates, such as sediment dwellers, who can die if unable to respire and feed. Gastropod populations are significantly reduced after major oil spills due to being washed away with the extra weight of oil adhering to the shell, this can result in increased predation or dehydration (Suchanek 1993).
Marine fishes	Discharge (other) - Petroleum products [3] - Mortality [12] B63MF Specific evidence – accidental release (grounding/collision/sinking) - Sockeye salmon smolt mortality increased, and herring stocks were severely depleted following exposure to oil spilled from the *Exxon Valdez* grounding (Thorne and Thomas 2008, 2014). The *Exxon Valdez* oil spill also caused elevated embryo mortality in some populations of pink salmon (Bue et al. 1998). Generic evidence – Mortality in marine fishes occurs mainly through toxic pathways. *Toxic impacts* - Mortality from toxic pathways in oil is generally caused by narcosis - low molecular weight hydrophobic petroleum hydrocarbons affect lipid membrane receptors and functions resulting in death (Campagna et al. 2003; Lee et al. 2015). The toxic chemicals that cause this are usually short lived (around two days) meaning mortalities are only usually significant with ongoing oil release scenarios (Lee et al. 2015). Early developmental stages of eggs and larvae, particularly in the water column, tend to be highly sensitive to oil chemicals, exhibiting acute responses (Patin 1999; USFWS 2010). Larval mortality is increased in Pacific herring and pink salmon when exposed to hydrocarbons (Carls et al. (1999) and Heintz et al. (1999), respectively, cited in (Muncaster et al. 2016). *Physical impacts* - Oil can impact fish physically by clogging the gills and impacting the digestive system (USFWS 2010)
Marine mammals	Discharge (other) - Petroleum products [3] - Mortality [12] B63MM Specific evidence – accidental release (grounding/collision/sinking) - Following the *Exxon Valdez* oil tanker grounding in 1989 in Alaska, which spilled 11 million gallons of crude oil, there were extensive sea otter deaths (>1000), with population level effects expected (Garshelis and Johnson 2013; Marty 2008; Matkin et al. 2008). Killer whales suffered severe impacts following the Exxon Valdez spill, with 14 of the 36 killer whales in the resident Price William Sound pod disappearing, presumed dead. A total of 22 killer whales were estimated to have been killed in

	this spill. The spill was also estimated to have killed 300 seals and 3000 sea otters in total (EVOSTC 2009). Spilled oil from the Deepwater Horizon spill (well blowout) resulted in an unusual mortality event of marine mammals in the Gulf of Mexico where the deaths of more than a thousand stranded animals were attributed to the spill impacts, and the majority of mortalities were common bottlenose dolphins (NOAA 2016; Venn-Watson et al. 2015b). The stranding of 1,300 bottlenose dolphins has been linked to impacts of this oil spill due to lung and adrenal damage in adults (Venn-Watson et al. 2015a), and in juveniles, most stillborn and juvenile dolphins stranded in the spill area had abnormal lungs (Colegrove et al. 2016). Some of the affected animals also had severe bacterial pneumonia disease which contributed to death (Venn-Watson et al. 2015a). A sea otter death was also reported after the smaller *Nestucca* collusion oil spill on the Pacific coast (a collision) (Duval et al. 1989; Waldichuk 1989). <u>Generic evidence</u> – There is well documented evidence of significant marine mammal mortalities following major oils spills, through toxic pathways for many species, but also physical impact pathways for some species such as sea otters, polar bears and fur-bearing pinnipeds. *Toxic impacts* - Cetaceans can be exposed to oil through skin, ingestion, aspiration and inhalation (NOAA 2016). Mortality may be higher, as only a fraction of carcasses are ever found (Williams et al. 2011b). In the Arctic, oil can be fatal to exposed polar bears (Oritsland et al. 1981) who have been reported to eat food fouled with oil, and to groom themselves when fouled increasing exposure (Amstrup et al. 2006). *Physical impacts* - For marine mammals with fur, fouling of fur by oil can cause fur to lose its insulation value, and can result in death by hypothermia – particularly for young animals that have not accumulated subdermal fat reserves for insulation. Additionally, ingestion and/or inhalation of oil as the animal attempts to clean the fur can result in lung, liver, and kidney damage, resulting in death (Patin 1999). In the Arctic, polar bears and their main prey (ringed seals) could become oiled as spilled oil is expected to concentrate in crevices and openings on the surface of the ice (Boehm et al. 2007).
Marine reptiles	Discharge (other) - Petroleum products [3] - Mortality [12] B63MR <u>Specific evidence</u> – <u>accidental release – (grounding/collision/sinking)</u> - After the *Deepwater Horizon* spill, fouled turtles would die unless rescued and cleaned (NOAA 2016). Sea turtle deaths have been attributed to oil spills resulting from ship collisions; sea turtle mortality was documented as a result of oiling after the barge Bouchard B155 collided with two tugs, releasing oil from the cargo hold, in the Tampa Bay area of Florida, The individual turtles affected were hatchlings (Shigenaka et al. 2010). <u>Generic evidence</u> – Sea turtle deaths following exposure to spilled oil are well documented, and the physical fouling of sea turtles is considered the most immediate and significant cause of death in this group (NOAA 2016). Deaths resulting from toxic impact pathways are less reported. *Toxic impacts* – Sea turtles can be exposed to oil through inhalation of vapour, oil droplets and smoke, and ingestion of contaminated water and prey (NOAA 2016). Death can result from increased toxic levels, as sea turtles selectively accumulate hydrocarbons, with body concentrations fifteen times higher than reference levels (Hall et al. 1983). *Physical impacts* - Physical fouling with oil causes significant mortality to sea turtles due to the coating of heavy oil impeding all life processes such as feeding, breathing, movement, and predator avoidance (NOAA 2016). In addition, when surfacing to breathe or rest, sea turtles can encounter heavy, lethally hot oil slicks, making it difficult to breathe. Sea turtles may inhale oil in efforts to breathe (NOAA 2016). In areas with more distributed patches of oil, sea turtles can ingest oil and tarballs, as they are indiscriminate ingesters. Dead sea turtles have been found with oil in their mouths, oesophagus and intestines (Hall et al. 1983). Stranded turtles killed after the Deepwater Horizon spill were determined to have died due to asphyxiation by oil and from the ingestion of large quantities of oil (Stacy 2012)).
Marine birds	Discharge (other) - Petroleum products [3] - Mortality [12] B63MB <u>Specific evidence</u> – <u>accidental release – (grounding/collision/sinking)</u> - The acute impacts of oil spills from grounding and collisions of vessels on marine birds from the Pacific coast are well documented. An estimated 250,000 marine birds were killed (40% of the murre population) following the *Exxon Valdez* grounding (EVOSTC 2009), and an estimated 47,500-68,500 were killed after the *Nestucca* collision (Ford et al. 1991, as cited in (Berger 1993)).

	Specific evidence – operational [movement underway, vessel at rest] – Seabirds are one of the only biotic groups where impacts of chronic oil pollution has been studied (Wiese 2002b). Atlantic Canada has the highest chronic oil pollution levels in the world (Wiese 2002a), and chronic oil pollution released from vessels has been attributed as the cause for the deaths of 300,000 seabirds in Atlantic Canada each year on average, although many discharges are illegal (Wiese 2002b). Particularly affected are populations of the thick-billed murre, which overwinters on the Grand Banks and breeds in the Arctic (Wiese 2002b). Seabird mortality rates resulting from chronic oil pollution has been suggested to be equal to or more severe than from infrequent larger spills (Wiese 2002a; Wiese and Ryan 2003). However, operational releases of oils are generally released as part of a mixture with many other substances so isolating evidence of impacts from only the petroleum products component of operational releases is challenging. Generic evidence – There is substantial evidence of severe seabird mortality events resulting from the physical impacts of oil to marine birds following oil exposure. Toxic impact from ingestion is also documented. *Toxic impacts* – The main pathway for toxic input is ingestion and inhalation, which can lead to serious impacts to internal organs, gut lesions, and reproductive impairment, amongst others (Berger 1993; Wiese 2002b). Even at low concentrations, oil can have severe effects on marine birds, while ingestion may lead to death (Burrowes et al. 2003). *Physical impacts* – The most significant physical impact from oil to birds is the fouling of feathers, which reduces their waterproofing and insulative value and can result in mortality by hypothermia or exhaustion (Adzigbli and Yuewen 2018; Höfer 1998). Birds that spend the most time on the water or diving underwater, such as auks and diving ducks, are more affected by oil pollution (Wiese and Ryan 2003).
Discharge (other) - Petroleum products [3] - Change in habitat [13]	
Physical habitats (substrate)	Discharge (other) - Petroleum products [3] - Change in habitat [13] B63HS Specific evidence – oil spill [grounding/collision/sinking] - Oil spilled from groundings into physical habitats has been shown to persist – for example, twenty years after the 1969 West Falmouth grounding and oil spill, sediment cores still bring up oil from that spill to 15cm depth (Suchanek 1993). Generic evidence – Spilled oil can sink deeply into sandy substrates and the muddy substrate of salt marshes, potentially affecting physical habitats (USFWS 2010) . Oil contamination could impact physical habitat (sediments) by filling in pore spaces or smothering the surface of sediment habitats, which can reduce benthic complexity and fragment habitats (Dennis and Bright 1988). Spilled oil can persist, particularly in sheltered areas, affecting benthic habitats such as subsurface sediments, gravel shorelines, and soft sediments (USFWS 2010) . Ongoing, low level oil contamination could hinder recovery and result in permanent changes to habitats which are unable to recover. Change in the cohesiveness of sediments after an oil spill could also impact habitat functionality, such as the ability of marine plants to remain anchored (Martin et al. 2015).
Physical habitats (water column)	Petroleum products [3] - Change in habitat [13] B63HW Specific evidence – oil spill [grounding/collision/sinking] – Evidence from spills indicate that though impacts to water quality are often documented after oil spills, this tends to be short term. For example, in the case of the spill resulting from the collision of the *Hebei Spirit* there were initially high concentrations of petroleum product contaminants in seawater for at least 15 days post spill and it took 10 months to return back to minimum water quality standards (Kim et al. 2010). In the case of oil spilled from the sinking of the *Prestige,* seawater was highly toxic for the first days post spill and lower degree toxicity persisted for two months in coastal water (Beiras and Saco-Alvarez 2006). Oil released after the groundings of a container ship (*Colombo Queen*) and an oil tanker (*W-O BUDMO*) resulted in initially elevated PAHs, turbidity, and other nutrients in the water column, before returning to baseline levels (Chen et al. 2017). The diffusion of hydrocarbons into the water column measured after oil discharged from the wrecked *Amoco Cadiz* supertanker, found hydrocarbons had a half-life of between 11 and 28 days in the water column (Marchand 1980). Generic evidence – Oil can be suspended in the water column following weathering and wave action. A contaminated water column habitat could affect planktonic species, such as jellyfish, that are passive swimmers not able to move away from contamination as much as more active swimming nekton (such as squid and fish). Plankton, as well as eggs and larvae, use the water column habitat and can be affected when this habitat becomes toxic. Early developmental

	stages of fish eggs and larvae in the water column are highly sensitive to oil chemicals, exhibiting acute responses (Patin 1999; USFWS 2010).
Physical habitats (sea ice)	Petroleum products [3] - Change in habitat [13] B63HI Specific evidence – oil spill [grounding/collision/sinking] – Not available. Generic evidence – The behaviour of spilled oil is different in areas with sea ice compared to open water areas (Hänninen and Sassi 2010) and oil can become trapped in the space between ice floes, within brine channels, cracks, and under ice (DFO 2012; Fingas and Hollebone 2003; Hänninen and Sassi 2010; Lee et al. 2015). This can change sea ice composition and structure, and consequently the habitat available to biota living within and on top of the ice. For example, trapped oil can significantly alter the breeding functions for sea ice used by ringed seals. Impacts can be persistent, as oil trapped in or under sea ice can be released into the marine environment during subsequent melts over multiple years lengthening contamination and exposure (Lee et al. 2015; Pew Charitable Trusts 2013; Prince et al. 2002). In addition, the trapped oil degrades at a relatively slower rate in Arctic environments due the low temperatures (DFO 2012; Prince et al. 2002), meaning it can persist from months to years (Fingas and Hollebone 2003). In pack ice, oil can accumulate at the surface as well as under the ice, and can move with the ice when there is more than 30% sea ice present (Lee et al. 2015). The accumulation of oil in pack ice results in a more concentrated impact to the area of accumulation and could impact microbial communities living in this habitat significantly (Lee et al. 2015). As well as being a habitat for species that use the surface of sea ice, the ice itself is a microhabitat for microbial communities that live in brine channels and cavities in the matrix of the ice. The communities living in this habitat have an important role in the marine food webs of these regions (Gerdes et al. 2005).

Table B6-4 - Evidence for the **Air emissions[4]** stressor

Vessel at Rest - Air emissions [4]	
This stressor examines the impacts of vessel emissions, which are produced when at rest and underway. The composition of substances in vessel emissions includes greenhouse gases, sulphur oxides, nitrogen oxides, particulate matter, volatile organic compounds and halocarbons (Jägerbrand et al. 2019). Effects from greenhouse gases are indirect, and out of scope for this stressor.	
Vessel at Rest - Air emissions [4] - Change in fitness [12]	
Marine plants and algae	Vessel at rest - Air emissions [4] - Change in fitness [12] B64FP Specific evidence – Pelagic plankton (away from the influence of agricultural runoff) may be affected by nitrogen emissions from ships because the nutrients from ship exhaust are readily biologically available, which may in turn enhance bacterial remineralisation of organic matter (Endres et al. 2018). Atmospheric nitrogen deposition from vessel emissions may affect pelagic phytoplankton productivity and biological nitrogen cycling (Endres et al. 2018). Generic evidence – Not applicable.
Marine mammals	Vessel at rest - Air emissions [4] - Change in fitness [12] B64FM Specific evidence – Airborne pollutants can be concentrated in the air-water interface and as marine mammals breathe and spend significant time at the surface of the water, they have increased exposure to atmospheric pollution (Lundin et al. 2018; Rawson et al. 1995). In areas of high vessel traffic vessel exhaust gases can occur at elevated levels, affecting health (Lachmuth et al. 2011). PAH contaminants from combustion engine emissions have been recorded in killer whale scat (Lundin et al. 2018). Due to respiratory anatomy and physiology, some marine mammals may be more sensitive to air pollution than terrestrial mammals (Lachmuth et al. 2011). Airborne pollutants are implicated in high levels of mercury levels of some cetaceans (Rawson et al. 1995). Marine mammals may also be vulnerable to increased retention time of airborne pollutants in their lungs from breath holding (Rawson et al. 1995; Wise et al. 2014).

	Generic evidence – Not applicable
Marine reptiles	Vessel at rest - Air emissions [4] - Change in fitness [12] B64FR Specific evidence – Direct impacts to the fitness of marine reptiles are not known. However, it is speculated that turtles could be vulnerable to air emissions from shipping in a similar way to marine mammals, as they also spend time at the sea surface interface where they can inhale airborne pollutants and so have the potential for respiratory exposure to airborne pollutants. As an air breathing animal that dives for extended periods they may also be vulnerable to increased retention time of airborne pollutants in their lungs from breath holding (Rawson et al. 1995; Wise et al. 2014). Generic evidence – Not applicable
Marine birds	Vessel at rest - Air emissions [4] - Change in fitness [12] B64FB Specific evidence – It is speculated that marine birds could be exposed to air emissions from shipping, especially for species that follow vessels and may be potentially vulnerable to airborne pollutants. Airborne pollutants including carbon monoxide (CO), ozone (O_3), sulphur dioxide (SO_2), nitrogen dioxide (NO_2), heavy metals, and other mixtures from industrial emissions can cause a change in fitness to birds. The impacts can include respiratory distress and illness, increased detoxification effort, elevated stress levels, immunosuppression, behavioural changes, and impaired reproductive success (Sanderfoot and Holloway 2017). Generic evidence – Not applicable
Vessel at Rest - Air emissions [4] - Change in habitat [13]	
Physical habitat (water column)	Vessel at rest - Air emissions [4] - Change in habitat [13] B64HW Specific evidence – Atmospheric emissions from combustion of low-grade, high-sulphur content fuel used by most commercial vessels includes significant amounts of carbon dioxide, sulphur oxides, nitrogen oxides, aerosols containing particulate matter such as organic carbon, black carbon, polycyclic hydrocarbons (PAHs) and heavy metals (Eyring et al. 2005), many of which could reach the water column. Particulate matter and aerosols from combustion and scrubber residues may introduce heavy metals, black carbon, polycyclic aromatic hydrocarbons, and other organic compounds to the water column, in addition to leading to a possible increase in turbidity in the water column (Endres et al. 2018). The presence of cruise ships in James Bay, Victoria, BC, increased atmospheric concentrations of fine particulate matter, nitrogen dioxide, and sulphur dioxide which could settle in adjacent waters (Poplawski et al. 2011). Generic evidence – Not applicable
Physical habitat (sea ice)	Vessel at rest - Air emissions [4] - Change in habitat [13] B64HI Specific evidence – More than half (57%) of ships operating in the Canadian Arctic use heavy fuel oils (Clear Seas 2019). The incomplete combustion of heavy fuel oils produces black carbon particles that fall to earth with precipitation (Clear Seas 2019). Vessels underway in Arctic waters can also emit up to 50% more black carbon when encountering challenging sea and ice conditions than in regular sea conditions, as it is related to engine loads (Lack and Corbett 2012). Releases of black carbon can fall with precipitation, darkening and reducing the albedo effect of snow and ice, accelerating ice melt rates and changing the physical sea ice habitat (Arctic Council 2009; CCA 2017; Choi et al. 2016; Clear Seas 2019). In the Arctic context, the impact of black carbon emitted from shipping exhaust could have significant regional impacts through accelerating ice melt (NWT Environment and Natural Resources 2015). Loss of sea ice habitat can impact biota such as marine mammals and birds that aggregate on the edge of sea ice in spring and summer for whelping and moulting (Arctic Council 2009). Other areas used by marine mammals for wintering (cetaceans) and as haul outs (pinnipeds) are also impacted. As a tertiary effect, loss of sea ice may allow new species, such as predatory killer whales or ecological competitors such as humpback whales, to migrate into Artic areas previously limited for them (e.g., (Ferguson et al. 2010). Generic evidence – Not applicable

Table B6-5 - Evidence for the **Other contaminants stressor [5]**

Discharge (other) - Other contaminants [5]	
This stressor encompasses releases of contaminants (other than petroleum products) but does not describe the impacts of the diverse types and mixtures of contaminants that can be released by vessels (such as in bilge water and grey water). Here, an example is provided by focusing on antifouling hull chemicals - the leaching of and flaking of anti-fouling paint particles released from vessels when underway, at rest, or during grounding/collisions/sinking. There are a variety of types of anti-fouling chemicals, but since the ban of widespread use of tributyl tin (TBT) in anti-fouling paints in 2008, copper has become one of the most commonly used biocides used in antifouling paint, but concerns over elevated copper levels in areas of high boating are raising concerns of impacts to biota (Brooks and Waldock 2009; Tornero and Hanke 2016; Warnken et al. 2004). Discharges of petroleum products are considered separately under the Petroleum products stressor.	
Discharge (other) - Other contaminants [5] - Change in fitness [14]	
Marine plants and algae	Discharge (other) - Other contaminants [5] - Change in fitness [14] B65FP Specific evidence (Vessel at rest, movement underway, grounding/collision/sinking) – Antifouling chemicals and less bioavailable antifouling paint particles can accumulate in sediments of marinas and anchoring areas (Simpson et al. 2013; Takahashi et al. 2012; Turner 2010). Marine plants rooted in these contaminated sediments may experience fitness impacts from ongoing exposure. Macroalgae can accumulate copper and zinc from antifouling paint particles (Turner et al. 2009). In addition to metal-based biocides, non-metallic biocides (e.g. diuron, DCOIT, irgarol 1051) may be present in antifouling paints and have been demonstrated to be toxic to seagrass and algae (Lindgren et al. 2016). The commonly used antifouling herbicide Irgarol causes decreased growth, inhibition of cell number and decreased photosynthetic activity in more than 7 species of marine algae, macroalgae and phytoplankton (Guardiola et al. 2012). The level of Irgarol in the water column of marinas has been noted to exceed toxicity benchmarks for phytoplankton (Sapozhnikova et al. 2013). Antifouling biocides including tributyltin, copper, and zinc, may inhibit the recruitment of algae into areas scoured by a grounded vessel (Ross et al. 2016). Some tin-free biocidal compounds in antifouling paint may inhibit photosynthesis. For example, Irgarol 1051 has been found to inhibit phytosynthetic electron transport in chloroplasts, reducing the growth of marine algae and possibly seagrasses and eelgrass (*Zostera marina*) (Panigada et al. 2008). Generic evidence – Impaired growth and reproductive capacity has been found in rockweed (*Fucus*) exposed to contaminants such as metals and PCB (Lauze and Hable 2017). Experiments have shown that growth rate and photochemical efficiency of Ulva is reduced due to cadmium exposure (Jiang et al. 2013).
Marine invertebrates	Discharge (other) - Other contaminants [5] - Change in fitness [14] B65FI Specific evidence – vessel at rest, movement underway, grounding/collision/sinking – Antifouling chemicals and less bioavailable anti fouling paint particles can accumulate in sediments of marinas and anchoring areas (Simpson et al. 2013; Takahashi et al. 2012)t(Turner 2010) potentially resulting in fitness effects to marine invertebrates residing in these areas. As antifouling biocides are developed to kill fouling organisms, marine invertebrates, and especially those with fouling characteristics are likely to be impacted by these chemicals more strongly. A wide range of effects to marine invertebrates from antifouling chemicals has been documented (Guardiola et al. 2012). Sediments containing antifouling paint particles are toxic to epibenthic invertebrates, reducing fecundity (e.g., in copepods; (Bao et al. 2014; Eklund et al. 2014; Soroldoni et al. 2017), inhibiting growth and shell deposition, and impairing immune functions (Bellas 2006). Copper is toxic at high concentrations and is reported as immunotoxic to molluscs and alters fertilisation and early life stages of bivalves and corals (Cima and Ballarin 2012). Antifouling biocides are also toxic to the development of sea urchin eggs and embryos

	(Kobayashi and Okamura 2002). The recruitment of algae and marine invertebrates may be inhibited by contaminants including tributyltin, copper, and zinc (Ross et al. 2016). Antifouling chemicals (organotins) were found in invertebrates, including sea urchins, gastropods, and lobsters, at the reef where a container ship had grounded (Ross et al. 2016). Contaminants, including tributyltin, copper, and zinc, may inhibit the recruitment of invertebrates into areas scoured by a grounded vessel (Ross et al. 2016). Sediment contaminated with tributyltin, copper and zinc from the antifouling paint of a grounded vessel inhibited larval sediment and metamorphosis of corals (Negri et al. 2002). In addition to metal-based biocides, non-metallic biocides (e.g. diuron, DCOIT, irgarol 1051) may be present in antifouling paints and have been demonstrated to be to be toxic to marine invertebrates (Lindgren et al. 2016). Generic evidence – Compounds from antifouling paints, such as organotins, can cause female gonochoristic prosobranch gastropods to become masculinised, bivalve shells may not form correctly, it may cause reproductive failure in bivalves, and could inhibit growth, impair immune function, and reduce fitness (Panigada et al. 2008), and references therein). A tin-free antifouling paint biocide, Irgarol 1051, causes larval malformation in the sea urchin *Paracentrotud lividus*, in addition to affecting sperm fertilisation (Panigada et al. 2008). The ability of mussels (*Mytilus galloprovincialis*) to survive in air is reduced by short term exposure to sublethal concentrations of pollutants, including copper (Viarengo et al. 1995). The embryo and larval stages of mussels, oysters, and sea urchins are sensitive to dissolved copper from antifouling paint (Thomas and Brooks 2010). Settlement behaviour of free-swimming larvae is altered by contamination (Roberts et al. 2008).
Marine fishes	Discharge (other) - Other contaminants [5] - Change in fitness [14] B65FF Specific evidence – vessel at rest, movement underway, grounding/collision/sinking - Antifouling chemicals (organotins) were found in fishes at the reef where a container ship had grounded, and were more frequently found in benthic, predatory fish than in demersal fish (Ross et al. 2016) and may have fitness impacts to exposed fishes. Generic evidence - There is significant evidence from several field and lab studies to indicate that antifouling chemicals can impact the immune system of fish potentially making them more susceptible to disease (reviewed in (Arai 2009; Nakayama et al. 2009). However, as fishes are mobile, the degree of impact may only be notable in fish resident in areas with high densities of vessels at rest. Compounds from antifouling paints, such as triphenyltin, can bioaccumulate through the food chain, with high levels of triphenyltin found in top predators such as Bluefin tuna and Blue shark (Panigada et al. 2008). Tributyltin and dibutyltin are immunosuppressants in fish (Berge et al. 2004).
Marine mammals	Discharge (other) -- Other contaminants [5] - Change in fitness [14] B65FM Specific evidence – vessel at rest, movement underway, grounding/collision/sinking - Not available. It may be that marine mammals can experience fitness effects after exposure to these toxins through the consumption of contaminated prey items. Generic evidence – Tributyltin and dibutyltin can have fitness effects as they are immunosuppressant chemicals in mammals (Berge et al. 2004). Compounds from antifouling paints, such as triphenyltin, can bioaccumulate through the food chain, with high levels of triphenyltin found in top predators such as the bottlenose dolphin (Panigada et al. 2008). Tributyltin and dibutyltin are immunsuppressants in mammals (Berge et al. 2004), but some mammals may be able to excrete organotins (Kim et al. 1996).
Marine reptiles	Discharge (other) - Other contaminants [5] - Change in fitness [14] B65FR Specific evidence – vessel at rest, movement underway, grounding/collision/sinking - Not available. Generic evidence – Elevated levels of trace elements, including tin and copper, have been found in the egg contents and tissues of live sea turtles (Ikonomopoulou et al. 2011). *Caretta caretta* hatching success was positively correlated with copper and zinc concentrations (Souza et al. 2018). Fitness effects in adults are not known but may be immunosuppressant as they are in mammals.
	Discharge (other) - Other contaminants [5] - Change in fitness [14] B65FB

Marine birds	Specific evidence – vessel at rest, movement underway, grounding/collision/sinking - Not available. It is possible that marine birds could experience fitness effects from exposure resulting from the consumption of contaminated prey. Generic evidence – Tributyltin and its breakdown products were found in the livers of marine coastal birds in concentrations up to 1100 ng/g (Kannan et al. 1998). However, seabirds may be able to excrete these compounds during moult (Becker et al. 2003). Fitness effects are not known but may be immunosuppressant as they are in mammals.
Discharge (other) – Other contaminants [5] - Mortality [15]	
Marine plants and algae	Discharge (other) - Other contaminants [5] - Mortality [15] B65MP Specific evidence – vessel at rest, movement underway, grounding/collision/sinking - Biocides present in antifouling paints have been demonstrated to be to be toxic to marine plants and algae (Lindgren et al. 2016). Some algal species, such as *Ulva*, display high levels of tolerance to copper compounds used in antifoulants. Because of this tolerance, antifoulants often also contain booster biocides (which are may be used in conjunction with copper) to enhance the effect (Lindgren et al. 2016). Generic evidence – Though most studies available reporting on impacts of antifouling biocides to this endpoint detail sub-lethal (fitness) effects rather than mortality, at a high enough concentration it is expected that antifouling biocides can become acute, as they have been demonstrated to be to be toxic to marine plants and algae (Lindgren et al. 2016).
Marine invertebrates	Discharge (other) - Other contaminants [5] - Mortality [15] B65MI Specific evidence – vessel at rest, movement underway, grounding/collision/sinking – Exposure of epibenthic marine invertebrates to sediments spiked with antifouling paint particles can result in mortality (Onduka et al. 2013; Soroldoni et al. 2017) likely due to the presence of metals such as copper and zinc (Soroldoni et al. 2017). Invertebrate groups documented to experience mortality from exposure to biocides in antifouling paint include crustaceans and polychaetes (Onduka et al. 2013). Marine invertebrate embryos and larvae are particularly susceptible to acute effects of contamination from antifouling paints (e.g., echinoderms and tunicates; (Bellas 2006), and are several orders of magnitude more sensitive to toxicants than adults (Bellas 2006) (His et al. 1999; Ringwood 1991). Non-metallic biocides (e.g., diuron, DCOIT, irgarol 1051) and metallic biocides (e.g., organotin) may be present in antifouling paints and have been demonstrated to be to be toxic to marine invertebrates (Lindgren et al. 2016). Sediment contaminated with greater than 8.0mg/kg tributyltin, 72 mg/kg copper, and 92 mg/kg zinc from the antifouling paint of a grounded vessel resulted in 100% mortality of coral larvae (Negri et al. 2002). Generic evidence – Significant differences in marine invertebrate epifaunal assemblages in marinas and harbours are found along a contaminant gradient (e.g., copper and zinc) likely due to the death of sensitive marine invertebrates (Turner et al. 1997).
Marine fishes	Discharge (other) - Other contaminants [5] - Mortality [15] B65MF Specific evidence – vessel at rest, movement underway, grounding/collision/sinking – Not available. Generic evidence – Laboratory experiments have determined that antifouling chemicals can cause mortality in marine fishes (Guardiola et al. 2012).
Discharge (other) – Other contaminants [5] - Change in habitat [16]	
Physical habitat (substrate)	Discharge (other) - Other contaminants [5] - Change in habitat [16] B65HS Specific evidence – vessel at rest, movement underway, grounding/collision/sinking - Not available. Antifouling chemicals and anti-fouling paint particles can accumulate in sediments of marinas and anchoring areas (Simpson et al. 2013; Takahashi et al. 2012; Turner 2010) but it is unclear whether their presence can result in a change of physical habitat (substrate). Organotins, copper and zinc from anti-fouling paint have been found in the sediment surrounding a grounded vessel indicating they are sources of contamination to the surrounding substrate (Ross et al. 2016).

	Generic evidence – Dissolved copper from antifouling paint adsorbs to suspended particulate matter, which leads to accumulation in the sediment and results in concentrations two to three orders of magnitude higher than in the water column. The antifouling biocides Irgarol 1051 and copper pyrithione also accumulate in the sediment when associated with sediment or paint particles, and Diuron and DCOIT will accumulate in the sediment when associated with paint particles (Thomas and Brooks 2010). Degrading antifouling paint compounds, such as those derived from organotin, have ecotoxicological impacts and are estimated to remain in seawater and sediments for extensive periods. For example, the half-life of tributyltin in seawater is 1-3 weeks, in shallow sediments for 1-5 years, and it could remain in deep sediments for 87+/-17 years (Panigada et al. 2008).
Physical habitat (water column)	Discharge (other) – Other contaminants [5] -Change in habitat [16] B65HW Specific evidence – vessel at rest, movement underway, grounding/collision/sinking - Antifouling chemicals and less bioavailable anti fouling paint particles can accumulate in sediments of marinas and anchoring areas (Simpson et al. 2013; Takahashi et al. 2012; Turner 2010). Generic evidence – While in the water column, tributyltin can be degraded into dibutyltin, monobutyltin, and inorganic tin, which are less toxic (Ross et al. 2016).

APPENDIX B7: REFERENCES (FOR APPENDICES B1-B6)

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