

# Threats and effects pathways of shipping related to non-renewable resource developments on Atlantic walruses (*Odobenus rosmarus rosmarus*) in Hudson Strait and Foxe Basin, Nunavut

D. Bruce Stewart, Jeff W. Higdon, and Robert E.A. Stewart

Fisheries and Oceans Canada  
Freshwater Institute,  
Central and Arctic Region  
501 University Crescent,  
Winnipeg MB R3T 2N6

2020

**Canadian Technical Report of  
Fisheries and Aquatic Sciences 3283**



Fisheries and Oceans  
Canada

Pêches et Océans  
Canada

**Canada**

## **Canadian Technical Report of Fisheries and Aquatic Sciences**

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of Fisheries and Oceans Canada, namely, fisheries and aquatic sciences.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in the data base *Aquatic Sciences and Fisheries Abstracts*.

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page.

Numbers 1-456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457-714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715-924 were issued as Department of Fisheries and Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

## **Rapport technique canadien des sciences halieutiques et aquatiques**

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques de Pêches et Océans Canada, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications à part entière. Le titre exact figure au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la base de données *Résumés des sciences aquatiques et halieutiques*.

Les rapports techniques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre.

Les numéros 1 à 456 de cette série ont été publiés à titre de Rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de Rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de Rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

Canadian Technical Report of  
Fisheries and Aquatic Sciences 3283

2020

THREATS AND EFFECTS PATHWAYS OF SHIPPING  
RELATED TO NON-RENEWABLE RESOURCE DEVELOPMENTS  
ON ATLANTIC WALRUSES (*Odobenus rosmarus rosmarus*)  
IN HUDSON STRAIT AND FOXE BASIN, NUNAVUT

by

D. Bruce Stewart<sup>1</sup>, Jeff W. Higdon<sup>2</sup>, and Rob E.A. Stewart<sup>3</sup>

Fisheries and Oceans Canada  
Freshwater Institute  
Central and Arctic Region  
501 University Crescent  
Winnipeg MB, R3T 2N6

-----  
<sup>1</sup> Arctic Biological Consultants, 95 Turnbull Drive, Winnipeg, MB, R3V 1X2

<sup>2</sup> Higdon Wildlife Consulting, 912 Ashburn Street, Winnipeg, MB, R3G 3C9

<sup>3</sup> 1218 Marchand Road, Howden, MB, R5A 1J6

© Her Majesty the Queen in Right of Canada, 2020.

Cat. No. Fs 97-6/3283E      ISBN 978-0-660-28520-7      ISSN 1488-5379

**Correct citation for this publication:**

Stewart, D.B., Higdon, J.W., and Stewart, R.E.A. 2020. Threats and effects pathways of shipping related to non-renewable resource developments on Atlantic walruses (*Odobenus rosmarus rosmarus*) in Hudson Strait and Foxe Basin, Nunavut. Can. Tech. Rep. Fish. Aquat. Sci. 3283: x + 59 p.

## TABLE OF CONTENTS

ABSTRACT.....	viii
RÉSUMÉ .....	ix
PREFACE .....	x
INTRODUCTION .....	1
WALRUS ECOLOGY .....	1
Population structure .....	1
Habitat requirements .....	2
Seasonal distribution and movements .....	4
Foxe Basin .....	4
Northern Hudson Bay, Hudson Strait, Ungava Bay .....	5
Life cycle and reproduction.....	7
Behaviour .....	8
Interspecific interactions .....	8
Foraging .....	8
Predation .....	9
Sensitivity to disturbance .....	10
SHIPPING AND RELATED ACTIVITIES .....	11
Quebec (Nunavik) .....	15
Raglan Mine, Deception Bay .....	15
Nunavik Nickel Project, Deception Bay .....	15
Ashram Rare Earths Project, Ungava Bay .....	15
Hopes Advance Bay, Ungava Bay .....	16
Duncan Lake Iron Project, James Bay .....	16
Nunavut (Kivalliq) .....	16
Kiggavik Uranium Project, Baker Lake .....	16
Meadowbank Gold Mine, Baker Lake .....	17
Meliadine Gold Project, Rankin Inlet .....	17
Nunavut (Qikiqtaaluk) .....	17
Mary River Iron Mine, Baffin Island .....	17
Roche Bay Iron Project, Melville Peninsula .....	17
EFFECTS PATHWAYS .....	18
Port construction and operation .....	18
Ship passage .....	19
Chemical releases .....	20
Physical habitat alteration .....	21
Disturbances .....	22
Ship strikes .....	23
Ship loading and unloading .....	23

Non-indigenous species introductions .....	24
SPATIAL ANALYSIS .....	25
Background .....	25
Habitat suitability .....	25
Uncertainty (predicted cf. observed) .....	28
Shipping .....	28
METHODS .....	29
STUDY AREA .....	29
HABITAT SUITABILITY ANALYSES .....	29
Depth .....	30
Seasonal ice cover .....	31
Distance to coast or floe edge (km) .....	32
Haulouts .....	32
Final habitat suitability scores .....	34
INDUSTRIAL DEVELOPMENT AND POTENTIAL THREATS.....	35
EXPECTED FUTURE (2020) SHIPPING .....	36
OVERLAP BETWEEN WALRUS HABITAT AND INDUSTRIAL ACTIVITY .....	36
RESULTS .....	36
HABITAT SUITABILITY RANKINGS .....	36
FUTURE INDUSTRIAL ACTIVITY.....	38
OVERLAP BETWEEN WALRUS HABITAT AND INDUSTRIAL ACTIVITY .....	40
SUMMARY .....	43
ACKNOWLEDGEMENTS .....	44
REFERENCES .....	45
APPENDIX 1. HABITAT SUITABILITY SCORING .....	58

## LIST OF FIGURES

Figure 1. Approximate distributions of the Atlantic walrus populations that use Canadian waters.....	2
Figure 2. Vessel tracks via Hudson Strait into Ungava Bay, Foxe Basin, and Hudson Bay .....	11
Figure 3. Mineral development projects in Canada’s North shown as tonnage per year at most probable marine ports of export .....	12
Figure 4. Effects pathways from ore shipment and related activities on Atlantic walruses in Hudson Strait and Foxe Basin. ....	19
Figure 5. Linkages between walrus life history parameters and environmental parameters.....	26
Figure 6. Map of eastern Canadian Arctic showing study area boundary, 2010 shipping routes (vessel tracks) and port locations (communities, mines, DEW). ....	30
Figure 7. Bathymetry data from the World Ocean Atlas at a 0.25 by 0.25 degree resolution.....	31
Figure 8. Seasonal extremes in ice cover during minimum ice conditions (left panel, “summer”) and maximum ice conditions (right panel, “winter”).....	32
Figure 9. Buffers for distance to coast (summer, left panel) or coast/floe edge (winter, right panel) .....	33
Figure 10. Locations, size, and status of walrus haulouts in the study area, with buffers at 50 km and 100 km. ....	34
Figure 11. Vessel density in 2010, measured as the total number of vessels that transited through a 0.25 by 0.25 degree grid cell.....	35
Figure 12. Habitat suitability for walrus during the seasons of minimum (left panel) and maximum (right panel) sea ice cover .....	37
Figure 13. Distribution of high and very high quality (normalized scores of 0.60-1.00) walrus habitat in the study area, showing areas (grid cells) that were scored highest in both summer and winter, in summer only, and in winter only. ....	38
Figure 14. Comparison of observed port site usage (number of vessels visiting each port) in 2010 (left panel) with expected (minimum) port visits in 2020 (right panel) based on proposed industrial development projects (as of 2014). ....	39
Figure 15. Comparison of observed vessel density (number of vessels transiting each 0.25 by 0.25 grid cell) in 2010 (left panel) with expected (minimum) vessel density in 2020 (right panel) based on proposed industrial development projects (as of 2014). ....	39
Figure 16. Projected changes in shipping intensity between 2010 and 2020.....	40
Figure 17. Distribution of vessel traffic in 2010 (black circles) and 2020 (open circles) overlaid on important walrus habitats within the study area .....	41

Figure 18. Distribution of highest intensity vessel traffic in 2010 (smaller black circles) and 2020 (larger open circles) overlaid on important walrus habitats within the study area.....	42
Figure 19. Distribution of highest intensity vessel traffic in 2010 (black circles) and 2020 (open circles) overlaid on important walrus habitats within the study area .....	42



## LIST OF TABLES

Table 1. Characteristics of the major mineral development projects with a marine transportation component in production or in advanced development stage in Canada's North as of 2014 .....	13
Table A1- 1. Scoring of depth ranges for habitat suitability modelling.....	58
Table A1- 2. Scoring of ice cover categories for habitat suitability modelling (winter only).....	58
Table A1- 3. Scoring of distance to the coast under open water conditions (i.e., <1/10 ice cover) and distance to the coast or landfast ice edge during winter conditions for habitat suitability modelling.....	58
Table A1- 4. Scoring for haulouts (uglit) and waters in their vicinity for habitat suitability modeling (summer only). ....	59
Table A1- 5. Habitat suitability scores for summer and winter, divided into five classes based on normalized values. ....	59

## ABSTRACT

Stewart, D.B., Higdon, J.W., and Stewart, R.E.A. 2020. Threats and effects pathways of shipping related to non-renewable resource developments on Atlantic walrus (*Odobenus rosmarus rosmarus*) in Hudson Strait and Foxe Basin, Nunavut. Can. Tech. Rep. Fish. Aquat. Sci. 3283: x + 59 p.

Mining-related shipping and port developments are likely to increase in Canada's eastern Arctic. Ore mines will ship product via Foxe Basin and Hudson Strait and all mines require resupply ships. Atlantic walrus are important in the Arctic food web and to Inuit and these ships will transit important walrus habitats. We used a GIS framework to map spatiotemporal overlap of walrus with shipping and related resource development. Shipping and infrastructure information available in 2014 was based on 2010 (current) and 2020 (projected) activities. The model combined this information with information on walrus ecology and habitat to conduct a preliminary assessment of potential impacts of these activities on walrus. We relied heavily on Inuit observations of changes in walrus distribution and abundance.

Habitat suitability was modelled for summer (September, minimum ice) and winter (March, maximum ice). Winter and summer habitat scores were highly correlated, indicating similarities in the seasonal rankings for the two models. There was a significant increase in vessel traffic, especially in Hudson Strait and central Foxe Basin, projected for 2020 over 2010. The results clearly identified northern Foxe Basin and western Hudson Strait as areas where walrus habitat and future industrial activity overlap. Disturbance (auditory, olfactory, visual) and disruption of ice habitats are the pathways of greatest concern. Future modelling should explore finer-scale environmental data, but our model also indicated specific knowledge deficiencies in walrus ecology, habitat, and distribution.

**Key words:** Atlantic walrus, *Odobenus rosmarus*, shipping, mining, habitat suitability, threats, development, environmental impact assessment, Hudson Bay, Arctic Canada

## RÉSUMÉ

Stewart, D.B., Higdon, J.W., and Stewart, R.E.A. 2020. Threats and effects pathways of shipping related to non-renewable resource developments on Atlantic walruses (*Odobenus rosmarus rosmarus*) in Hudson Strait and Foxe Basin, Nunavut. Can. Tech. Rep. Fish. Aquat. Sci. 3283: x + 59 p.

Le transport maritime et le développement portuaire liés l'exploitation minière sont susceptibles d'augmenter dans l'est de l'Arctique canadien. Les exploitants de mines de minerai expédieront leurs produits par le bassin Foxe et le détroit d'Hudson, et toutes les mines auront besoin de navires de ravitaillement. Ces navires traverseront d'importants habitats du morse de l'Atlantique, qui est une espèce importante pour le réseau trophique de l'Arctique et pour les Inuits. Nous avons utilisé un cadre SIG pour cartographier le chevauchement spatio-temporel des morses avec le transport maritime et le développement de ressources connexes. L'information disponible en 2014 sur le transport maritime et sur les infrastructures était fondée sur les activités de 2010 (en cours) et de 2020 (prévues). Cette information a été combinée aux renseignements sur l'écologie et l'habitat du morse dans le modèle afin d'effectuer une évaluation préliminaire des répercussions potentielles de ces activités sur les morses. Nous nous sommes fortement appuyés sur les changements observés par les Inuits en ce qui concerne la répartition et l'abondance des morses.

La qualité de l'habitat a été modélisée pour l'été (septembre, glace minimale) et pour l'hiver (mars, glace maximale). Les cotes de qualité de l'habitat en été et en hiver montraient une forte corrélation, indiquant des similitudes dans les classements saisonniers des deux modèles. Une augmentation importante du trafic maritime, en particulier dans le détroit d'Hudson et le centre du bassin Foxe, a été prévue pour 2020 par rapport à 2010. Les résultats montrent clairement un chevauchement entre l'habitat du morse et les futures activités industrielles dans le nord du bassin Foxe et l'ouest du détroit d'Hudson. Les perturbations auditives, olfactives et visuelles ainsi que la perturbation des habitats de glace sont les voies d'effets les plus préoccupantes. Les futurs travaux de modélisation devraient examiner des données environnementales à plus petite échelle. Toutefois, notre modèle a également mis en lumière des lacunes dans les connaissances sur l'écologie, l'habitat et la répartition du morse.

**Mots-clés :** morse de l'Atlantique, *Odobenus rosmarus*, navigation, exploitation minière, qualité de l'habitat, menaces, développement, évaluation des impacts environnementaux, baie d'Hudson, Arctique canadien

## **PREFACE**

This document was initially submitted in October 2014 and publication has been greatly delayed through no fault of the authors. Similarly, while assigned a publication date of 2018, the authors received the galleys in 2020. The authors advise readers to be aware that some details may be dated. The main impacts of this delay are related to the status of future mining developments, some of which have been suspended (e.g., Roche Bay), reviewed but not approved (e.g., Kiggavik), or delayed (e.g., Mary River). The latter development has the greatest potential for future shipping, as it has been approved. In 2014 this shipping was expected to begin in 2020, but is now expected to begin ca. 2024. Although the commencement of shipping has been delayed, the relevant threats and effects pathways, modelling results, and recommendations remain valid.

## INTRODUCTION

Port development and operation, and large-scale shipping are planned in the near future to transport ore from mining developments in the eastern Canadian Arctic via Hudson Strait and Foxe Basin to markets in Europe and Asia. These waters are occupied by large numbers of Atlantic walrus (*Odobenus rosmarus rosmarus*), which may be impacted by these activities. Walrus are an important link in the Arctic food web between benthic invertebrates and humans. Their importance to Inuit is substantial in both cultural and economic terms.

Our primary objective here is to map the expected overlap (in space and time) between Atlantic walrus and shipping and related resource development threats that have potential to affect walrus in Hudson Strait and Foxe Basin. We explore a way to assess cumulative impacts of shipping for non-renewable resource developments on walrus using a Geographic Information System (GIS) framework. This requires mapping of both walrus distribution and industrial activities, using data from a variety of sources. Effects pathways are also identified for these potential threats. If the approach is meritorious, it will convey information to decision-making, on areas of overlap where there is a need to mitigate the impacts of ore-bearing ship traffic on walrus in Hudson Strait and Foxe Basin in a graphic format.

The report describes walrus ecology, shipping and related infrastructure, and threats pathways. This information is the foundation upon which the mapping analysis that follows is built and interpreted.

## WALRUS ECOLOGY

The population structure, seasonal distribution and ecology of Atlantic walrus in Hudson Strait and Foxe Basin are important determinants of whether, and how these animals may be impacted by shipping activities related to ore extraction. This section summarizes key aspects of walrus ecology to provide background for the choice of parameters used to model habitat suitability and for the discussion of threats pathways.

### Population structure

Walrus in both Foxe Basin and Hudson Strait belong to the Central Arctic Population, which is shared with Greenland (Dietz et al 2014, Schafer et al 2014; Figure 1). Within this population the animal's geographical distributions, lead isotope ratios, and growth patterns suggest that walrus in northern Foxe Basin, central Foxe Basin, and northern Hudson Bay-Davis Strait lead their lives differently and constitute separate management stocks (Stewart 2008). However, genetic analyses have been unable to differentiate between the animals in these areas (de March et al. 2002, Shafer et al. 2014). Consequently, it is unclear how impacts in one area may affect walrus in another.

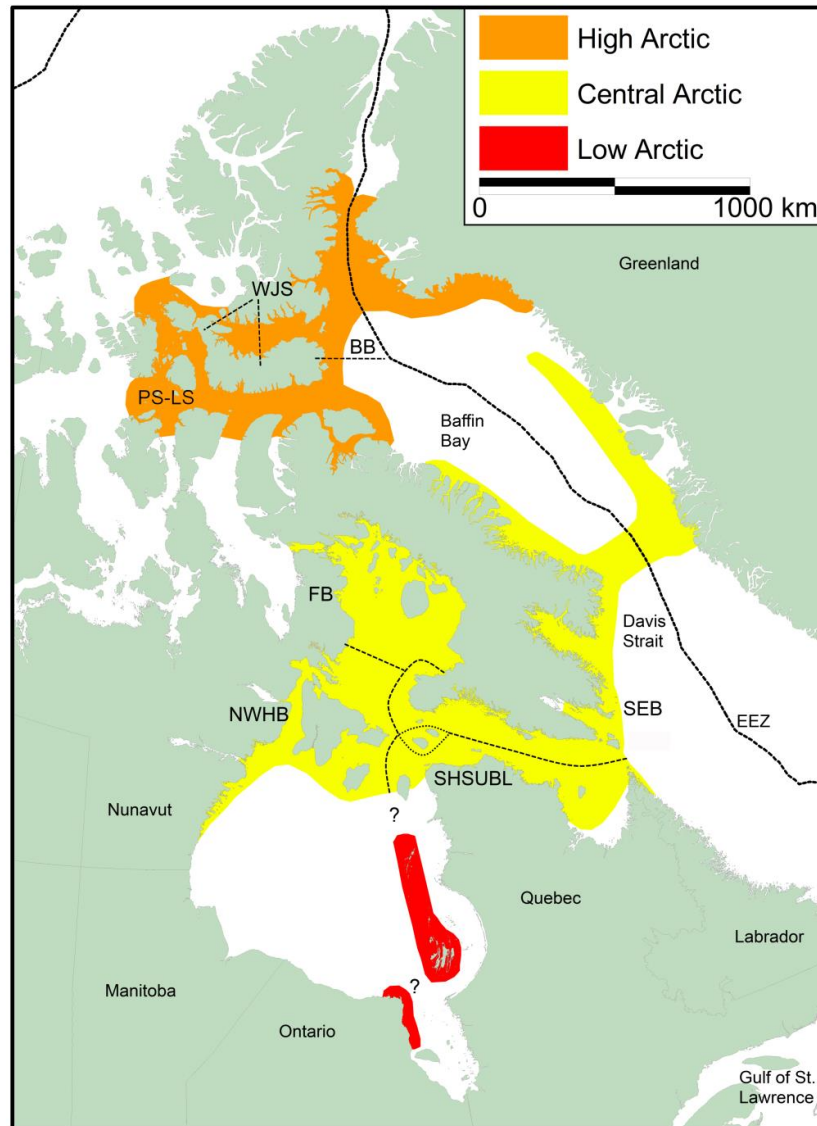


Figure 1. Approximate distributions of the Atlantic walrus populations that use Canadian waters (from D.B Stewart et al. 2014). Walrus management stocks within these populations include: BB = Baffin Bay, FB = Foxe Basin, NWHB = North and West Hudson Bay, PS-LS = Penny Strait-Lancaster Sound, SEB = South and East Baffin, and SHSUBL = South Hudson Strait-Ungava Bay-Labrador, and WJS = West Jones Sound. Question marks (?) indicate uncertainty with respect to distributions and/or movements.

### Habitat requirements

Atlantic walruses inhabit a relatively narrow ecological niche (Born et al. 1995). They require large areas of shallow water (80 m or less) with productive bivalve communities, open water over these feeding areas, and suitable ice or land nearby upon which to haul out (Davis et al. 1980). They are gregarious, often gathering in large herds. They are associated with moving pack ice for much of the year and when ice is lacking tend to congregate and haul out on land in a few predictable locations (Mansfield 1973). These haulouts (*uglit* singular *ugli*) are often situated on low shores with steep or shelving subtidal zones that afford animals easy access to

the water for feeding and quick escape from predators (Mansfield 1959; Salter 1979a,b; Miller and Boness 1983; Stewart et al. 2013b, 2014a-c). The animals generally move to more sheltered areas when there are strong onshore winds and heavy seas (Mansfield 1959).

The seasonal movement patterns of walruses and the influences of environmental conditions on those movements are not well documented in the study area. The seasonal occurrence of male Atlantic walruses (n=17) around Svalbard seems to be driven by their seasonally distinct breeding and feeding needs, with breeding occurring in pack-ice areas in the winter/spring and feeding occurring mainly in coastal areas in summer (Freitas et al. 2009). They did not simply follow the expansion and contraction of the ice edge but instead actively moved into areas of high ice concentration (>90%) during winter, travelling as far as 600 km into the dense ice pack. They also demonstrated high inter-annual, seasonal site fidelity.

The environmental variables with greatest influence on habitat use by male walruses around Svalbard varied seasonally (Freitas et al. 2009). Sea ice concentration was the most important environmental variable influencing first passage time (FPT) during the winter season ( $R^2 = 0.162$ ) although other, as yet unidentified, factors also influenced their winter occurrence. FPT provides a comparison of time spent in a particular habitat and thereby habitat selection. These walruses remained in areas with high ice coverage, far from their coastal summering areas, and spent much of their time hauled out or in surface waters (Freitas et al. 2009). Water depth and distance from the coast did not affect their winter distribution but were important determinants (FPT;  $R^2 = 0.571$ ) of their habitat use in summer when they fed intensively. Outside the breeding season male walruses made intense use (high FPTs) of shallow areas ( $\leq 40$  m), close to the coast ( $\leq 20$  km) (Freitas et al. 2009). They were 2.6 times more likely to leave an area deeper than 80 m than one shallower than 20 m, and 9 times less likely to remain in an area over 60 km from the coast than one up to 20 km from the coast. These 2 variables explained 57.1% of the variability in the occurrence data.

In March and April of 2012, walruses in Hudson Strait were most abundant in areas of open water with adjacent ice cover (<50%) and numbers peaked over water depths of 100 m (Elliott et al. 2013). In winter Inuit hunters from Coral Harbour and Cape Dorset see walruses near the floe edge, either swimming or hauled out on floating ice (Orr and Rebizant 1987). The hunters' movements farther offshore are typically limited by pack ice, preventing them from assessing walrus use of ice farther offshore. In west Greenland waters, walruses seen during aerial surveys in March-April showed preference for dense pack ice (Born et al. 1994). Most were seen in >60% ice cover. In April-May, tagged walruses showed preference for 50-60% ice cover, with males showing preference for significantly ( $P=0.019$ ) greater ice cover than females (64 cf. 52%) (Dietz et al. 2014).

Information on the entrapment of walruses in ice is scant. Walruses can break ice with their tusks to keep holes open and can climb out onto the ice using their tusks. Large male Pacific walruses can break through ice up to 20 cm thick by ramming it from below with their heavy, dense skull (e.g., Bruemmer 1977, Riewe and Amsden 1979). Atlantic walruses can travel over the ice for at least 6 km when they are frozen out (e.g., Calvert and Stirling 1990, Piugattuk 1986, Ijjangiaq 1990), typically in a straight line regardless of obstacles (Freuchen 1921). They sometimes become stranded inland and die (Siakuluk 1996).

## Seasonal distribution and movements

Atlantic walrus can swim or ride ice floes long distances but their seasonal movements in the Canadian Arctic are poorly known. Tagged animals cross Davis Strait over the narrowest part (Dietz et al. 2014), which is ~500-1500 m deep, but those that cross from east Greenland to Svalbard travel at least 700 km and cross water over 2500 m deep (Born and Gjertz 1993). Annual seasonal site fidelity in both summer and winter seems to be strong, at least in northeast Greenland (Born et al. 2005) and Svalbard (Freitas et al. 2009). Walrus in these areas follow the same seasonal migration pattern regardless of annual variations in ice and temperature regimes. Walrus feeding on shallow banks do not seem to be easily displaced by moving pack ice (Jay et al. 2010, Dietz et al. 2014). Summer habitat use appears to be driven by feeding requirements and the availability of *uglit* on land or of sea ice (Freitas et al. 2009).

### Foxe Basin

Walrus are widely distributed in the relatively shallow waters of Foxe Basin, where they live year-round (Loughrey 1959, Mansfield 1959, Crowe 1969, Beaubier 1970, Brody 1976a, Orr et al. 1986, NDEDT 2008). Distance may not completely separate walrus in Foxe Basin from those to the north and south but it likely limits interchange. There is some north-south movement of walrus in Foxe Basin but no evidence of concerted movement to or from Hudson Strait (Anderson and Garlich-Miller 1994). Walrus winter in both areas, so they presumably do not move *en masse* to seek wintering habitat. The species' seasonal distribution in southeastern Foxe Basin is poorly known, although between ca. 1915 and 1940 many walrus were landed in the Cape Dorchester area of Baffin Island (Reeves and Mitchell 1986, D.B Stewart et al. 2014). Significant seasonal movements of walrus through Fury and Hecla Strait are thought unlikely (Loughrey 1959, Mansfield 1959, Davis et al. 1980, Guinn and Stewart 1988, Garlich-Miller cited in Stewart 2002).

The seasonal movements of walrus in Foxe Basin are apparently in response to changing ice conditions (Mansfield 1958, Loughrey 1959). Inuit elders recognize two groups of walrus in Foxe Basin on the basis of differences in the animals' size, colour, flavour, and distribution (DFO 2002). Movements have been observed between summering areas around the islands in northern Foxe Basin—particularly the Spicers, and wintering areas along the floe edge that forms along the north side of Rowley Island and extends southward, parallel to the Melville Peninsula, to about 67°30'N (Loughrey 1959, Orr et al. 1986). There is also some north-south movement by walrus in northern Foxe Basin (Anderson and Garlich-Miller 1994). Observations along a north-south transect through central Foxe Basin in April to October 2008 suggest that walrus are more common there in June and August than was previously known, and uncommon there earlier and later in the year (LGL Limited and North/South Consultants Inc. 2011).

The summer distribution of walrus in Foxe Basin has changed over the past 50 years (Anders 1966, Crowe 1969, Beaubier 1970, Brody 1976a, Orr et al. 1986). Until the 1940s or 1950s, walrus were abundant at *uglit* along the east coast of Melville Peninsula. The establishment of a Hudson's Bay Company post at Igloodik in 1939 and a DEW Line Station at Hall Beach in 1955–1956 encouraged settlement of the Inuit of Foxe Basin in these locations. This increased local hunting pressure and disturbance by boat traffic. In the mid-1990s, elders from Foxe Basin considered walrus numbers to be increasing or stable (Aqatsiaq 1996, Ivalu 1996, Makkik and Ipkangnak 1996). Catches had been much reduced compared to the mid-1900s because of



smaller boats, a reduced need for dog food, and the fact that not all capable men went hunting (Kappianaq 1992, Ivalu 1996, Qamaniq 2005). Hunters do not believe that the overall number of walrus in northern Foxe Basin has changed over the past 25 years but they believe the animals have moved farther from the communities, perhaps into northeastern Foxe Basin (DFO 2002, 2013). Three islands in western Foxe Basin continue to have large concentrations of animals in the fall, and three others that had not been used for some time are now being used again. In the summer of 2010, Inuit hunters observed more walrus along the east coast of Melville Peninsula than was common in recent memory (D. Irngaut, Igloodik, NU, pers. comm. 2010; S. Qanatsiaq, Hall Beach, NU, pers. comm. 2010). They attributed this change to sea ice melting earlier in the season and forcing the animals ashore.

A September 2011 survey of Foxe Basin *uglit* counted 6,043 walrus with a best estimate of 10,379 and corrected estimates ranging from 8,153 to 13,452 (Stewart et al. 2013b). Both the maximum count and the estimates were much greater than previous estimates for this stock but no temporal trend can be established, as the coverage and methodology were different from earlier studies.

Walrus habitats in southern Foxe Basin have not been surveyed systematically. This is an important gap in knowledge of habitat use and in how walrus may be affected by shipping. Historically the Cape Dorchester area of southern Foxe Basin supported many walrus (D.B Stewart et al. 2014). Walrus are still present in southern Foxe Basin but their seasonal habitat use of the area, which is likely to become a major year-round shipping route, is poorly known (LGL Limited and North/South Consultants Inc. 2011).

#### Northern Hudson Bay, Hudson Strait, Ungava Bay

Some walrus remain in northern Hudson Bay and Hudson Strait all year, apparently moving inshore and offshore in response to changes in the ice. Others appear to undertake significant seasonal migrations. Evidence for the extent of these movements is circumstantial, based on local observations. Whether the wintering and migratory animals represent different populations is unknown (Stewart 2002).

Walrus occupy the north side of Chesterfield Inlet in the spring, are absent near the community in summer, and are present in the Chesterfield Inlet–Roes Welcome Sound area in winter (Brice-Bennett 1976, Fleming and Newton 2003). They occur in Wager Bay when ice is minimal, and Inuit indicate that they prefer areas with strong currents. Walrus are common in the Repulse Bay area but less so when the summer ice concentration remains high. Their presence also depends on the strength of the current, which varies each summer. When the current is stronger, they sometimes approach within 60 km of Repulse Bay in the fall; they are sometimes seen at the floe edge in winter.

In the past, walrus were more common and numerous along the west coast of Hudson Bay between Arviat and Chesterfield Inlet (Loughrey 1959, Born et al. 1995). They have abandoned various *uglit* in western Hudson Bay, some as recently as the 1950s (Low 1906, Degerbøl and Freuchen 1935, Loughrey 1959, Reeves 1978, Born et al. 1995, DFO 2002, Fleming and Newton 2003). They are now found mostly north of Chesterfield Inlet, where Inuit reported they were more numerous in the early 1990s than in the past (Fleming and Newton 2003). *Aivalik* (the place of the walrus), a camp at the head of Repulse Bay that was once the focus of walrus hunting in the area was abandoned by the 1930s because walrus had been hunted out of the

area (Beaubier 1970)<sup>1</sup>. No survey estimates were available for walruses in western Hudson Bay.

Walruses are present year-round in northern Hudson Bay and western Hudson Strait (Orr and Rebizant 1987, Elliott et al. 2013). Tagging studies in the mid-1950s at Bencas, Coats and Southampton islands, using harpoon-head tags (147 tagged, 4 recaptured), revealed only local movements (Mansfield 1958, Loughrey 1959). However, hunters report seasonal movements in response to changing ice conditions (Orr and Rebizant 1987). Walruses occur off the floe edge along the south and east coasts of Southampton Island and west and southwest coasts of Foxe Peninsula in winter, favour the pack ice of Evans Strait and Hudson Strait in late spring and summer, and move ashore to *uglit* as pack ice dissipates. During a late winter survey of Hudson Strait (10 March to 2 April 2012), walruses were seen more frequently along the coasts in relatively shallow water with areas of lighter ice composed of nilas and small ice pans (Elliott et al. 2013). Abundance peaked in water depths of 100 m, and in areas of open water with adjacent ice cover (<50% ice cover). In the fall walruses are concentrated at or near *uglit* on Bencas, Walrus, Coats, Mills, Nottingham, and Salisbury islands and on western Foxe Peninsula (Orr and Rebizant 1987).

Cape Dorset hunters have reported walrus herds of between 500 and 1000 animals on the ice or at *uglit* along western Foxe Peninsula in summer, particularly between Cape Dorset and Cape Dorchester, with a similar number in the area between Salisbury and Nottingham islands (Orr and Rebizant 1987). They also reported an increase in the number of walruses near the community over the 30 years prior to 2000 (DFO 2002). An aerial survey in August 1990 resulted in a count of 461 walruses on Nottingham Island (Richard 1993), and 714 walruses were counted around Salisbury Island during a Bowhead Whale (*Balaena mysticetus*) survey in August 2010 (J-F. Gosselin and S. Turgeon, DFO, Mont-Joli, QC, pers. comm. 2014).

Inuit from Akulivik and Ivujivik have seen walruses moving northward from Hudson Bay into Hudson Strait in the fall (Reeves 1995, Fleming and Newton 2003). Walruses remain in the Ivujivik area year-round but are seldom seen near Akulivik in summer (Fleming and Newton 2003). “Akulik” (Salisbury Island) and “Pilik” Island, which does not appear on maps, are important sites for these animals. In the early 1990s, Ivujivik hunters would go to Akulik when they did not see walruses elsewhere in winter.

There is a general westward movement of walruses through Ungava Bay and Hudson Strait in summer to Nottingham (Tutjaat) and Salisbury islands, with a return movement in the fall (Degerbøl and Freuchen 1935, Loughrey 1959). Currie (1963) described an influx of walruses to the southeast coast of Akpatok Island in Ungava Bay as soon as ice conditions permitted in June or early July, and their subsequent dispersal in late July or August northwest past Cape Hopes Advance into Hudson Strait, with a return migration following the same general route but further offshore from the cape in September and October. Smith et al. (1979) observed a large influx of walruses, apparently from Hudson Strait, into the Hall Peninsula area in mid-September. Some walruses are present year-round near Nottingham and Salisbury Islands, where strong currents maintain polynias through the winter (Kemp 1976, Orr and Rebizant 1987).

<sup>1</sup> As understood in 2014. See Preface.

Inuit report seeing more walrus along the Nunavik coast of Hudson Strait in recent years (DFO 2013). These walrus also appear in June instead of August and stay later in the fall, extending the hunting period. At Quaqtaq they can be seen from town in December and from a boat in July. These changes in seasonal distribution may be related to later formation and earlier breakup of the sea ice.

A walrus haulout survey of Hudson Strait and southern Foxe Basin was conducted in the fall of 2014 but the results are not yet available (B. Dunn, DFO, Winnipeg, MB, pers. comm. 2014)<sup>2</sup>. The North and West Hudson Bay area was last surveyed in 1990<sup>3</sup>, when 1,376 walrus were counted (Richard 1993). At the same time 461 walrus were counted on Nottingham Island. There are no survey data from the Southern Hudson Strait-Ungava Bay-Labrador region or from the Baffin coast of Hudson Strait, which is part of the South and East Baffin group<sup>3</sup>. Walrus numbers in these areas are likely reduced from their historical levels but no trend can be established and survey coverage is incomplete. Inuit have observed changes in walrus distribution and seasonal availability.

An aerial strip transect survey of Hudson Strait in 10 March to 2 April 2012 resulted in estimates for the two replicates of 4,675 (CV 0.45) and 6,020 (CV 0.40) walrus (Elliott et al. 2013). The summering areas of walrus wintering in this area are unknown. Most animals were seen in central and western Hudson Strait, and they may be a mix of animals from the Northwest Hudson Bay, Southeast Baffin and southern Hudson Strait to Labrador areas.

### **Life cycle and reproduction**

Walrus are gregarious and polygynous (Fay 1981, LeBoeuf 1986, Sjare and Stirling 1996). Relatively little is known about their reproductive behaviour since mating occurs in the water in remote areas from February through April (Born 1990, 2003, Sjare and Stirling 1996). Detailed observations of breeding behaviour were made at a High-Arctic polynia surrounded by fast ice (Dundas Island 76°05'N, 94°58'W; Sjare and Stirling 1996), where males competed for and defended access to females for up to five days. During the breeding season males compete intensely for females, vocalizing underwater to communicate dominance and attract females.

Sea ice stability may be an important determinant of breeding behavior (Sjare and Stirling 1996). The mating system in fast-ice/polynia habitat apparently differs from what has been described for Pacific walrus breeding in pack ice. In pack ice Pacific walrus exhibit a lekking behaviour in which several mature males vocalize from small, defended territories. It is not known whether the behaviour of Atlantic walrus breeding in pack ice is more like that observed in Pacific walrus.

Implantation of the embryo is delayed until late June or early July (Born 1990, 2001, Garlich-Miller and Stewart 1999). Active gestation lasts about 11 months. In the North Water polynia, young are born between 4 February and 11 November, with a mean birth date of 20 June (Born 2001).

<sup>2</sup> As understood in 2014. See Preface.

<sup>3</sup> Most recent survey took place in 2017, however the data has not yet been analysed.

Young walrus can be suckled for up to 25 or even 27 months (Fisher and Stewart 1997). Females take their calves to sea while they forage for food (Kovacs and Lavigne 1992); the young can be nursed in the water (Loughrey 1959, Miller and Boness 1983). Adoption may be widespread and important to Pacific walrus (Fay 1982) but has not been studied in Atlantic walrus.

## **Behaviour**

Walrus hauled out on the land spend most of their time resting, often lying in contact with one another (Salter 1979a, Miller and Boness 1983). This inactivity enables them to maintain high, stable temperatures in their skin and appendages, which may be crucial during the moult, and possibly for the healing of wounds and the survival of young calves (Fay and Ray 1968, Ray and Fay 1968). While comparatively slow and awkward on land, walrus are good swimmers. Their cruising speed seldom exceeds 6 or 8 km/h but they can accelerate to about 30 km/h for a short time when chased (Brummer 1977). Foraging trips can last 72 h between haul-outs (Born et al. 2003).

Females with calves favour the central and seaward areas of the *ugli*, where the calves are better protected from polar bears (*Ursus maritimus*) (Miller 1982, Miller and Boness 1983). Males in mixed herds tend to occupy the inland locations or central positions (R.E.A. Stewart, pers. obs.). In the water, males tend to be separated from females with offspring, possibly owing to differences in food requirements and to time and energy budgets related to nursing (Miller and Boness 1983).

Walrus use a wide variety of vocalizations both in and out of the water to communicate threats, submission, and distress, as well as to maintain contact between females and calves (Miller and Boness 1983, Miller 1985, Stirling et al. 1987, Sjare and Stirling 1996, Sjare et al. 2003, Stirling and Thomas 2003, Charrier et al. 2009).

## **Interspecific interactions**

### *Foraging*

Atlantic walrus feed primarily on benthic invertebrates, especially bivalve molluscs (Degerbøl and Freuchen 1935, Vibe 1950, Mansfield 1958, Fisher 1989, Fisher and Stewart 1997). They also eat Ringed Seals (*Pusa hispida*), Bearded Seals (*Erignathus barbatus*), fishes and squids (Vibe 1950, Mansfield 1958, Hantzsch 1977), and prey upon seabirds such as the Thick-billed Murre (*Uria lomvia*) (Gjertz 1990, Donaldson et al. 1995, Mallory et al. 2004). Observations on Pacific walrus suggest that most seal-eating is predation rather than scavenging (Lowry and Fay 1984). Inuit note that predation on seals is most prevalent in areas where deep water makes it harder for walrus to reach the bottom (Gunn et al. 1988, Piugattuk 1990, Kappianaq 1992, 1997).

Seasonal feeding patterns in the Canadian Arctic are not well known, although walrus may feed more intensively in the fall (Fisher and Stewart 1997). Intense benthic feeding was observed in summer by male walrus in Svalbard but their diving behavior indicated little feeding activity enroute to, or at their winter breeding areas (Freitas 2008, Freitas et al. 2009). Strong fidelity to the previous year's summering areas, with home range overlaps as high as 71%, may be explained by the predictable availability of their benthic food resources in particular areas.

Atlantic walrus forage mostly at depths of 10 to 80 m (Vibe 1950, Mansfield 1958, Wiig et al. 1993, Gjertz et al. 2001, Born et al. 2003, Born and Acquarone 2007) although adult males can dive to at least 250 m in both summer and winter (Born et al. 2005). The depth range of most foraging corresponds closely to the depth distribution of important clam prey species. Dive data are lacking from the Canadian Arctic, so foraging depths for habitat suitability must be surmised from prey abundance and from the diving and foraging patterns of Atlantic walrus around Greenland and Svalbard, and Pacific walrus in the Bering and Chukchi seas. Foraging behaviours are likely to vary with locale depending upon prey density, distribution of prey, or sediment type (Levermann et al. 2003).

In Barrow Strait, few *Mya truncata*, an important food of walrus, were observed at 5 m depth. Numbers increased sharply between 10 and 15 m, peaked at 15 m then declined exponentially with depth down to 80 m (Welch et al. 1992). The biomass of *Macoma calcaria* was highest between 10 and 30 m depth. The low densities in shallow waters are related to ice scour and exposure to freezing, which vary geographically with ice conditions and tidal ranges. Similar patterns of clam distributions occur elsewhere in the eastern Canadian Arctic (e.g., Qikiqtarjuaq, Coral Harbour), where *M. truncata* density peaks at 30 to 40 m and then declines to zero at 80 to 100 m (T. Siferd, DFO, Winnipeg, MB, pers. comm. 2014). *Serripes* spp. have a slightly shallower distribution.

The depauperate zone in terms of walrus benthic prey extends down to between 5 and 10 m but gaps in walrus diving suggest that the down-slope distribution and abundance of preferred prey is not always continuous. Pacific walrus in Bristol Bay, Alaska for example, can show a paucity of foraging in the depth range from 10 to 20-35 m (Jay et al. 2001, Jay and Hillis 2005). This could reflect the effects of substrates, tides, and/or scour among other factors on prey abundance or simply prey preference on the part of the individual walrus studied. The depth of the depauperate zone should be relatively constant in relation to the lowest tide but as the tidal range varies with location by over 7 m in Foxe Basin and 10 m in Hudson Strait this could be a significant source of error—particularly where high tides and low slopes correspond, such as the head of Ungava Bay.

### Predation

Polar bears prey on Atlantic walrus (Freuchen 1921, Loughrey 1959, Killian and Stirling 1978). Walrus are most vulnerable to predation when they are frozen out of their breathing holes or must rely on a very limited area of open water for breathing and haul-out, particularly where rough ice provides bears cover for stalking (Calvert and Stirling 1990). Predation may also be high if the open-water period lengthens, forcing walrus to make greater use of terrestrial sites and spend more time in open water (Garlich-Miller et al. 2011). Sub-adults are more vulnerable than adults, which are aggressive and possess large tusks for defence. Polar bears in Foxe Basin derived more of their ingested biomass from walrus (7%  $\pm$  1%) than did bears elsewhere in the Canadian Arctic (Thiemann et al. 2008). Walrus consumption was greatest among large adult male bears and increased with age for both sexes. Killer whales (*Orcinus orca*) in the eastern Canadian Arctic do not appear to regularly hunt Atlantic walrus (Ferguson et al. 2012) but they might acquire this behaviour and learn to hunt them successfully in the future if hunting opportunities increase.

## Sensitivity to disturbance

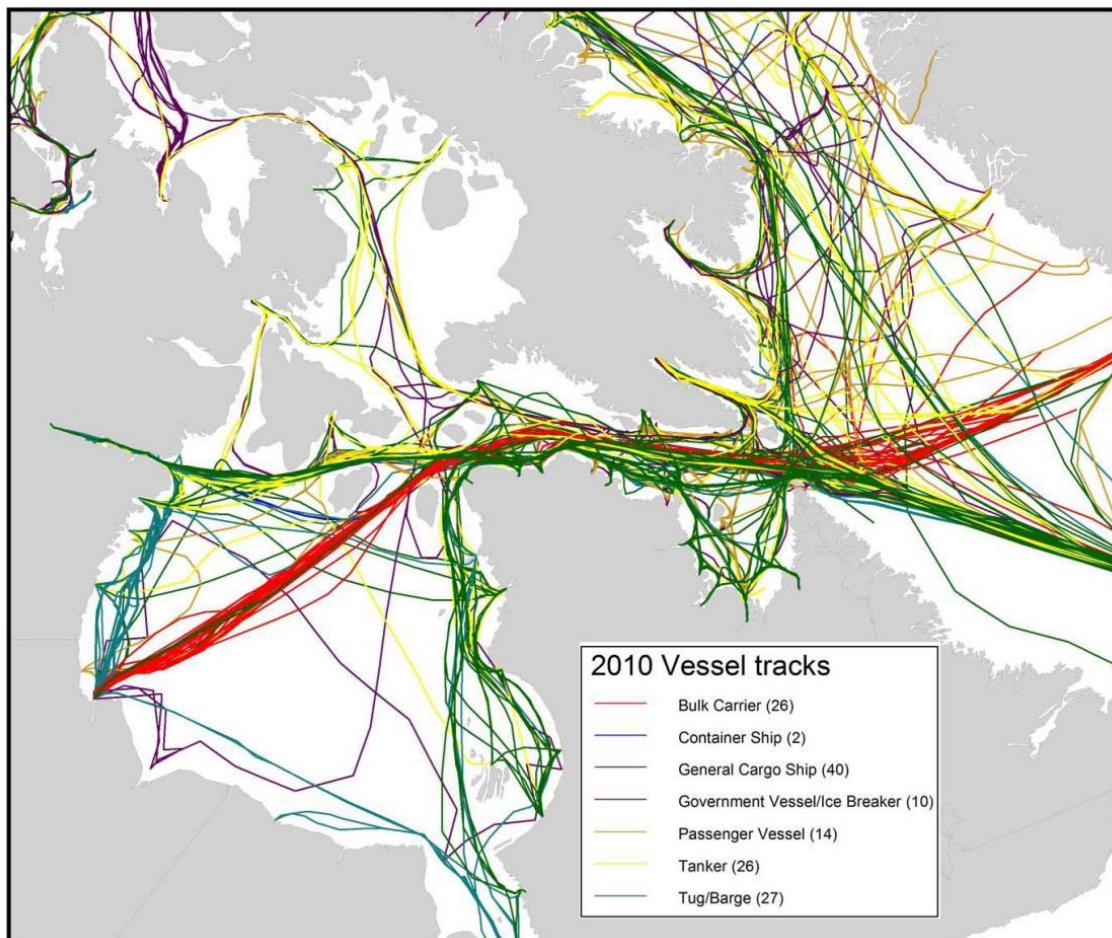
Walruses have poor eyesight but fairly acute hearing and an acute sense of smell, on land and while swimming (Loughrey 1959). They can probably distinguish large moving objects such as boats visually at a distance of ~60 m but were unable to identify a stationary person who was not silhouetted within 6 m. Atlantic walruses will reply to hunters imitating their vocalizations from a distance of ~1,000 m (Loughrey 1959). They detected the sound of a Bell 206 helicopter up to 8 km away, oriented toward the sea when it was within 1.3 km and sometimes escaped into the water immediately thereafter (Salter 1979a). Pacific walruses dispersed when a jet aircraft passed overhead at an altitude of about 9000 m (Okonek et al. 2009), and when a plane flew within 800 m (Okonek et al. 2010). Walruses seem to rely on their sense of smell to warn of danger (Loughrey 1959). They can be approached closer than 6 m from downwind provided the threat cannot be identified visually or by sound but when approached from upwind will stampede into the water before the threat (e.g., person) can be seen.

The reactions of walruses to vessel noise vary depending upon their previous experiences (Born et al. 1995). Animals from hunted populations tend to be skittish when approached by boats but when asleep can sometimes be approached within 10–20 m. Ice breaking activities cause Pacific walruses to enter the water: females and calves when the ship is within 500–1000 m, and males when it is within 100–300 m. They move 20–25 km away from the disturbance if it continues, but return after it stops. The effects, if any, of pulsed noise from seismic exploration on walruses are unknown, as is the ability of walruses to habituate to noise. Underwater noise might disrupt the transmission of important sounds made by walruses, such as vocalizations during the breeding season and mother-calf communications (Moore et al. 2012, Stewart et al. 2012).

The response to disturbance may affect population dynamics by causing stampedes, interfering with feeding and increasing energy expenditures—particularly on the part of calves, and by masking communications, impairing thermoregulation and increasing stress levels (Stewart 1993). Young walruses and those in poor condition are vulnerable to trampling if herds are stampeded onshore or offshore (Salter 1979a; Born et al 1995; Okonek et al. 2009, 2010). These stampedes typically result in few deaths but the number of deaths can be quite high in large stampedes. In one incident at St. Lawrence Island in the Bering Sea, where at least 537 Pacific walruses died, trampling may have been one cause of the mortality (Fay and Kelly 1980). Some of the animals examined had been attacked by killer whales, which may have stampeded the large herd ashore, resulting in death by trampling of smaller or weaker individuals. About 400 carcasses also washed ashore from various sources and about 15% of the total mortality consisted of aborted fetuses. The latter likely resulted from physical trauma, but an infectious or toxic agent could not be ruled out. Mortality on such a scale has not been reported for Atlantic walruses but stampedes do cause some mortality (Loughrey 1959). At some 'rocky' summer haul-out sites tusk breakage may also be a problem if animals startle and stampede into the water (B. Sjare, DFO St. John's, NL pers. comm. 2005). Broken tusks can sometimes result in massive infections in the tusk socket (R.E.A. Stewart, pers. obs.). Prolonged or repeated disturbances may cause walruses to abandon *uglit* (Salter 1979a).

## SHIPPING AND RELATED ACTIVITIES

Current (2010) shipping patterns are a poor predictor of future shipping in the eastern Canadian Arctic (Figure 2). Shipping in the region is likely to increase substantially by 2025 and even more by mid-century. These changes are driven primarily by demand for mineral resources and by climate change. If iron mines that have been approved (Mary River) or are under various stages of permitting or development (Roche Bay, Cape Hopes Advance Bay, Duncan Lake) proceed as planned, new deepwater ports will be required to support loading of very large ore carriers. Within the study area, two of these ports would be located in Foxe Basin (Steensby Inlet, Roche Bay) and one in Ungava Bay (Hopes Advance Bay). These docking facilities will be substantial and possibly permanent, with the capacity to load at least one Cape Class ore carrier efficiently, possibly several at once.



*Figure 2. Vessel tracks via Hudson Strait into Ungava Bay, Foxe Basin, and Hudson Bay (data from Gaston et al. 2013).*



This section provides background information on marine shipping and port infrastructure related to mineral development projects that, in 2014<sup>4</sup>, were in production or in the advanced development stage and that may affect walrus within the study area (Table 1, Figure 3). This information provides the basis for considering threat pathways and comparing existing and projected shipping patterns to walrus habitat suitability.

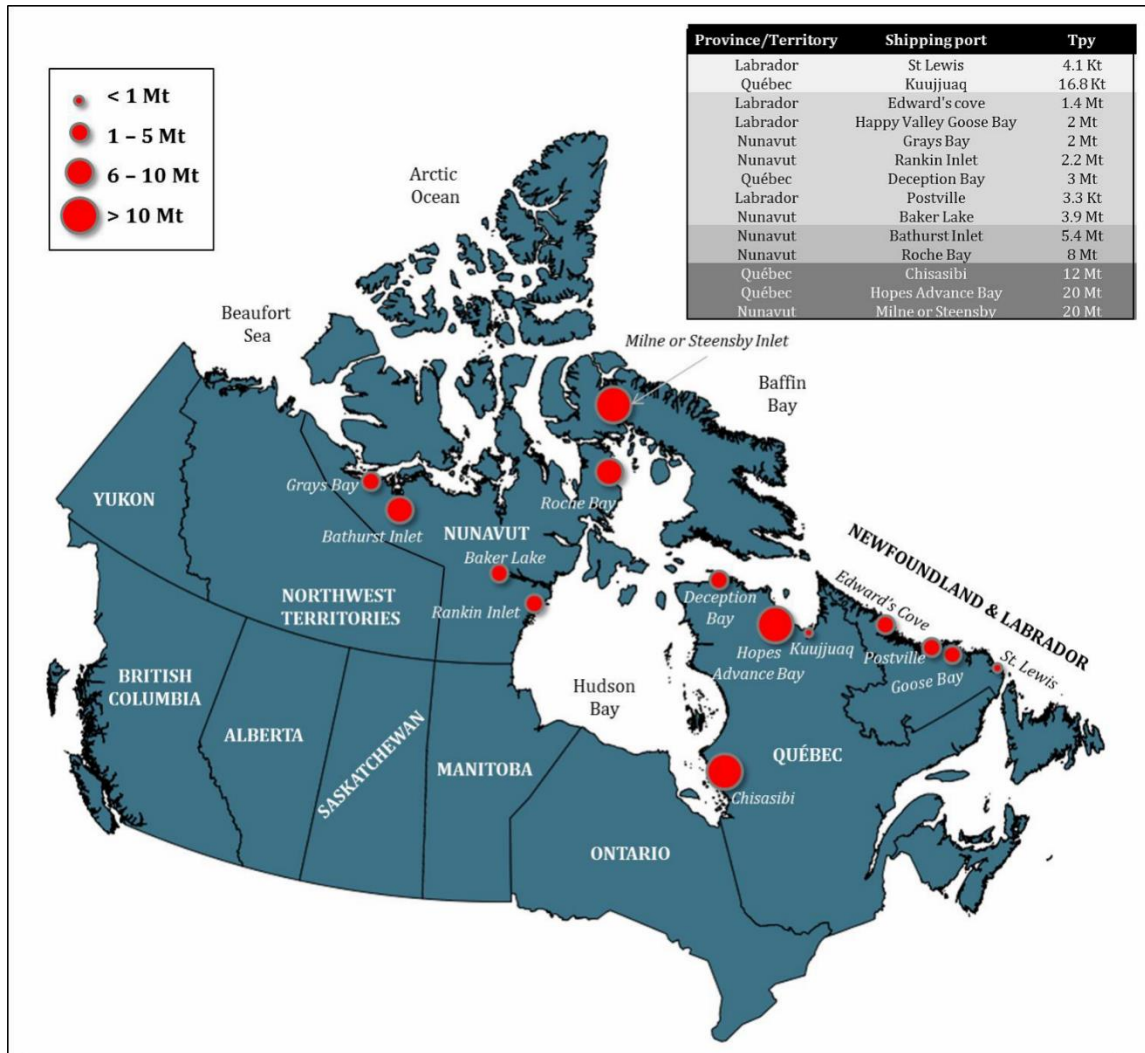


Figure 3. Mineral development projects in Canada's North shown as tonnage per year at most probable marine ports of export. Tonnage per year is based on peak production and is subject to change with fluctuations in the economy (Gavrilchuk and Lesage 2014).

<sup>4</sup> See Preface.



Table 1. Characteristics of the major mineral development projects with a marine transportation component in production or in advanced development stage in Canada's North as of 2014. Values or estimates are for the operational periods of each mine, most of which have the potential to overlap (CEAA = Canadian Environmental Assessment Agency, DWT = deadweight tonnes, FEIS = Final Environmental Impact Statement, FS = Feasibility Study, Mt = million tonnes, NIRB = Nunavut Impact Review Board, PEA = Preliminary Economic Assessment, PFS = Preliminary Feasibility Study, OW = open water (~mid-July to mid-October), YR = year-round (except for short periods to mitigate impacts to Ringed Seal pupping), SS = stretched season (June-December)).

Project name (company/proponent)	Mine or deposit location (ore destination(s))	Coordinates	Project status in Sept. 2014	Mine life (start year)	Annual production transported by ship (Mt)	Ore vessel shipment s/year (season)	Vessel type (DWT)	Resupply shipments	Vessel type (DWT)	Sources	Comments
<b>QUEBEC (Nunavik)</b>											
Raglan (Xstrata Nickel)	Deception Bay (Quebec City)	Mine: 61.68N, 73.68W Port: 62.15N, 74.69W	Production (since 1997)	25 yr (1997)	0.173 Mt ore concentrate (Ni, Cu, Co)	7-9 (YR)	Ore carrier ( <i>M.V. Arctic</i> 28,000)	3?	Cargo vessel and fuel tanker (DWT unknown)	MDDEP (2008), Gavrilchuk and Lesage (2014)	The Raglan Mine is constructing new underground mines and upgrading its facilities to increase production in 2016 by about 38% from 2009 levels (Xstrata Nickel 2011; see also <a href="#">Raglan Nickel Copper Mine, Quebec</a> ). This could increase the annual voyages required by the <i>M.V. Arctic</i> to about nine.
Nunavik Nickel (Canadian Royalties)	Deception Bay (Finland, China)	Mine 61.50N, 73.68W Port: 62.14N, 74.68W	Production (test shipments copper 2013, zinc 2014)	15 yr (2013)	??? Mt ore concentrate (Ni, Cu, Pd, Pt)	7-9 (YR)	Ore carrier ( <i>M.V. Nunavik</i> 25,000)	3	Cargo vessel and fuel tanker (DWT unknown)	MDDEP (2008), CBC (2014), Gavrilchuk and Lesage (2014), <a href="#">FEDNAV Nunavik</a>	<i>M.V. Nunavik</i> carried 24,000 DWT of nickel concentrate via Hudson Strait, Baffin Bay, and the NW Passage to China, Sept. 19-Oct. 14, 2014 ( <a href="#">Nunatsiag News 2014</a> ).
Ashram Project (Commerce Resources)	130 km south of Kuujuaq (unknown)	Mine: 56.93N, 68.04W Port: 58.11N, 68.40W	Development (PEA in 2012)	25+ yr (2017)	0.036 rare earths	1?	Unknown	Unknown	Cargo vessel (~30,000-35,000 DWT) Fuel tanker (unknown)	Gagnon et al. (2012), Gavrilchuk and Lesage (2014)	This includes the Eldor Property (Gagnon et al. 2012).
Hopes Advance Bay (Oceanic Iron ore)	West of Ungava Bay near Aupaluk (China and Europe)	Mine: 59.29N, 69.98W Port: 59.30N, 69.60W	Development (PFS in 2012)	30+ yr (2017)	10-20 Mt iron ore	56-111 (OW)	Cape Class ore carriers (180,000); possibly Suez Class (240,000) during open water	Unknown	Cargo vessel (10,000) Fuel tanker (25,000)	Golder and Associates (2012), Oceanic Iron Ore (2013), Gavrilchuk and Lesage (2014)	-

Project name (company/proponent)	Mine or deposit location (ore destination(s))	Coordinates	Project status in Sept. 2014	Mine life (start year)	Annual production transported by ship (Mt)	Ore vessel shipment s/year (season)	Vessel type (DWT)	Resupply shipments	Vessel type (DWT)	Sources	Comments
Duncan Lake (Century Iron Mines and Augyva Resources)	East of James Bay 40 km south of Radisson (Europe 30%, China 70%)	Mine: 53.45N, 78.13W Port: 53.81N, 78.92W	Development (PEA in 2013)	20 yr (2017)	12 Mt iron ore	66 (OW)	Cape Class ore carriers (180,000); possibly Suez Class (240,000) during open water	Unknown	Year-round road access, diesel fuel trucked to mine	Bilodeau et al. (2013), Gavrilchuk and Lesage (2014)	-
<b>NUNAVUT (Kivalliq)</b>											
Kiggavik (AREVA Resources)	West of Baker Lake (southern markets)	Mine: 64.31N, 97.94W Port: 64.32N, 96.02W	In review (FEIS to NIRB Sept. 2014)	14 yr (2017)	Uranium ore milled on site, product (0.05) transported by air to southern transportation networks	0	-	6 4	Cargo vessel (~12,000) Fuel tanker (~15,000)	AREVA (2013a), Gavrilchuk and Lesage (2014)	AREVA estimated its shipping requirements for Kiggavik based on the experience of Meadowbank.
Meadowbank (Agnico-Eagle)	North of Baker Lake (southern markets)	Mine: 65.02N, 96.07W Port: 64.32N, 96.02W	Production (since 2010)	7 yr (2010)	Gold ore processed on site, no marine ore transport required	0	-	3 4	Cargo vessel (~10,000) Fuel tanker (20,000 to 30,000)	AREVA (2013a), Gavrilchuk and Lesage (2014)	-
Meliadine (Agnico-Eagle)	West of Rankin Inlet (southern markets)	Mine: 63.03N, 92.21W Port: 62.81N, 92.10W	Approved by NIRB, awaiting Ministerial approval (NIRB 2014)	13 yr (2018)	Gold ore processed on site, no marine ore transport required	0	-	4-6 4-6	Cargo vessel (~10,000) Fuel tanker (20,000 to 30,000)	Agnico Eagle (2013a, 2014), Gavrilchuk and Lesage (2014), NIRB (2014)	-
<b>NUNAVUT (Qikiqtaaluk)</b>											
Mary River (Baffinland)	North central Baffin Island (Rotterdam)	Mine: 71.32N, 79.21W Port: 70.30N, 78.50W	Project approved (NIRB 2012)	21 yr (2019)	18 Mt iron ore	102 (YR)	Cape Class ore carriers (180,000)	3 3-6	Cargo vessel (20,000) Fuel tanker (18,000 to 45,000); up to 22 cargo vessels could visit annually during construction	NIRB (2012), Gavrilchuk and Lesage (2014)	The approved Steensby Inlet option has been postponed until ca. 2018 in favour of the Early Revenue Plan which has been approved to ship 3.5 Mt/yr to Rotterdam (NIRB 2014).
Roche Bay (Savik Iron Mines Ltd.)	Melville Peninsula (unknown)	Mine: 68.55N, 82.24W Port: 68.52N, 82.20W	Development (FS in 2012)	15+ yr (2017)	5.5-8 Mt iron ore	29-47(SS)	Cape Class ore carriers (172,000) more if Panamax size (74,000)	Unknown	Unknown	Advanced Explorations (2012, 2014), Saul et al. (2012), Gavrilchuk and Lesage (2014)	-

## **Quebec (Nunavik)**

### *Raglan Mine, Deception Bay*

The only port in the study area that is designed and equipped to load ore carriers (e.g., *M.V. Arctic*; Handy-Size; 28,418 DWT) and to handle cargo is located at Deception Bay in Nunavik, to serve the Raglan Nickel Mine (MDDEP 2007, Wright 2014). The original dock, which was installed in 1972, was rebuilt and expanded (length ~93 m) using concrete caissons in 2007 after serious bacterial metal corrosion was found in the old dock.

The mine processes a large quantity of nickel ore and mills it on site. This reduces the number and size of the mine's annual ore shipments, relative to iron mines that ship the crushed, unprocessed ore. Raglan is currently the only mine in the region that ships during both the open water and ice-cover seasons. Ore is transported east via Hudson Strait to Quebec City. Shipping is however suspended from mid-March to mid-June to avoid disturbing seals during the pupping season (BIMC 2012: vol. 10, app. 10D-10, p. 26 of 58). Further mine expansion is planned (Xstrata Nickel 2011).

### *Nunavik Nickel Project, Deception Bay*

In 2013, a temporary floating dock was installed at Deception Bay to load bagged copper ore from the Nunavik Nickel Project for shipment to Europe (FRPN 2013, Wright 2014). Construction of a permanent dock designed for bulk loading was planned for 2014 but has been postponed (T. Keane, FedNav, Montreal, QC, pers. comm. 2014). Ships maneuvering at the wharf will impact benthic communities in an area of about 24,000 m<sup>2</sup> and these impacts will continue over the life of the infrastructure (FRPN 2013).

The *M.V. Nunavik*, FedNav's new Polar Class 4 icebreaking ore carrier, will service the mine. It has a maximum capacity of ~25,000 DWT and is about 190 m long. The proponent estimates that nine trips will be made each year between mid-June and mid-March (FRPN 2013). This is the shipping period that has been agreed upon with the Inuit and that was specified in the certificate of authorization issued by the Quebec Department of Sustainable Development, Environment and Parks (MDDEP) in 2008 (MDDEP 2008). The *M.V. Nunavik* will follow the same route in Deception Bay as shipping for the Raglan Mine, but ore concentrate will be shipped to Europe and China. With the three trips required to supply fuel and goods, the new mine, once it is fully operational will add about 12 trips per year to vessel traffic in Hudson Strait and Deception Bay, two of which would be in ice-covered waters. In September 2014, the *M.V. Nunavik* carried a cargo of nickel concentrate to China via Hudson Strait, Baffin Bay and the Northwest Passage. Shipments to Europe will travel east via Hudson Strait.

### *Ashram Rare Earths Project, Ungava Bay*

A preliminary economic assessment of the Ashram Rare Earths Project considered a docking facility south of Ungava Bay on the east shore of the Koksoak River, near Mackay's Island (Gagnon et al. 2012). High capacity cargo vessels (30,000-35000 DTW) would unload/load their cargo in the middle of the river onto barges that would offload at the dock for transport via all-season road to the mine site. Acid-cracked rare earth concentrate would be transported to a processing facility by ship during the open water season.

#### Hopes Advance Bay, Ungava Bay

In 2014, this Project was in the development stage (Environmental Impact Statement preparation) and if it proceeds to operation would require construction of a deepwater port on the southwest coast of Ungava Bay, near Aupaluk, capable of handling Cape Class or even Suez Class (240,000 DWT) ore carriers (Golder Associés 2012). Iron ore would be shipped during ice free months from Breakwater Point (59°21'6"N, 69°37'52"W) to a trans-shipment point(s) (e.g., Rotterdam, Netherlands; Nuuk, Greenland; St. Pierre and Miquelon) and then transshipped to markets in China and possibly Europe during the winter (Oceanic Iron Ore Corp. 2013). Port facilities proposed for the Project include a 328 m causeway to a 330 m wharf for loading iron ore (Golder Associés 2012). The wharf would be a caisson gravity base structure containing hollow concrete precast boxes for the iron ore wharf, commercial and tug wharf in a series configuration. When connected together these boxes will be filled with sand/rock. The caisson will be submerged without hammering and anticipated dredging is limited to the preparation of a flat base on which to place the caissons. No dredging is anticipated for the approach channel. The total surface area occupied by wharfs would be about 1 ha. This is potentially a very large mine with a long life that would greatly increase open water shipping via eastern Hudson Strait to and from western Ungava Bay.

#### Duncan Lake Iron Project, James Bay

Two potential port sites have been identified by the Duncan Lake Iron Project for shipment of iron ore to market (Bilodeau et al. 2013). Wastikun Island (53°57'N, 79°09'W) offers easy access that facilitates construction of docking for vessels up to 75,000 DWT; Stromness Island (53°52'N, 79°08'W) has deeper water and a better approach channel that allow docking for vessels up to 200,000 DWT, which are suitable for direct shipping to China or Europe during the ice-free season. In 2014, this Project was still in the development stages. If this Project advances to full production it would substantially increase shipping in eastern James Bay, eastern Hudson Bay, and presumably Hudson Strait. While walruses are no longer in the port area, they were present historically in eastern James Bay until at least 1934 (Fleming and Newton 2003).

### **Nunavut (Kivalliq)**

#### Kiggavik Uranium Project, Baker Lake

The Kiggavik Project is currently (October 2014) under review by the Nunavut Impact Review Board (NIRB). If it is approved and proceeds to operation, the Project will substantially increase shipping via northern Hudson Bay and Chesterfield Inlet. The Proponent (AREVA 2011, 2013a) estimates that 55.4 kt of diesel and 91 kt of bulk dry goods per year will be shipped through Chesterfield Inlet to Baker Lake. Based on their preferred cargo vessels this will entail 8-12 deep sea ships (2-3 fuel, 6-9 container) anchored off Chesterfield Inlet during a 60-day shipping season lightering to 20-30 tug/barge combinations (AREVA 2013b). The fuel would be shuttled from a larger tanker that anchors about 20 nm east of Chesterfield Inlet near Helicopter Island by two smaller tankers the *Nanny* (9,176 DWT) and *Dorsch* (10,556 DWT), which would each make about 15 fuel delivery transits per year (TSB 2014). There are no plans to transport uranium ore by sea.

#### Meadowbank Gold Mine, Baker Lake

In 2010 a large dock was constructed at Baker Lake to support the Meadowbank Gold Mine, which requires cargo transfer but does not use bulk ore carriers (Wright 2014). None of the other communities in the study area has a dock suitable for cargo transfer, so their dry cargo is still lightered ashore and fuel is transferred ashore via a floating hose. The shipping season lasts from late July until early October. Diesel fuel is transshipped near the entrance of Chesterfield Inlet from tankers to barges, which transport it via Chesterfield Inlet and Baker Lake to the dock. The fuel is then pumped to a lined and bermed tank farm at Baker Lake.

#### Meliadine Gold Project, Rankin Inlet

This project is currently (October 2014) awaiting the Government of Canada decision to approve or reject it following submission of the NIRB recommendations (NIRB 2014). If it is approved a small seasonal spudded dock is planned at Melvin Inlet to handle cargo moving to and from the mine. Approximately 40,000 t of dry cargo (equipment and supplies) and 122 million litres of diesel fuel will be required annually for the operations of the Meliadine Project. To meet these needs, 4 to 6 vessels will annually deliver dry goods, and 4 to 6 tankers will annually deliver diesel fuel for the Project. All shipping will be during the open water season (typically from early August to late October) and will follow established shipping lanes that are presently in use for the annual sealift to Rankin Inlet and other communities (Agnico Eagle 2013, 2014). There will not be any ice breaking to extend the shipping season. Ships will not be serviced in Rankin Inlet and will arrive with enough fuel for the return voyage south. Fuel and cargo will be transferred from large ships anchored in Melvin Bay to smaller vessels (e.g., barges) that will transport them to Itivia Harbour. Cargo will be offloaded at the dock and fuel pumped ashore via floating hoses to a bermed tank farm. If approved, this Project will add to existing vessel traffic through Hudson Strait and northern Hudson Bay to Rankin Inlet.

### **Nunavut (Qikiqtaaluk)**

#### Mary River Iron Mine, Baffin Island

The main phase of the Mary River Iron Mine Project has been postponed (BIMC 2013) but has government approval to export 18 Mt of iron ore annually over a period of at least 21 years (BIMC 2012, NIRB 2012). This will require construction of a deepwater port with a two-berth ore loading dock capable of handling Cape Class ore carriers. Ore transport will require 102 trips annually by these ice-breaking vessels each capable of carrying about 180,000 t of ore. The ore would be loaded at Steensby Inlet in northern Foxe Basin and delivered via Foxe Basin and Hudson Strait to Rotterdam in Netherlands. Project vessels enroute from Rotterdam are expected to conduct mid-ocean exchange of ballast water and then treat the ballast water they have loaded enroute before it is discharged into Foxe Basin or Steensby Inlet (BIMC 2012, vol.10, app.10D-10, s.4.2 and app. 6). Treatment methods have yet to be determined and their efficiency under Arctic winter conditions is untested. Shipping would continue year-round with discharges of ballast at intervals of about 43 h. Ice breaking tugs will keep the deepwater port open in winter and assist with maneuvering the large ore vessels.

#### Roche Bay Iron Project, Melville Peninsula

This Project is currently (October 2014) in the development stage (Saul et al. 2012, Advanced Explorations Ltd. 2014). The Project plans to construct a single berth deepwater wharf, with a minimum wharf face of 300 m and depth at the face of 20 m, capable of handling Cape Class

ore carriers. Additional berth space for smaller support vessels along one side of the main wharf will provide room for an optional standby tug, mooring launch, and spill response vessel. If this Project proceeds to operation it will substantially increase traffic by Cape Class ore carriers via Hudson Strait and Foxe Basin to and from western Melville Peninsula. Most shipping will be conducted during the open water period but ice class vessels may be used to extend the shipping window from approximately June to December (163-day season). Like the Mary River Project, it would affect important walrus habitats in Hudson Strait. If the two projects operate simultaneously, habitats on both eastern and western Foxe Basin will be exposed almost daily to disturbance from very large ore carriers.

## **EFFECTS PATHWAYS**

At workshops and hearings, Inuit and scientists have expressed concern about the potential impacts from non-renewable resource exploration and development (e.g., Qikiqtani Inuit Association 2011, 2012, 2013, 2014; DFO 2013a; A. McPhee, DFO pers. comm. 2014). The effects of shipping activities on walrus and their habitats vary among project development components and often overlap. These pathways are depicted in the accompanying schematic (Figure 4). For discussion purposes, activities related to shipping have been divided into port construction and operation, ship passage, and ship loading and unloading. The pressures on walrus from these activities stem primarily from chemical releases, physical alteration of habitat, disturbances, ship strikes, and non-indigenous species introductions. These pressures can cause direct mortality or may reduce fitness through contaminant loading, social disruption, displacement or confinement, injury, parasites or diseases, or nutritional changes stemming from food chain alteration. In combination these effects may reduce walrus abundance, thereby having ecological impacts on predator and prey species, and have socio-economic costs by affecting hunting, tourism, and handicrafts. The discussion that follows is organized by activity, with more detailed discussion of primary pathways under the pertinent activity.

### **Port construction and operation**

Chemical releases, physical habitat alteration, and disturbances are all the pathways by which port construction and operation may impinge upon walrus. These pressures are likely to work together to displace walrus from the port areas during construction and this displacement may outlast the ports themselves. Each of these pressures contributes unfamiliar smells, sounds, and sights, in and above the water to which walrus are sensitive and avoid. The extent and period of displacement will likely vary depending upon the environmental controls placed on construction methods (e.g., use of blasting curtains); environmental controls on operational noise from machinery and discharges from water treatment facilities, ships, and incinerators; requirements for ice-breaking and harbour dredging; material mobilization by prop scour; human presence; visual cues such as tall lit structures; and other factors such as exposure, availability of alternative habitats, and direction of the prevailing winds (i.e., is the project upwind of walrus habitat). Noise and possibly olfactory disturbances may also cause social disruption by interfering with mother-calf communications and recognition, and interfering with male vocalizations during the breeding season.

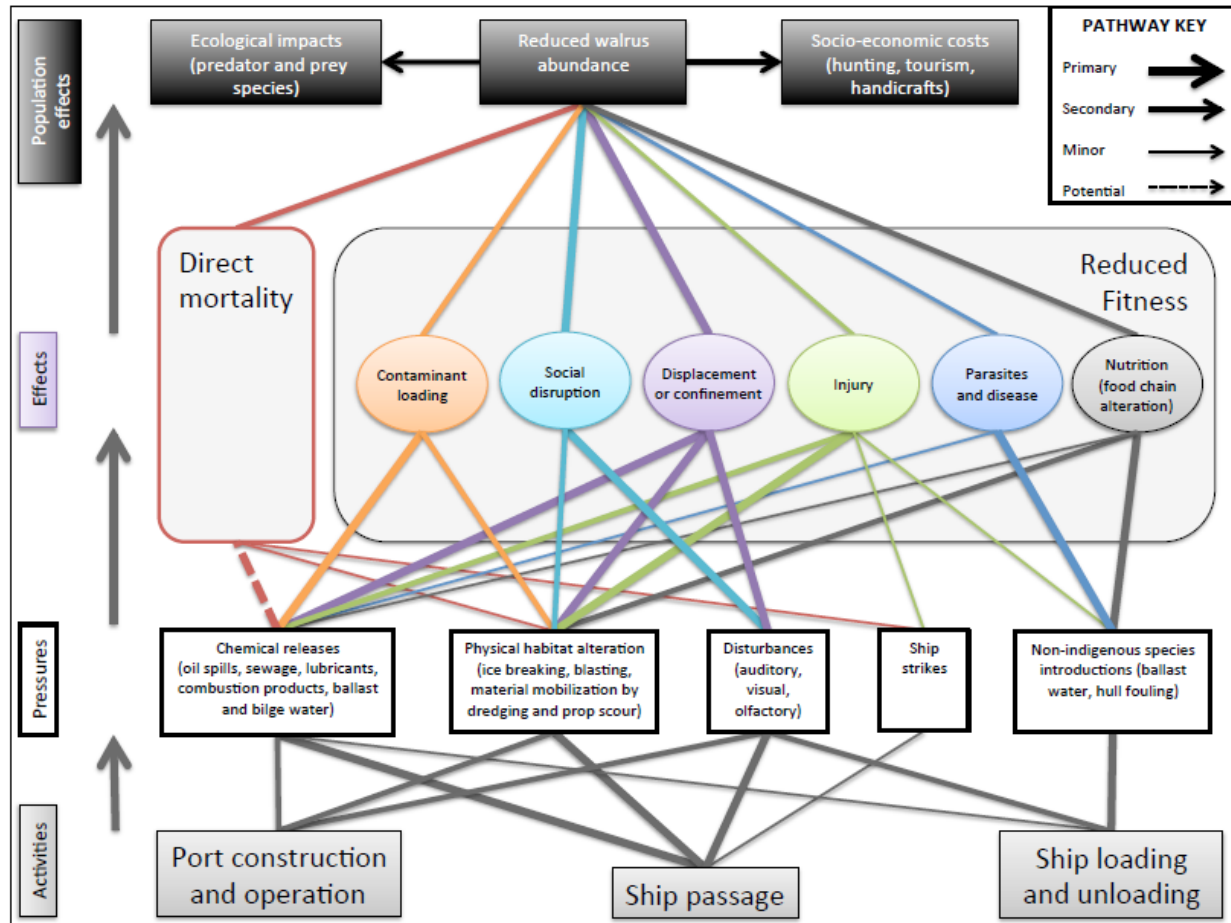


Figure 4. Effects pathways from ore shipment and related activities on Atlantic walrus in Hudson Strait and Foxe Basin.

Chemical releases and physical habitat alterations can also lead to contaminant loading and injury but disturbances are apt to displace walrus from the immediate area of the port at the outset of construction, perhaps 20-25 kilometers (Born et al. 1995). This should limit the effects of accidental spills of fuels or lubricants, and sediment mobilization by dredging or prop scour that can contribute toxic, sometimes persistent, chemicals to the environment. Blasting, dredging, prop scour, and ice breaking all have the potential to cause injury or alter the local marine community but again, once construction begins, the walrus are likely to avoid the area. However, such displacement is not without cost to the walrus as they may be forced to inhabit sub-optimal habitats, forced into competition with other walrus, or may become at greater risk of mortality from predators, hunters, or environmental conditions. Lessened impact by one factor because walrus have already altered their behaviour in response to another impact is not mitigative.

### Ship passage

Most of the primary threat pathways are related to ship passage, which includes chemical releases, physical habitat alteration, and disturbances. Pressures on walrus related to ship

passage in Hudson Strait and Foxe Basin will increase dramatically if the Mary River Iron Mine project on northern Baffin Island proceeds as approved (BIMC 2012, NIRB 2012). Delivering ore year-round from Steensby Inlet, in northern Foxe Basin to Europe will require about 102 round trips per year through Hudson Strait and Foxe Basin by large ice-breaking Cape Class ore carriers (180,000 DWT). In late winter 2012, the highest densities of walrus in Hudson Strait were observed within 3 km of the planned year-round shipping route; where densities decreased steadily with distance from the route (Elliott et al. 2013). A further doubling of ship traffic would occur if other metal mining projects near southern Ungava Bay (Nunatsiaq News 2012), Deception Bay (Xstrata Nickel 2011), western Foxe Basin (Advanced Explorations Inc. 2012, 2014; Saul et al. 2012), west of Hudson Bay (Agnico Eagle 2013, 2014; NIRB 2014), near Baker Lake (AREVA 2013b), and east of James Bay (Bilodeau et al. 2013) proceed with their current plans.

This shipping would affect walrus habitat along the various shipping routes, in some cases year-round. Although the existing shipping routes would continue to be in use, there could be very significant traffic increases via Hudson Strait to southern Ungava Bay, eastern James Bay, northern Foxe Basin, and Melville Peninsula. The primary threats pathways from ship passage are discussed below along with a minor pathway, ship strikes. These pathways all have the potential to reduce fitness and several could cause mortality.

#### Chemical releases

Activities related to shipping could expose walrus in Hudson Strait and Foxe Basin to a variety of contaminants, including heavy metals and organic compounds. Walrus in northern Foxe Basin already have elevated concentrations of cadmium, lead, and mercury in their tissues relative to other mammals in the region (Outridge et al. 1994, Wagemann and Stewart 1994, Wagemann et al. 1995) and to walrus in the Thule area of Greenland (Born et al. 1981). The Foxe Basin walrus appear to be accumulating these metals from natural sources (Outridge et al. 1997, 2002), as the metal concentrations in their tissues have paralleled those in the tissue of local clams, with the exception of cadmium (Wagemann and Stewart 1994). Levels of organochlorines in walrus tissues are generally low because they primarily feed low in the food web. Walrus typically have 4–10 times lower concentrations of organochlorine contaminants than belugas (*Delphinapterus leucas*) from the same area but a similar pattern of residues (Norstrom and Muir 2000). The highest levels are found in individuals that are thought to eat seals, which accumulate these contaminants in their fat (Muir et al. 1995). The effects of these metal and organic contaminants on walrus are unknown (Wagemann and Stewart 1994, AMAP 1998, Fisk et al. 2003).

The direct and indirect effects of crude oil and petroleum products on walrus have not been studied. Born et al. (1995) believed that several aspects of the species' ecology may make it vulnerable to oil pollution, in particular, its gregariousness which may spread oil from animal to animal, its preference for coastal areas and loose pack ice where oil may be more likely to accumulate, and its reliance on benthic molluscs which may accumulate petroleum hydrocarbons or succumb to the oil. Walrus populations may be most vulnerable to harm from oil spills during the calving period, and calves may be the most vulnerable component of the population. Exposure could reduce fitness by weakening the animals, which makes them more susceptible to parasites, diseases, and predation, and can also lead to mortality in extreme



cases. Oil could also mask the scent of mothers and calves and interfere with the mother-calf bond.

While the risks from crude oil and petroleum products are often downplayed in environmental impact assessments, in part due to lack of data from the Arctic for use in predictive modeling, shipping accidents do occur. The Coastal Shipping Limited Woodward oil tanker *Nanny* ran aground in 2010 at Gjoa Haven (Drouin 2011), and again in 2012 at Chesterfield Narrows (TSB 2014). In the latter incident one of her ballast water tanks was holed. There are numerous examples of tankers losing most or all of their oil cargo (Stewart et al. 2012). The risk of hydrocarbon pollution does exist and will increase with increasing vessel traffic under both open water and ice-covered conditions.

Sediment mobilization related to shipping will occur during port construction and operation, along shallow portions of the shipping routes, and during maneuvering while in port. The dispersal of sediment mobilized during dock construction can be controlled using sediment curtains, but sediment dispersal may be harder to control if dredging is required. Vessels passing over shallow bottoms, particularly where the same ship track is used frequently, year-round over many years by very large vessels (e.g., BIMC 2012) or in port, could mobilize sediment over a potentially significant area of bottom. This could expose walrus and their prey to higher levels of metals that would otherwise be sequestered in the sediment. Walrus are constantly disturbing sediment to feed on benthic organisms, so exposure to sediment released by surface scouring may be undetectable. However, spikes in dental lead concentration that were observed in Foxe Basin walrus after a period of unusually strong winds (Outridge and Stewart 1999) suggest that mobilization of deeper sediments could alter tissue metal concentrations. The effects of elevated metals on walrus are not well understood.

Walrus displacement by disturbances should reduce the threat of contamination related to sediment mobilization by limiting the animal's exposure. In the event of an oil spill, particularly in ice, displacement may not limit the animal's exposure as effectively.

#### *Physical habitat alteration*

Ice-breaking ore carriers will experience highly variable ice conditions at certain times of the year. This variation will also influence the distribution and abundance of walrus along the shipping routes by influencing migration timing, use of terrestrial haulouts, and selection of breeding and foraging habitats (see WALRUS ECOLOGY), possibly impacting Inuit harvesting practices. It is not possible to predict vessel interactions with sea ice with absolute certainty, but fragmentation of sea ice can have ecological consequences (Sahanatien and Derocher 2012). Fragmentation of sea ice by ice breaking vessels could affect habitat use by walrus during low ice years when pack ice for hauling out is limited, or alter breeding habitat. There may also be a risk of walrus mortalities from following ship tracks through the ice if these tracks then freeze, or risk of mortalities or injuries from crushing by shifting ice. Walrus may not be able to penetrate refrozen ship tracks which can provide rough ice in which polar bears may hide more easily.

Sediment mobilization, which was discussed above in relation to contaminants, can also affect foraging opportunities for walrus. Depending upon the depth and type of sediment prey eaten by walrus may be exposed to elevated water turbidity and metal concentrations. Sediment will also be redistributed, with scouring in some areas and higher sedimentation in others. These

changes may alter the prey composition and abundance, particularly near the port but also along shallow sections of the ship tracks. The effects of these changes on walrus are likely to be localized or limited, at least in part due to displacement from affected areas by disturbances from shipping or port activities.

### Disturbances

The cumulative effects of chronic auditory, visual, and olfactory disturbances could have major impacts on the distribution of walrus in Hudson Strait and Foxe Basin. These disturbances are a concern to communities along the ship routes. Disturbance from motorized transportation has caused walrus herds to abandon *uglit* near communities (Born et al. 1995). The ability of walrus to habituate to disturbance and reoccupy abandoned *uglit* is unknown (COSEWIC 2006), but responses to disturbance at Round Island in Alaska did not show habituation within or between years (Stewart et al. 2012).

Auditory disturbances related to ship passage are likely to become the most pervasive and widespread disturbance to walrus in Hudson Strait and Foxe Basin. Noise from the Cape Class ore carriers BIMC proposes to use will be heard by walrus at distances of up to 250 km (BIMC 2012: vol. 8, s.5.7.2.2). The diameter of the noise impact is therefore at least 500 km (radius 250 km). Southern Foxe Basin is approximately 250 km wide, so most walrus in the Basin may hear each vessel come and go. Hudson Strait is narrower for the most part, and the length of the strait (between Salisbury and Resolution islands) is less than 700 km. Based on the proposed shipping schedule, there could be three, possibly four, ore-carriers along the shipping route to Steensby Inlet at any given time. If the Mary River and Roche Bay iron projects are in operation simultaneously, noise levels would further increase in both Hudson Strait and Foxe Basin.

The impacts of these disturbances on walrus are a concern to scientists and to Inuit communities along the ship routes. Walrus need not be injured or displaced to suffer adverse effects from disturbance. Chronic noise disruption (masking or interference) of important mother-young acoustic communications (Charrier et al. 2009) and/or of vocalizations during the breeding season (Sjare and Stirling 1996), for example, could have a large impact on walrus populations by causing social disruption that will be difficult to monitor. Noise could also impact walrus energetics (including thermoregulation), nursing, or feeding which would also reduce fitness (QIA 2011: App. D, TC D-25).

There has been a general shift in walrus distribution away from human communities to areas that are relatively inaccessible (Kopaq 1987, Born et al. 1995, Kuppaq 1996, Immaritok 1996, Paniaq 2005). This is not a new phenomenon and is related to changes in technology (Brody 1976a). It began with the introduction of whaleboats in the 1920s, which extended hunting ranges and enabled open-water hunting; accelerated with the introduction of motorized technology ca. 1940-60; and continues as the range and speed of boats increase (see also Crowe 1969, Beaubier 1970, Orr et al. 1986). The extent to which distributional changes reflect declines as opposed to shifts in the walrus populations is not always clear (DFO 2002).

Little is known about the reactions of Atlantic walrus to large vessel traffic as hitherto there has been little overlap between the two or study. Ice breaking activities cause Pacific walrus to enter the water: females and calves when the ship is within 500–1000 m, and males when it is within 100–300 m (Born et al. 1995). Walrus will move 20–25 km away from the disturbance if it continues but return after it stops.

Tourist activities can cause walrus stampedes (Cody 2003). There is concern among Inuit and scientists, not only that disturbance from tourism may cause stampedes but also that it could drive herds further into the pack ice or away from their traditional *uglit* (Stewart 2002; Dueck 2003, C. Chenier, OMNR, Cochrane, ON, pers. comm. 2003). This concern prompted the Igloodik HTO to ban all forms of tourism related to the northern Foxe Basin walrus population from ca. May 2008 through May 2011 (CBC News 2008; Gagnon 2011). International tours were later resumed, bringing visitors to view walrus at *uglit* in Foxe Basin in July and August.

### Ship strikes

No studies of walrus mortality or injury from ship strikes were found during this work. Walrus are quick and maneuverable in the water and should be able to detect and avoid vessels approaching in open water. Icebreaking may represent a more serious threat, especially during the breeding season when animals may be clustered, males aggressively defend their territories, and when escape options are limited by ice. The species' gregarious nature and vigorous defense of calves may cause individuals or groups to challenge ships, which could lead to injury or possibly mortality if they are struck, trapped by ice, or entrained by propeller suction. Walrus in Hudson Strait will have limited experience with ship passage, particularly in winter. Few walrus in Foxe Basin will have been exposed to summer shipping and few if any to icebreaking. Whether this unfamiliarity will make them more or less apt to avoid ships is unknown. Ship strikes are unlikely during port construction and operation, and ship loading and unloading.

### **Ship loading and unloading**

The pressures on walrus from vessel loading and unloading are difficult to predict and assess. Non-indigenous species introductions via ballast water and hull fouling are a primary pathway with the potential to expose animals to unfamiliar parasites and diseases, and to affect walrus nutrition by altering the marine food chain (Figure 4). Both of these effects could reduce walrus fitness. Risks associated with non-indigenous species introductions are likely greatest in the immediate vicinity of ports.

Olfactory, auditory, and visual disturbances related to the vessel presence and operations in port are a secondary pathway that is likely to displace walrus from the port area. The extent and duration of this displacement is uncertain. Such displacement is undesirable from an ecological standpoint as it may force displaced animals into sub-optimal habitats as well as inadvertently reduce their near-field exposure to any non-indigenous species introductions. This displacement should also limit the exposure of walrus to chemical releases, which should be a minor pathway in relation to ship loading and unloading and walrus. The chemical releases of greatest concern are likely from accidental spills of fuel or other toxic chemicals. Spills in port should have less impact on walrus than spills that occur along the shipping routes as the animals may already avoid the ports, and the ports should be better equipped to handle spills. Treatment of ballast water to avoid non-indigenous species introductions could have residual chemical effects (e.g., anoxia) that affect biota downstream of the release point, but these should be local and unlikely to affect walrus.

A more detailed discussion of the current and future pressure from non-indigenous species introductions follows. The secondary and minor pathways were discussed in greater detail earlier under ship passage.

### Non-indigenous species introductions

The impact of introduced species on the receiving ecosystem can be severe and widespread. These species can affect native species by competing with them for resources or space, preying upon them, poisoning them, disrupting their habitats, altering their gene pool through hybridization, introducing parasites or diseases to which they have little resistance, and/or the uncoupling of important biological linkages (e.g., Carlton 1992, Claudi et al. 2002, NRC 1996, Hallegraeff 1998, Sax et al. 2007). Lacking natural predators, the introduced populations may expand quickly into adjacent areas and their rate of population increase may be high. This can lead to dramatic changes in community function and in the value of coastal waters for food, recreation, and industrial uses.

Little is known about what non-indigenous species might be introduced, their ability to establish, or potential impacts to indigenous species such as the Atlantic walrus (Stewart and Howland 2009, Chan et al. 2012, Stewart et al. 2015). Possible pathways are both direct and indirect. Introduced diseases and parasites could directly affect walrus populations. New and attractive but non-nutritious prey species could lead to malnutrition. Indirectly, introduced diseases, parasites and competitors of benthic species, and competitive consumers of benthic species could seriously affect walrus food sources. It is important that there be better understanding of this pathway, given that shipping is likely to increase substantially by 2025 and that the massive ore carriers will arrive empty and in ballast.

The annual volume of ballast water discharged at ports in the eastern Canadian Arctic has been low, reflecting the regions' limited exports relative to Atlantic and Pacific ports in Canada. At present and over the past decade (i.e., 2004-2014), most vessels enroute in ballast to destinations within the study area have entered from the east via Hudson Strait to load ore concentrate (Ni, Cu, Co) from the Raglan Mine at Deception Bay (Stewart and Howland 2009, Chan et al. 2012). The ore is transported to Quebec City by the *M.V. Arctic* (T. Keane, FedNav, Montreal, QC, pers. comm. 2012). This ice-breaking vessel remains in coastal waters but voluntarily exchanges ballast water on the trip north to reduce the potential for introducing non-invasive species. Merchant vessels loaded with cargo or fuel (e.g., sealift), cruise ships, fishing vessels, and government vessels (scientific, Coast Guard, navy) also visit the study area. These vessels require less ballast water to ensure stability than the unloaded bulk carriers and often remain within Canada's Economic Exclusion Zone (EEZ).

Deception Bay and Churchill are connected to other locations in the region by international merchant vessels or coastal domestic merchant vessels that discharge small quantities of ballast water ( $<1,800 \text{ m}^3/\text{y}$ ) (Stewart and Howland 2009, Chan et al. 2012). These connections could facilitate the transfer of non-indigenous species from these ports to other areas within the study area. However, Iqaluit is more likely to serve as a hub for the spread of non-indigenous species within the region as it receives more ballast water from coastal domestic vessels that have not conducted mid-ocean exchange (Chan et al. 2012).

If the Mary River Iron Mine project on northern Baffin Island proceeds as approved by the Government of Canada, the annual discharge of ballast water into the Steensby Inlet area of Baffin Island by project ore vessels would be  $20.4 \times 10^6 \text{ m}^3/\text{year}$  (BIMC 2012, v.8, s.2.6.2.2, p.17). This is about 70x greater than the average annual discharge of ballast water that Chan et al. (2012) reported at Canadian Arctic ports in 2005 through 2008 ( $275,714 \text{ m}^3/\text{year} \pm 6,644 \text{ SEM}$ ). If the mine operates as planned, the Steensby Inlet area would receive 3x more ballast

water of foreign origin annually than the port of Sept-Îles, which is a leading recipient of foreign ballast water on the east coast of Canada (see Adams et al. 2013). The project vessels will load ballast water when they unload ore in Rotterdam (Netherlands), which is an international hub for invasive species. To reduce the risk of introducing non-indigenous species they are expected to conduct mid-ocean exchange of ballast water and then treat the ballast water they have loaded enroute before it is discharged into Foxe Basin or Steensby Inlet (BIMC 2012, vol. 10, app. 10D-10, s. 4.2 & app. 6; see also BIMC response to QIA FEIS IR D-02). Treatment methods have yet to be determined and their efficiency under Arctic winter conditions is untested.<sup>4</sup> Shipping would continue year-round with discharges of ballast at intervals of about 43 h.

Ballast water discharges could also increase substantially in other areas of the study area where iron and zinc projects are located if these projects begin operation (Table 1). The new icebreaking ore carrier, *M.V. Nunavik*, which services the Nunavik Nickel Mine is equipped with a ballast water treatment system (Nunatsiaq News 2014). Even without the introduction of foreign species, 'aseptic' ballast water in large amounts can depopulate the benthic community over which it settles.

## SPATIAL ANALYSIS

### Background

To facilitate comparison of walrus habitat-use with shipping activities in the absence of seasonal survey coverage of much of the study area, two habitat suitability maps have been developed, one for the period of least ice cover and another for the period of greatest ice cover. The objective is to conduct a preliminary comparison of overlap in space and time between Atlantic walrus and shipping activities related to non-renewable resource developments in Hudson Strait and Foxe Basin. To assess uncertainty, the seasonal survey results are compared with the habitat suitability predicted by the modeling exercise.

### Habitat suitability

Habitat suitability for walrus was modeled by combining four environmental variables, each of which is related to their life history requirements, hence habitat use, and provides comparable data for the entire study area (Figure 5). These variables are water depth, seasonal ice cover, distance to the coast or ice, and proximity to a terrestrial haulout. Bottom substrate was considered but not included because its distribution is not well known and there is typically a fining trend in grain size with depth (e.g., Grant 1971, Thomson 1982), enabling the use of depth as a proxy. Reference material supporting the variable categories used below is cited in the Walrus Ecology section.

**Water depth** is an important determinant of benthic foraging success and energetics. Five depth ranges were used for analysis (Appendix 1, Table A1- 1):

- Shallow (<10 m depth) water does not appear to provide optimal benthic foraging habitat for walrus, however, walrus do make extensive use of these shallow habitats in the vicinity of deeper waters with greater seasonal variation in salinity and temperature. These habitats

<sup>4</sup> As understood in 2014. See Preface.

are subject to scouring by sea ice and to desiccation and freezing through tidal exposure. They tend to have coarser grained prey such as *M. truncata*, *M. calcareea*, and *Serripes* spp. in shallow water. The lower limit of this depth range will likely vary based upon the depth of ice scour and tidal range, extending from ca. 5 m in sheltered areas with small tidal ranges to about 20 m in exposed areas or those with extreme tidal ranges such as the head of Ungava Bay.

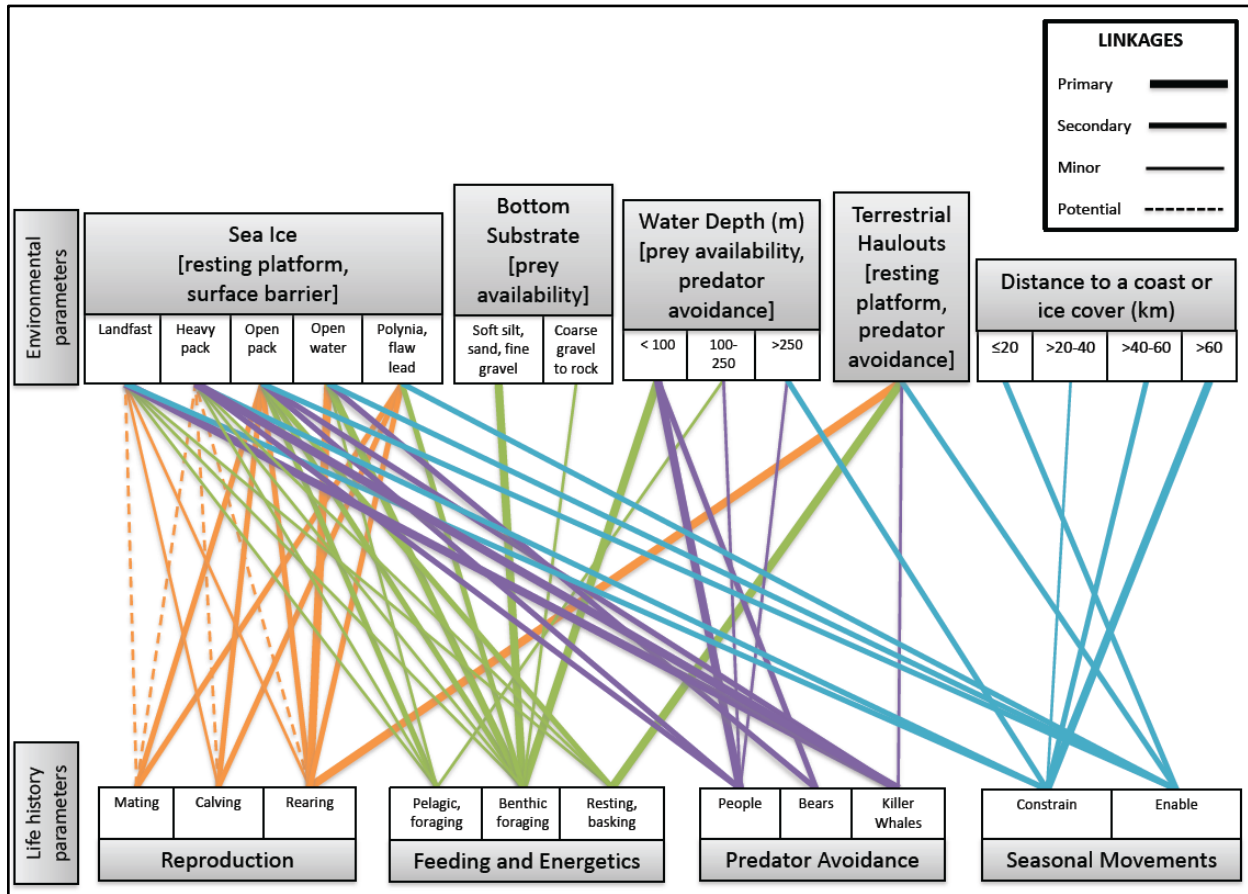


Figure 5. Linkages between walrus life history parameters and environmental parameters.

- Optimal (10 m to <50 m) benthic foraging habitat, as demonstrated by the relatively high frequency of foraging dives and peak abundance of key bivalve species, appears to extend from below the scour zone to about 50 or 60 m depth.
- Sub-optimal (50 m to <100 m) but still well-used foraging habitats offer a lower abundance of key bivalve prey. Tagged walrus typically visit these depths less often. This depth range extends downward to the approximate limit (~100 m) of the annual mixing processes of the Arctic surface waters (Roff and Legendre 1986, Tang et al. 2004).
- Marginal (100 m to <250 m) foraging habitat seems to be partly or entirely within the diving ability of most adult walrus. Some animals eat benthic invertebrates captured within this depth range but tagged walrus seldom visited bottom habitats this deep and when they did, little time was spent on the bottom. Foraging at these depths may occur more

frequently when sea ice or distance prevent the walruses from accessing benthic habitats in shallower water.

- Deep ( $\geq 250$  m) benthic habitats may only be accessible to walruses with superior diving ability. Some large adult males can descend to a depth of over 250 m. The V-patterns of these dives suggest that their purpose may be exploratory rather than for foraging. While benthic foraging at depths  $>250$  m appears to be uncommon, walruses do use waters that are too deep for them to forage on the bottom for other purposes. Some animals in these waters forage on pelagic species, such as seals or fish, and many will inhabit or transit deepwater areas on a seasonal basis.

**Seasonal ice cover** is an important determinant of walrus distributions, foraging opportunities, reproduction, vulnerability to predation, and other aspects of their life history. Five ice cover categories were used for the habitat suitability modeling (Appendix 1, Table A1- 2):

- Landfast ice (10/10ths cover) is particularly limiting as it can prevent access to benthic foraging habitats in coastal waters. Walruses that haul out on landfast ice, particularly if they are not at the ice edge, are vulnerable to predation by humans and polar bears, particularly in areas of rough ice.
- Heavy pack ice (7-9+/10ths cover) offers access to water and benthic habitats, and limits hunter access. Adult male walruses in Svalbard travel long distances through  $>9/10$ ths ice cover from foraging habitats to and from breeding habitats (Freitas et al. 2009). Movement of heavy ice does not necessarily displace foraging walruses. Males tend to move deeper into heavy pack ice than females, particularly females with calves.
- Open pack ice (1-6/10ths cover) offers easier mobility and greater foraging opportunities. The higher covers limit hunter and killer whale predation while enabling access by polar bears. The abundance of walruses in Hudson Strait in March and April 2012 peaked in areas of open water adjacent to  $<50\%$  ice cover (i.e.,  $<5/10$ ths) and over depths of  $\sim 100$  m (Elliott et al. 2013).
- Open water ( $<1/10$ ths cover) is well used adjacent to ice cover but use is likely to diminish with distance from suitable haulouts on ice or land (see below) unless animals are simply in transit through the area.

**Polynias and persistent flaw leads** are particularly important wintering habitats for walruses. Polynias offer open water year-round that enables walruses to winter in northwestern Foxe Basin and western Hudson Strait, and persistent flaw leads enable them to winter of the landfast ice edge of northern Hudson Strait. Where polynias are small their grid cell has been coded (see Habitat Suitability Analysis section) as if it were all polynia to capture the relative importance of the polynia as overwintering habitat.

**Distance to a coast or ice** is another important aspect of habitat suitability for walruses. Walruses need to haul out of the water to rest between foraging trips. Research on Atlantic walruses in Svalbard during the open water period has demonstrated that they spend more time in waters near the coast (e.g., within 20 km) than they do farther offshore (e.g., over 60 km) (Freitas et al. 2009). This likely reflects tradeoffs between a combination of factors related to foraging energetics, in particular the greater energetic costs of swimming farther and diving deeper, the abundance of preferred prey, the time available for foraging, and need to haulout and rest between foraging trips. Distance to the coast or landfast ice edge has been ranked in

four different categories to reflect seasonal differences in the use of open water habitats related to the proximity of suitable haulouts (Appendix 1, Table A1- 3).

This variable provides a general sense of areas that may be preferred where there is open water but it does not consider the suitability of the coastal or ice habitats for hauling out to rest. To address this gap, the use of terrestrial haulouts has been included in the habitat suitability modelling. Documented haulouts (see below) provide evidence of suitable habitats but these are undoubtedly a subset of the locations in use over the course of a single year or multiple-years, since both scientific surveys and Inuit observations have been constrained by seasonal access. Shallow, muddy, low-slope coastlines such as the Great Plains of the Koukdjuaq in southeastern Foxe Basin, and steep cliffs like those bordering sections of Hudson Strait probably limit the value of these coasts as walrus haulouts during the open water period. While the presence of sea ice extends the haulout opportunities for walruses, some areas may still be out of reach for foraging for much of the year.

**Terrestrial haulouts** and their surrounding waters are very important to walruses. Eight categories have been used to rank haulouts and the waters in their vicinity, based on evidence of maximum use and distance. During the open water period walruses haul out on land to rest and socialize between foraging trips. Hauled out animals are not vulnerable to predation by killer whales and typically fend off marauding polar bears. These sites have been ranked on the basis of known use, as demonstrated by the maximum number of animals observed there at any one time (Appendix 1, Table A1- 4). Waters within 50 km of the haulout have been ranked higher than those between 50 and 100 km distant to reflect both the probability that the closer habitats receive greater use and are likely to be particularly important to the walruses, and that the haulouts are particularly sensitive habitats that require the protection of buffers.

Walrus haulout sites were obtained from the DFO GPS database (B. Dunn and R.E.A. Stewart, DFO Winnipeg, unpubl. data) and updated with relevant literature, which also provided useful data (e.g., Freeman 1976; Born et al. 1995; Reeves 1995; Stewart et al. 2013b, 2014b,c). The buffer zones established around each haulout are somewhat arbitrary but should be precautionary. The inner 50 km buffer is based roughly on the estimated distance that walruses in various areas travel in a day (40 km/day - Stewart 2008; 46 km/day - Dietz et al. 2014; 45.3 km/day Stewart et al. 2014b; see also Stewart et al. 2013b). The outer 100 km buffer is based on the 95% kernel range for both sexes combined, a maximum distance of ~100 km (Dietz et al. 2014, Stewart et al. 2014b). Haulouts that have been used in the past but may now be abandoned were included in the buffer zones as the underlying reasons for their past use likely remain – presumably suitable haulout habitat and rich, accessible shellfish beds.

### **Uncertainty (predicted cf. observed)**

To assess uncertainty the open water and mid-winter habitat modeling results for habitat suitability were compared visually to the presence of walrus as demonstrated by available seasonal survey data.

### **Shipping**

In Hudson Strait and Foxe Basin, the primary industrial activities that could have an impact on walrus are related to shipping and the construction of ports and other coastal infrastructure (see Shipping and Related Activities section). The spatial analysis that follows is based on vessel



presence in the recent past (2010) and projected vessel presence in the near future (2020).<sup>5</sup> These data are compared with the habitat suitability to identify areas where shipping related activities might be most likely to impact walrus. The putative pathways of these impacts and potential interactions with walrus are described in the section above on Effects of Pathways.

## **METHODS**

### **STUDY AREA**

The study area for this assessment is Hudson Strait, Foxe Basin, and northwest Hudson Bay. A bounding box from 50° to 75° North latitude and 60° to 100° West longitude was first created for initial clipping of environmental and industrial development data. A second polygon was created to focus the assessment on the study area (i.e., to remove areas in Davis Strait, Baffin Bay, etc., from the assessment) and ensure that weightings of relative habitat suitability and industrial threat levels are focused on the study area only (Figure 6).

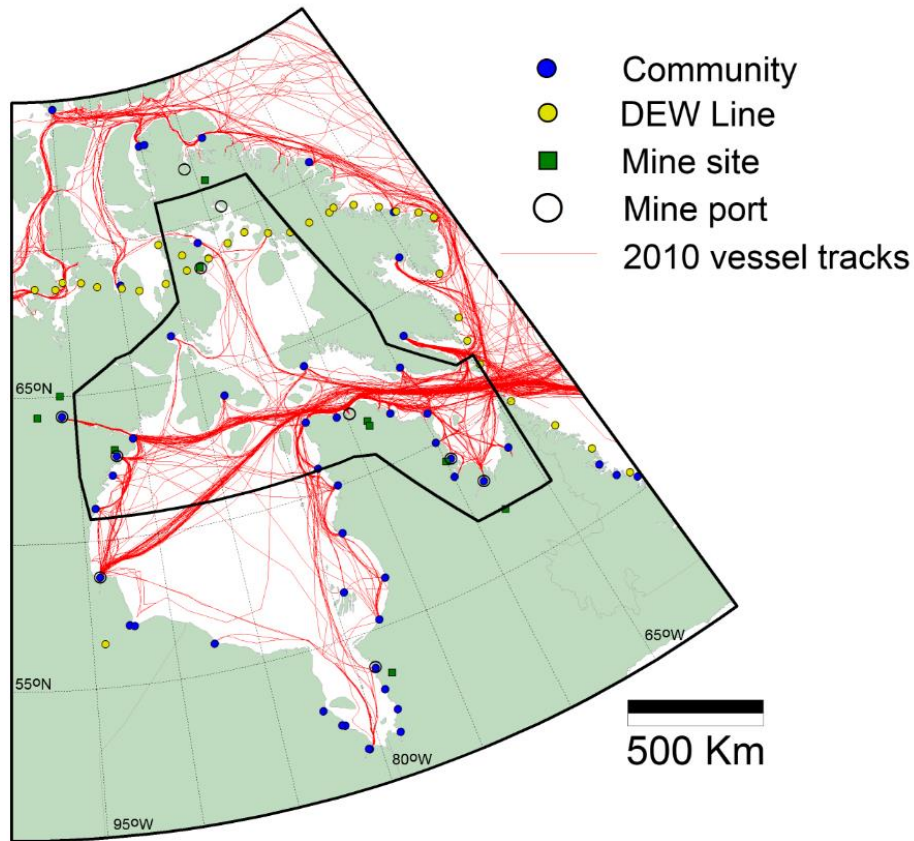
### **HABITAT SUITABILITY ANALYSES**

All habitat suitability modelling was conducted using 0.25 by 0.25 degree grid cells (using a vector grid or fishnet). This cell size was chosen because it matches the resolution of the bathymetric data used (Boyer and Mishonov 2013) and provides a sufficient resolution for habitat suitability mapping given our current knowledge of walrus distribution and habitat use (at the Arctic Circle, a 0.25 by 0.25 degree grid is 27.9 km latitude by 11.4 km longitude). All polygon data layers were vector-based, and values were assigned to each grid cell based on the location of the cell centre. Spatial analyses were conducted using ArcView 3.3 (ESRI Inc., Redlands, CA) and various extensions and scripts.

All GIS data are maintained and stored using geographic coordinates (i.e., latitude-longitude based, or unprojected), but all analyses were conducted and mapped with the data projected using a Lambert Conformal Conic projection and the parameters used by the Canadian Ice Service (Clarke 1866 spheroid, NAD27 datum, central meridian 100° W, latitude of origin 40° N, standard parallels 49°N and 77°N).

Habitat suitability models were created for two seasons - sea ice minimum ("summer") and sea ice maximum ("winter"), to represent the environmental extremes that occur in walrus habitats. The summer model has four layers (depth, ice concentration, distance to coast, and haulouts), and the winter model uses three layers (depth, ice concentration, and distance to the landfast ice edge (i.e., excluding haulouts)).

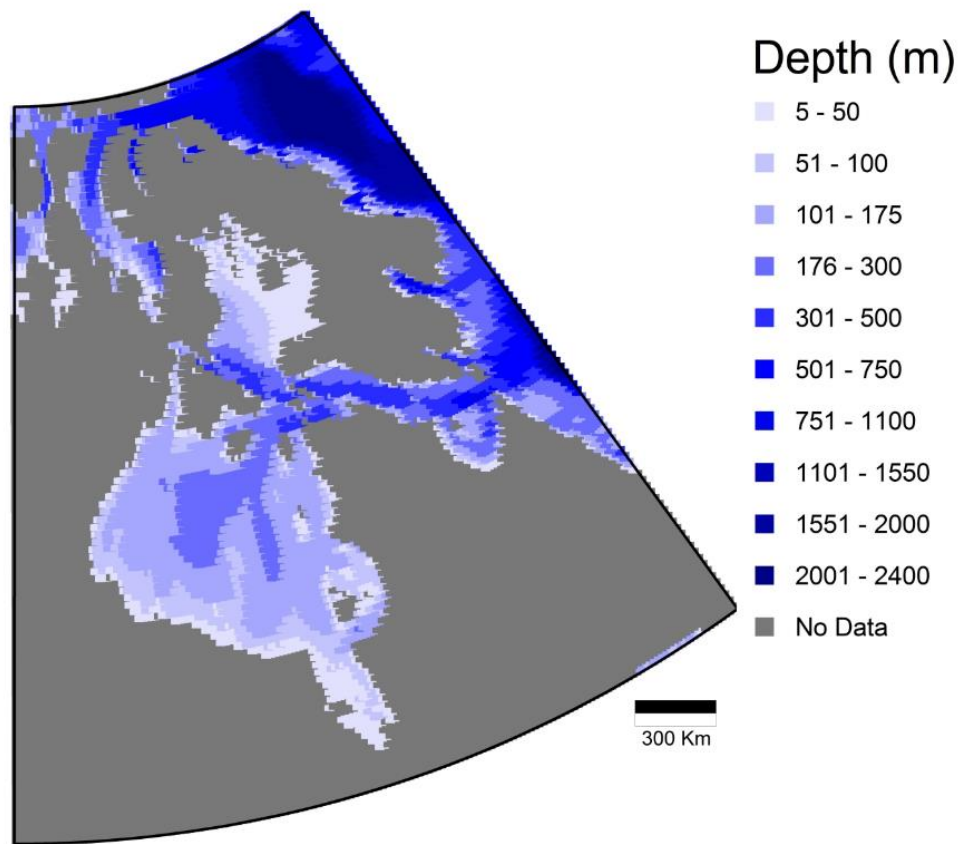
<sup>5</sup> As understood in 2014. See Preface.



*Figure 6. Map of eastern Canadian Arctic showing study area boundary, 2010 shipping routes (vessel tracks) and port locations (communities, mines, DEW).*

## Depth

Bathymetry data were compiled from a land-sea mask file available from the World Ocean Atlas (Boyer and Mishonov 2013) (Figure 7). These files are produced at both one degree and quarter-degree resolution, for the entire globe. Bathymetric data are provided in a number of standard depth bins, with variable resolution with depth. The files provide the standard depth level number at which the bottom of the ocean is first encountered. Land cells have a value of 1, corresponding to the surface (depth = 0 m), and other cells have a value from 2 to 137, corresponding to depths of 5 m to 9000 m. Levels 2-21 correspond to depths from 5 to 100 m in 5-m increments, levels 22-37 correspond to depths from 125 to 500 m in 25-m increments, levels 38-67 correspond to depths of 550 m to 2000 m in 50-m increments, and levels 68-137 correspond to depths of 2100 m to 9000 m in 100-m increments.

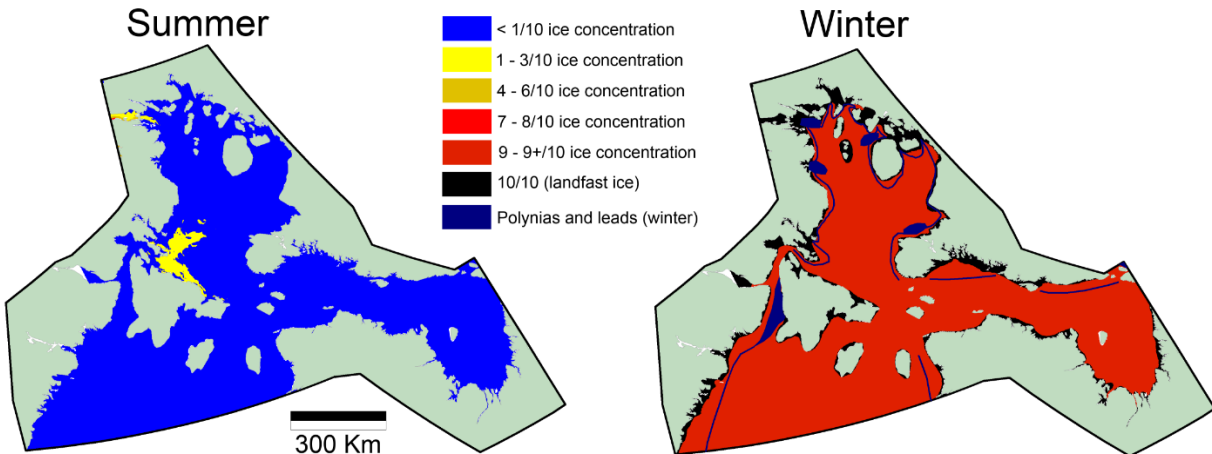


*Figure 7. Bathymetry data from the World Ocean Atlas at a 0.25 by 0.25 degree resolution.*

The global quarter-degree land-sea mask was saved as an ASCII text file, cropped to the northern area of interest (to facilitate data import), and then imported into ArcView 3.3 and converted to a point shapefile. Point data were then mapped to the vector grid (fishnet). Values for each point were assigned based on the bin value (depth class) and scored on the basis of habitat suitability as discussed in the previous section (Appendix 1, Table A1- 1). Shallow depth (<10 m) includes the 5 m depth bin, Optimal (10-<50 m) includes the 10 m to 45 m depth bins, Sub-optimal (50-<100) the 50 m to 95 m depth bins, 4) Marginal (100-<250) the 100 m to 225 m depth bins, and 5) Deep ( $\geq 250$  m) the 250 m and deeper bins. As depth values remain constant, this layer was used for both seasonal habitat suitability models.

### **Seasonal ice cover**

Two habitat suitability layers were created, one for each of the two seasonal extremes. In addition, two data sources were combined for the winter ice cover layer (one was sufficient for the summer layer). The primary data used are from the Canadian Ice Service (CIS). Median ice concentration data for 1981-2010 (30-year climatology) (Canadian Ice Service 2011) are available via FTP from the CIS as ESRI polygon shapefiles. The September 10 shapefile was used for annual sea ice minimum, and the March 12 shapefile was used for annual sea ice maximum (Figure 8).



*Figure 8. Seasonal extremes in ice cover during minimum ice conditions (left panel, “summer”) and maximum ice conditions (right panel, “winter”). Polynias and persistent flaw leads also shown for winter.*

The CIS regional ice atlas data identifies areas with low winter ice concentrations or where ice break-up occurs earlier/faster, but does not specifically identify polynias and persistent flaw leads. Data on polynias and flaw leads are from Mallory and Fontaine (2004) and were provided by Environment and Climate Change Canada staff as polygon shapefiles. These polygons were used in place of the CIS concentration data when assigning habitat suitability scores for the relevant grid cells (Figure 8). Each 0.25 by 0.25 degree grid cell was assigned an ice cover value and scored on the basis of habitat suitability as discussed in the previous section (Appendix 1, Table A1- 2).

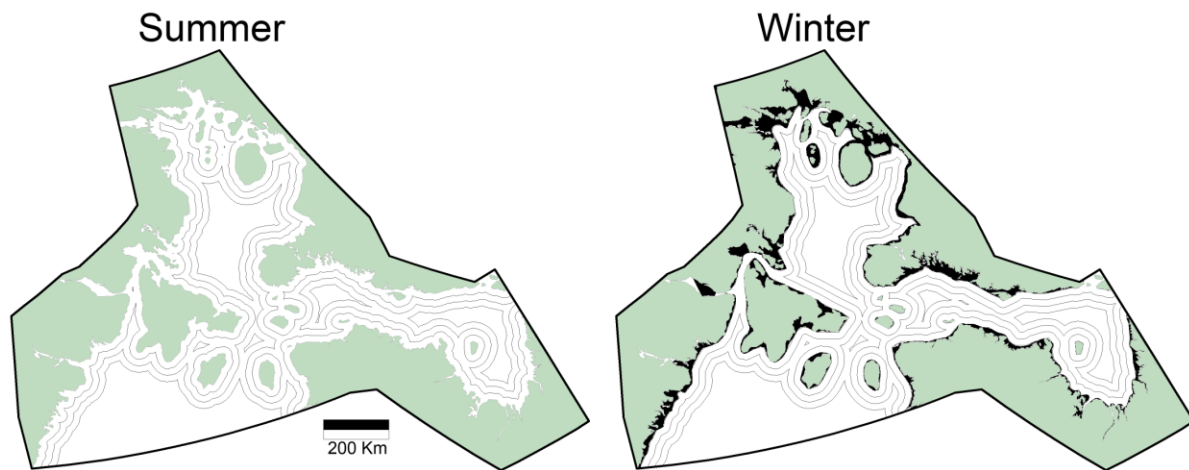
### **Distance to coast or floe edge (km)**

Habitat suitability layers were created for each of the two seasonal extremes. For the summer layer, all coastlines (including islands) (ESRI Canada shapefile) were buffered at 20 km, 40 km, and 60 km using ArcView's Geoprocessing Wizard. Similar buffers were created using the landfast ice edge for the winter ice condition layer (Figure 9). Cells were scored on the basis of their habitat suitability as discussed in the previous section (Appendix 1, Table A1- 3).

### **Haulouts**

This layer was used for summer habitat modeling only. The database of walrus haulout locations was built from a variety of sources. The primary data source was a Garmin Mapsource (.gdp) file of waypoint locations of walrus haulouts in Nunavut created by DFO and provided by J. Blair Dunn (29 November 2012). The Garmin file contained waypoints of individual walrus haulout locations, primarily for the areas that DFO had surveyed in (including Foxe Basin but not Hudson Strait or Bay). This was converted to an ESRI point shapefile using the DNRGarmin software and the database exported for updating with additional data. Other haulout sites were added to the database, using a variety of sources and including both science-based and Inuit

observations. Sources that were relied on extensively included a comprehensive assessment of the status of Atlantic walrus populations (Born et al. 1995) and the Inuit Land Use and



*Figure 9. Buffers for distance to coast (summer, left panel) or coast/floe edge (winter, right panel). Black area on winter panel is landfast ice.*

Occupancy Study (Freeman 1976). The level of information available in the Inuit land use study varied by chapter and author. For example, Brice-Bennett (1976) described areas where Repulse Bay Inuit hunted walrus but did not specifically mention haulouts (but see Brody 1976b). In some cases, Inuit were noted to hunt walruses “among the islands” (e.g., east of Bibby Island in the Kivalliq region, Welland 1976), but there was no specific mention of whether or not these were haulout sites.

Foxe Basin haulouts were mostly from the GPS database, updated with information from Stewart et al. (2013) and R.E.A. Stewart (unpublished data). Important sources for the northwestern Hudson Bay (e.g., Southampton Island, Coats Island, Bencas Island) area included Loughrey (1959), FRBC (1962), Freeman (1962), Orr and Rebizant (1987), and COSEWIC (2006) (in addition to the two main sources listed above)<sup>6</sup>. Haulout sites in the southern Baffin Island were compiled from the Brody (1976b) and Born et al. (1995) maps in addition to those reported/mapped in Loughrey (1959), Orr and Rebizant (1987), COSEWIC (2006), and Stewart and Howland (2009). Supplementary sources for haulouts in southern Hudson Strait included many of those noted above, in addition to Brooke and Kemp (1986) and Reeves (1995). Many of these haulouts were classed as either “inactive” or “uncertain” status. The primary haulout areas for walruses in Hudson Strait are found on Salisbury and Nottingham Islands, and locations were mapped from Born et al. (1995), Reeves (1995), and Stewart and Howland (2009) (also see Russell 1966).

Locations have variable accuracy, depending on the quality of information in the original sources, e.g., high-quality waypoints from field-based research versus small points on a map covering a large geographic area, where locations can only be approximated. The size (number

<sup>6</sup> As understood in 2014. See Preface.

of walrus supported) and status of each haulout was determined based on available literature and expert opinion (Figure 10). A number of walrus haulouts were reported to have been abandoned in the early to mid-1900s. These were classed as inactive unless there were indications that animals may be re-colonizing, in which case they were ranked as uncertain status. If no information on recent numbers or use could be found but the haulout was not reported as inactive or abandoned, then it was classed as uncertain status and given the lowest size score.

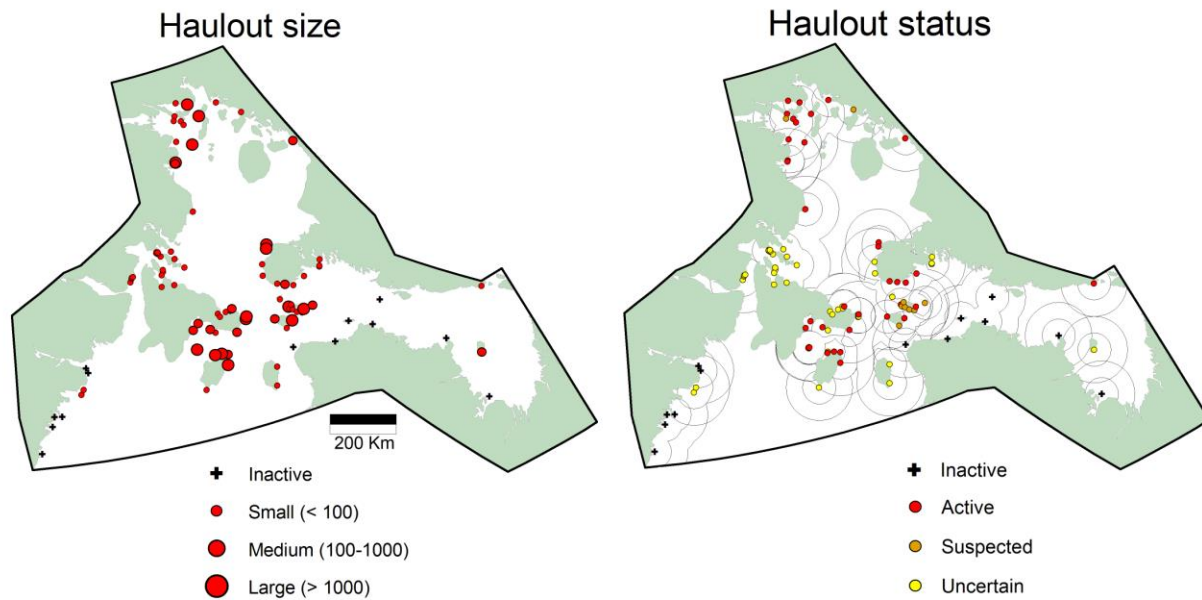


Figure 10. Locations, size, and status of walrus haulouts in the study area, with buffers at 50 km and 100 km.

Each haulout site was buffered at 50 km and 100 km using the Geoprocessing Wizard. Buffers were created for each walrus haulout (score) category separately, and values were assigned to the analyses grid starting with the largest haulouts (and highest scores) first, to ensure that grid cells that occurred within multiple buffer areas were always given the highest relevant score. Cells were scored on the basis of their habitat suitability as discussed in the previous section (Appendix 1, Table A1- 4). Some small offshore areas were excluded from all buffers, ranked as Very low quality, and assigned a value of 0.25.

### Final habitat suitability scores

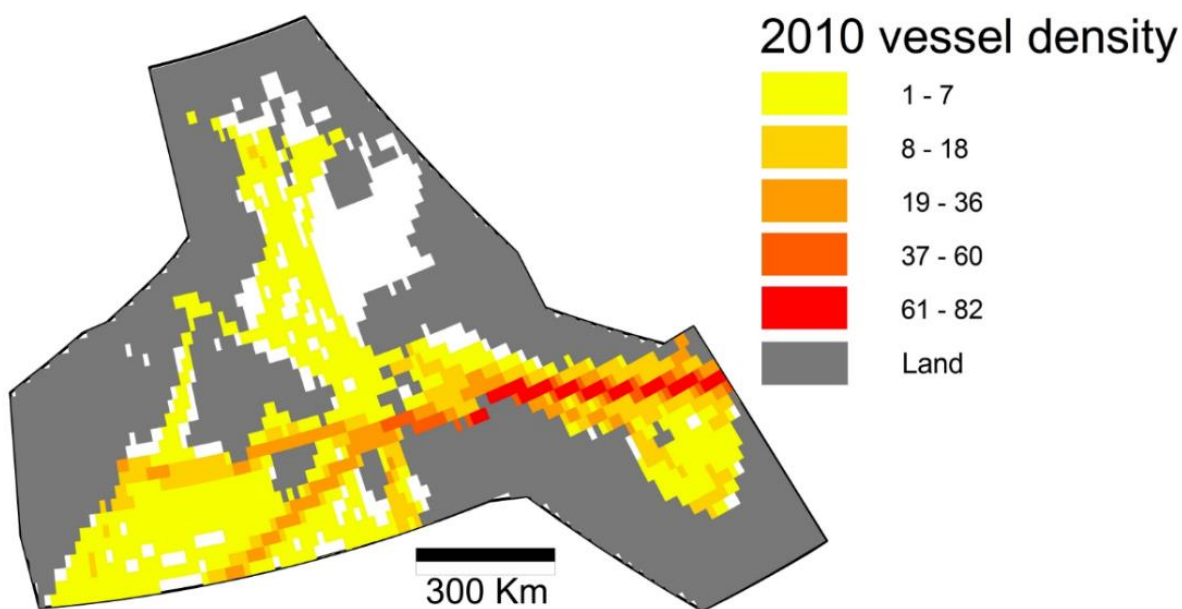
Final summer and winter habitat suitability scores were calculated as the average of the variables used ( $n = 4$  for summer,  $n = 3$  for winter). The range of cell scores for the summer and winter habitat assessment were normalized to a 0-1 scale for mapping.



## INDUSTRIAL DEVELOPMENT AND POTENTIAL THREATS

Data on established and proposed Arctic shipping routes were available from a variety of sources. For vessel routes (Figure 2) and shipping intensity, we used a spatial database of 2010 vessel traffic created by Transport Canada (Transport Canada 2011) and available as online supplementary material in Gaston et al. (2013). The data can be downloaded as a Google Earth (.kmz) file, which was then converted to a format that could be imported into ArcView (as a point file, which were then converted to polylines (one per vessel transit)).

The vessel database includes eight “VesselType” categories for 16 “Gen\_Vessel” categories. The “VesselType” classes were reduced to five general vessel type descriptions, so that “bulk carriers”, “container ships”, and “general cargo ships” were all classed as “cargo”. The database provides information on the entry and exit dates into and out of the NORDREG zone, but does not provide the actual date of each point location. Vessel density was calculated by mapping the individual track lines to the quarter-degree vector grid (Figure 11).



*Figure 11. Vessel density in 2010, measured as the total number of vessels that transited through a 0.25 by 0.25 degree grid cell.*

Vessels that trade into the Hudson Bay region make various ports of call, including communities (cargo, fuel, cruise ships), mine sites and associated ports (cargo, fuel, bulk mineral exports), and Distant Early Warning (DEW) Sites (cargo, fuel, material export) as part of clean-up efforts. The locations of these ports of call were compiled from various sources (internet, Government statistics, mining company materials, etc.) and imported to the GIS as a point shapefile. For each port site, the total number of vessels visiting in 2010 was determined using the 2010 vessel tracks

## **EXPECTED FUTURE (2020) SHIPPING**

Expected future shipping routes for industrial development projects were compiled from a map presented by Gavrilchuk and Lesage (2014) and other project-specific sources. Many mining projects (e.g., Meliadine, Kiggavik) will be using market vessels that will follow existing shipping routes to communities. Expected<sup>7</sup> 2020 shipping volumes were estimated by adding the expected shipping levels (fuel and cargo deliveries, ore carriers) for the different projects to the 2010 shipping levels. This was done for both vessel routes and intensity of port usage.

## **OVERLAP BETWEEN WALRUS HABITAT AND INDUSTRIAL ACTIVITY**

We examined the degree of spatial overlap between industrial activity (primarily vessel traffic) and important walrus habitats (defined as cells with normalized scores of 0.61-1.00) for both existing (2010) and projected (2020). Important habitat cells with vessel traffic (at least one vessel) were identified for both years, using winter and summer (and overlap, see Results) habitat cells. The areas (cells) with the highest vessel traffic in both years were quantified using the 75th and 95th percentiles of vessel density and mapped to identify overlap with important walrus habitats, to allow comparison of current and future distribution of potential risk and identify areas of management concern. Shipping intensity was again compared to habitat suitability models for both seasons. The level of shipping between summer and winter is presently quite different although vessel traffic is expected to increase during the winter.

## **RESULTS**

### **HABITAT SUITABILITY RANKINGS**

The study area included 3,713 0.25 x 0.25 degree grid cells, including 2,058 cells (i.e., 55% of the study area) classed as land (based on the original bathymetric data from the World Ocean Atlas).

For the summer model, there is a maximum potential cumulative score (highest rank in all four categories) of 3.75 per cell, or average across the four variables of 0.94. The maximum possible value does not sum to 4.00 (i.e., 1.00 per variable) because the maximum summer sea ice score is 0.75 (leads and polynias are ranked as 1.00 but occur for the winter layer only). The minimum potential cumulative score (lowest rank in all four categories) is 1.5, or an average score of 0.38. In the winter model, the maximum potential cumulative score for the three variables (excluding haulouts) is 3.00, or average score of 1.00, and the minimum potential cumulative score is 0.75, or average score of 0.25.

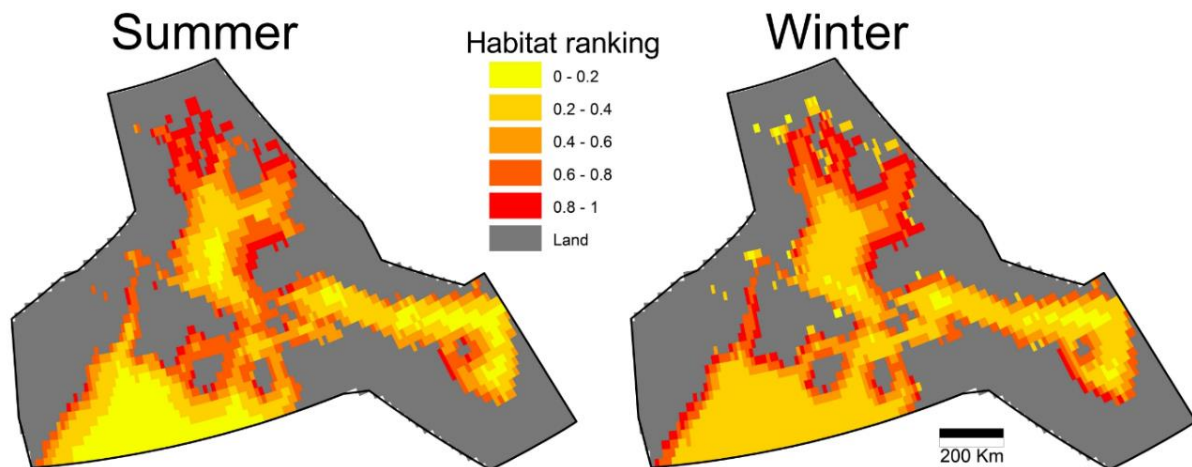
For the summer layer, both the minimum and maximum potential scores occurred in the final layer and defined the overall spread of values (0.38-0.94), suggesting that the variable combination is sufficient for some preliminary relative comparisons of walrus habitat value within the study area (with sea ice as a possible exception, see below). For winter habitat, the maximum potential average score (1.00) did occur, but the minimum score for all non-land cells

<sup>7</sup> As understood in 2014. See Preface.



was 0.33, and no cells scored the theoretical minimum score of 0.25. Six cells scored 0.33, and all received the lowest scores (0.25) for ice conditions and distance to coast (areas of landfast ice), but were in marginal depth areas (100 m to 225 m depth bins, score 0.50) and not deeper water that would score the minimum. There are deep-water areas, particularly in Hudson Strait, but they all occur within 60 km of the coast/floe edge or within a polynia/flaw lead environment. As such, it is not possible for the lowest theoretical score to be achieved for this landscape configuration, and the winter habitat suitability index therefore does span the entire range of possible values of model results.

The habitat suitability scores were normalized on a 0-1 scale and mapped using five equal intervals (Figure 12). The distribution of cell values (by defined habitat suitability class) was generally similar for both summer and winter. In both seasons, high quality and very high quality comprised ca. 32% of the non-land cells.

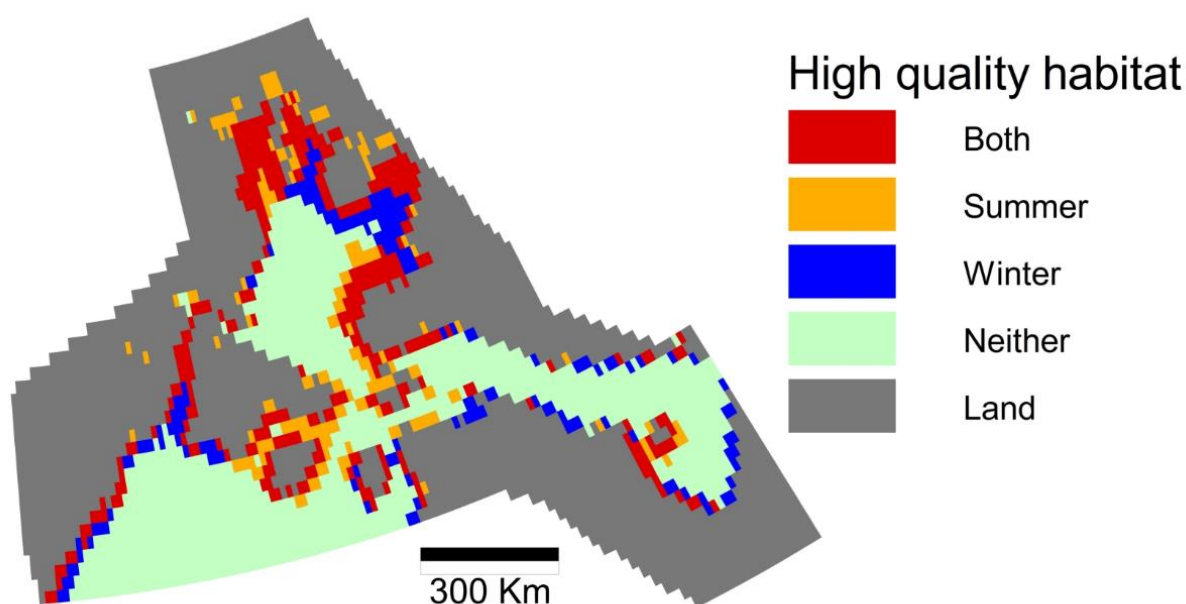


*Figure 12. Habitat suitability for walrus during the seasons of minimum (left panel) and maximum (right panel) sea ice cover. Values are normalized to a 0-1 scale and divided into five equal intervals.*

Winter and summer habitat scores were highly correlated ( $r = 0.738$ ,  $n = 1,655$  (non-land cells),  $p < 0.001$ ), indicating similarities in the seasonal habitat rankings. In the summer model, 527 cells scored as high quality or very high quality (i.e., normalized score  $> 0.60$ ), and most of these (68%) also scored high or very high for winter (the winter model had a similar number of high and very high quality cells - 525). Similarly, of the 676 low or very low quality cells in summer, 665 of these were also low or very low quality in winter. The overlap in highest quality habitat (measured as High and Very high classes, see Appendix 1, Table A1- 5) was most pronounced in northern Foxe Basin, the area around Southampton, Coats, Salisbury and Nottingham islands, and in Roes Welcome Sound (Figure 13). A number of grid cells around the walrus haulouts in western Hudson Strait/Southampton Island were scored as the highest quality habitat in summer only, along with areas of Foxe Basin that are covered with extensive

landfast ice in winter. A number of areas that get scored as highest quality habitat in winter only are found in regions with polynias or recurrent leads (e.g., Hudson Strait, Foxe Basin).

This similarity is in part due to the lack of resolution on sea ice types in the CIS data and subsequent similarity in variable scores across large areas (e.g., in the summer model, all non-land cells scored 0.75). We originally envisioned variable scores for lighter and heavier pack ice, but the winter CIS chart did not indicate anything other than heavy pack ice in the region in the March median concentration chart. It is known however that areas of lighter pack ice occur in the area at this time, and are used by walrus (e.g., Elliott et al. 2013). A different source of sea ice information is likely needed to improve modeling during the season of maximum ice cover.



*Figure 13. Distribution of high and very high quality (normalized scores of 0.60-1.00) walrus habitat in the study area, showing areas (grid cells) that were scored highest in both summer and winter, in summer only, and in winter only.*

## **FUTURE INDUSTRIAL ACTIVITY**

Vessel density (annual number of vessels per grid cell) from 2010 (data from Gaston et al. 2013) was updated to reflect potential increases in vessel traffic by 2020 using 2014 Project statuses and plans (Figure 14) based on the assumed traffic required for each of the mines in development (Table 1). The 2020 traffic was measured as the number of ore carriers (if applicable), tankers, and cargo vessels expected annually at each mine (assuming the median number when a range was given by the various proponents). The Meadowbank mine was not included in the 2020 traffic as its lifespan should be over by then, and no traffic was added for Raglan as it is currently an active mine and is captured in the 2010 traffic (although production, and subsequent shipping could increase in the future).

Both vessel density maps (Figure 15, Figure 16) were colour-coded using the same scale, to show the significant increase in vessel traffic expected, especially in Hudson Strait and central Foxe Basin. The 2020 traffic map may be conservative as we used the median expected number of ore carriers for mining projects and there is no accounting for increasing community needs for fuel tankers and cargo supply shipments as human populations increase in Nunavut hamlets.

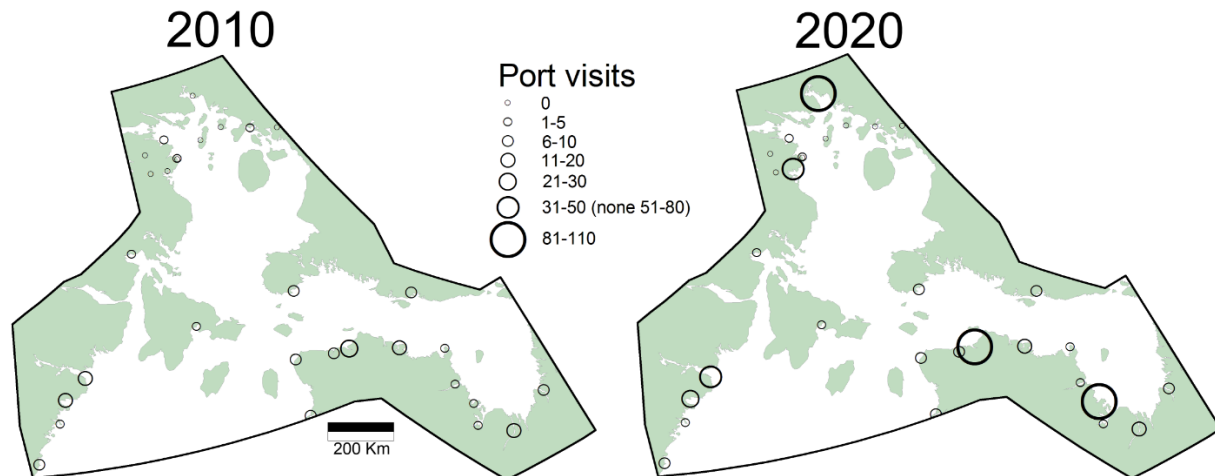


Figure 14. Comparison of observed port site usage (number of vessels visiting each port) in 2010 (left panel) with expected (minimum) port visits in 2020 (right panel) based on proposed industrial development projects (as of 2014).

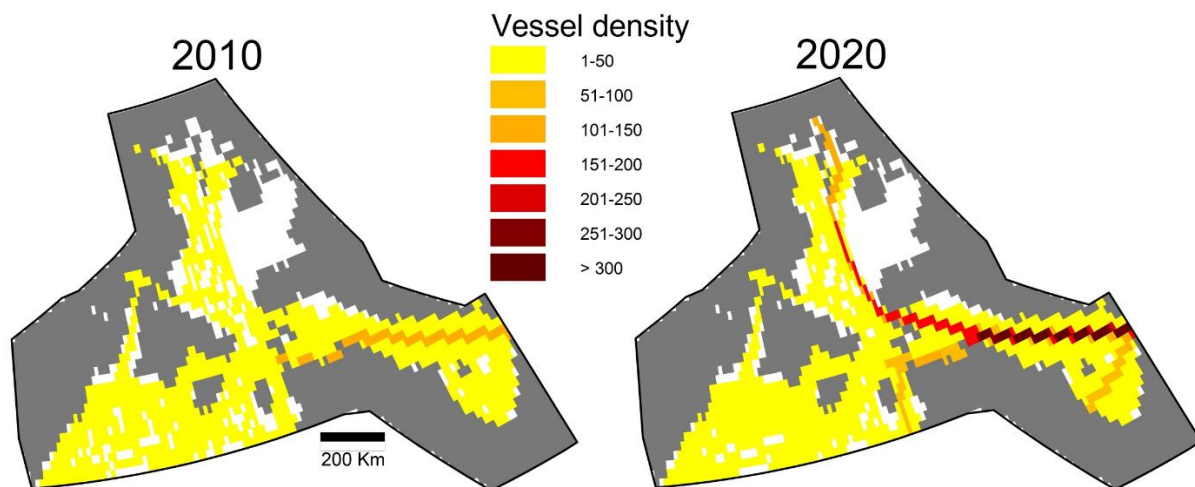
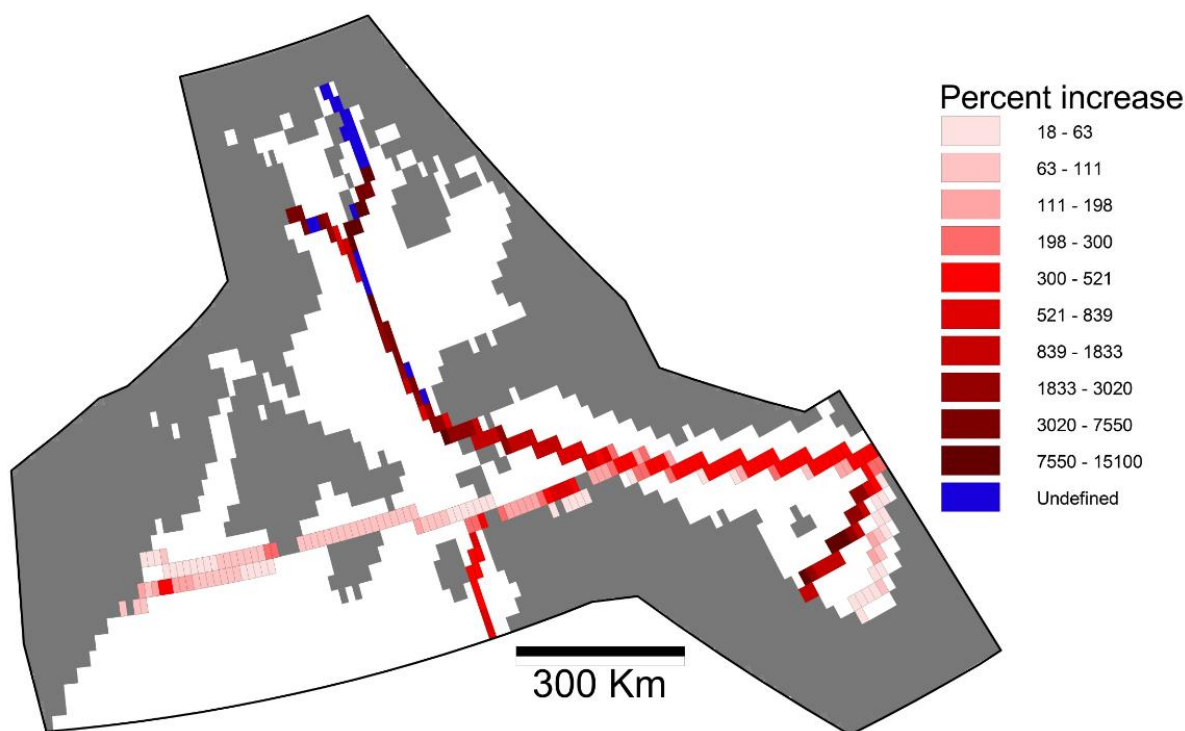


Figure 15. Comparison of observed vessel density (number of vessels transiting each 0.25 by 0.25 grid cell) in 2010 (left panel) with expected (minimum) vessel density in 2020 (right panel) based on proposed industrial development projects (as of 2014).

## OVERLAP BETWEEN WALRUS HABITAT AND INDUSTRIAL ACTIVITY

We examined the degree of spatial overlap between industrial activity (primarily vessel traffic) and important walrus habitats. In 2010, 384 of the high-quality habitat cells contained vessel traffic (defined as being transited by at least 1 vessel), which was similar to the 402 high quality habitat cells in 2020 (Figure 17). Overall, the pattern of total vessel distribution is similar for

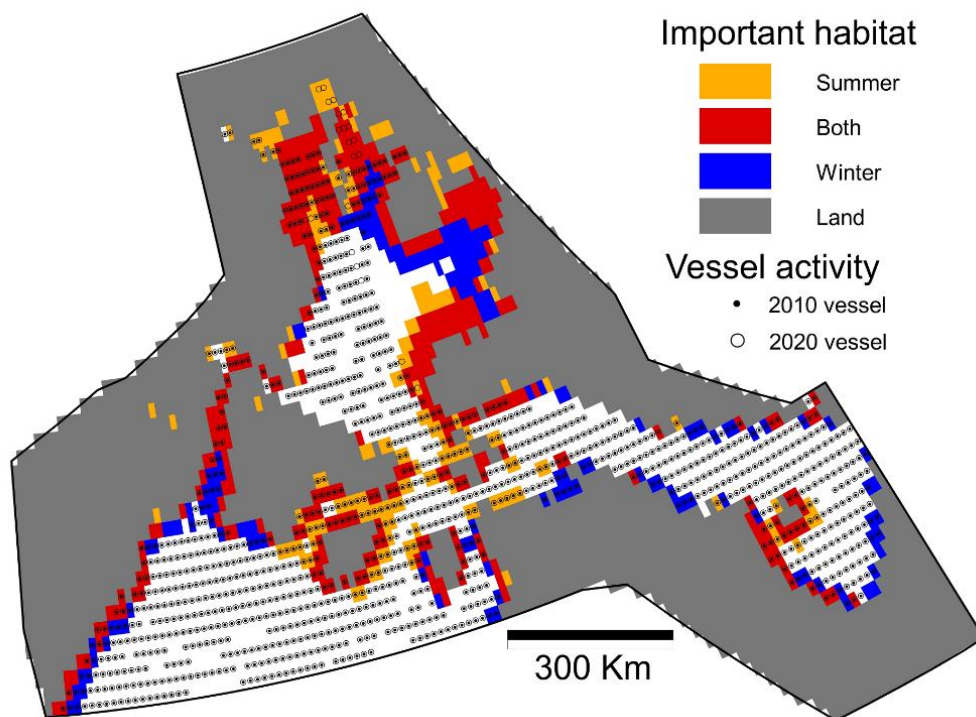


*Figure 16. Projected changes in shipping intensity between 2010 and 2020, measured as the percent increase in vessel density in each 0.25 by 0.25 degree grid cell. Cells mapped as "undefined" (in blue), including the final approach to Steensby Inlet in northern Foxe Basin, do not show a percent increase as there was no vessel traffic in these cells in 2010, but vessel traffic will increase substantially. This comparison does not account for increasing vessel sizes, so the percentage increase on a DWT basis would be greater.*

2010 and 2020, with the exception of Foxe Basin, where vessel traffic is anticipated to occur in new areas with iron ore extraction activities. The 2010 cells included 160 cells (ca. 42%) that were classed as high-quality habitat in both winter and summer, 84 cells that were classed as high-quality summer habitat, and 140 cells that were classed as high-quality winter habitat (but, as discussed below, very few current transits occur in winter). The 2020 cells included 201 (50%) cells that were classed as high-quality habitat in both winter and summer, 109 cells that were classed as high-quality summer habitat, and 92 cells that were classed as high-quality winter habitat. The results suggest a decrease in vessel activity in important winter habitats, but this is not the case as the number of winter transits will increase in the near future (i.e., nearly all of the areas that are identified in the 2010 dataset are not currently transited in winter, whereas many of those identified in 2020 will experience winter vessel activity). However



defining “vessel traffic” as any cell with at least one passage does not address the intensity of vessel activity in a cell (see below).



*Figure 17. Distribution of vessel traffic in 2010 (black circles) and 2020 (open circles) overlaid on important walrus habitats within the study area. Vessel distribution measured as all cells with at least one vessel transit.*

Cells with the highest vessel traffic in both years were quantified using the 75th and 95th percentiles of vessel density ( $n = 1,655$  non-land cells). The 75th percentile of vessel density was 7 vessels in 2010 and 11 vessels in 2020, and the 95th percentile of vessel density was 29 vessels in 2010 and 157 in 2020, indicating a substantial increase in the intensity of vessel traffic for some areas. This increase in traffic is most pronounced in Foxe Basin, Southampton/Coats Island area, and south of Salisbury and Nottingham Islands (Figure 18, see 75th percentile distribution, left panel), and also in Hudson Strait (where all vessels that enter the study area must transit).

Finally, we compared changes in shipping intensity and overlap with walrus habitat, using average vessel density. The average vessel density (per cell) in 2010 was 7, which increased to an average of 25 for 2020 (average calculated including 0 values). We therefore determined which cells contained over 25 vessels in both 2010 and 2020 and mapped this distribution (Figure 19, over 25 vessels). Relatively few cells currently (2010) see 25 or more vessels per year, mostly limited to Hudson Strait and including many cells that were not modeled as high-quality walrus habitat. Exceptions include the area south of Nottingham and Salisbury islands, and the area north of Coats Island. In contrast, expected 2020 shipping levels result in

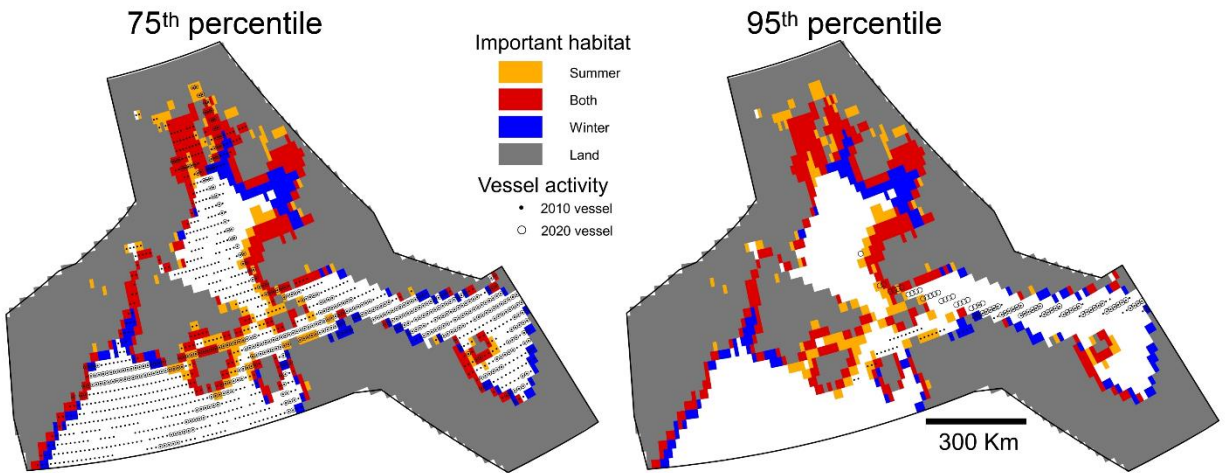


Figure 18. Distribution of highest intensity vessel traffic in 2010 (smaller black circles) and 2020 (larger open circles) overlaid on important walrus habitats within the study area. High intensity vessel distribution measured as all cells transited by at least as many vessels are the upper 75<sup>th</sup> (left panel) and 95<sup>th</sup> (right panel) percentiles in each year.

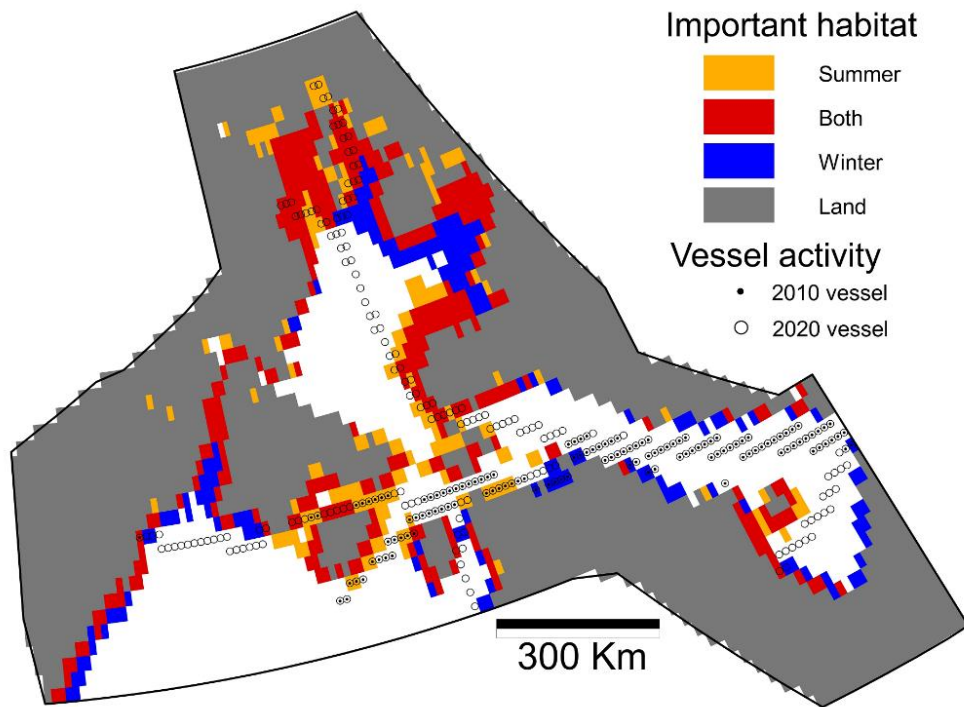


Figure 19. Distribution of highest intensity vessel traffic in 2010 (black circles) and 2020 (open circles) overlaid on important walrus habitats within the study area. High intensity vessel distribution measured as all cells transited by at least 25 vessels (the average number of vessel transits per cell in 2020).

numerous high-quality habitat cells being transited by 25 or more vessels, and this increase is most pronounced in northern Foxe Basin and the area directly west of the Foxe Peninsula.

While we identified walrus habitat for two separate seasons, we did not include a seasonal breakdown of shipping distribution. However, current shipping is almost exclusively conducted outside the winter season, and summer habitat is the more important focus. In 2010, 92 vessels entered Hudson Strait, and almost all (97%) of these transits occurred in either summer (July to September,  $n = 66$ ) or fall (October and November,  $n = 23$ ). Only three transits occurred in winter (December-March,  $n = 2$ ) and spring (April-June,  $n = 1$ ), and all were the *M. V. Arctic* trading into Deception Bay in central Hudson Strait. The level of winter shipping will increase significantly in the near future however, as both the Mary River (year-round) and Roche Bay (June-December) iron mines in Foxe Basin are proposing winter shipping with icebreaking vessels, winter shipping will continue at the Raglan mine, and similar activity will also occur at the Nunavik Nickel port, also in Deception Bay.

## SUMMARY

A GIS-based approach to cumulative impact assessment shows promise in that it identifies areas that are important to walrus and exposed to potential impacts from industrial activity. It also has heuristic value in identifying key information gaps.

The area of study was large, therefore the input data, analysis, and representation conducted were necessarily coarse. CIS ice data provide little resolution of sea ice types and spatial variation in pack ice concentration during the winter season. Finer-grained sea ice data should be explored for any future modeling exercises. Bathymetric data limited the model resolution to 0.25 by 0.25 degrees. Probably as a consequence of these coarse-grain data, habitat suitability in Hudson Strait was underestimated leading to an underestimate in potential impacts. Surveys in the area estimated approximately 5000-6000 walrus occupy an area in the middle (east/west) part of the north side of the strait (Elliot et al. 2013), but such occupancy was not predicted in our analysis. This is a serious shortcoming because the largest numbers were found on the proposed Mary River ship track (Elliot et al. 2013).

Finer-grain bathymetric data are available and could be used for future assessments, but more information on walrus abundance, distribution, and habitat use within the study area is required to justify more detailed modeling. In addition to Hudson Strait, winter surveys have found walrus in central Foxe Basin (LGL Limited and North/South Consultants Inc. 2011). Clearly more geographically and temporally comprehensive data are required.

Information on terrestrial haulouts requires continuous updating. Sources may differ in defining a site such that two places a couple of kilometers apart on one island will be classified as one haulout site or two sites, depending on author. Also, walruses may relocate a few kilometers along the shore or across the fiord between two sites from year to year. Some of this uncertainty was resolved by using relatively large cell sizes around each site, but better resolution of locations would be beneficial. Determining 'importance' is also problematic because the maximum counts obtained at any haulout site can vary greatly between and within years (Gaston and Ouellet 1997; Stewart et al. 2014b, c). It takes several consecutive years of repeated observations to suggest that a site is inactive or abandoned, and just as many to determine that it is used by >1000 animals instead of a few hundred.

Aside from the Elliot et al. (2013) survey, which took place after the model had been developed, the model has not been tested against existing information (e.g., survey results, tagging studies). Given the lack of region-specific information on walrus, there are few data with which to conduct extensive validation. The high-quality habitat agreed well with known walrus hotspots in western Hudson Strait, between Coats and Southampton islands, and in northern Foxe Basin.

Similarly, there are shortcomings in the ‘impact’ data as well. The database of vessel tracks from Gaston et al. (2013) includes seasonal information but not dates for each location along the route. Such data (e.g., daily location points with associated dates) are available as part of NORDREG, and additional analyses should request these from the Canadian Coast Guard for a more detailed assessment of shipping impacts on walrus would require more detailed data on the temporal distribution of vessels. The estimates of future traffic should be updated as new information (new project proposals, adjustments to proposed mining activities, community shipping levels) becomes available, and over time, the current years data could be used to assess the accuracy of predictions (i.e., in 2021, the 2020 “real” data will be available to compare against the model predictions reported here).

There are also knowledge gaps in how walrus and their habitat interact with shipping activities. A better understanding of the pathways of effects is required before it will be productive to attempt to model the effects individually or combined. Among the pathways identified, the most important are probably disturbances (olfactory, auditory, visual) and disruption of ice habitats. These are the pathways related to shipping that are most likely to affect walruses over a large area over time. Their effects may differ with the age and sex of the walruses, the type of habitat, and the presence and quality of the ice cover. It is important to know at what distance(s) animals react, how they react, degree of recovery or habituation (if any), and the implications of walrus habitat occupancy, fitness, and mortality. Other pathways such as contaminants (e.g., oil spills) and non-indigenous species are more difficult to study and less predictable in terms of occurrence or impact, but since their effects could cause “nasty surprises”, it behooves us to learn more before they do. Without these sorts of information, impact prediction related to walrus will continue to be uncertain and the risks from major shipping projects will remain.

Finally, and despite the foregoing identified information gaps, the modelling attempted did identify areas of concern regarding increasing levels of industrial activity. These areas are northern Foxe Basin and the western mouth of Hudson Strait, both of which contain a large proportion of high-quality walrus habitat. Shipping activity is already pronounced in western Hudson Strait, and will increase substantially in Foxe Basin with proposed mining projects.

## **ACKNOWLEDGEMENTS**

Funding for this study was provided under the Strategic Program for Ecosystem-Based Research and Advice (SPERA) program and overseen by Robert Young and Pierre Richard of DFO Central and Arctic (DFO CA) in Winnipeg, MB. Blair Dunn of DFO CA provided haulout data and Joclyn Paulic of DFO CA who helped to see it through to publication. Their efforts have enabled and improved this work and we thank them.



## REFERENCES

- Adams, J.K., Ellis, S.M., Chan, F.T., Bronnenhuber, J.E., Simard, N., McKenzie, C.H, Martin, J.L., and Bailey, S.A. 2013. [Relative risk assessment for ship-mediated introductions of aquatic nonindigenous species to the Atlantic Region of Canada](#). DFO Can. Sci. Advis. Sec. Res. Doc. 2012/116. v + 403 p.
- Advanced Explorations Inc. 2012. [News Release: Advanced Explorations Inc. announces filing of feasibility report for Roche Bay Iron Project](#). Toronto, Ontario (Marketwired – Sept, 24, 2012). 4 p.
- Advanced Explorations Inc. 2014. [Advanced Explorations Inc. and Parkson Star Ltd. \(HK\) agree to form strategic joint venture to advance the Roche Bay Iron Ore Project](#). Toronto, Ontario (Marketwired – May 14 2014)
- Agnico Eagle. 2013. Draft detailed environmental assessment report (DDEAR) – Meliadine Gold Project, Nunavut. Volume 2. Project description. March 2013. xxxviii + 283 p.
- Agnico Eagle. 2014. Final environmental impact statement (FEIS) – Meliadine Gold Project, Nunavut. April 2014. 11 vols.
- AMAP. 1998. Chapter 6: Persistent organic pollutants. *In* AMAP Assessment Report: Arctic pollution issues. Edited by B.G.E. de March, C.A. de Wit and D.C.G. Muir. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. pp. 183–371.
- Anders, G. 1966. Northern Foxe Basin, an area economic survey, 1965. Canada, Department of Northern Affairs and National Resources, Area Economic Survey Report 65–2: iv + 139 p.
- Anderson, L.E., and Garlich-Miller, J. 1994. [Economic analysis of the 1992 and 1993 summer walrus hunts in northern Foxe Basin, Northwest Territories](#). Can. Tech. Rep. Fish. Aquat. Sci. 2011: iv + 20 p.
- Aqatsiaq, V. 1996. Interview IE376. Archives of the Inullariit Society, Igloodik Research Centre, Igloodik, Nunavut.
- AREVA (AREVA Resources Canada Inc.). 2011. Kiggavik Project environmental impact statement, Tier 1, Vol. 1, Main Document. 20 December 2011. vi + 159 p.
- AREVA (AREVA Resources Canada Inc.). 2013a. Kiggavik Draft EIS information requests. Responses to Environment Canada. January 31, 2013. 101 p
- AREVA (AREVA Resources Canada Inc.). 2013b. Kiggavik Project. Responses to technical comments. Kiggavik Draft Environmental Impact Statement, Appendices 1–10, 15 May 2013. 753 p.
- Beaubier, P.H. 1970. The hunting pattern of the Igluligmiut: with emphasis on the marine environment. Montreal, Québec. Thesis (MA) McGill University, Montréal, QC. ix + 250 p.
- Bilodeau, M.L., Buchanan, M.J., Buro, Y.J., Cauchon, C.H., Gagnon, D.H., Gaudreault, R., Houde, D., Ibrango, S., and Rivard, S. 2013. [NI 43-101 Technical report. Preliminary economic assessment of the Duncan Lake iron property James Bay, Quebec – Canada](#). NTS Sheets 33F05 and 33F12. 2011-031: vi + 227 p + Appendices.

- BIMC (Baffinland Iron Mines Corporation). 2012. Mary River Project, Final Environmental Impact Statement. 10 volumes. [Nunavut Environmental Impact Review Board (NIRB) File No. 08MN053]
- BIMC (Baffinland Iron Mines Corporation). 2013. Early Revenue Phase, Addendum to Final Environmental Impact Statement. 10 Volumes. [Nunavut Environmental Impact Review Board (NIRB) File No. 08MN053]
- Born, E.W. 1990. Distribution and abundance of Atlantic walrus (*Odobenus rosmarus rosmarus*) in Greenland. Prepared by Greenland Home Rule, Department for Wildlife Management, Sjøreleboerne 2, 1016 Copenhagen, Denmark for The International Workshop on Population Ecology and Management of Walruses. Seattle, WA. 65 p.
- Born, E.W. 2001. Reproduction in female Atlantic walruses (*Odobenus rosmarus rosmarus*) from northwestern Greenland. J. Zool. 255(2): 165–174.
- Born, E.W. 2003. Reproduction in male Atlantic walruses (*Odobenus rosmarus rosmarus*) from the North Water (N. Baffin Bay). Mar. Mamm. Sci. 19(4): 819–831.
- Born, E.W., and Acquarone, M. 2007. Estimation of walrus (*Odobenus rosmarus*) predation on bivalves in the Young Sound area (NE Greenland). Medd Grønland Biosci. 58:176–191.
- Born, E.W., and Gjertz, I. 1993. A link between walruses (*Odobenus rosmarus*) in northeast Greenland and Svalbard. Polar Record 29(171): 329.
- Born, E. W., Kraul, L., and Kristensen, T. 1981. Mercury, DDT and PCB in the Atlantic walrus (*Odobenus rosmarus rosmarus*) from the Thule District, North Greenland. Arctic 34(3): 255–260.
- Born, E.W., Heide-Jørgensen, M.P., and Davis, R. 1994. The Atlantic walrus (*Odobenus rosmarus rosmarus*) in West Greenland. Meddr. Grønland Biosci. 40: 1–33.
- Born, E.W., Gjertz, I., and Reeves, R.R. 1995. Population assessment of Atlantic walrus. Norsk Polarinst. Medd. 138: 1–100.
- Born, E.W., Rysgaard, S., Ehlme, G., Sejr, M., Acquarone, M., and Levermann, N. 2003. Underwater observations of foraging free-living Atlantic walruses (*Odobenus rosmarus rosmarus*) and estimates of their food consumption. Polar Biol. 26(5): 348–357.
- Born, E.W., Aquarone, M., Knutsen, L.Ø., and Toudal, L. 2005. Homing behavior in an Atlantic walrus (*Odobenus rosmarus rosmarus*). Aquat. Mamm. 31(1): 11–21.
- Boyer, T., and Mishonov, A. (eds.). 2013. World Ocean Atlas 2013 Product Documentation. Ocean Climate Laboratory, NODC/NESDIS/NOAA, Silver Spring, MD. 14 p.
- Brice-Bennett, C. 1976. Inuit land use in the east central Canadian arctic. In: Freeman, M.M.R. (ed.); Inuit land use and occupancy study, Vol. 1. Canada Department of Indian and Northern Affairs, OT. 63–81.
- Brody, H. 1976a. Inuit land use in northern Baffin Island and northern Foxe Basin. In: M.M.R. Freeman (ed.) Inuit land use and occupancy study, Vol. 1. Canada Department of Indian and Northern Affairs, OT. 153–172.

- Brody, H. 1976b. Land occupancy: Inuit perceptions. In Inuit land use and occupancy study, Vol. 1. Edited by M.M.R. Freeman; Canada Department of Indian and Northern Affairs, OT. 185–242.
- Brooke, L.F., and Kemp, W.B. 1986. Marine resources harvest study 1985. Prepared for the Department of Fisheries and Oceans. Makivik Corporation, Kuujuaq. 58 p. + Appendix.
- Bruemmer, F. 1977. The gregarious but contentious walrus. Nat. Hist. 86: 52–61.
- Calvert, W., and Stirling, I. 1990. Interactions between polar bears and overwintering walruses in the central Canadian High Arctic. Int. Conf. Bear Res. and Manage. 8: 351–356.
- Canadian Ice Service 2011. [Sea Ice Climatic Atlas for Northern Canadian Waters 1981–2010](#). Canadian Ice Service, Environment Canada, Ottawa, ON. 995 p.
- Carlton, J.T. 1992. Marine species introductions by ship's ballast water: an overview. *In* Introductions and transfers of marine species. Edited by M.R. DeVoe. South Carolina Sea Grant Consortium, Charleston, SC. pp. 23–26.
- CBC News North. 2008. [Ban on walrus tourism divides Igloolik](#). May 7, 2008, 3:45 pm CT.
- Chan, F.T., Bronnenhuber, J.E., Bradie, J.N., Howland, K., Simard, N., and Bailey, S.A. 2012. [Risk assessment for ship-mediated introductions of aquatic nonindigenous species to the Canadian Arctic](#). DFO Can. Sci. Advis. Sec. Res. Doc. 2011/105. vi + 93 p.
- Charrier, I., Aubin, T., and Mathevon, N. 2009. Mother-calf vocal communication in Atlantic walrus: a first field experimental study. Anim. Cogn. 13(3): 471–482.
- Claudi, R., Nantel, P., and Muckle-Jeffs, E. (eds.) 2002. [Alien invaders in Canada's waters, wetlands, and forests](#). Natural Resources Canada, Ottawa, ON. 320 p.
- Cody, M. 2003. Round Island field report, May 3 - August 10, 2003. Marine Mammals Management, U. S. Fish and Wildlife Service, Anchorage, Alaska. 67 p.
- COSEWIC. 2006. COSEWIC assessment and update status report on the Atlantic walrus *Odobenus rosmarus rosmarus* in Canada. Committee on the Status of Endangered Wildlife in Canada, OT. ix + 65 p.
- Crowe, K.J. 1969. A cultural geography of northern Foxe Basin. Northern Science Research Group: Department of Indian Affairs and Northern Development (NSRG) 69–2: xii + 130 p.
- Currie, R.D. 1963. Western Ungava area economic survey. Canada Department of Northern Affairs and National Resources, Area Economic Survey Report 62–2: 103 p.
- Davis, R.A., Finley, K.J., and Richardson, W.J. 1980. The present status and future management of Arctic marine mammals in Canada. LGL Limited Environmental Research Associates, Toronto for Science Advisory Board of the Northwest Territories, Yellowknife, NWT. 93 p.
- de March, B.G.E., Maiers, L.D., and Stewart, R.E.A. 2002. [Genetic relationships among Atlantic walrus \(\*Odobenus rosmarus rosmarus\*\) in the Foxe Basin and Resolute Bay–Bathurst Inlet area](#). DFO Can. Sci. Advis. Sec. Res. Doc. 2002/092: 20 p.

- Degerbøl, M., and Freuchen, P. 1935. Mammals. Report of the Fifth Thule Expedition 1921–24. The Danish expedition to Arctic North America in charge of Knud Rasmussen Ph.D. 2(4–5): 1–278. Gyldendalske Boghandel, Nordisk Forlag. Copenhagen, Denmark.
- DFO. 2002. [Atlantic walrus](#). DFO Can. Sci. Advis. Sec. Stock Status Rep. E5–17, 18, 19, 20: 19 p.
- DFO. 2013. [Proceedings of the Pre-COSEWIC Peer Review Meeting for Atlantic walrus \(\*Odobenus rosmarus rosmarus\*\); February 28 to March 1, 2012](#). DFO Can. Sci. Advis. Sec. Proceed. Ser. 2012/041: iv + 29 p.
- Dietz, R., Born, E.W., Stewart, R.E.A., Heide-Jørgensen, M.P., Stern, H., Rigét, F., Toudal, L., Lanthier, C., Jensen, M.V., and Teilmann, J. 2014. Movements of walruses (*Odobenus rosmarus*) between central West Greenland and southeast Baffin Island, 2005-2008. NAMMCO Sci. Publ. 9: 53–74.
- Donaldson, G.M., Chapdelaine, G., and Andrews, J.D. 1995. Predation of thick-billed murre, *Uria lomvia*, at two breeding colonies by polar bears, *Ursus maritimus*, and walruses, *Odobenus rosmarus*. Can. Field-Nat. 109: 112–114.
- Drouin, M. 2011. [Tanker with diesel fuel stranded for 2 weeks after running aground in Northwest Passage](#). Professional Mariner, March 2, 2011 12:00 AM.
- Dueck, L. 2003. [Proceedings of the RAP Meeting on Atlantic walrus, 29–30 January, 2000, Navigator Inn, Iqaluit, NU](#). DFO Can. Sci. Advis. Sec. Proceed. Ser. 2002/024: 20 p.
- Elliott, R.E., Moulton, V.D., Raborn, S.W., and Davis, R.A. 2013. Hudson Strait marine mammal surveys, 10 March – 2 April 2012. LGL Report No. TA8129-2. Prepared by LGL Limited, King City, ON for Baffinland Iron Mines Corporation, Toronto, ON. 87 p.
- Fay, F.H. 1981. Walrus *Odobenus rosmarus* (Linnaeus, 1758). In Handbook of Marine Mammals, Volume 1. The walrus, sea lions, fur seals, and sea otter. Edited by S.H. Ridgway and R.J. Harrison. Academic Press, London. pp. 1–23.
- Fay, F.H. 1982. Ecology and biology of the Pacific walrus, *Odobenus rosmarus divergens* Illiger. U.S. Department of the Interior, Fish and Wildlife Service, North American Fauna No. 74: vi + 279 p.
- Fay, F.H., and Kelly, B.P. 1980. Mass natural mortality of walruses (*Odobenus rosmarus*) at St. Lawrence Island, Bering Sea, Autumn 1978. Arctic. 33(2): 226–245.
- Fay, F.H., and Ray, C. 1968. Influence of climate on the distribution of walruses, *Odobenus rosmarus* (Linnaeus). I. Evidence from thermoregulatory behavior. Zool. 53: 1–18.
- Ferguson, S.H, Higdon, J.W., and Westdal, K.H. 2012. Prey items and predation behavior of killer whales (*Orcinus orca*) in Nunavut, Canada based on Inuit hunter interviews. Aquat. Biosys. 8: 3. doi: 10.1186/2046-9063-8-3
- Fisher, K.I. 1989. Food habits and digestive efficiency in walrus, *Odobenus rosmarus*. Thesis (M.Sc.) University of Manitoba, Winnipeg, MB. x + 88 p.
- Fisher, K.I., and Stewart, R.E.A. 1997. Summer foods of Atlantic walrus, *Odobenus rosmarus rosmarus*, in northern Foxe Basin, Northwest Territories. Can. J. Zool. 75(7): 1166–1175.

- Fisk, A.T., Hobbs, K., and Muir, D.C.G. (eds.). 2003. Contaminant levels, trends and effects in the biological environment. Canadian Arctic Contaminants Assessment Report II. Canada Department of Indian Affairs and Northern Development, Ottawa, ON. xix + 175 p.
- Fleming, M., and S. Newton. 2003. Hudson Bay TEKMS Report on select Hudson Bay features. Prepared for consideration by Bruce Stewart for incorporation into Hudson Bay Ecosystem Overview, 24 p.
- FRBC (Fisheries Research Board of Canada). 1962. Fisheries Research Board of Canada Annual Report of Eastern Arctic Fisheries Investigations, 1961-1962 report. Ottawa, ON.
- Freeman, M.M.R. 1962. Walrus hunting and conservation: a report based on field work at Southampton Island, May-October, 1961. Unpublished typescript report, available at Fisheries and Oceans Canada, Mont-Joli, QC. 31 p. + map.
- Freeman, M.M.R. (Ed). 1976. Inuit land use and occupancy study, Vol. 3. Land use atlas. Canada Department of Indian and Northern Affairs, Ottawa, xxiii + 153 maps.
- Freitas, C. 2008. Habitat selection by Arctic pinnipeds: patterns, tactics, and predictions in a dynamic environment. Thesis (Ph.D.) University of Tromsø, Norway. 192 p.
- Freitas, C., Kovacs, K.M., Ims, R.A., Fedak, M.A., Lydersen, C. 2009. Deep into the ice: overwintering and habitat selection in male Atlantic walruses. *Mar. Ecol. Progr. Ser.* 375: 247–261.
- Freuchen, P. 1921. Om hvalrossens forekomst og vandringer ved Grønlands vestkyst (Occurrence and migrations of the walrus near the west coast of Greenland). *Dansk naturhistorisk forening i København. Videnskabelige meddelelser.* 72: 237–249. [Translated from Danish by Can. Transl. Fish. Aquat. Sci. 2383, 1973.]
- FRPN (Federal Review Panel North). 2013. Environmental and social impact assessment of Canadian Royalties Inc.'s port infrastructure construction project in Deception Bay, Nunavik. Recommendations report presented to the Federal Administrator under Section 23 of the James Bay and Northern Quebec Agreement, 27 June 2013. 37 p.
- Gagnon, G., Rousseau, G., Camus, Y., and Gagné, J. 2012. NI 43-1-1 Technical report. preliminary economic assessment Ashram rare earth deposit. Prepared by SGS Canada Inc. (Geostat), Montreal, QC for Commerce Resources Corp. 219 p.
- Gagnon, J. 2011. Walrus tourism back on. Nunavut News/North, Monday, May 16, 2011, p. 4. [Web site: [https://archive.nnsi.com/2011-05/may16\\_11wrs.html](https://archive.nnsi.com/2011-05/may16_11wrs.html)].
- Garlich-Miller, J.L., and Stewart, R.E.A. 1999. Female reproductive patterns and fetal growth of Atlantic walruses (*Odobenus rosmarus rosmarus*) in Foxe Basin, Northwest Territories, Canada. *Mar. Mamm. Sci.* 15(1): 179–191.
- Garlich-Miller, J., MacCracken, J.G., Snyder, J., Meehan, R., Myers, M., Wilder, J.M., Lance, E., and Matz, A. 2011. Status review of the Pacific walrus (*Odobenus rosmarus divergens*). U.S. Fish and Wildlife Service, Anchorage, AK. vi + 155 p.

- Gaston, A.J., and Ouellet, H. 1997. Birds and mammals of Coats Island, N.W.T. *Arctic* 50(2): 101-118.
- Gaston, A.J., Elliott, K.H., Robert-Coudert, Y., Kato, A., Macdonald, C.A., Mallory, M.L., and Gilchrist, H.G. 2013. Modeling foraging range for breeding colonies of thick-billed murres *Uria lomvia* in the Eastern Canadian Arctic and potential overlap with industrial development. *Biol. Conserv.* 168: 134–143.
- Gavrilchuk, K., and Lesage, V. 2014. [Large-scale marine development projects \(mineral, oil and gas, infrastructure\) proposed for Canada's North](#). Can. Tech. Rep. Fish. Aquat. Sci. 3069: viii + 84 pp.
- Gjertz, I. 1990. Walrus predation on seabirds. *Polar Rec.* 26(159): 317.
- Gjertz, I., Griffiths, D., Krafft, B.A., Lydersen, C., and Wiig, Ø. 2001. Diving and haul-out patterns of walruses *Odobenus rosmarus* on Svalbard. *Polar Biol.* 24(5): 314–319.
- Golder Associés. 2012. Oceanic Iron Ore Corp.'s Hopes Advance Project: description of a designated project under the Canadian Environmental Assessment Act, 2012. Golder Associés Ltée, Montréal, QC. 53 p.
- Grant, A.C. 1971. Distributional trends in recent marine sediments of northern Baffin Bay. *Maritime Sediments.* 7(2): 41–63.
- Guinn, B., and Stewart, D.B. 1988. Marine mammals of central Baffin Island, Northwest Territories. Lands Directorate of Environment Canada and Northern Environment Directorate of Indian and Northern Affairs, Northern Land Use Information Series, Background Report No. 6: ii + 65 p. + map.
- Gunn, A., Arlooktoo, G., and Kaomayok, D. 1988. The contribution of ecological knowledge of Inuit to wildlife management in the Northwest Territories. *In* Traditional knowledge and renewable resource management in northern regions. Edited by M.M.R Freeman and L. N. Carbyn, The University of Alberta Press Occasional Publication 23: 22–30.
- Hallegraeff, G.M. 1998. Transport of toxic dinoflagellates via ships' ballast water: bioeconomic risk assessment and efficacy of possible ballast water management strategies. *Mar. Ecol. Prog. Ser.* 168: 297–309.
- Hantzsch, B.A. 1977. My life among the Eskimos: Baffinland journeys in the years 1909 to 1911. University of Saskatchewan, Mawdsley Memoir 3: xxii + 395 p. + map. [Translated from German and edited by L.H. Neatby].
- Ijjangiaq, M. 1990. Interviews IE-081 and IE-132. Archives of the Inullariit Society, Igloolik Research Centre, Igloolik, Nunavut.
- Immaroitok, E. 1996. Interview IE-377. Archives of the Inullariit Society, Igloolik Research Centre, Igloolik, Nunavut.
- Ivalu, A. 1996. Interview IE-355. Archives of the Inullariit Society, Igloolik Research Centre, Igloolik, Nunavut.
- Jay, C.V., and Hills, S. 2005. Movements of walruses radio-tagged in Bristol Bay, Alaska. *Arctic.* 58(2): 192–202.
- Jay, C.V., Farley, S.D., and Garner, G.W. 2001. Summer diving behavior of male walruses in Bristol Bay, Alaska. *Mar. Mamm. Sci.* 17(3): 617–631.



- Jay, C.V., Udevitz, M.S., Kwok, R., Fischbach, A.S., Douglas, D.C. 2010. Divergent movements of walrus and sea ice in the northern Bering Sea. *Mar. Ecol. Prog. Ser.* 407: 293–302.
- Kappianaq, G. 1992. Interview IE-234. Archives of the Inullariit Society, Igloolik Research Centre, Igloolik, Nunavut.
- Kappianaq, G. 1997. Interview IE-409. Archives of the Inullariit Society, Igloolik Research Centre, Igloolik, Nunavut.
- Kemp, W.B. 1976. Inuit land use in south and east Baffin Island. *In* Inuit land use and occupancy project. Volume 1: Land use and occupancy. Edited by M.M.R. Freeman. Supply and Services Canada, Ottawa, ON. pp 125–151.
- Killian, H.P.L., and Stirling, I. 1978. Observations on overwintering walruses in the eastern Canadian High Arctic. *J. Mammal.* 59(1): 197–200.
- Kopaq, M. 1987. Interview IE-017. Archives of the Inullariit Society, Igloolik Research Centre, Igloolik, Nunavut.
- Kovacs, K.M., and Lavigne, D.M. 1992. Maternal investment in otariid seals and walruses. *Can. J. Zool.* 70(10): 1953–1964.
- Kupaaq, M. 1996. Interview IE-360. Archives of the Inullariit Society, Igloolik Research Centre, Igloolik, Nunavut.
- LeBoeuf, B.J. 1986. Sexual strategies of seals and walruses. *New Sci.* 1491: 36–39.
- Levermann, N., Galatius, A., Ehme, G., Rysgaard, S., and Born, E.W. 2003. Feeding behaviour of free-ranging walruses with notes on apparent dexterity of flipper use. *BMC Ecol.* 3: 9.  
doi:10.1186/1472-6785-3-9
- LGL Limited and North/South Consultants Inc. 2011. Appendix 8A-2. Marine mammal baseline. In Baffinland Iron Mines Corporation. Mary River Project Final Environmental Impact Statement, February 2012, Vol. 8. Marine environment.
- Loughrey, A.G. 1959. Preliminary investigation of the Atlantic walrus *Odobenus rosmarus rosmarus* (Linnaeus). *Can. Wildl. Serv. Bull. (Ott.) (Series 1)* 14: 123 pp.
- Low, A.P. 1906. Report of the Dominion Government expedition to Hudson Bay and the Arctic Islands on board the D.G.S. *Neptune*, 1903–1904. Government Printing Bureau, Ottawa, ON. xvii + 355 p + map.
- Lowry, L.F., and Fay, F.H. 1984. Seal eating by walruses in the Bering and Chukchi Seas. *Polar Biol.* 3(1): 11–18.
- Makkik, G., and Ipkangnak, E. 1996. Interview IE-356. Archives of the Inullariit Society, Igloolik Research Centre, Igloolik, Nunavut.
- Mallory, M.L., and Fontaine, A.J. 2004. [Key marine habitat sites for migratory birds in Nunavut and the Northwest Territories](#). Environment Canada, Canadian Wildlife Service, Ottawa, ON. Occasional Paper Number 109: 92 p.
- Mallory, M.L., Woo, K., Gaston, A.J., Davies, W.E., and Mineau, P. 2004. Walrus (*Odobenus rosmarus*) predation on adult thick-billed murre (*Uria lomvia*) at Coats Island, Nunavut, Canada. *Polar Res.* 23(1): 111–114.

- Mansfield, A.W. 1958. The biology of the Atlantic walrus *Odobenus rosmarus rosmarus* (Linnaeus) in the eastern Canadian Arctic. Fish. Res. Board Can. Manuscr. Rep. 653: xiii + 146 p.
- Mansfield, A.W. 1959. The walrus in the Canadian arctic. Fish. Res. Board Can. Arctic Unit Circ. 2: 1–13.
- Mansfield, A.W. 1973. The Atlantic walrus *Odobenus rosmarus* in Canada and Greenland. IUCN (Intl Union Conserv. Nat. Nat. Resour.) Publ. New Ser. Suppl. Pap. 39: 69–79.
- MDDEP (Québec, Ministère du Développement durable, Environnement et Parcs). 2007. Modification: Projet de travaux de reconstruction au quai de Baie Deception - Mine Raglan, Québec. N/Ref.: 3215-14-03. Québec, 1 June 2007.
- MDDEP (Québec, Ministère du Développement durable, Environnement et Parcs). 2008. Certificate d'autorisation: Projet minier Nunavik Nickel. N/Ref.: 3215-14-007. Québec, 20 May 2008.
- Miller, E.H. 1982. Herd organization and female threat behavior in Atlantic walruses *Odobenus rosmarus rosmarus* (L.). Mammalia. 46(1): 29–34.
- Miller, E.H. 1985. Airborne acoustic communication in the walrus *Odobenus rosmarus*. Natl Geogr. Res. 1: 124–145.
- Miller, E.H., and Boness, D.J. 1983. Summer behavior of Atlantic walruses *Odobenus rosmarus rosmarus* (L.) at Coats Island, N.W.T. Z. Säugetierkd. 48: 298–313.
- Moore, S.E., Reeves, R.R., Southall, B.L., Ragen, T.J., Suydam, R.S., and Clark, C.W. 2012. A new framework for assessing the effects of anthropogenic sound on marine mammals in a rapidly changing Arctic. BioScience. 62(3): 289–295.
- Muir, D.C.G., Segstro, M.D., Hobson, K.A., Ford, C.A., Stewart, R.E.A., and Olpinski, S. 1995. Can seal eating explain elevated levels of PCBs and organochlorine pesticides in walrus blubber from eastern Hudson Bay (Canada). Environ. Pollut. 90(3): 355–348.
- NDEDT (Nunavut Department of Economic Development and Transportation). 2008. Nunavut coastal resource inventory – Iglulik Pilot Project. Government of Nunavut, Department of Economic Development and Transportation (now Department of Environment), Fisheries and Sealing Division, Iqaluit, NU. 197 p.
- NIRB (Nunavut Impact Review Board). 2012. In the matter of the Nunavut Land Claims Agreement, Nunavut Land Claims Agreement Act, S.C., 1993, c. 29 Article 12, Part 5 And In the matter of an application by Baffinland Iron Mines Corporation for development of the Mary River Project Proposal in the Qikiqtani Region of Nunavut NIRB PROJECT CERTIFICATE [NO.: 005], December 28, 2012. Unpaginated [73 p.]
- NIRB (Nunavut Impact Review Board). 2014. Final Hearing Report. Meliadine Gold Project. Agnico Eagle Mines Limited. NIRB File No. 11MN034. xxvii + 295 p. + Appendices.



- Norstrom, R.J., and D.C.G. Muir. 2000. Organochlorine contamination in the Arctic marine ecosystem: implications for marine mammals. *In* The Atlantic Coast Contaminants Workshop 2000 "Endocrine disruptors in the marine environment: impacts on marine wildlife and human health". The Marine Environmental Research Institute (MERI), University of Connecticut Department of Pathobiology, and Jackson Laboratory, Bar Harbor, Maine. pp. 38–43.
- NRC (National Research Council). 1996. Stemming the tide: controlling introductions of nonindigenous species by ships' ballast water. National Academy Press, Washington, D.C. xiii + 141 p.
- Nunatsiaq News. 2012. Big Nunavik iron mine project heads into federal review. Posted online October 15, 2012, 10:15 am. Web site:
- Nunatsiaq News. 2014. Fednav introduces its latest Arctic ship: MV *Nunavik*. Nunatsiaq Online News: Around the Arctic. March 20, 2014.
- Oceanic Iron Ore Corp. 2013. Oceanic receives results of shipping optimization study. Press Release, September 12, 2013. [Accessed online 18 October 2014 at: [www.oceanicironore.com](http://www.oceanicironore.com)]
- Okonek, D.C., Okonek, B., and Snively, M. 2009. Walrus Islands State Game Sanctuary annual report 2008. Alaska Department of Fish and Game, Division of Wildlife Conservation, Anchorage, Alaska. 60 p.
- Okonek, D.C., Sell, S.K., and Weiss, E.K. 2010. Walrus Islands State Game Sanctuary annual management report 2009. Alaska Department of Fish and Game, Division of Wildlife Conservation, Special Areas Management Report. iii + 70 p.
- Orr, J.R., and Rebizant, T. 1987. [A summary of information on the seasonal distribution and abundance of walrus \(\*Odobenus rosmarus\*\) in the area of northern Hudson Bay and western Hudson Strait, NWT, as collected from local hunters](#). Can. Data Rep. Fish. Aquat. Sci. 024: iv + 16 p.
- Orr, J.R., Renooy, B., and Dahlke, L. 1986. Information from hunts and surveys of walrus (*Odobenus rosmarus*) in northern Foxe Basin, Northwest Territories, 1982-1984. Can. Manuscr. Rep. Fish. Aquat. Sci. 1899: iv + 29 p.
- Outridge, P.M., and Stewart, R.E.A. 1999. Stock discrimination of Atlantic walrus (*Odobenus rosmarus rosmarus*) in the eastern Canadian Arctic using lead isotope and element signatures in teeth. Can. J. Fish. Aquat. Sci. 56(1): 105–112.
- Outridge, P.M., MacDonald, D.D., Porter, E., and Cuthbert, I.A. 1994. An evaluation of the ecological hazards associated with cadmium in the Canadian environment. Environ. Rev. 2(1): 91–107.
- Outridge, P.M., Evans, R.D., Wagemann, R., and Stewart, R.E.A. 1997. Historical trends of heavy metals and stable lead isotopes in beluga (*Delphinapterus leucas*) and walrus (*Odobenus rosmarus*) in the Canadian Arctic. Sci. Total Environ. 203(3): 209–219.
- Outridge, P.M., Hobson, K.A., McNeely, R., and Dyke, A. 2002. A comparison of modern and preindustrial levels of mercury in the teeth of beluga in the Mackenzie Delta, Northwest Territories, and walrus at Igloodik, Nunavut, Canada. Arctic. 55(2): 123–132.

- Paniaq, H. 2005. Interview IE-523. Archives of the Inullariit Society, Igloolik Research Centre, Igloolik, Nunavut.
- Piugattuk, N. 1986. Interview IE-010. Archives of the Inullariit Society, Igloolik Research Centre, Igloolik, Nunavut.
- Piugattuk, N. 1990. Interview IE-136. Archives of the Inullariit Society, Igloolik Research Centre, Igloolik, Nunavut.
- Qamaniq, N. 2005. Interview IE-525. Archives of the Inullariit Society, Igloolik Research Centre, Igloolik, Nunavut.
- Qikiqtani Inuit Association. 2011. Conformity Technical Review – October 5, 2011, QIA submission of Technical Review Comments titled “Submission of Technical Review Comments”. Appendix D: Fresh water aquatics and marine, 96 p.
- Qikiqtani Inuit Association. 2012. Qikiqtani Inuit Association’s final written submission for Baffinland Iron Mines Corporation, Mary River Project, Final Environmental Impact Statement. Submitted May 30th, 2012 to the Nunavut Impact Review Board (NIRB). 40 p + appendices.
- Qikiqtani Inuit Association. 2013. Qikiqtani Inuit Association’s Technical Review Submission for Baffinland Iron Mines Corporation, Mary River Project, Addendum to the Final Environmental Impact Statement. Submitted October 18, 2013 to the Nunavut Impact Review Board. 176 p. (variously paginated).
- Qikiqtani Inuit Association. 2014. Qikiqtani Inuit Association’s final written submission for Baffinland Iron Mines Corporation, Mary River Project, Addendum to the Final Environmental Impact Statement. Submitted January 13, 2014 to the Nunavut Impact Review Board. 110 p.
- Ray, C., and Fay, F.H. 1968. Influence of climate on the distribution of walruses, *Odobenus rosmarus* (Linnaeus). II. evidence from physiological characteristics. Zool. 53: 19–32.
- Reeves, R.R. 1978. Atlantic walrus (*Odobenus rosmarus rosmarus*): a literature survey and status report. U.S. Department of the Interior, Fish and Wildlife Service, Wildlife Research Report, Washington, D.C. 10: ii + 41 p.
- Reeves, R.R. 1995. Walruses of Nunavik. Prepared for Canada Department of Fisheries and Oceans under the Quebec Federal Fisheries Development Program (QFFDP), Quebec. x + 48 p.
- Reeves, R.R., and Mitchell, E. 1986. Early abundance and distribution of walruses in eastern Hudson Bay, Hudson Strait, and Ungava Bay, based on historical records: preliminary report. Report to Fisheries and Oceans Canada in fulfillment of contract 12SD.FP 715-5-2664. 64 p.
- Richard, P.R. 1993. Summer distribution and abundance of walrus in northern Hudson Bay, western Hudson Strait, and Foxe Basin: 1988–1990. Background document prepared for the Arctic Fisheries Science Advisory Meeting, 17–18 February 1993 by Canada Department of Fisheries and Oceans, Central and Arctic Region, Winnipeg, MB. 11 p. + figures.

- Riewe, R.R., and Amsden, C.W. 1979. Harvesting and utilization of pinnipeds by Inuit hunters in Canada's eastern High Arctic. *In* Thule Eskimo culture: an anthropological retrospective. Edited by A.P. McCartney.) Nat. Mus. Man. Archaeol. Surv. Can. Pap. 88 (Mercury Series). pp. 324–348.
- Roff, J.C., and Legendre, L. 1986. Chapter 14: Physio-chemical and biological oceanography of Hudson Bay. *In* Canadian inland seas. Edited by I.P. Martini. Elsevier Oceanography Series 44. Elsevier Science Publishers, Amsterdam. pp. 265–291.
- Russell, C. 1966. Walrus! Walrus! Walrus Galore! North. 13(2): 1–9.
- Sahanatien, V., and Derocher, A.E. 2012. Monitoring sea ice habitat fragmentation for polar bear conservation. *Anim. Conserv.* 15(4): 39–407.
- Salter, R.E. 1979a. Site utilization, activity budgets, and disturbance responses of Atlantic walruses during terrestrial haul-out. *Can. J. Zool.* 57(6): 1169–1180.
- Salter, R.E. 1979b. Observations on social behaviour of Atlantic walruses (*Odobenus rosmarus* (L.)) during terrestrial haul-out. *Can. J. Zool.* 58(3): 461–463.
- Saul, B., Notpol, C., Foster D., Watters, G., Zhang, G., Ghaffari, H., Kondratas, H., Stoyko, H.W., Stratton, J., Tamburini, J.R., Jansons, K., Bodi, L., Palmer, P., Guedez, P., Broad, P., Bridson, P., Tinnevely, R., Dejan, V., and Habibova, Z. 2012. Feasibility study on the Roche Bay Iron Ore Project. Prepared by Tetra Tech Wardrop, Toronto for Advanced Explorations Inc. 1191360400-REP-R0019-03. 509 p.
- Sax, D.F., Stachowicz, J.J., Brown, J.H., Bruno, J.F., Dawson, M.N., Gaines, S.D., Grosberg, R.K., Hastings, A., Holt, R.D., Mayfield, M.M., O'Connor, M.I., Rice, R.W. 2007. Ecological and evolutionary insights from species invasions. *Trends Ecol. Evol.* 22(9): 465–471.
- Shafer, A.B.A., Davis, C.S., Coltman, D.W., and Stewart, R.E.A. 2014. Microsatellite assessment of walrus (*Odobenus rosmarus rosmarus*) stocks in Canada. *NAMMCO Sci. Publ.* 9: 15–32.
- Siakuluk, N. 1996. Interview IE-385. Archives of the Inullariit Society, Igloodik Research Centre, Igloodik, Nunavut.
- Sjare, B., and Stirling, I. 1996. The breeding behavior of Atlantic walruses, *Odobenus rosmarus rosmarus*, in the Canadian High Arctic. *Can. J. Zool.* 74(5): 897–911.
- Sjare, B., Stirling, I., and Spencer, C. 2003. Structural variation in the songs of Atlantic walruses breeding in the Canadian High Arctic. *Aquat. Mamm.* 29(2): 297–318.
- Smith, T.G., Hammill, M.H., Doidge, D.W., Cartier, T., and Sleno, G.A. 1979. [Marine mammal studies in southeastern Baffin Island. Final report to the eastern Arctic Marine Environmental Studies \(EAMES\) project.](#) Can. Manuscr. Rep. Fish. Aquat. Sci. 1552: 70 p.
- Stewart, D.B., and Howland, K.L. 2009. [An ecological and oceanographical assessment of the alternate ballast water exchange zone in the Hudson Strait Region.](#) DFO Can. Sci. Advis. Sec. Res. Doc. 2009/008: vi + 92 p.

- Stewart, D.B., Higdon, J.W., Reeves, R.R., and Stewart, R.E.A. 2014. A catch history for Atlantic walrus (*Odobenus rosmarus rosmarus*) in the eastern Canadian Arctic. NAMMCO Sci. Publ. 9: 219–314.
- Stewart, D.B., Nudds, S.H., Howland, K.L., Hannah, C.G., and Higdon, J.W. 2015. [An ecological and oceanographical assessment of alternate ballast water exchange zones in the Canadian eastern Arctic](#). DFO Can. Sci. Advis. Sec. Res. Doc. 2015/037. vi + 75 p.
- Stewart, R.E.A. 2002. [Review of Atlantic walrus \(\*Odobenus rosmarus rosmarus\*\) in Canada](#). Can. Sci. Advis. Sec. Res. Doc. 2002/091: 20 p.
- Stewart, R.E.A. 2008. Refining walrus stocks in Canada. Arctic. 61(3): 292-308.
- Stewart, R.E.A., Richard, P.R., and Stewart, B.E. (eds.). 1993. Report of the 2<sup>nd</sup> Walrus International Technical and Scientific (WITS) Workshop, 11-15 January 1993, Winnipeg, Manitoba, Canada. Can. Tech. Rep. Fish. Aquat. Sci. 1940: viii + 91 p.
- Stewart, R.E.A., V. Lesage, J.W. Lawson, H. Cleator and K.A. Martin. 2012. [Science Technical Review of the draft Environmental Impact Statement \(EIS\) for Baffinland's Mary River Project](#). DFO Can. Sci. Advis. Sec. Res. Doc. 2011/086. vi + 62 p.
- Stewart, R.E.A., Hamilton, J.W., and Dunn, J.B. 2013b. [Results of Foxe Basin walrus \(\*Odobenus rosmarus rosmarus\*\) surveys: 2010-2011](#). DFO Can. Sci. Advis. Sec. Res. Doc. 2013/017. iv + 12 p.
- Stewart, R.E.A., Born, E.W., Dietz, R., Heide-Jørgensen, M.P., Rigét, F.F., Laidre, K., Villum Jensen, M., Fossette, L.Ø., and Dunn, J.B. 2014a. Abundance of Atlantic walrus in in western Nares Strait, Baffin Bay stock, during summer. NAMMCO Sci. Publ. 9: 123 – 140.
- Stewart, R.E.A., Born, E.W., Dietz, R., and Ryan, A.K. 2014b. Estimates of minimum population size for walrus near southeast Baffin Island, Nunavut. NAMMCO Sci. Publ. 9: 141–158.
- Stewart, R.E.A., Born, E.W., Dunn, J.B., Koski, W.R., and Ryan, A.K. 2014c. Use of multiple methods to estimate walrus (*Odobenus rosmarus rosmarus*) abundance in the Penny Strait-Lancaster Sound and west Jones Sound stocks, Canada. NAMMCO Sci. Publ. 9: 95–122.
- Stirling, I., and Thomas, J.A. 2003. Relationships between underwater vocalizations and mating systems in phocid seals. Aquat. Mamm. 29(2) 227–246.
- Stirling, I., Calvert, W., and Spencer, C. 1987. Evidence of stereotyped underwater vocalizations of male Atlantic walruses (*Odobenus rosmarus rosmarus*). Can. J. Zool. 65(9): 2311–2321.
- Tang, C.L., Ross, C., Yao, T., Petrie, B., DeTracey, B.M., and Dunlap, E. 2004. The circulation, water masses and sea-ice of Baffin Bay. Prog. Oceanogr. 63(4):183–228.
- Thiemann, G.W., Iverson, S.J., and Stirling, I. 2008. Polar bear diets and Arctic marine food webs: insights from fatty acid analysis. Ecol. Monogr. 78(4): 591–613.
- Thomson, D.H. 1982. Marine benthos in the eastern Canadian high Arctic: multivariate analyses of standing crop and community structure. Arctic. 35(1): 61–74.

- TSB (Transportation Safety Board). 2014. Grounding: Tanker *Nanny*, Chesterfield Narrows, Nunavut, 25 October 2012. Transportation Safety Board of Canada, Marine Investigation Report M12H0012: 24 p.
- Transport Canada. 2011. Canadian Arctic Shipping Routes for 2010, Transport Canada, Special Projects and Arctic Shipping, 2011, S. Harder (Producer and Distributor), Marine. Transport Canada, Pacific Region, Data format: computer files.
- Vibe, C. 1950. The marine mammals and the marine fauna in the Thule District (northwest Greenland) with observations on ice conditions in 1939–41. *Medd. Grønland*. 150(6): 93-97.
- Wagemann, R., and Stewart, R.E.A. 1994. Concentrations of heavy metals and selenium in tissues and some foods of walrus (*Odobenus rosmarus rosmarus*) from the eastern Canadian Arctic and sub-Arctic, and associations between metals, age, and gender. *Can. J. Fish. Aquat. Sci.* 51(2): 426–436.
- Wagemann, R., Lockhart, W.L., Welch, H., and Innes, S. 1995. Arctic marine mammals as integrators and indicators of mercury in the arctic. *Water Air Soil Pollut.* 80 (1-4): 683-693.
- Welch, H.E., Bergmann, M.A., Siffred, T.D., Martin, K.A., Curtis, M.F., Crawford, R.E., Conover, R.J., and Hop, H. 1992. Energy flow through the marine ecosystem of the Lancaster Sound Region, Arctic Canada. *Arctic*. (45) 343–357.
- Welland 1976. Inuit land use in Keewatin District and Southampton Island. In: Freeman, M.M.R. (ed.); Inuit land use and occupancy study, Vol. 1. Canada Department of Indian and Northern Affairs, Ottawa, ON. 83–114 p.
- Wiig, Ø., Gjertz, I., Griffiths, D., and Lydersen C. 1993. Diving patterns of an Atlantic walrus *Odobenus rosmarus rosmarus* near Svalbard. *Polar Biol.* 13: 71–72.
- Wright, C. 2014. Ports and infrastructure in the Arctic. Company of Master Mariners Arctic Seminar, The Evolving Arctic, Challenges and Opportunities, Halifax, April 29, 2014.
- Xstrata Nickel. 2011. Xstrata Nickel Raglan Mine invests in the development of new mining projects in Nunavik. News Release, Rouyn-Noranda, August 2, 2011. 2 p.

## APPENDIX 1. HABITAT SUITABILITY SCORING

*Table A1- 1. Scoring of depth ranges for habitat suitability modelling.*

Water depth	Suitability rank	Scoring for analysis
Shallow (<10 m)	Low	0.50
Optimal (10-<50 m)	High	1.00
Sub-optimal (50-<100 m)	Moderate	0.75
Marginal (100-<250 m)	Low	0.50
Deep (≥250 m)	Very low	0.25

*Table A1- 2. Scoring of ice cover categories for habitat suitability modelling (winter only).*

Ice cover	Suitability rank	Scoring for analysis
Landfast ice (10/10)	Very low	0.25
Heavy pack ice (7-9+/10)	Low	0.75
Open pack ice (1-6/10)	Moderate	0.75
Open water (<1/10)	Moderate	0.75
Polynia; persistent flaw lead	High	1.00

*Table A1- 3. Scoring of distance to the coast under open water conditions (i.e., <1/10 ice cover) and distance to the coast or landfast ice edge during winter conditions for habitat suitability modelling.*

Distance to the coast or floe edge (km)	Suitability rank	Scoring for analysis
<20	High	1.00
>20-40	Moderate	0.75
>40-60	Low	0.50
>60	Very low	0.25

*Table A1- 4. Scoring for haulouts (uglit) and waters in their vicinity for habitat suitability modeling (summer only).*

Haulout (# of animals counted)	Suitability rank	Buffer diameter (km)	Scoring for analysis
Large (>1000)	Very high	50	1.00
	High	100	0.90
Medium (>100-1000)	High	50	0.90
	Moderate	100	0.70
Small (≤100)	Moderate	50	0.70
	Low	100	0.50
Formerly occupied (?)	Low	50	0.50
	Low	100	0.50

*Table A1- 5. Habitat suitability scores for summer and winter, divided into five classes based on normalized values.*

Habitat class (score)	Summer	Winter
<b>Very high (0.80-1.00)</b>	162	184
<b>High (0.60-0.80)</b>	365	341
<b>Moderate (0.40-0.60)</b>	382	283
<b>Low (0.20-0.40)</b>	447	788
<b>Very low (0.00-0.20)</b>	299	59
<b>Total</b>	1655	1655