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Risk Assessment for ship-mediated introductions of aquatic nonindigenous species to the Canadian Arctic

Évaluation du risque d'introduction d'espèces aquatiques non indigènes par les navires dans l'Arctique canadien

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ABSTRACT

Ballast water has historically been the predominant ship-mediated vector for aquatic non-indigenous species (NIS) introductions to Canada, while hull fouling is recognized as a leading sub-vector for the introduction of marine aquatic NIS worldwide. To the best of our knowledge, there has been no ship-mediated NIS established in the Canadian Arctic. However, if shipping activities increase as expected with a warming climate, propagule pressure will also increase and the Arctic will be more vulnerable to future invasions. The objective of this report was to conduct a relative risk assessment of shipping vectors (hull fouling and ballast water) to Canadian Arctic ports. First, the probability of introduction was estimated by combining the individual probabilities of successful transition through each stage of the invasion process (i.e., arrival, survival and establishment), based on ship arrival/ballast water discharge data and environmental conditions at Arctic and potential source ports. Second, the potential magnitude of consequences of introduction was estimated based on the number of high impact ship-mediated NIS recorded for eco-regions of ports directly connected to Arctic ports through shipping activities. The probability of introduction and potential magnitude of consequences were then combined for a final relative invasion risk rating. Finally, we identify priorities and make recommendations for future management needs.

A transit analysis shows that Canadian Arctic ports are connected with international and coastal domestic ports, resulting in potential for species transfers *via* hull fouling and ballast water discharge. The final relative invasion risk for fouling NIS is higher for Churchill (Manitoba), intermediate for Iqaluit and Erebus Bay/Beechey Island (Nunavut) and lower for other Arctic ports, with moderate uncertainty. The final relative invasion risk for ballast-mediated NIS is higher for Churchill and lower for all other ports, with moderate uncertainty. It is important to note that results presented in this document are based on relative rankings among top Arctic ports. Ports identified as higher risk in this study may not be high risk in a national scale considering the relatively low shipping traffic and harsh environmental conditions in the Arctic; these ratings will be recalibrated to differentiate risk among top ports from all Canadian regions in a subsequent national risk assessment.

RÉSUMÉ

Au Canada, l'introduction d'espèces aquatiques non indigènes par les navires se produit surtout par les eaux de ballast, alors qu'à l'échelle mondiale, ce sont les salissures biologique de la coque des navires qui sont reconnues comme principal sous-vecteur d'introduction. Au meilleur de nos connaissances, aucune espèce aquatique non indigène introduite par les navires ne s'est établie dans l'Arctique canadien. Cependant, si le transit augmente tel que prévu en conséquence du réchauffement climatique, la pression propagulaire augmentera également, et l'Arctique deviendra plus vulnérable aux futures invasions. Ce rapport a pour objectif d'évaluer le risque relatif des vecteurs d'introduction par navire (salissures de la coque et eaux de ballast) dans les ports de l'Arctique canadien. Tout d'abord, la probabilité d'introduction a été estimée en combinant les probabilités de transition réussie à chaque étape du processus d'invasion (c.-à-d. l'arrivée, la survie et l'établissement), selon les données sur l'arrivées des navires et du déchargement des eaux de ballast, les conditions environnementales dans l'Arctique et les ports d'origine potentiels. Ensuite, l'ampleur des répercussions liées à l'introduction de ces espèces a été estimée d'après le nombre d'espèces aquatiques non indigènes à impact élevé introduites par les navires qui ont été signalées dans les régions écologiques caractérisées par des activités maritimes reliant directement les ports à des ports de l'Arctique. La probabilité d'introduction et l'ampleur des répercussions potentielles ont ensuite été combinées pour déterminer le risque relatif final d'invasion. Enfin, nous avons établi les priorités et fait nos recommandations relativement aux futures besoins de gestion.

Une analyse du transit montre que les ports de l'Arctique canadien sont reliés à des ports internationaux et nationaux, ce qui favorise le transfert potentiel des espèces par l'entremise des salissures de la coque des navires et des eaux de ballast. Le risque relatif final d'invasion d'espèces aquatiques non indigènes due à des salissures est élevé à Churchill (au Manitoba), intermédiaire à Iqaluit, dans la baie Erebus et dans l'île Beechey (au Nunavut) et faible dans les autres ports de l'Arctique, avec un degré d'incertitude modéré. Le risque relatif final d'invasion d'espèces aquatiques non indigènes introduites par les eaux de ballast est élevé à Churchill et faible dans tous les autres ports, avec un degré d'incertitude modéré. Il est important de noter que les résultats présentés dans ce document sont fondés sur les données de classement relatives recueillies dans les principaux ports de l'Arctique. Les ports déterminés comme présentant un risque plus élevé dans le cadre de cette étude peuvent ne pas présenter de risque élevé à l'échelle nationale si l'on tient compte du trafic maritime relativement faible dans l'Arctique et des conditions environnementales difficiles de cette région; ces résultats seront revus dans le cadre d'une évaluation nationale du risque visant à déterminer le risque dans chacun des principaux ports des régions canadiennes.

INTRODUCTION

Species that have established populations outside of their native range are known as nonindigenous species (NIS). The impact of NIS invasions has become increasingly problematic as globalization has increased both intentional and unintentional species transfers, allowing the establishment of NIS worldwide. NIS may impact recipient ecosystems by competing with native species for limited resources and disrupting the natural food web (Shea and Chesson 2002). In fact, NIS introductions are the second greatest cause of extinction globally and the greatest threat to biodiversity in freshwater ecosystems (MEA 2005; Lawler et al. 2006). NIS have caused irreparable damage to ecosystem function and natural resources in many terrestrial and aquatic systems (Carlton and Geller 1993; Allen and Humble 2002; Crooks 2002; Pimental et al. 2005). Resultant long-term economic consequences have impacted industry and society both directly and indirectly amounting to costs between $13.3 and $34.5 billion/year in Canada alone (Mack et al. 2000; MEA 2005; Colautti et al. 2006*a*). Examples of aquatic NIS impacts include the depletion of commercially important fisheries, increased industrial maintenance costs from NIS-fouled equipment, and the need for ongoing, costly mitigation programs. All ecosystems are vulnerable to, and may suffer severe impacts from, NIS unless comprehensive prevention and management programs are introduced (United States Congressional Office 1993).

The objective of this report is to conduct a semi-quantitative, relative risk assessment of two shipping vectors (hull fouling and ballast water) to Canadian Arctic ports, as a sub-component of a national risk assessment for the four coasts of Canada (including also the West Coast, East Coast and the Great Lakes-St. Lawrence River). Once all regional documents are completed, a national risk assessment will be completed which re-evaluates the relative risks on a national scale and addresses the following questions posed to the authors by formal science advice request in advance of the project:

1. What is the level of risk posed by ships transiting to, or from, Arctic ports for the introduction of AIS to Canadian waters;
2. What is the level of risk posed by ships operating within the ballast water exchange exemption zones on the East and West Coasts;
3. What is the level of risk posed by domestic shipping activities; and
4. Do current ballast water management regulations provide sufficient protection against ship-mediated AIS introductions?

In general, each regional report will provide a synopsis of biological invasion theory, the role of shipping vectors in species introductions, the history and concerns of AIS in the region, and the risk assessment. This particular document provides guidance on the relative risks of ship-mediated introductions within the Canadian Arctic. This risk assessment is based upon the best available information and methodology, and was peer-reviewed at a workshop attended by international aquatic invasive species, shipping and risk assessment experts and was overseen by DFO's Centre of Expertise for Aquatic Risk Assessment.

THE BIOLOGICAL INVASION PROCESS

Founding individuals, known as propagules, must pass through multiple stages of the invasion process to be successfully introduced to a new location (Figure 1). First, the propagules must be taken up by, and survive conditions within, a transport vector to be moved from the source region to a new environment. Once released, the propagules must survive in the new environment. If enough propagules successfully arrive, survive and form a reproductive population (Establishment), the recipient habitat can then act as a new source of propagules for secondary spread, making the process cyclical. The successful transition between any two stages of the invasion process is dependent on at least three factors: propagule pressure, physical-chemical requirements and biological requirements. Propagule pressure is a measure of the number of propagules released per event coupled with the number of release events over a given time period and is positively related to the probability of introduction (Wonham et al. 2000; Kolar and Lodge 2001; Colautti et al. 2006*b*). Physical-chemical and biological requirements also directly affect transition between invasion stages, with inhospitable environmental conditions (e.g., intolerable temperature, salinity, or substrate type) or community interactions (e.g., severe predation or limited food supply) decreasing the probability of introduction (Lockwood et al. 2006, 2009). Efforts to manage NIS introductions can target any or all stages of the invasion process, although preventative efforts focused at reducing propagule pressure at the transportation stage are regarded as most effective and cost-efficient (ISSG 2001; ANSTF 2007). Since transportation vectors are numerous, risk assessments identifying priority or high-risk vectors are necessary to direct limited resources for control efforts.

THE ROLE OF SHIPPING AS A PATHWAY OF AQUATIC NIS INTRODUCTIONS

Transportation vectors for aquatic NIS in Canada's freshwater and marine ecosystems include intentional (i.e., authorized stocking programs) and unintentional releases of aquatic species. Unintentional releases are associated with commercial shipping activities (e.g., ballast water discharge or hull fouling), escape from aquaculture facilities, and unauthorized releases of aquarium, bait fish, and ornamental pond species. Commercial shipping activities are of particular interest because shipping has been implicated in a substantial number of aquatic invasions globally and management strategies for this vector are relatively straight-forward and enforceable (Carlton 1985; Ruiz et al. 2000; MacIsaac et al. 2002; Leppäkoski et al. 2002; Grigorovich et al. 2002, 2003, Ruiz and Carlton 2003).

Ballast water has historically been the predominant ship-mediated vector for aquatic NIS introductions to Canada (Ricciardi 2001; de Lafontaine and Costan 2002). Natural adjacent water is pumped into ballast tanks to control the trim, stability and stresses on operational ships. Diverse communities of plankton present in the water column may be inadvertently pumped into ballast tanks during water uptake, transported to the destination port and subsequently released (Carlton 1985). In this way, ballast water transfer allows plankton to travel distances far greater than natural dispersal via active or passive mechanisms (Locke et al. 1993; Minton et al. 2005). Port sediments, and the associated benthic community, can also be resuspended and entrained in ballast tanks during uptake of ballast water (Bailey et al. 2003; Duggan et al. 2005; Kipp et al. 2010). Suspended sediments can settle out of ballast water and accumulate on the bottom of ballast tanks, providing good habitat for benthic life stages and resting eggs and serving as an additional transport vector for NIS (Bailey et al. 2005; Duggan et al. 2005, 2006). The amount of sediment and associated fauna resuspended and released during ballast discharge is thought to be low, but studies indicate ballasting operations may promote hatching of resting stages within ballast tanks such that individuals can enter the water column and be available for release (Bailey et al. 2005). Furthermore, water-sediment slurries may form in tanks with only residual ballast, providing an intermediate medium for NIS survival and introduction to recipient waters (Sutherland et al. 2009). The transfer of aquatic NIS *via* ballast water, slurry or sediment can be managed by regulating ballast practices since ballast water discharge is required to ultimately release individuals from ballast tanks. Conversely, the transport and release of taxa associated with the external underwater surfaces of a vessel, is not directly dependent on the ship's ballast activities and is more difficult to manage (Carlton 1985; Minchin and Gollasch 2003). Ship hulls, sea chests, propellers and other underwater surfaces can harbour fouling organisms, such as algae, hydroids, bryozoans, barnacles and bivalves (i.e. sessile taxa), in dense colonies that offer crustaceans and other motile organisms structural habitat and protection against the shearing forces experienced during ship movement, hereafter generalized as 'hull fouling' (Gollasch 2002; Lewis et al. 2004). Fouling taxa can be detached from the hull or can release reproductive propagules at any time along a vessel transit, thereby potentially establishing a nonindigenous population in any location through which the vessel travels. In fact, hull fouling is recognized as a leading vector for the introduction of marine aquatic NIS worldwide (Carlton 1985; Gollasch 2002; Coutts et al. 2003). Anchor chains, which are submerged in water at port and relatively protected during transit, are an additional, potentially important mechanism of ship-mediated introductions (West et al. 2007). However, because anchor chains are understudied as a vector of introductions, we are not able to assess its relative importance here. While shipping activities may also be important vectors for terrestrial NIS introductions through the movement of wood dunnage and/or infested cargo containers, the analysis of ship-mediated terrestrial introductions is beyond the scope of this study.

Ship type, ship size and trade patterns influence the invasion risk associated with a given vessel and the relative risk posed by each vector within that vessel (Simkanin et al. 2009). Vessels that rely heavily on ballast water for cargo operations, such as bulk carriers and tankers, are high-risk for transportation of aquatic NIS *via* ballast water and sediment. Risk is concordant with ship size since ship size influences the amount and capacity of ballast tanks. Vessels that do not regularly discharge ballast water, such as passenger vessels, barges and tugboats, are less important for introductions *via* ballast water and sediment. Trans-oceanic vessels have been considered to be most high-risk for aquatic NIS introductions because they provide a mechanism for the fauna of distant ports to be exchanged (Carlton 1985), however domestic or coastal vessels have the potential to contribute to the secondary spread of established aquatic NIS (Humphrey 2008; Simkanin et al. 2009; Sutherland et al. 2009; Rup et al. 2010).

More recently, hull fouling has been identified as an important vector of marine NIS. In contrast to ballast water, ship type does not influence risk because all vessels have the capacity to transport fouling organisms on exterior surfaces, regardless of ballasting practices. Like ballast water, the risk associated with hull-fouling introductions can increase with ship size, because larger ships have a greater underwater surface area on which propagules can attach. Hull fouling risk is also influenced by season, mooring time, elapsed time since antifouling application, vessel speed and trade route (Coutts 1999; Ruiz and Smith 2005; Sylvester and MacIsaac 2010). As mooring time and/or time since last antifouling coating increase, the risk associated with a given vessel increases because more fouling organisms are able to accumulate (Coutts 1999; Sylvester and MacIsaac 2010). The invasion risk decreases as vessel speed increases, because high speeds can remove or kill organisms attached to the hull (Coutts and Taylor 2004). In addition to the level of risk, trade patterns influence the type of introductions that can be expected from a vector. In the case of hull fouling, the shipping route influences the conditions to which organisms are exposed during transit thereby influencing survival rates. Ships that trade coastally are more likely to be a risk for invasion than ships that must pass through high-salinity oceanic waters (Sylvester and MacIsaac 2010). However, some fouling organisms, such as bryozoans and isopods, are capable of surviving broad changes in salinity (0 – 37 ppt), temperature (9.9 – 31.6 °C), latitude (32°) and longitude (43°) (Davidson et al. 2008).

Consideration of factors affecting NIS introductions can be used to better predict high-risk introduction vectors for Canada. Given that these factors will affect invasion risk in different ways for different recipient regions, risk must be assessed separately for the different regions of

Canada. Here, we conduct a risk assessment for ship-mediated introductions of aquatic NIS to the Canadian Arctic as a sub-component of a national risk assessment for ship-mediated introductions to Canada.

BALLAST WATER MANAGEMENT REGULATIONS

Ballasted transoceanic ships have been considered risky for aquatic NIS introductions because each ship can discharge a large volume of ballast which can contain a large number of propagules. On average, ships in the Great Lakes region discharge 5,190 m^3 of ballast water, whereas ships in the Pacific and Atlantic regions discharge 13,915 m^3 and 39,842 m^3 respectively (Humphrey 2008). In the Arctic region, ships discharge an average of 13,400 m^3 at Churchill, the only major seaport in the region (Stewart and Howland 2009). To prevent aquatic NIS introductions, Canada established ballast water management regulations in 2000 requiring all vessels entering and operating in Canadian waters, that are at least 50 m in length with a minimum ballast capacity of eight m^3, to undertake ballast water exchange at sea (Transport Canada 2007), with following exceptions:

- (i) ships that operate exclusively in Canadian waters,
- (ii) ships that operate exclusively in the American waters of the Great Lakes or the French waters of St. Pierre and Miquelon when outside Canadian waters,
- (iii) search and rescue vessels,
- (iv) vessels used in government non-commercial service,
- (v) ships that carry only permanent ballast in sealed tanks.

Ballast water exchange (BWE) is a process in which a ship exchanges ballast water loaded near shore with open-ocean saltwater. Empirical studies indicate that BWE purges 80 – 100% of coastal planktonic organisms entrained at the source port and is particularly effective (>99%) in reducing the abundance of freshwater taxa (Gray et al. 2007; Ruiz and Reid 2007; Bailey et al. 2011). It is hypothesized that any open-ocean taxa present in exchanged ballast tanks will not thrive in coastal and freshwater environments and will be low-risk for invasion. To maximize BWE efficacy, vessels practicing empty-refill exchange must replace a minimum of 95% of their ballast water, whereas flow-through exchange must pump a minimum of three tank volumes through each ballast tank (Canada Shipping Act 2006). Ballast water exchange must occur ≥ 200 nautical miles from land where water depth is ≥ 2000 meters and must achieve a final salinity of ≥ 30 parts per thousand (Canada Shipping Act 2006). If the vessel does not pass an area that meets the minimum requirements during its voyage, Canada will accept exchange in an area ≥ 50 nautical miles from shore where the water depth is ≥ 500 meters (Levings and Foreman 2004). There are also two alternate exchange zones available for vessels which are unable to successfully complete ballast exchange before entering the Canadian Arctic (Transport Canada 2007). Incoming vessels en route to the Hudson Bay region can conduct ballast water exchange in the Hudson Strait east of 70° west longitude with a minimum water depth of 300 meters. Vessels en route to higher Arctic ports can conduct ballast water exchange in Lancaster Sound east of 80° west longitude at a minimum water depth of 300 meters.

Prior to 2006, ships declaring ‘no ballast on board’ were exempt from BWE because ballast tanks were considered empty by industrial standards. Further research revealed that ships declaring ‘no ballast on board’ can contain tonnes of unpumpable residual water, slurry and/or sediment that may introduce NIS during multi-port ballast operations (Bailey et al. 2003; Colautti et al. 2003; Duggan et al. 2005; Sutherland et al. 2009). As a result, Canada implemented the *Ballast Water Control and Management Regulations* requiring tank flushing of unpumpable residuals as well as BWE, such that all ballast tanks entering Canadian waters are managed

(Canada Shipping Act 2006). Similar to BWE, tank flushing involves rinsing ‘empty’ tanks with open-ocean water in an area ≥ 200 nautical miles from shore to achieve a final salinity of ≥ 30 parts per thousand (Transport Canada 2007). Additionally, the uptake of sediment must be minimized, must be monitored and removed on a regular basis, and, when possible, should be deposited at a reception facility. Non-compliant ships are required to either: (i) retain all non-compliant ballast water on board while in Canadian waters, (ii) exchange ballast water at a specified location, (iii) discharge ballast water at a specified location, or (iv) treat ballast water in accordance with an approved method (Canada Shipping Act 2006). As of yet, no alternative treatments have been approved by Canada, although sodium chloride brine has been examined as an emergency treatment for non-compliant tanks (Bradie et al. 2010; Wang 2011).

The International Maritime Organization (IMO), an agency of the United Nations that works to improve maritime safety and prevent pollution from ships, introduced the *International Convention for the Control and Management of Ships Ballast Water and Sediments,* also known as the Ballast Water Convention in February 2004 (IMO 2004). This convention set maximum allowable discharge limits, known as the IMO D-2 discharge standard, for organisms and indicator microbes released with ballast water after ballast treatment. In addition to maximum discharge limits, the Convention requires that BWE be completely phased out and replaced by on-board treatment systems by 2016. There are at least 41 treatment systems in development that use various mechanisms such as filtration, biocides, heat exposure, electric pulse treatment, ultraviolet rays, ultrasound, magnetic fields, deoxygenation, and antifouling coatings to eliminate ballast water taxa (NRC 1996; Environment Canada 2007; Lloyd’s Register 2010; Mamlook et al. 2008). Presently no treatment systems have been approved for use in Canada due to concerns about efficacy and toxicology in cold and fresh waters. Domestic vessels are currently exempt from ballast water regulations in Canada.

HISTORY OF AQUATIC NIS IN THE CANADIAN ARCTIC

The Canadian Arctic constitutes more than 40% of Canada’s land mass and nearly 75% of Canada’s coastline (DFO 2009*a*; Government of Canada 2009). It is one of the harshest marine environments in the world, characterized by low precipitation and cold temperatures (McCalla 1994). Nonetheless, the Arctic is home to over 100,000 Canadians, abundant animal and plant life, and large deposits of important minerals (Arctic Council 2009; Government of Canada 2009). In addition, there are many ecologically senstive areas in the region where animals congregate in large numbers for mating and nursing, and may be vulnerable to impacts from shipping (Arctic Council 2009; Stewart and Howland 2009). Therefore, a balance between development and environmental protection must be maintained to preserve the integrity of the ecosystem and to sustain culturally and economially-important Arctic fish, marine mammals, and natural resources for future generations.

Shipping plays an important role in supporting Arctic communities and transporting Arctic resources to domestic and international markets (McCalla 1994). Re-supply shipping is the predominant way for delivery of food, clothing, transportation equipment, building materials, and fuels to northern communities (McCalla 1994). Moreover, resources such as grain and minerals are regularly shipped out to domestic and international markets. For example, grain is shipped through Churchill because of its proximity to the Canadian prairies and its connection to the rail system (McCalla 1994; Niimi 2007). Nickel concentrates are shipped from a mine operation at Deception Bay (Québec) to Québec City (Québec) for processing (Arctic Council 2009). Recently, there have been plans for mineral and petroleum resource extractions and explorations as well as tourism and community development that may increase exposure of Arctic ports to ships (Arctic Council 2009; Stewart and Howland 2009).

To the best of our knowledge, there has been no ship-mediated NIS established in the Canadian Arctic. However, if shipping activities increase as expected, propagule pressure will also increase and the Arctic will be more vulnerable to future invasions. Approximately 10% of aquatic NIS invasions have had large negative impacts (Ricciardi and Kipp 2008), so we expect that at least some NIS will cause problems for Canadian Arctic ecosystems if introduced. The Arctic Environmental Protection Strategy was enacted in 1991 by Canada, Denmark, Finland, Iceland, Norway, Sweden, the Soviet Union, and the United States. As part of this Strategy, the Arctic countries agreed to take preventative measures to protect the marine environment against pollution and to "cooperate for the conservation of Arctic flora and fauna, their diversity, and their habitats" (Arctic Council 1991). As such, Canada is duty-bound to implement strategies to prevent establishment of a high impact invader.

SPECIFIC ISSUES OF CONCERN TO THE CANADIAN ARCTIC

BIOLOGICAL INVASIONS IN THE ARCTIC

The Arctic has been perceived as an unlikely region for Biological Invasions. First, shipping activity is relatively low in the North compared to temperate ports, thereby limiting vector strength for both ballast water and hull fouling. Second, the harsh environmental conditions in the Arctic are expected to reduce the probability of survival of NIS (Ruiz and Hewitt 2009). Yet, the low occurrence of NIS in Arctic waters may simply result from limited research effort and taxonomic knowledge (Niimi 2004; Ruiz and Hewitt 2009). The lack of baseline information about native Arctic species leads to problems determining if newly reported species are native or nonindigenous, since knowledge of the natural species composition is incomplete.

At least 10 NIS have been reported in Arctic and sub-Arctic waters elsewhere, although information on their modes of transportation and long-term presence (establishment) are not well documented (Hines and Ruiz 2000; Streftaris et al. 2005; Gollasch 2006; Ruiz and Hewitt 2009). In the Antarctic and sub-Antarctic regions, at least 207 NIS have been recorded (Frenot et al. 2005). In addition, a few studies have demonstrated the ability of temperate species to survive the harsh environment of Antarctic waters (Lewis et al. 2006; Lee and Chown 2009). Therefore, Biological Invasions in high latitudes, including the Canadian Arctic, are possible and should be explored further.

CLIMATE CHANGE

Climate change may alter temperature regimes, ocean currents, sea level and other key physical processes, leading to profound changes in species dispersal and survivability (ACIA 2004; Hellmann et al. 2008; Ruiz and Hewitt 2009). In the Northern Hemisphere, both native and nonindigenous species may expand their northern range limits *via* natural dispersal if climate warming occurs. A Pacific diatom (*Neodenticula seminae*), for example, was found in the northern Atlantic Ocean for the first time in 1998 (Reid et al. 2007). The diatom is thought to have migrated from the Northeast Pacific Ocean, across the Canadian Arctic archipelago and into Baffin Bay in the Atlantic Ocean following the melting of sea ice in the previous year (Reid et al. 2007). There has also been increased incidence of Pacific salmonids, including sockeye (*Oncorhynchus nerka*), pink (*O. gorbuscha*), and coho (*O. Kisutch*) salmons, in the Northwest Territories of Canada (Babaluk et al. 2000). Trans-arctic migration may also occur by other species, including molluscs, fishes, and invertebrates, taking advantage of similar dispersal opportunities as a result of more conducive environmental conditions for colonization in the Arctic (Vermeij and Roopnarine 2008; Cheung et al. 2009).

In addition to enhanced natural dispersal, ship-mediated vectors may deliver increasing numbers of NIS to the Arctic. Global climate change is expected to open waterways and shipping channels in the Arctic Ocean along North American and Eurasian coastlines (ACIA 2004; Niimi 2004). For example, the Northwest Passage was ice-free and navigable during the summers of 2007 and 2008 (Cressey 2007; NSIDC 2008), while the Northeast Passage has already been utilized to drastically reduce the time and cost of shipping goods between Europe and Asia (Smith 2009). Furthermore, increasingly warm surface water temperatures may extend the shipping season in the Arctic (ACIA 2004; Howell and Yackell 2004), thus enhancing the probability of an introduction event occurring during favourable conditions for establishment (Bailey et al. 2009; Simberloff 2009). As a result, greater shipping activity and an extended shipping season are likely to increase the ship-mediated invasion risk in the region.

SHIP-MEDIATED INVASIONS *VIA* DOMESTIC SHIPPING ACTIVITIES

Domestic shipping is often overlooked as a vector for NIS transfer, especially for vessels operating within a single biogeographic region. However, intra-coastal shipping can disperse species within a region at much higher rates than would occur naturally, and can also transport species to regions which could not be reached via natural mechanisms (Rup et al. 2010). Since intra-coastal voyages are often short in duration, high survival in ballast tanks is expected and a potentially high number of propagules could be released, making domestic shipping a pathway of interest (Wasson et al. 2001, Simkanin et al. 2009). As Canada does not currently regulate discharges of domestic ballast water, ships can directly transport ballast water from Canadian temperate waters to Canadian Arctic waters without any form of management. This transfer of domestic ballast water may facilitate the establishment of NIS in Arctic waters through the introduction of species which are native to temperate ports but are not native to the Arctic or through the secondary introduction (spread) of NIS previously introduced to temperate Canadian ports.

HULL FOULING IN THE ARCTIC

Hull fouling is known to be an important vector for the transfer of marine and coastal aquatic NIS (Carlton 1985; Gollasch 2002; Coutts 2003) but its importance in transporting NIS to the Arctic is currently unknown. Some research has shown that sea ice present in Arctic environments can scrape hulls thereby removing or negatively affecting fouling taxa (Lewis et al. 2004; Lee and Chown 2009). This may decrease the risk of NIS introduction by killing fouling taxa, or alternatively, it may increase the risk by causing fouling species to be released into the water. In addition, some hull fouling species have been found to survive great salinity, temperature, and latitudinal and longitudinal changes during voyages (Davidson et al. 2008). Viable temperate fouling NIS have been reported following prolonged voyages to sub-Antarctic coastlines, and therefore the possibility of successfully introducing fouling NIS across regions cannot be dismissed (Lewis et al. 2006). Further research on hull fouling biota of vessels operating in the Arctic is necessary to fully evaluate the risk associated with this vector. In 2008, use of the highly effective tributyl tin-based anti-fouling paint was banned by international Convention, which may result in a subsequent increase in fouling organisms transported by vessels. Canada does not currently have domestic hull fouling regulations, although it has supported the adoption of international guidelines for control and management of ships' biofouling.

METHODS

STUDY AREA

For the purpose of this study, the Canadian Arctic covers all Canadian waters north of 60˚ and also includes Ungava Bay, Hudson Bay, and James Bay, as defined by Transport Canada (Figure 2). All harbour zones and wharfs, hereafter referred to as ‘ports’, that received vessel traffic between 2005 and 2008 in the Northern Canada Vessel Traffic Services (NORDREG) Zone were included in the analysis.

DETERMINING HULL FOULING-MEDIATED INVASION RISK

The relative risk posed by a NIS is the product of the probability of introduction and the consequences of introduction. The risk assessment for hull fouling-mediated introductions used a three-step process, following the methods of Orr (2003) and the National Code on Introductions and Transfers of Aquatic Organisms (DFO 2009*b;* Figure 3). First, the probability of introduction was estimated by combining the individual probabilities of successful transition through each stage of the invasion process (i.e., arrival, survival and establishment), based on ship arrival data and environmental conditions at Arctic ports. Second, the potential magnitude of consequences of introduction was estimated based on the number of high impact hull fouling-mediated NIS recorded for eco-regions of ports directly connected to Arctic ports through ship traffic. Finally, the probability of introduction and potential magnitude of consequences were combined for a final relative invasion risk rating. To ensure that uncertainty is characterized in a standardized way for each component of the assessment, we assigned levels of uncertainty, ranging from very high to very low, based on the quality of data available for analysis (Table 1).

Step 1A: Estimating Probability of Arrival (Hull Fouling)

A comprehensive database of vessel arrivals at Canadian Arctic ports was assembled using the Canadian Coast Guard’s Information System on Marine Navigation (INNAV) as the primary data source. Canada requires all commercial vessels to report to the INNAV when entering each Canadian Maritime Communications and Traffic Services Zone, while voluntary reporting typically occurs within each zone for emergency safety reasons. Information reported to the INNAV includes arrival and departure events, and cargo and ballast operations at ports. Vessels were grouped into three categories based on operational region: international, coastal domestic and Arctic, and were further classified into categories according to vessel type (Table 2). Shipping data was organized by month of arrival, vessel class and operational region in order to quantify vessel arrivals and estimate arrival potential associated with different vessel categories. Where logical, we report standard error of the mean (± S.E.M.) with annual average values.

We used the number of vessel arrivals as a proxy for propagule pressure and colonization pressure (i.e., the number of species) of fouling NIS potentially arriving at ports, and hereafter use the term ‘propagule supply’ to describe a joint measure of propagule and colonization pressure. We recognize that the number of vessel arrivals is a coarse proxy for propagule supply as the actual number of NIS individuals and species arriving to the recipient environment have not been quantified. Sailing speed, port layover time, anti-fouling management, and voyage history can all affect the propagule supply associated with hull fouling of individual ships (Minchin and Gollasch 2003; Coutts and Taylor 2004; Sylvester and MacIsaac 2010), but due to data limitations these factors could not be incorporated here.

A ranking system was used to convert the number of vessel arrivals into a relative probability of arrival, where the maximum number of annual arrivals to a single port was divided into five equal categories (Table 3). The choice of five equal categories assumes a positive linear relationship between the two variables, which is consistent with general invasion theory; however, because the number of arrivals is a very coarse proxy for the actual propagule supply received by hull fouling, the associated uncertainty is moderate. Due to the large number of ports in the region and limited time and resources available to complete the risk assessment, we prioritized the top three ports in each vessel category, based on the probability of arrival, for further assessment. It was noted during the peer review that ports ranked below the top three sometimes had values only marginally lower than those ports selected for full assessment; given additional resources in the future, analyses of additional ports below the top three (in all vessel categories) may be of interest.

Step 1B: Estimating Probability of Survival (Hull Fouling)

After being released into a new environment, introduced propagules must survive in the recipient environment in order for an invasion to occur. Species-specific risk assessments typically estimate probability of survival by comparing environmental conditions of native and recipient ranges using data-intensive environmental niche models (e.g. Therriault and Herborg 2007; Therriault et al. 2008a, b). Vector-based risk assessments, involving hundreds to thousands of species, each with individual habitat requirements, prohibit the use of such complex models. While coarse comparison of environmental similarity between source and recipient regions is manageable, the case of hull fouling is further complicated by the potentially long history of species accumulation at a variety of ports. Species encrusted on vessels can represent a menagerie of sources, with the most recent port-of-call contributing perhaps only a very small fraction of the total fouling community (Fofonoff et al. 2003; Mineur et al. 2007). Source-recipient port comparisons would require data on all ports visited since the vessel was last cleaned in drydock, as well the mooring duration at each port and application of any fouling management practices. Since our dataset included only information on the last port-of-call, we could only assign probabilities of survival at a very coarse level. While hull fouling is documented as an important vector of NIS to coastal marine habitats, the risk for fouling by transoceanic vessels appears much lower for freshwater habitats (Sylvester and MacIsaac 2010); therefore, recipient ports which are exclusively freshwater (salinity <2 parts per thousand) were assigned the lowest probability of survival while all other ports were categorized as highest probability of survival. This estimate carries a moderate level of uncertainty since salinity can vary both spatially and temporally with a single port, and because biological analyses of hull-fouling taxa have not been conducted in the Arctic previously.

Step 1C: Calculating Probability of Introduction (Hull Fouling)

The probabilities of arrival and survival were calculated as separate, independent events. However, because the overall probability of introduction is dependent on the sequential occurrence of arrival and survival, a minimum probability approach was used to determine the overall probability that all stages are passed successfully (Orr 2003; DFO 2009*b*). For example, given a very low probability of arrival and a very high probability of survival, the overall probability of introduction would be very low, because high survival probabilities are offset by a very low number of arriving individuals made available to survive. Due to the very large number of potential hull-fouling species, we were unable to estimate the probability that a reproductive population of any one NIS could establish at a recipient Arctic port or become widespread within Canada (but see section 3.5 on ship-mediated secondary spread). Excluding these two stages of invasion from the analysis essentially sets their probabilities at the highest level since the minimum probability approach retains the value of the component with the lowest rating. The minimum probability approach is widely used in qualitative risk assessments (e.g., Canadian

Food Inspection Agency Weed Risk Assessment Guidelines, Aquatic Nuisance Species Task Force, and Commission for Environmental Cooperation Risk Assessment Guidelines) and produces risk ratings most consistent with quantitative risk approaches (Koops and Cudmore 2009). In contrast, we retained the highest level of uncertainty for any one stage of invasion as the uncertainty associated with the probability of introduction.

Step 2: Estimating the Magnitude of Consequences (Hull Fouling)

Predicting potential impacts of NIS involves evaluating the physical-chemical requirements of the NIS and their interactions with native species at recipient sites; a species-specific estimate for potential impact (Colautti and MacIsaac 2004; Lockwood et al. 2006). Again, predicting potential impact for a vector-based risk assessment is complicated by the wide range of possible NIS associated with the vector. Since up-to-date, port-specific lists of native species and established NIS are not available for most ports, we compiled a list of high impact fouling NIS for connected source ports using data from the Nature Conservancy's Marine Invasive Database (Molnar et al. 2008; available at http://conserveonline.org/workspaces/global.invasive.assessment). The database includes 81 high impact fouling NIS in 232 ecoregions. High-impact NIS are defined as introduced species that disrupt multiple species, ecosystem function, and/or keystone or threatened species (Molnar et al. 2008). We first tabulated the number of high impact fouling NIS recorded for the ecoregion of each source port directly connected to each top Arctic port, assuming that each connected port may be a donor of all high impact fouling NIS established within the ecoregion; therefore, multiple tally counts are given to a single NIS that could originate from multiple source ports.

A ranking system was used to convert the cumulative number of high impact NIS connected to each top Arctic port into a relative magnitude of consequences, where the maximum value was divided into five equal categories (Table 4). Again, the choice of five equal categories assumes a positive linear correlation, consistent with general theory to date. Because the list of high impact species was available for ecoregions rather than specific ports, does not account for species that may cause high impacts in new recipient regions despite low or negligible impact in source regions, and does not account for high impact species that are native to the source region, the level of uncertainty associated with magnitude of consequences was considered moderate.

Step 3: Calculating Final Invasion Risk (Hull Fouling)

The probability of introduction (Step 1) and magnitude of consequences (Step 2) of hull fouling-mediated NIS were combined into a final relative invasion risk based on a symmetrical mixed-rounding matrix that reduces the final ratings to three levels (modified from Therriault and Herborg 2007; Table 5). The colouring of this matrix was determined by consensus at the peer review meeting to be the most balanced approach for assigning levels of risk; however, the matrix can easily be changed to accommodate differing risk tolerance levels by risk managers and/or stakeholders. The highest level of uncertainty assigned to either probability of introduction or magnitude of consequences was retained as the uncertainty associated with the final invasion risk.

ESTIMATING SHIP-MEDIATED SECONDARY SPREAD (HULL FOULING)

The dataset assembled to estimate the probability of arrival provided opportunity to estimate the potential for secondary spread of fouling NIS from top Arctic ports to other Canadian ports by fouling of domestic ships. Recognizing that NIS introduced via hull fouling may spread by a variety of natural and anthropogenic vectors other than hull fouling, for which we have no information, this measure of secondary spread was not incorporated into the probability of introduction. Further, it was not clear if spread should be included in a vector-based risk assessment as a component of the probability of introduction or the magnitude of consequences, since the extent of secondary spread can influence the magnitude of impact. However, we include the information here as a valuable resource that could be used to direct hull fouling management activities.

Assuming that each vessel arriving to an Arctic port would subsequently depart to a next port-of-call, the number of coastal domestic and Arctic vessel arrivals at each top port was used as a surrogate measure for the number of coastal domestic and Arctic vessel departures from Arctic top ports. A ranking system was used to convert the data into a relative probability of spread, where the maximum value was divided into five equal categories (Table 6). Again, the choice of five equal categories assumes a positive linear correlation, consistent with general theory to date. The level of uncertainty is considered moderate for the same reasons described for probability of arrival for hull fouling.

DETERMINING BALLAST-MEDIATED INVASION RISK

A three step process, similar to that outlined above for hull fouling, was utilized to determine the relative level of invasion risk posed by ballast water (Figure 4). First, the probability of introduction was estimated by combining the individual probabilities of successful transition through each stage of the invasion process (i.e., arrival and survival), based on ballast water discharge data and environmental similarity between source and recipient ports. Second, the potential magnitude of consequences of introduction was estimated based on the number of high impact ballast-mediated NIS recorded for eco-regions of source ports. Finally, the probability of introduction and potential magnitude of consequences were combined for a final invasion risk rating. To ensure that uncertainty is characterized in a standardized way for each component of the assessment, we assigned levels of uncertainty, ranging from very high to very low, based on the quality of data available for analysis (Table 1). We recognize that residual sediments in ballast tanks may increase the propagule supply associated with ballast water discharge by commercial vessels (Bailey et al. 2007); however, we did not have adequate data to evaluate this vector for this study.

Step 1A: Estimating Probability of Arrival (Ballast Water)

Ballast water information obtained from the Transport Canada Ballast Water Database (https://wwwapps2.tc.gc.ca/saf-sec-sur/4/cpscs-scepc/default.asp, accessed March 2009), for all ships arriving between 2005 and 2008, was incorporated into the ship arrivals database described in Section 3.2, Step 1A. Data self-reported by vessels to Transport Canada provides information on the ballast history for each vessel transit, including ballast tank capacities, ballast uptake and discharge events, and any management activities. All vessels with a ballast capacity greater than eight m^3 are required to submit ballast water reports prior to the first port of call in Canadian waters. Only merchant vessels, comprising 1,161 transits or 54% of total shipping traffic in the Arctic, were considered for the ballast water assessment because other vessel types carry very little or no ballast water and do not consistently report ballast activities to Transport Canada. We cross-referenced ballast water activities reported to Transport Canada with cargo activities reported to INNAV for validation purposes. Cargo and ballast information is typically reported to INNAV in binary format (load or unload; volumes are not reported), and all reports are date and time coded. Because vessels operating within Canadian waters are not required to submit ballast water reports in Canada, ballast information for vessels on domestic transits were obtained directly from shipping companies and/or reconstructed from INNAV data. We contacted 18 shipping agents and Captains, representing 26 coastal domestic vessels that regularly operated in the Canadian Arctic during the study period, for ballast water information. Four contacted personnel were able to provide ballast water records for six coastal domestic vessels. Therefore, INNAV data was used to fill in gaps in ballast water data for 1,083 coastal domestic transits, representing 93% of total merchant transits. Following Rup et al. (2010), we assumed that ballast water was discharged when cargo was loaded, and vice versa, resulting in 77 transits with ballast water discharge. Discharge volumes were estimated for 50 of these transits using the historical median discharge volume previously reported by the same vessel on non-Arctic transits. For the remaining 27 transits, discharge volumes were assigned according to vessel type and size class, assuming that 'sister ships' carry the same volume of ballast water (see Rup et al. 2010). Further, it was assumed that the last port-of-call was the source of the ballast water and that the ballast was moved directly between ports since domestic transits are exempt from ballast water management regulations, unless voluntary ballast water reports with ballast water source and/or exchange information were available. For ease of summary, the geographic location of ballast water sources was summarized by region, including the Arctic, Northwest Atlantic, Northeast Atlantic, West-central Atlantic, East-central Atlantic, Southeast Atlantic, and Mediterranean and Black Sea, as described by the Food and Agriculture Organization (FAO 2009) (Figure 5) and as used in past ballast water studies (e.g., Amoako-Atta and Hicks 2004; Simard and Hardy 2004; Claudi and Ravishankar 2006).

The volume of foreign ballast water discharged by international vessels was corrected to account for reduction in propagule supply due to mandatory management activities. This correction was also applied to ballast water discharged by coastal domestic vessels that reported conducting voluntary ballast water exchange to Transport Canada. Ballast water exchange can reduce propagule supply by flushing out most entrained organisms and killing those that remain via osmotic stress associated with rapid salinity change (Wonham et al. 2001; Ruiz and Smith 2005). However, some viable NIS propagules entrained at the source port may remain viable in tanks despite full compliance by ships (Wonham et al. 2001; Levings and Foreman 2004; Ruiz and Smith 2005). A correction factor of 0.1 for ships with ballast water from saline ports, or 0.01 for freshwater ports, was applied to the reported volumes of exchanged ballast water to estimate propagule supply. These values were derived from ballast water exchange efficacy rates, as determined by total zooplankton abundance, reported for saline water (90%) and freshwater (99%) ports, respectively (Ruiz and Smith 2005; Gray et al. 2007). Ballast water discharged by international and coastal domestic merchant vessels was evaluated separately because vessels in different operational regions will likely carry different species assemblages with different characteristics and requirements affecting invasion risk. There were no Arctic merchant vessels operating in the Canadian Arctic during the study period. Where logical, we report standard error of the mean (± S.E.M.) with annual average volumes.

We used the corrected volume of ballast water discharged as a proxy for the propagule supply of NIS potentially arriving at ports by ballast water. Ballast volume acts like a scaling coefficient, where large volumes are more likely to transport larger propagule pressure, but can also transport low propagule pressure. While propagule pressure associated with the ballast water of any single vessel is expected to be more directly related to physico-chemical and/or geographic-seasonal factors like water salinity, age of ballast water and management practices than total volume (Aguirre-Macedo et al. 2008; Burkholder et al. 2007; McCollin et al. 2008; Villac and Kaczmarska 2011), the available dataset did not include these data. While imperfect, the use of volume is consistent with previous studies (Drake and Lodge 2004; Herborg et al. 2007; Simkanin et al. 2009).

A ranking system was used to convert the volume of ballast water discharged into a relative probability of arrival, where the maximum mean annual corrected volume of ballast water discharged at a single Arctic port was divided into five equal categories (Table 7). The choice of five equal categories assumes a positive linear relationship between the two variables, which is consistent with general invasion theory; recognizing that the volume of ballast water discharged is a robust but not a direct measurement of the propagule supply within the water, the associated uncertainty level was set as low. Due to the large number of ports in the region and limited time and resources available to complete the risk assessment, we prioritized the top three ports in each vessel category, based on the probability of arrival, for full assessment. It was noted during the peer review that ports ranked below the top three sometimes had values only marginally lower than those ports selected for full assessment; given additional resources in the future, analyses of additional ports below the top three (in all vessel categories) may be of interest.

Step 1B: Estimating Probability of Survival (Ballast Water)

Following the reasoning outlined in section 3.2, Step 1B, we conduct a comparison of the environmental similarity between source and recipient ports of ballast water to estimate the probability of survival. Environmental similarity analysis between NIS source and recipient ports is common in ballast water risk assessments (see Hilliard et al. 1997; Gollasch and Leppäkoski 1999; Hayes and Hewitt 2001; Mills and Thomas 2006; Herborg et al. 2007; Keller et al. 2010). The main advantage of this approach is that it rapidly assesses the likelihood of NIS survival post-arrival based on the environmental conditions of the source and recipient sites (Barry et al. 2008). All ports directly connected to each top Arctic port as a source of ballast water were noted, allowing identification of source-recipient port-pairs. Following methodology of Keller et al. (2010) we selected four parameters to estimate environmental similarity between port-pairs, including annual average water temperature, mean water temperature during the warmest month, mean water temperature during the coldest month and annual average salinity. We recognize that additional variables such as pH, dissolved oxygen, tidal range, rainfall, day length and ice cover can influence species survival potential at the recipient environment. However, we focused our analysis on temperature and salinity because they are fundamental physical factors for survival and reproduction of aquatic organisms (Kinne 1963; Anger 1991; Browne and Wanigasekera 2000; Verween et al. 2007). In addition, including variables that are not related to invasion risk for some or all potential NIS can dramatically influence the sensitivity of the environmental similarity measure (Barry et al. 2008).

Following Keller et al. (2010), environmental similarity between top ports and global ports was calculated using Euclidean distance in four-dimensional space. Euclidean distance was used because it is a simple method to measure linear distance and is commonly used to measure environmental similarity between two locations (Barry et al. 2008). Sensitivity analysis revealed that salinity was the most influential variable in this calculation, and thus had approximately equal overall weight in the outcome as the three temperature parameters (Keller et al. 2010). We obtained data for the four environmental parameters for 6,651 global ports from Keller et al. (2010). In addition, we interpolated data for these four environmental parameters in ArcGIS 10 (ESRI Inc.) for 56 Arctic ports not included in Keller et al. (2010) using data from the World Ocean Atlas (Antonov et al. 2006; Locarnini et al. 2006). All environmental values were standardized using a z-transformation so that each variable had equal weight in the calculation. Euclidean distance values between each top port and all connected source ports were averaged to obtain a final rating for survival potential.

A ranking system was used to convert the average Euclidean distance value for each port into a

relative probability of survival, where the maximum value for any single source-recipient port-pair (of all possible global port-pairs, not just those that were identified as connected in this dataset) was divided into five equal categories (Table 8). Again, the choice of five equal categories assumes a positive linear correlation, consistent with general theory to date. This estimate carries a moderate level of uncertainty since spatial and temporal variation in salinity at a single port are likely not well represented by the annual average salinity.
Further, we recognized that biological interactions may also enhance or impede NIS survival at the recipient port (Colautti and MacIsaac 2004) but we were unable to assess these interactions due to the large number of species potentially associated with the ballast water vector.

Step 1C: Calculating Probability of Introduction (Ballast Water)

As described above for hull fouling, probabilities of arrival and survival were combined into a probability of introduction using the minimum probability method, while retaining the highest level of uncertainty. Probabilities of establishment and spread were not included in this risk assessment, but information about potential for ship-mediated secondary spread is provided below.

In addition, to identify potentially important source ports of ballast-mediated NIS, we overlaid propagule supply and environmental similarity measures between all connecting port-pairs ArcGIS 10. Port-pairs in the upper two categories for both components were considered most likely sources of NIS due to sufficient propagule supply and environmental matching (Orr 2003).

Step 2: Estimating the Magnitude of Consequences (Ballast Water)

Similar to the methodology described above for hull fouling, we compiled a list of high impact ballast-mediated NIS for connected source ports using the Nature Conservancy's Marine Invasive Database (Molnar et al. 2008). The database includes a total of 90 high impact ballast-mediated NIS in 232 ecoregions. We first tabulated the number of high impact ballast-mediated NIS recorded for the ecoregion of each source port directly connected to each top Arctic port, assuming that each connected port may be a donor of all high impact ballast-mediated NIS established within the ecoregion; therefore, multiple tally counts are given to a single NIS that could originate from multiple source ports.

A ranking system was used to convert the cumulative number of high impact NIS connected to each top Arctic port into a relative magnitude of consequences, where the maximum value was divided into five equal categories (Table 9). Again, the choice of five equal categories assumes a positive linear correlation, consistent with general theory to date. Because the list of high impact species was available for ecoregions rather than specific ports, does not account for species that may cause high impacts in new recipient regions despite low or negligible impact in source regions, and does not account for high impact species that are native to the source region, the level of uncertainty associated with magnitude of consequences was considered moderate.

Step 3: Calculating Final Invasion Risk (Ballast Water)

The probability of introduction (Step 1) and magnitude of consequences (Step 2) of ballast-mediated NIS were combined into a final relative invasion risk based on a symmetrical mixed-rounding matrix, as described above for hull fouling (Table 5). The highest level of uncertainty assigned to either probability of introduction or magnitude of consequences was retained as the uncertainty associated with the final invasion risk.

ESTIMATING SHIP-MEDIATED SECONDARY SPREAD (BALLAST WATER)

As described in Section 3.3 above, the assembled dataset provided opportunity to estimate the potential for secondary spread of ballast-mediated NIS from top Arctic ports to other Canadian ports by domestic ships, but was not considered comprehensive enough to include as a probability of spread in the risk assessment. We were unable to estimate the volume of ballast water being transferred among ports since coastal domestic and Arctic vessels are not required to submit ballast water report forms, and we could not reasonably assign a given volume of ballast loaded per ship due to the multi-port, variable cargo activities of domestic vessels in the Arctic. Instead, we assessed only the number of ballast water uptake events, assuming that all vessels that discharged cargo subsequently loaded ballast water before departing for the next domestic port-of-call. Essentially, the number of ballast water uptakes at each top Arctic port was calculated by subtracting the number of ballast water discharge events from the number of arrivals, for all coastal domestic and Arctic vessels. A ranking system was used to convert the data into a relative probability of spread, where the maximum value was divided into five equal categories (Table 10). Again, the choice of five equal categories assumes a positive linear correlation, consistent with general theory to date. The level of uncertainty is considered moderate for the same reasons described for probability of arrival for ballast water.

RESULTS AND DISCUSSION

VESSEL ARRIVALS IN THE CANADIAN ARCTIC

A total of 2,397 distinct vessel arrivals were recorded between 2005 and 2008, arriving at 135 of 195 Canadian Arctic ports registered in the INNAV database. The annual number of vessel arrivals averaged 599 (± 67; value as SEM, hereafter), with a trend of increasing numbers over time ($R^2 = 0.95$) (Table 11). The increase in vessel arrivals was due to a higher intensity of shipping traffic in September and October of 2007 and 2008 rather than an extended shipping season (Figure 6). Ninety-nine percent of vessel arrivals took place between July and November, with peak arrivals occurring in August. Significant differences in annual arrivals by vessel type were observed (Kruskal-Wallis test, $p < 0.05$), with international merchant (168 ± 26) and passenger (166 ± 22) vessels having the greatest number of arrivals, followed by coastal domestic merchant vessels (122 ± 10)(Figure 7). The remaining vessel types, including Coast Guard, fishing, special purpose, and research vessels, accounted for 24% of the annual arrivals. All vessel types operated internationally and within the Canadian EEZ, although some Coast Guard vessels and barges/tugs operated exclusively within the Canadian Arctic.

Strong spatial variation in shipping patterns was noted in the Canadian Arctic. The majority of vessels entering Arctic waters were destined for ports in the Hudson Bay region (Figure 8) and were primarily merchant vessels, followed by passenger vessels and tugs/barges (Figure 9). Vessels destined for ports in the Eastern Arctic were mainly passenger vessels followed by merchant vessels, while tugs/barges were the main vessel type to visit ports in the Western Arctic (Figure 9). The Hudson Bay region received the highest number of international and coastal domestic arrivals, followed by the Eastern Arctic. In contrast, the Western Arctic primarily received vessels from Canadian Arctic ports (Figure 10).

Probability of Arrival (Hull Fouling)

International Merchant Vessels
An average of 168 (± 26) distinct international merchant vessel arrivals was reported at 55 Canadian Arctic ports during the study period. Churchill (Manitoba), Iqaluit (Nunavut) and Deception Bay (Québec) were the top three ports receiving the greatest number of international merchant vessel arrivals (Table 12). However, only Churchill and Iqaluit had highest or higher probabilities of arrival *via* international merchant vessels, respectively. Arrival probabilities for the remaining top ports ranged from lowest (not shown in Table 12) to intermediate. Port locations are shown in Figure 11.

International merchant vessels operate within a truly global network, providing opportunity for introduction of a wide variety of NIS (Kaluza et al. 2010; Keller et al. 2010). Transoceanic voyages, however, generally expose fouling organisms to long voyages, high travelling speeds and large variation in temperature and salinity, which may decrease survival and subsequent invasion risk (Coutts 2003; Coutts and Taylor 2004).

Coastal Domestic Merchant Vessels
An average of 122 (± 10) distinct coastal domestic merchant vessel arrivals was reported at 53 Canadian Arctic ports during the study period. Iqaluit, Deception Bay and Kuujjuaq (Fort Chimo, Québec) were the top three ports receiving the greatest number of coastal domestic merchant vessel arrivals (Table 13). However, only Iqaluit had highest probability for arrival of hull-mediated NIS *via* coastal domestic vessels. Arrival probabilities for the remaining Arctic ports ranged from lowest to intermediate. Port locations are shown in Figure 11.

Coastal domestic merchant vessels may be more likely than international merchant vessels to transport viable fouling organisms to the Arctic, since coastal domestic voyages are generally a shorter geographic distance, and sometimes within similar latitudes, presumably resulting in less variable temperature and salinity regimes (Coutts and Taylor 2004). However, coastal domestic vessels likely play a more prominent role in the spread of native nuisance species and/or established NIS, rather than the introduction of new NIS from foreign sources (Carlton and Hodder 1995; Lavoie et al. 1999).

International Non-merchant Vessel Arrivals
An average of 178 (± 23) distinct international non-merchant vessel arrivals was reported at 86 Canadian Arctic ports during the study period. Erebus Bay/Beechey Island (Nunavut), Iqaluit and Dundas Harbour (Nunavut) were the top three ports receiving the greatest number of international non-merchant vessel arrivals (Table 14). However, only Erebus Bay/Beechey Island had higher probability for arrival of hull-mediated NIS *via* international non-merchant vessels[1]; although not a structurally defined ‘port’ per se, passenger vessels often stop at Erebus Bay/Beechey Island to view graves from the Franklin expedition. Arrival probabilities for the remaining Arctic ports ranged from lower to intermediate. Port locations are shown in Figure 11.

[1] It was noted by industry experts during the peer review that passenger vessels arriving to Beechey Island may be converted icebreakers with hulls coated in an epoxy paint that allows the vessel to slip easily through the ice; the ability of NIS to foul hulls with this coating was questioned. Thus, risk of arrival of hull fouling species may be overestimated here, and further research is recommended.

Similar to international merchant vessels, international non-merchant vessels are connected to a variety of foreign ports, which may provide opportunity for introduction of a variety of foreign NIS. Some non-merchant vessel types, such as fishing vessels, passenger ships and yachts, can have long port layover time and/or low travelling speed, factors that enhance fouling on hulls (Minchin and Gollasch 2003; Sylvester and MacIsaac 2010). As a result, non-merchant vessels can exhibit a higher abundance of fouling on hulls compared to merchant vessels (Minchin and Gollasch 2003; Coutts and Taylor 2004; Farrapeira et al. 2007).

Coastal Domestic Non-merchant Vessel Arrivals

An average of 65 (± 15) distinct coastal domestic non-merchant vessel arrivals was reported at 34 Canadian Arctic ports during the study period. Baker Lake/Qaminituak (Nunavut), Churchill and Chesterfield Inlet/Iguligaarjuk (Nunavut) were the top three ports receiving the greatest number of coastal domestic non-merchant vessel arrivals (Table 15). However, only Baker Lake/Qaminituak had higher probability for arrival of hull-mediated NIS *via* coastal domestic non-merchant vessels. Arrival probabilities for the remaining Arctic ports ranged from lowest to intermediate. Port locations are shown in Figure 11.

As above, the non-merchant nature of this vessel category may correlate with higher abundance of fouling on hulls; however, being coastal domestic, these ships are more likely to spread native nuisance species and/or established NIS from other Canadian ports, rather than introduce new foreign NIS.

Arctic Non-merchant Vessel Arrivals

An average of 66 (± 16) distinct Arctic non-merchant vessel arrivals was reported at 41 Canadian Arctic ports during the study period. Cambridge Bay/Ikaluktutiak (Nunavut), Tuktoyaktuk (Northwest Territories) and Baker Lake/Qaminituak were the top three ports receiving the greatest number of Arctic non-merchant vessel arrivals (Table 16). None of the top Arctic ports had higher or highest probability for arrival of hull-mediated NIS *via* Arctic non-merchant vessels; arrival probabilities for all top ports ranged from lowest to intermediate. Port locations are shown in Figure 11.

As above, Arctic non-merchant vessels may be associated with spread of native nuisance species and/or established NIS between Arctic ports.

Probability of Survival (Hull Fouling)

Baker Lake was the only top Arctic port with an annual average salinity < 2 parts per thousand and therefore had lowest probability for survival of NIS *via* hull fouling among top Arctic ports (Table 17). All of the remaining top Arctic ports considered in this risk assessment have annual average salinities >2 parts per thousand and had highest probability for survival of NIS *via* hull fouling.

Probability of Introduction (Hull Fouling)

Churchill and Iqaluit have the highest probability for introduction of hull fouling-mediated NIS, *via* international merchant and coastal domestic merchant vessels, respectively (Table 17). Iqaluit, and Erebus Bay/Beechey Island have higher probability of introduction of hull fouling-mediated NIS *via* international merchant and international non-merchant vessels, respectively (Table 17). Probability of introduction for the remaining top ports ranged from lowest to intermediate, thus hull fouling-mediated NIS introduction is less likely at these ports.

Magnitude of Consequences (Hull Fouling)

The cumulative number of high impact fouling NIS at each top port by vessel category ranged from 0 to 776, representing 61 distinct NIS (Table 18; Appendix E). Churchill was rated highest for magnitude of potential consequences of NIS *via* international merchant vessels, with a cumulative number of 776 high impact fouling NIS (60 distinct NIS). The remaining top ports were rated lowest for magnitude of potential consequences of fouling NIS, with two top ports having zero fouling NIS reported from connected ecoregions.

Final Invasion Risk (Hull Fouling)

Churchill has higher risk for hull-mediated invasions *via* international merchant vessels (Table 19). The invasion risk for the remaining top ports for each vessel category ranged from lower to intermediate.

SECONDARY SPREAD BY HULL FOULING

Iqaluit and Baker Lake/Qaminituak have the highest potential to act as sources for hull fouling-mediated spread of NIS within Canada (Table 20). Iqaluit is a top port for international and coastal domestic merchant vessel arrivals as well as international non-merchant vessel arrivals, whereas Baker Lake/Qaminituak is a top port for coastal domestic and Arctic non-merchant vessel arrivals. Churchill and Chesterfield Inlet/Iguligaarjuk have higher potential for hull fouling-mediated spread of NIS. Churchill is a top port for international merchant and coastal domestic non-merchant vessel arrivals, whereas Chesterfield Inlet/Iguligaarjuk is a top port for coastal domestic non-merchant vessel arrivals. Fouling NIS introduced to these ports by the aforementioned vessel categories may spread to other Canadian ports by domestic transport pathways. As a result, these top ports may serve as hubs for stepping stone invasions if fouling NIS successfully establish at these sites. Spread potential for the remaining top ports ranged from lowest to intermediate and may play a less prominent role in the spread of fouling NIS within Canada.

BALLAST WATER DISCHARGES IN THE CANADIAN ARCTIC

During the study period, merchant vessels conducted 39 (± 2) ballast water discharges at 29 Arctic ports, averaging 275,714 (± 6,644) m^3 annually. After correcting for the reduction in propagule supply as a result of ballast water exchange, the average annual volume discharged was 92,625 (± 11,251) m^3 (Table 21). The number of discharge events decreased over time (R^2 = 0.95), though a similar volume was reported each year (Table 21). The annual total corrected volume discharged differed significantly by source region (Kruskal-Wallis test, $p < 0.05$), with most water originating from Canadian ports in the Northwest Atlantic and Arctic, followed by unknown sources and foreign ports in Northeast Atlantic, Mediterranean and Black Sea, West-central Atlantic, East-central Atlantic and Southeast Atlantic (Figure 12). All foreign-sourced ballast water was exchanged at sea prior to discharge, resulting in a relatively small volume after application of the correction factors. Voluntary ballast water exchange was reported for 22 coastal domestic vessel transits, to which correction factors were also applied.

Strong spatial variation was observed for ballast water activities (Figure 13). Ports in the Hudson Bay region received the greatest total corrected volume of ballast water (76,145 ± 9,757 m^3), which mainly originated from ports in the Arctic, followed by the Northwest Atlantic and unknown regions (Figure 14). Eastern Arctic ports received 16,308 (± 5,057) m^3 of total corrected ballast water annually, all of which originated from either the Arctic or Northwest Atlantic. Finally, only one port in the Western Arctic received ballast water (173 ± 173 m^3), sourced directly from the Arctic, during the study period.

Probability of Arrival (Ballast Water)

International Merchant Vessels

During the study period, international merchant vessels conducted 27 (± 1.7) ballast water discharges at 24 Arctic ports, averaging 197,589 (± 15,271) m^3 per year. After correcting for the reduction in propagule supply as a result of ballast water exchange, the average annual volume discharged was 70,097 (± 8,182) m^3. Churchill, Milne Inlet (Nunavut) and Deception Bay were the top three ports receiving the greatest total corrected volume of ballast water discharged by international merchant vessels (Table 22). However, only Churchill had highest probability for ballast-mediated NIS arrival *via* international merchant vessel discharges. Arrival probabilities for the remaining top ports ranged from lowest to lower. Port locations are shown in Figure 15.

Ballast water from international source ports must now be exchanged or flushed on the open ocean, which dramatically reduces potential propagule supply to Canadian ports (Bailey et al. 2011). Therefore, ballast water discharged by international merchant vessels may no longer play a prominent role in introducing NIS from foreign sources.

Coastal Domestic Merchant Vessels

During the same period, coastal domestic merchant vessels conducted 12 (± 2.0) discharges at 15 Arctic ports, averaging 78,125 (± 13,802) m^3 annually. After correcting for the reduction in propagule supply as a result of ballast water exchange, the average annual volume discharged was 22,528 (± 3,947) m^3. Churchill, Deception Bay and Iqaluit were the top three ports receiving the greatest total corrected volume of ballast water discharged by coastal domestic vessels (Table 23). The probability of arrival of ballast-mediated NIS *via* coastal domestic merchant vessel discharges was lowest for all top Arctic ports. Port locations are shown in Figure 15.

Ballast water discharged by coastal domestic vessels may have a higher propagule supply compared to international vessels due to the inverse relationship between duration of voyage and propagule survival – plankton are more likely to survive the environmental conditions, and resist predation and competition inside a ballast tank over a shorter period of time (Lavoie et al. 1999; Verling et al. 2005; Simkanin et al. 2009). However, coastal domestic vessels likely play a more prominent role in the spread of native nuisance species and/or established NIS, rather than the introduction of new NIS from foreign sources (Carlton and Hodder 1995; Lavoie et al. 1999).

Probability of Survival (Ballast Water)

International Merchant Vessels

Forty-eight foreign, two coastal domestic and one Arctic ballast water source ports were identified and evaluated for environmental similarity with Churchill (Table 24). The overall probability of survival at Churchill was intermediate, with 29 source ports having higher or highest environmental similarity to Churchill. Port Alfred (Québec) has a higher environmental similarity to Churchill and may act as a source of ballast-mediated NIS because it also had a higher volume of ballast water discharge (Figure 16). The remaining connected ports are less likely sources of ballast-mediated NIS to Churchill because of either low propagule supply and/or environmental mismatch between individual port-pairs. A list of all global ports with highest environmental similarity to Churchill is provided in Appendix A; NIS originating from these ports would have the highest probability for survival if introduced to Churchill.

One coastal domestic ballast water source port, Port Alfred, was identified and evaluated for environmental similarity with Milne Inlet (Table 25). The environmental similarity between Milne Inlet and Port Alfred indicates an intermediate probability of survival. Despite high propagule supply, Port Alfred does not appear to be a likely source for ballast-mediated NIS because of environmental mismatch (Figure 17). A list of all global ports with highest environmental similarity to Milne Inlet is provided in Appendix B; NIS originating from these ports would have the highest probability for survival if introduced to Milne Inlet.

One foreign, two coastal domestic and one Arctic ballast water source ports were identified and evaluated for environmental similarity with Deception Bay (Table 26). The overall probability of survival at Deception Bay was higher, with four source ports having higher or highest environmental similarity to Deception Bay. Despite the higher environmental similarity, none of the source ports are likely sources of ballast-mediated NIS to Deception Bay because of low propagule supply (Figure 18). A list of all global ports with highest environmental similarity to Deception Bay is provided in Appendix C; NIS originating from these ports would have the highest probability for survival if introduced to Deception Bay.

Coastal Domestic Merchant Vessels

One coastal domestic and five Arctic ballast water source ports were identified and evaluated for environmental similarity with Churchill (Table 27). All connected source ports had highest environmental similarity to Churchill, indicating highest probability of survival at Churchill. In contrast, all connected ports have low propagule supply to Churchill, making these ports unlikely sources of ballast-mediated NIS (Figure 19).

Five coastal domestic ballast water source ports were identified and evaluated for environmental similarity with Deception Bay (Table 28). The overall probability of survival at Deception Bay was intermediate, with one source port having highest environmental similarity to Deception Bay. No connected ports were identified as likely sources of ballast-mediated NIS to Deception Bay because of low propagule supply and/or environmental mismatch (Figure 20).

Two Arctic ballast water source ports were identified and evaluated for environmental similarity with Iqaluit (Table 29). All connected source ports had highest environmental similarity with Iqaluit, indicating highest probability of survival. However, all connected ports have low propagule supply to Iqaluit, making these ports unlikely sources of ballast-mediated NIS (Figure 21). A list of all global ports with highest environmental similarity to Iqaluit is provided in Appendix D; NIS originating from these ports would have the highest probability for survival if introduced to Iqaluit.

Probability of Introduction (Ballast Water)

All top ports have a lowest to intermediate probability of introduction of ballast-mediated NIS (Table 30).

Magnitude of Consequences (Ballast Water)

The cumulative number of high impact ballast-mediated NIS at each top port by vessel category ranged from 1 to 875, representing 78 distinct NIS (Table 31; Appendix F). Churchill was rated highest for magnitude of potential consequences of NIS *via* international merchant vessels, with a cumulative number of 875 ballast-mediated NIS (78 distinct NIS). The remaining top ports from all vessel categories rated lowest for magnitude of potential consequences by ballast-mediated NIS.

Final Invasion Risk (Ballast Water)

Churchill has higher invasion risk for ballast-mediated invasions *via* international merchant ballast water discharges (Table 32). The invasion risk for the remaining top ports was lower.

SECONDARY SPREAD BY BALLAST WATER

Iqaluit has the highest potential for ballast-mediated spread of NIS within Canada (Table 33). Iqaluit is a top port for domestic direct and exchanged ballast water discharges by coastal domestic merchant vessels. Iqaluit may serve as a hub for stepping stone invasions if ballast-mediated NIS successfully establish at this port. Spread potential for the remaining top ports ranged from lowest to lower potential and therefore these ports may play a less prominent role in the spread of ballast-mediated NIS within Canada.

THE FUTURE OF SHIP-MEDIATED INVASIONS IN THE ARCTIC

The results presented in this report are based on current shipping patterns and environmental conditions; any changes to one or both factors in the future would lead to changes in ship-mediated invasion risk. In particular, several large-scale resource developments have been proposed for the next 20 years, including mining operations at Mary River on Baffin Island for iron ore, Roche Bay on Baffin Island for magnetite and High/Izok Lake near Yellowknife for lead/zinc/copper concentrate (Arctic Council 2009). These resource operations would require shipping for bulk exports as well as logistics and fuel imports (Arctic Council 2009). In addition, plans to diversify international commodity shipments at Churchill to increase the port's viability (Stewart and Howland 2009) and proposals to develop deepwater ports, such as the one at Iqaluit, to allow larger vessels to access more areas of the Arctic will further increase shipping traffic in the region (Stewart and Howland 2009; City of Iqaluit 2010). The Government has also announced plans and allocated resources to promote social and economic development through the Northern Strategy (Government of Canada 2010). The region will likely experience rapid growth and development, and rely on shipping for supply/resupply. The growing popularity of Arctic marine tourism and the cruise industry's plan to expand and diversify the Arctic market may lead to increases in non-merchant shipping (Arctic Council 2009). As a result, shipping traffic is expected to increase due to demand for goods by growing communities, expanding resource development projects, and increasing tourism in the region (Arctic Council 2009). This trend is already apparent in our four-year shipping data, particularly in late summer. Further, the aforementioned activities may demand development of new and existing shipping routes. For example, commercial vessels began using the Northwest Passage for cargo shipments in 2009; two German merchant vessels traversed the Passage from Ulsan, South Korea to Rotterdam, Netherlands with 3,500 tonnes of construction parts (GPS World 2009). The number of vessels travelling through the Northwest Passage doubled from seven vessels in 2009 to a minimum of 18 in 2010 (CBC News 2010). Therefore, global ports with high environmental similarity to Arctic ports, which are not currently connected by shipping activities, may become an invasion risk if new shipping routes and port connections are established; these global ports are listed in Appendices A, B, C and D. This information will be useful for monitoring ship-mediated invasions in the Arctic if shipping patterns change.

Furthermore, models from the Intergovernmental Panel on Climate Change (IPCC) predict that climate warming is expected to be most intense in the Arctic. For example, IPCC Fourth Assessment Report (AR4) models suggest that summer air temperatures may increase by up to two °C by the year 2100 (Anisimov et al. 2007). As a result, environmental similarity between Arctic and temperate ports will likely increase. A reanalysis of environmental similarity between donor and recipient port-pairs, using environmental variables as projected under climate change, may be useful to predict future invasion risk in the region.

CONCLUSIONS

- Canadian Arctic ports are connected to international and coastal domestic ports, resulting in potential for species transfers *via* hull fouling and/or ballast water discharge.
- Although most ship arrivals and ballast water discharge originated from foreign ports, coastal domestic ports may contribute the greatest propagule supply to the Arctic due to shorter vessel transits, exemption from ballast water exchange, and higher environmental similarity between source and recipient ports.
- The final invasion risk for nonindigenous species (NIS) *via* hull fouling was higher for Churchill (Manitoba), intermediate for Iqaluit (Nunavut) and Erebus Bay/Beechey Island (Nunavut), and lower for all remaining top Arctic ports, with moderate uncertainty.
- Churchill was also identified as having higher invasion risk for NIS *via* ballast water, while all remaining top Arctic ports had lower final invasion risk, with moderate uncertainty.
- Port Alfred (Québec) is a potentially important source of ballast-mediated NIS for Churchill due to relatively high propagule supply and environmental similarity.
- Biological sampling of ship vectors should be conducted at top Arctic ports to further quantify relative invasion risk with consideration of species-specific and site-specific characteristics.
- Future research and/or monitoring activities at Arctic ports should be prioritized at locations identified as higher risk by this assessment.
- As a number of ports are now being planned or developed in the Arctic, shipping patterns may change significantly. As shipping traffic or global climate conditions change, a re-assessment may be required.
- It is important to note that results presented in this document are based on a relative risk ranking system, allowing prioritization of ports within the Canadian Arctic. Ports identified as higher or highest risk in this study may not remain as higher or highest risk in the comprehensive national risk assessment considering the relatively low shipping traffic and harsh environmental conditions in the Arctic.

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TABLES

Table 1. Description of uncertainty levels (level of knowledge; source of data), modified from Therriault and Herborg (2007).

Level of uncertainty	Description
Very high	Little or no scientific information; no supporting data
High	Limited scientific information; circumstantial evidence
Moderate	Moderate level of scientific information; first hand, unsystematic observations
Low	Substantial scientific information; expert opinion
Very low	Extensive scientific/systematic information; peer-reviewed data sources/information

Table 2. Vessel classification system, based on operational region and ship type, with corresponding definitions and examples.

Vessel classification	Definition/Example
Operational region	
Arctic	Vessels that operated exclusively within the Canadian Arctic region during the study period and are not required to conduct ballast exchange/flushing
Coastal domestic	Vessels that operated exclusively within the Canadian Exclusive Economic Zone (EEZ) during the study period and are not required to conduct ballast exchange/flushing
International	Vessels that operated outside of the Canadian EEZ for at least part of the study period and are required to conduct ballast exchange/flushing prior to entering the Canadian EEZ; some vessels will move domestic ballast water (not required to exchange/flush) on subsequent voyages within the EEZ
Ship type	
Merchant	Bulk carriers, tankers, general cargo, and roll on/roll off vessels
Coast Guard	Coast guard tenders and icebreakers
Fishing	Fishing vessels and trawlers
Passenger	Cruise ships and yachts
Research	Research vessels
Special Purpose	Cable vessels and heavy-lift ship
Tug/Barge	Supply tugs, harbour tugs, ocean tugs, and barges

Table 3. Ranking system for probability of arrival of NIS to Canadian Arctic ports via hull fouling, based on the mean annual number of vessel arrivals to each Arctic port by vessel type.

Mean annual number of vessel arrivals	P(Arrival)
14.25 – 17.80	Highest
10.69 – 14.24	Higher
7.13 – 10.68	Intermediate
3.57 – 7.12	Lower
0.00 – 3.56	Lowest

Table 4. Ranking system for magnitude of consequences of invasion by hull fouling-mediated species, based on the cumulative number of high impact NIS recorded by Molnar et al. (2008) in ecoregions of all ports directly connected to each Arctic top port.

Cumulative number of high impact fouling NIS	Magnitude of consequence
621 - 776	Highest
466 - 620	Higher
311 - 465	Intermediate
156 - 310	Lower
0 - 155	Lowest

Table 5. Matrix used to combine probability of introduction and magnitude of consequences of introduction into final risk rankings, modified from Therriault and Herborg (2007); green = lower risk, yellow = intermediate risk and red = higher risk.

		P (Introduction)				
		Lowest	**Lower**	**Intermediate**	**Higher**	**Highest**
Consequence	**Highest**	Yellow	Yellow	Red	Red	Red
	Higher	Yellow	Yellow	Yellow	Red	Red
	Intermediate	Green	Yellow	Yellow	Yellow	Red
	Lower	Green	Green	Yellow	Yellow	Yellow
	Lowest	Green	Green	Green	Yellow	Yellow

Table 6. Ranking system for probability of spread of NIS among Canadian ports via hull fouling, based on the mean annual number of vessel departures from top Arctic ports by coastal domestic and Arctic vessels.

Mean annual number of vessel departures	P(Spread)
17.41 – 21.50	Highest
13.01 – 17.40	Higher
8.61 – 13.00	Intermediate
4.31 – 8.60	Lower
0.00 – 4.30	Lowest

Table 7. Ranking system for probability of arrival of NIS to Canadian Arctic ports via ballast water, based on the mean annual corrected volume of ballast water discharged at a single Arctic port.

Mean annual corrected volume of ballast water discharged (m^3)	P(Arrival)
27,733.61 – 34,667.00	Highest
20,800.21 – 27,733.60	Higher
13,866.81 – 20,800.20	Intermediate
6,933.41 – 13,866.80	Lower
0.00 – 6,933.40	Lowest

Table 8. Ranking system for probability of survival of NIS at top Arctic ports, based on environmental distance between top Arctic ports and all connected ballast water source ports.

Environmental distance	P(Survival)
0.00 – 1.40	Highest
1.41 – 2.80	Higher
2.81 – 4.20	Intermediate
4.21 – 5.60	Lower
5.61 – 7.00	Lowest

Table 9. Ranking system for magnitude of consequences of introduction of ballast-mediated species, based on the cumulative number of high impact NIS recorded by Molnar et al. (2008) in ecoregions of all ports directly connected to each Arctic top port.

Cumulative number of high impact ballast-mediated NIS	Magnitude of consequence
701 - 875	Highest
526 - 700	Higher
351 - 525	Intermediate
176 - 350	Lower
0 - 175	Lowest

Table 10. Ranking system for probability of spread of NIS among Canadian ports via ballast water, based on the mean annual number of ballast water uptake events at top Arctic ports by coastal domestic and Arctic merchant vessels.

Mean annual number of uptake events	P(Spread)
11.71 – 14.50	Highest
8.91 –11.70	Higher
6.11 – 8.90	Intermediate
3.31 – 6.10	Lower
0.50 – 3.30	Lowest

Table 11. Total number of vessel arrivals at Canadian Arctic ports, with mean (± S.E.M.) annual value.

Year	Number of vessel arrivals
2005	420
2006	591
2007	652
2008	734
Mean (± S.E.M.)	599 (± 67)

Table 12. Arrival statistics for international merchant vessels at the top 10 Arctic ports. The asterisk (*) denotes the top three ports for this vessel category.

Top ports	Mean (± S.E.M.) annual number of arrivals	P(Arrival) at port
Churchill, MB*	17.75 (± 1.65)	Highest
Iqaluit, NU*	12.00 (± 1.08)	Higher
Deception Bay, QC*	8.75 (± 4.15)	Intermediate
Salluit (Saglouc), QC	7.50 (± 1.55)	Intermediate
Kuujjuaq (Fort Chimo), QC	6.25 (± 1.65)	Lower
Tasiujaq, QC	5.50 (± 1.04)	Lower
Puvimituq, QC	5.25 (± 0.48)	Lower
Aupaluk, QC	5.25 (± 0.75)	Lower
Wakeham Bay/Kangiqsujuaq/Maricourt, QC	5.00 (± 0.91)	Lower
Kangiqsualujjuaq (George River), QC	4.75 (± 1.89)	Lower

Table 13. Arrival statistics for coastal domestic merchant vessels at the top 10 Arctic ports. The asterisk (*) denotes the top three ports for this vessel category.

Top ports	Mean (± S.E.M.) annual number of arrivals	P(Arrival) at port
Iqaluit, NU*	15.00 (± 1.87)	Highest
Deception Bay, QC*	9.50 (± 1.50)	Intermediate
Kuujjuaq (Fort Chimo), QC*	6.00 (± 1.08)	Lower
Rankin Inlet/Kangiqliniq, NU	4.50 (± 0.65)	Lower
Hall Beach/Sanirayak, NU	4.00 (± 0.58)	Lower
Churchill, MB	3.75 (± 2.06)	Lower
Cape Dorset/Kingait, NU	3.50 (± 0.65)	Lowest
Wakeham Bay/Kangiqsujuaq/Maricourt, QC	3.25 (± 0.25)	Lowest
Igloolik, NU	3.25 (± 0.48)	Lowest
Akulivik, QC	3.25 (± 1.11)	Lowest

Table 14. Arrival statistics for international non-merchant vessels at the top 10 Arctic ports. The asterisk (*) denotes the top three ports for this vessel category.

Top ports	Mean (± S.E.M.) annual number of arrivals	P(Arrival) at port
Erebus Bay/Beechey Island, NU*	12.00 (± 0.71)	Higher
Iqaluit, NU*	9.25 (± 1.60)	Intermediate
Dundas Harbour, NU*	9.00 (± 0.71)	Intermediate
Resolute Bay/Qausuittuq, NU	9.00 (± 0.82)	Intermediate
Pond Inlet/Mittimatalik, NU	9.00 (± 1.35)	Intermediate
Monumental Island Port, NU	7.50 (± 2.02)	Intermediate
Akpatok Island/Cape Dorset, NU	7.50 (± 2.25)	Intermediate
Prince Leopold Island, NU	5.25 (± 0.25)	Lower
Croker Bay, NU	5.25 (± 0.63)	Lower
Lower Savage Island, NU	5.25 (± 0.75)	Lower

Table 15. Arrival statistics for coastal domestic non-merchant vessels at the top 10 Arctic ports. The asterisk (*) denotes the top three ports for this vessel category.

Top ports	Mean (± S.E.M.) annual number of arrivals	P(Arrival) at port
Baker Lake/Qaminituak, NU*	10.75 (± 4.13)	Higher
Churchill, MB*	10.25 (± 2.78)	Intermediate
Chesterfield Inlet/Iguligaarjuk, NU*	8.75 (± 3.47)	Intermediate
Rankin Inlet/Kangiqliniq, NU	7.00 (± 2.55)	Lower
Iqaluit, NU	6.50 (± 0.29)	Lower
Arviat/Eskimo Point, NU	2.75 (± 0.95)	Lowest
Resolute Bay/Qausuittuq, NU	2.25 (± 0.85)	Lowest
Whale Cove/Tikirarjuaq, NU	2.25 (± 1.11)	Lowest
Coral Harbour/Salliq, NU	1.75 (± 0.75)	Lowest
Deception Bay, QC	1.75 (± 0.75)	Lowest

Table 16. Arrival statistics for Arctic non-merchant vessels at the top 10 Arctic ports. The asterisk (*) denotes the top three ports for this vessel category.

Top ports	Mean (± S.E.M.) annual number of arrivals	P(Arrival) at port
Cambridge Bay/Ikaluktutiak, NU*	10.00 (± 2.08)	Intermediate
Tuktoyaktuk, NT*	9.00 (± 1.00)	Intermediate
Baker Lake/Qaminituak, NU*	5.50 (± 3.20)	Lower
Gjoa Haven, NU	4.50 (± 0.29)	Lower
Johansen Bay, NU	3.50 (± 2.02)	Lowest
Kugluktuk/Coppermine, NU	3.25 (± 0.63)	Lowest
Chesterfield Inlet/Iguligaarjuk, NU	3.25 (± 2.02)	Lowest
Wise Bay, NT	3.00 (± 1.22)	Lowest
Robert's Bay, NU	2.75 (± 1.44)	Lowest
Taloyoak/Spence Bay, NU	2.25 (± 0.48)	Lowest

Table 17. Probability of introduction of hull-mediated NIS to top Arctic ports, by vessel category, with level of uncertainty indicated in brackets below each column heading.

	P(Arrival) (moderate)	**P(Survival)** (moderate)	**P(Introduction)** (moderate)
International merchant vessels			
Churchill, MB	Highest	Highest	Highest
Iqaluit, NU	Higher	Highest	Higher
Deception Bay, QC	Intermediate	Highest	Intermediate
Coastal domestic merchant vessels			
Iqaluit, NU	Highest	Highest	Highest
Deception Bay, QC	Intermediate	Highest	Intermediate
Kuujjuaq (Fort Chimo), QC	Lower	Highest	Lower
International non-merchant vessels			
Erebus Bay/Beechey Island, NU	Higher	Highest	Higher
Iqaluit, NU	Intermediate	Highest	Intermediate
Dundas Harbour, NU	Intermediate	Highest	Intermediate
Coastal domestic non-merchant vessels			
Baker Lake/Qaminituak, NU	Higher	Lowest	Lowest
Churchill, MB	Intermediate	Highest	Intermediate
Chesterfield Inlet/Iguligaarjuk, NU	Intermediate	Highest	Intermediate
Arctic non-merchant vessels			
Cambridge Bay/Ikaluktutiak, NU	Intermediate	Highest	Intermediate
Tuktoyaktuk, NT	Intermediate	Highest	Intermediate
Baker Lake/Qaminituak, NU	Lower	Lowest	Lowest

Table 18. Magnitude of consequences of introduction of hull fouling-mediated species at top Arctic ports, by vessel category, based on the cumulative number of high impact NIS recorded by Molnar et al. (2008) in ecoregions of all ports directly connected to each Arctic top port.

	Cumulative number of high impact fouling NIS	Magnitude of consequence
International merchant vessels		
Churchill, MB	776	Highest
Iqaluit, NU	32	Lowest
Deception Bay, QC	124	Lowest
Coastal domestic merchant vessels		
Iqaluit, NU	48	Lowest
Deception Bay, QC	33	Lowest
Kuujjuaq (Fort Chimo), QC	17	Lowest
International non-merchant vessels		
Erebus Bay/Beechey Island, NU	0	Lowest
Iqaluit, NU	9	Lowest
Dundas Harbour, NU	0	Lowest
Coastal domestic non-merchant vessels		
Baker Lake/Qaminituak, NU	11	Lowest
Churchill, MB	20	Lowest
Chesterfield Inlet/Iguligaarjuk, NU	9	Lowest
Arctic non-merchant vessels		
Cambridge Bay/Ikaluktutiak, NU	2	Lowest
Tuktoyaktuk, NT	3	Lowest
Baker Lake/Qaminituak, NU	2	Lowest

Table 19. Relative invasion risk to top Arctic ports by hull fouling NIS, by vessel category, with level of uncertainty indicated in brackets below each column heading.

	P(Introduction) (moderate)	**Magnitude of consequence** (moderate)	**Invasion risk** (moderate)
Top ports for international merchant arrivals			
Churchill, MB	Highest	Highest	Higher
Iqaluit, NU	Higher	Lowest	Intermediate
Deception Bay, QC	Intermediate	Lowest	Lower
Top ports for coastal domestic merchant arrivals			
Iqaluit, NU	Highest	Lowest	Intermediate
Deception Bay, QC	Intermediate	Lowest	Lower
Kuujjuaq (Fort Chimo), QC	Lower	Lowest	Lower
Top ports for international non-merchant arrivals			
Erebus Bay/Beechey Island, NU	Higher	Lowest	Intermediate
Iqaluit, NU	Intermediate	Lowest	Lower
Dundas Harbour, NU	Intermediate	Lowest	Lower
Top ports for coastal domestic non-merchant arrivals			
Baker Lake/Qaminituak, NU	Lowest	Lowest	Lower
Churchill, MB	Intermediate	Lowest	Lower
Chesterfield Inlet/Iguligaarjuk, NU	Intermediate	Lowest	Lower
Top ports for Arctic non-merchant arrivals			
Cambridge Bay/Ikaluktutiak, NU	Intermediate	Lowest	Lower
Tuktoyaktuk, NT	Intermediate	Lowest	Lower
Baker Lake/Qaminituak, NU	Lowest	Lowest	Lower

Table 20. Departure statistics for coastal domestic and Arctic vessels from top Arctic ports as a measure of potential for hull-mediated secondary spread.

	Mean (± S.E.M.) annual number of departures	P(Spread)
Top ports for international merchant vessels		
Churchill, MB	15.00 (± 3.08)	Higher
Iqaluit, NU	21.50 (± 2.06)	Highest
Deception Bay, QC	11.25 (± 1.70)	Intermediate
Top ports for coastal domestic merchant vessels		
Iqaluit, NU	21.50 (± 2.06)	Highest
Deception Bay, QC	11.25 (± 1.70)	Intermediate
Kuujjuaq (Fort Chimo), QC	6.25 (± 1.18)	Lower
Top ports for international non-merchant vessels		
Erebus Bay/Beechey Island, NU	0.00 (± 0.00)	Lowest
Iqaluit, NU	21.50 (± 2.06)	Highest
Dundas Harbour, NU	0.25 (± 0.25)	Lowest
Top ports for coastal domestic non-merchant vessels		
Baker Lake/Qaminituak, NU	18.75 (± 7.18)	Highest
Churchill, MB	15.00 (± 3.08)	Higher
Chesterfield Inlet/Iguligaarjuk, NU	15.00 (± 5.73)	Higher
Top ports for Arctic non-merchant vessels		
Cambridge Bay/Ikaluktutiak, NU	10.25 (± 2.06)	Intermediate
Tuktoyaktuk, NT	9.00 (± 1.00)	Intermediate
*Baker Lake/Qaminituak, NU	18.75 (± 7.18)	Highest

*Note that Baker Lake is freshwater and hull fouling NIS are likely to be marine. Any freshwater NIS that may foul ship hulls at Baker Lake are likely to die in transit through marine waters to the next port.

Table 21. Annual discharge statistics at Canadian Arctic ports, by source of ballast water. Correction factors (10% for saline and 1% for freshwater source ports, respectively) were applied to account for reduction in propagule supply due to exchange/flushing. 'Direct' refers to water that was not exchanged prior to discharging.

		Ballast water discharge volume (m^3)								
	Number of discharge events	Grand total	Corrected foreign exchanged		Corrected coastal domestic exchanged		Coastal domestic direct	Arctic direct	Unknown source	Corrected total
			10%	1%	10%	1%				
2005	44	259,623	7,934	34	69	641	46,282	55,044	10,802	120,805
2006	41	291,652	15,402	0	1,025	513	0	50,190	25,927	93,057
2007	36	272,890	18,489	27	1,973	205	9,297	24,375	11,397	65,763
2008	35	278,690	11,846	0	0	820	38,548	39,663	0	90,877
Mean	39	275,714	13,418	15	767	545	23,532	42,318	12,032	92,625
(±S.E.M.)	(2)	(6,644)	(2,277)	(9)	(465)	(130)	(11,178)	(6,788)	(5,321)	(11,251)

Table 22. Ballast water discharge statistics for international merchant vessels at the top 10 Arctic ports. Correction factors (10% for saline and 1% for freshwater source ports, respectively) were applied to account for reduction in propagule supply due to exchange/flushing. 'Direct' refers to water that was not exchanged prior to discharging. The asterisk (*) denotes the top three ports for this vessel category.

Top 10 ports	**Number of discharge events**	**Mean (± S.E.M.) annual volume of ballast water discharge (m^3)**										
		Grand total	**Corrected foreign exchanged**		**Corrected coastal domestic exchanged**		**Coastal domestic direct**	**Arctic direct**	**Unknown source**	**Corrected total**	**P(Arrival)**
			10%	**1%**	**10%**	**1%**					
Churchill, MB*	17 (2)	157,675 (19,409)	12,945 (1,976)	15 (9)	402 (402)	6 (6)	8,721 (8,721)	1,466 (865)	11,112 (4,474)	34,667 (8,661)	Highest
Milne Inlet, NU*	0.3 (0.3)	6,959 (6,959)	0 (0)	0 (0)	0 (0)	0 (0)	6,959 (6,959)	0 (0)	0 (0)	6,959 (6,959)	Lower
Deception Bay, QC*	1.5 (0.3)	8,069 (4,020)	374 (374)	0 (0)	91 (91)	0 (0)	1,250 (1,250)	1,250 (1,250)	919 (651)	3,884 (2,073)	Lowest
Iqaluit, NU	1.3 (0.3)	3,679 (1,548)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	3,679 (1,548)	0 (0)	3,679 (1,548)	Lowest
Aupaluk, QC	0.8 (0.3)	3,236 (1,105)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	3,236 (1,105)	0 (0)	3,236 (1,105)	Lowest
Kangiqsujuaq (George River), QC	0.8 (0.3)	2,802 (1,044)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2,802 (1,044)	0 (0)	2,802 (1,044)	Lowest
Quaqtaq (Koartak), QC	0.5 (0.3)	1,876 (1,157)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1,876 (1,157)	0 (0)	1,876 (1,157)	Lowest
Tasiujaq, QC	0.5 (0.3)	1,614 (1,119)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1,614 (1,119)	0 (0)	1,614 (1,119)	Lowest
Wakeham Bay/ Kangiqsualujjuaq/ Maricourt, QC	0.3 (0.3)	1,250 (1,250)	0 (0)	0 (0)	0 (0)	0 (0)	1,250 (1,250)	0 (0)	0 (0)	1,250 (1,250)	Lowest
Arviat/Eskimo Point, NU	0.5 (0.3)	1,225 (803)	0 (0)	0 (0)	0 (0)	0 (0)	1,225 (803)	0 (0)	0 (0)	1,225 (803)	Lowest

Table 23. Ballast water discharge statistics for coastal domestic merchant vessels at the top 10 Arctic ports. Correction factors (10% for saline and 1% for freshwater source ports, respectively) were applied to account for reduction in propagule supply due to exchange/flushing. 'Direct' refers to water that was not exchanged prior to discharging. The asterisk (*) denotes the top three ports for this vessel category.

Top 10 ports	Number of discharge events	Mean (± S.E.M.) annual volume of ballast water discharge (m^3)						
		Grand total	Corrected coastal domestic exchanged		Coastal domestic direct	Arctic direct	Corrected total	P(Arrival)
			10%	1%				
Churchill, MB*	2 (1.4)	5,221 (3,319)	0 (0)	0 (0)	2,849 (2,849)	2,371 (1,658)	5,221 (3,319)	Lowest
Deception Bay, QC*	6 (1.2)	60,144 (11,852)	256 (256)	538 (128)	3,752 (2,287)	0 (0)	4,457 (2,102)	Lowest
Iqaluit, NU*	0.5 (0.3)	1,536 (896)	0 (0)	0 (0)	0 (0)	1,536 (896)	1,536 (896)	Lowest
Chesterfield Inlet/Iguligaarjuk, NU	0.3 (0.3)	1,468 (1,468)	0 (0)	0 (0)	0 (0)	1,468 (1,468)	1,468 (1,468)	Lowest
Nanisivik, QC	0.3 (0.3)	1,468 (1,468)	0 (0)	0 (0)	0 (0)	1,468 (1,468)	1,468 (1,468)	Lowest
Pelly Bay/Kuggaruk, NU	0.3 (0.3)	1,468 (1,468)	0 (0)	0 (0)	0 (0)	1,468 (1,468)	1,468 (1,468)	Lowest
Resolute Bay/Qausuittuq, NU	0.3 (0.3)	1,125 (1,125)	0 (0)	0 (0)	0 (0)	1,125 (1,125)	1,125 (1,125)	Lowest
Repulse Bay/Aivilik, NU	0.5 (0.3)	1,095 (819)	0 (0)	0 (0)	0 (0)	1,095 (819)	1,095 (819)	Lowest
Inukjuak (Port Harrison), QC	0.5 (0.3)	846 (846)	0 (0)	0 (0)	0 (0)	846 (846)	846 (846)	Lowest
Cape Dorset/Kingait, NU	0.3 (0.3)	613 (613)	0 (0)	0 (0)	0 (0)	613 (613)	613 (613)	Lowest

Table 24. Environmental distance between Churchill and source ports connected via ballast water discharge by international merchant vessels. The asterisk (*) denotes source ports that received higher or highest probability of survival.

Source port	Source port country	Environmental distance	P(Survival)
Algiers	Algeria	3.59	Intermediate
Amsterdam*	Netherlands	2.32	Higher
Annaba	Algeria	3.64	Intermediate
Antwerp	Belgium	2.84	Intermediate
Aughinish*	Ireland	2.27	Higher
Aupaluk*	Canada	1.26	Highest
Aviles*	Spain	2.75	Higher
Baltimore	United States	3.53	Intermediate
Belfast*	United Kingdom	1.68	Higher
Bremen*	Germany	1.95	Higher
Cartagena	Spain	3.64	Intermediate
Casablanca	Morocco	3.46	Intermediate
Ceyhan	Turkey	4.02	Intermediate
Charleston	United States	3.97	Intermediate
Civitavecchia	Italy	3.43	Intermediate
Dublin*	Ireland	1.47	Higher
Foynes*	Ireland	2.23	Higher
Gdynia*	Poland	2.10	Higher
Ghent*	Belgium	2.79	Higher
Gibraltar	Gibraltar	3.09	Intermediate
Gijon*	Spain	2.74	Higher
Greenore*	Ireland	1.53	Higher
Hamburg*	Germany	1.91	Higher
Houston	United States	4.54	Lower
Ijmuiden*	Netherlands	2.00	Higher
Klaipeda*	Lithuania	2.32	Higher
Liepaja*	Latvia	2.20	Higher
London*	United Kingdom	2.74	Higher
Londonderry*	United Kingdom	1.87	Higher
Lorient*	France	2.42	Higher
Malaga	Spain	3.63	Intermediate
Matadi	Congo	4.94	Lower
Newport*	United Kingdom	2.19	Higher
Newport News	United States	3.44	Intermediate
Oran	Algeria	3.80	Intermediate
Port Alfred*	Canada	1.84	Higher
Port Everglades	United States	5.10	Lower
Portbury*	United Kingdom	2.03	Higher
Québec	Canada	2.90	Intermediate
Ravenna	Italy	3.23	Intermediate
Riga*	Latvia	2.36	Higher
Rönnskär*	Sweden	1.86	Higher
Rotterdam*	Netherlands	2.70	Higher
Santiago	Cuba	4.88	Lower
Savannah	United States	4.24	Lower

Straumsvik*	Iceland	0.94	Highest
Sunndalsøra*	Norway	1.97	Higher
Tampa*	United States	4.68	Lower
Tarragona	Spain	3.47	Intermediate
Teesport*	United Kingdom	1.51	Higher
Terneuzen*	Netherlands	2.29	Higher
Overall		**2.83**	**Intermediate**

Table 25. Environmental distance between Milne Inlet and source ports connected via ballast water discharge by international merchant vessels.

Source port	Source Port country	Environmental distance	P(Survival)
Port Alfred	Canada	2.94	Intermediate
Overall		**2.94**	**Intermediate**

Table 26. Environmental distance between Deception Bay and source ports connected via ballast water discharge by international merchant vessels. The asterisk (*) represents source ports that received higher or highest probability of survival.

Source port	Source port country	Environmental distance	P(Survival)
Aarhus	Denmark	2.81	Intermediate
Belledune*	Canada	2.09	Higher
Rankin Inlet*	Canada	1.16	Highest
Saint John*	Canada	2.75	Higher
Overall		**2.20**	**Higher**

Table 27. Environmental distance between Churchill and source ports connected via ballast water discharge by coastal domestic merchant vessels. The asterisk (*) represents source ports that received higher or highest probability of survival.

Source port	Source port country	Environmental distance	P(Survival)
Arviat*	Canada	0.51	Highest
Baker Lake*	Canada	0.75	Highest
Igloolik*	Canada	1.30	Highest
Rankin Inlet*	Canada	0.48	Highest
Repulse Bay*	Canada	1.18	Highest
Sept Iles*	Canada	1.03	Highest
Overall		**0.87**	**Highest**

Table 28. Environmental distance between Deception Bay and source ports connected via ballast water discharge by coastal domestic merchant vessels. The asterisk (*) represents source ports that received higher or highest probability of survival.

Source port	Source port country	Environmental distance	P(Survival)
Bécancour	Canada	3.87	Intermediate
Chicoutimi	Canada	3.74	Intermediate
Montréal	Canada	4.11	Intermediate
Québec	Canada	3.86	Intermediate
Voisey's Bay*	Canada	0.27	Highest
Overall		**3.17**	**Intermediate**

Table 29. Environmental distance between Iqaluit and source ports connected via ballast water discharge by coastal domestic merchant vessels. The asterisk (*) represents source ports that received higher or highest probability of survival.

Source port	Source port country	Environmental distance	P(Survival)
Kangiqsujuaq*	Canada	0.91	Highest
Killinek*	Canada	1.03	Highest
Overall		**0.97**	**Highest**

Table 30. Probability of introduction of ballast-mediated NIS to top Arctic ports, by vessel category, with level of uncertainty in brackets below each column heading.

	P(Arrival) (low)	**P(Survival)** (moderate)	**P(Introduction)** (moderate)
International merchant vessel ballast water discharges			
Churchill, MB	Highest	Intermediate	Intermediate
Milne Inlet, NU	Lower	Intermediate	Lower
Deception Bay, QC	Lowest	Higher	Lowest
Coastal domestic merchant vessel ballast water discharges			
Churchill, MB	Lowest	Highest	Lowest
Deception Bay, QC	Lowest	Intermediate	Lowest
Iqaluit, NU	Lowest	Highest	Lowest

Table 31. Magnitude of potential consequences of introduction of ballast-mediated species at top Arctic ports, by vessel category, based on the cumulative number of high impact NIS recorded by Molnar et al. (2008) in ecoregions of all ports directly connected to each top port.

	Cumulative number of high impact ballast-mediated NIS	Magnitude of consequence
International merchant vessel ballast water discharges		
Churchill, Manitoba	875	Highest
Milne Inlet, Nunavut	3	Lowest
Deception Bay, Québec	47	Lowest
Coastal domestic merchant vessel ballast water discharges		
Churchill, Manitoba	8	Lowest
Deception Bay, Québec	12	Lowest
Iqaluit, Nunavut	1	Lowest

Table 32. Relative invasion risk to top Arctic ports by ballast-mediated NIS, by vessel category, with level of uncertainty indicated in brackets below each column heading.

	P(Introduction) (moderate)	**Magnitude of consequence** (moderate)	**Invasion risk** (moderate)
Top ports for international merchant ballast water discharges			
Churchill, Manitoba	Intermediate	Highest	Higher
Milne Inlet, Nunavut	Lower	Lowest	Lower
Deception Bay, Québec	Lowest	Lowest	Lower
Top ports for coastal domestic merchant ballast water discharges			
Churchill, Manitoba	Lowest	Lowest	Lower
Deception Bay, Québec	Lowest	Lowest	Lower
Iqaluit, Nunavut	Lowest	Lowest	Lower

Table 33. Ballast water uptake statistics for coastal domestic merchant vessels at top Arctic ports as a measure of potential for ballast-mediated secondary spread.

	Mean (± S.E.M.) annual number of ballast water uptake events	P(Spread)
Top ports for international merchant vessels		
Churchill, MB	1.75 (± 0.75)	Lowest
Milne Inlet, NU	0.50 (± 0.50)	Lowest
Deception Bay, QC	3.50 (± 2.18)	Lower
Top ports for coastal domestic merchant vessels		
Churchill, MB	1.75 (± 0.75)	Lowest
Deception Bay, QC	3.50 (± 2.18)	Lower
Iqaluit, NU	14.50 (± 1.66)	Highest

FIGURES

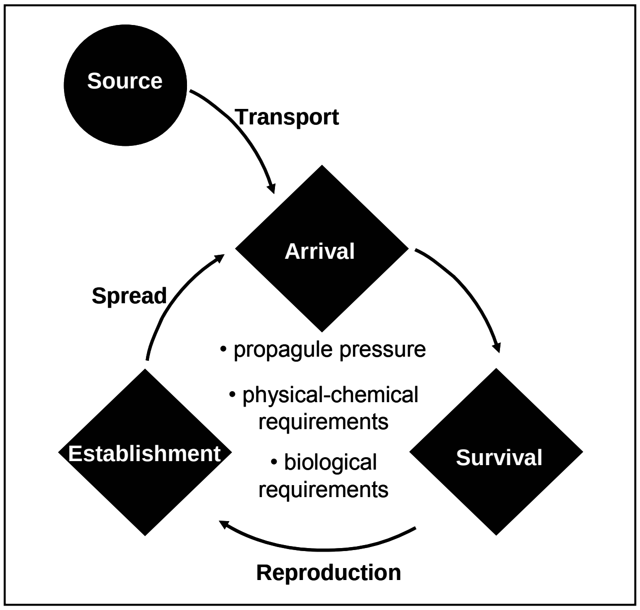


Figure 1. Stages of the biological invasion process.

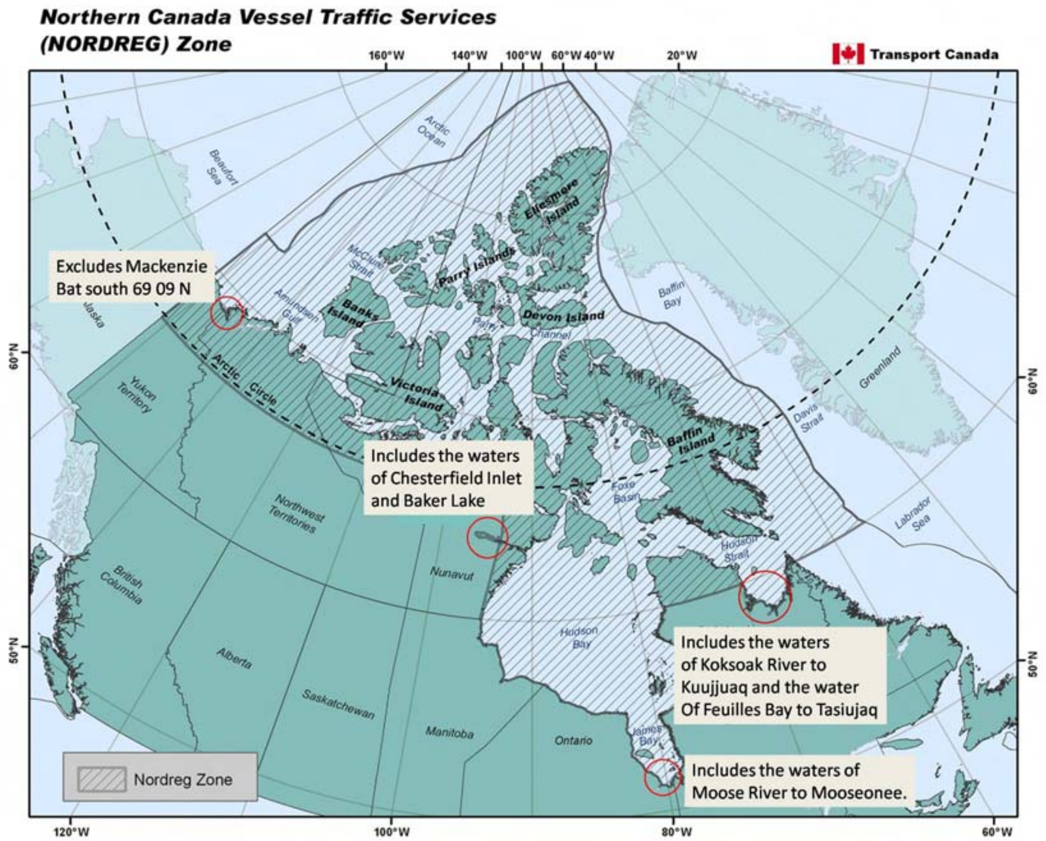
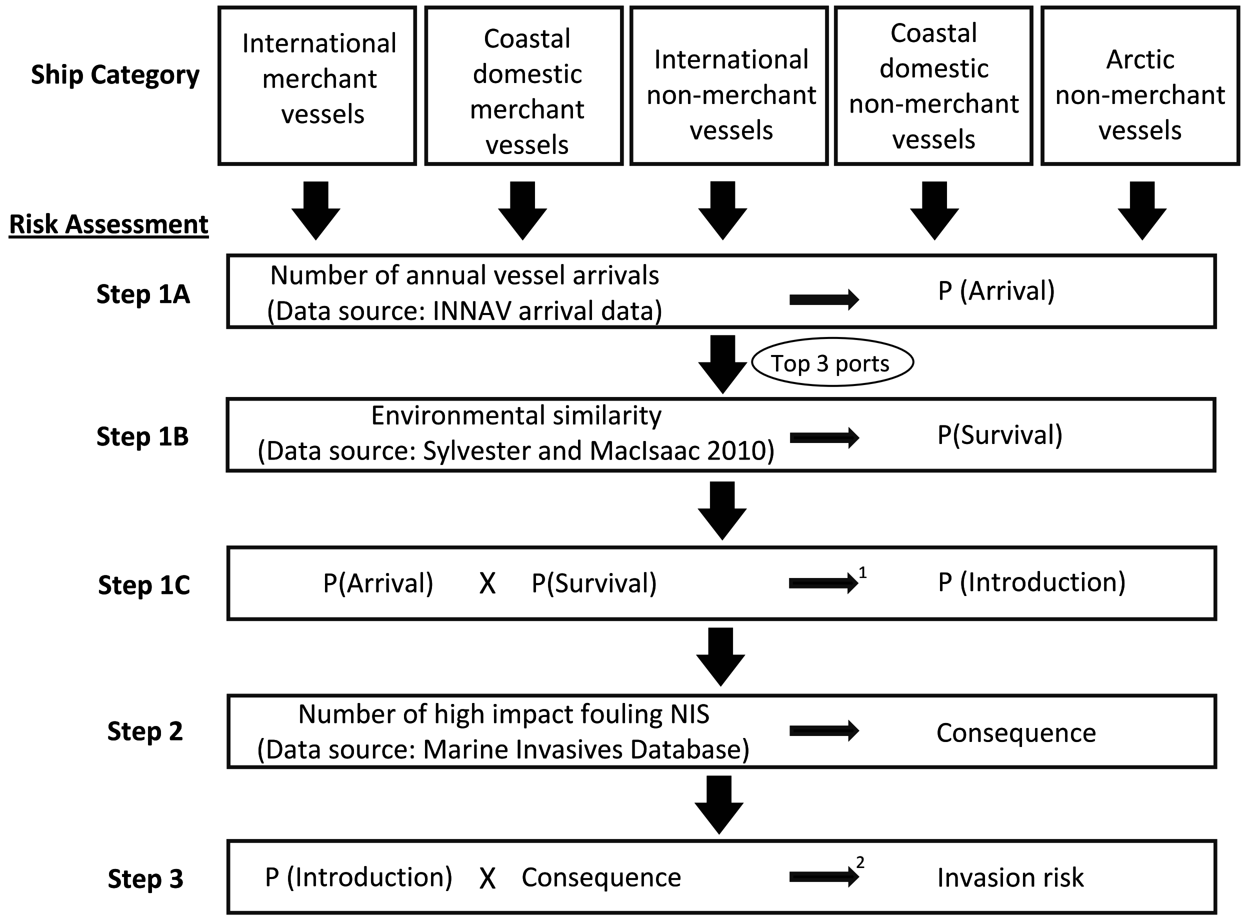


Figure 2. Map illustrating the study area, Canadian Arctic waters, as defined by Transport Canada (modified from Transport Canada 2010).



[1]Minimum probability approach; [2]Mixed rounding symmetrical approach

Figure 3. Flow chart illustrating steps for risk assessment of hull fouling-mediated invasions. A filtering approach was used after Step 1A to prioritize the risk assessment to the top three Arctic ports for each ship category.

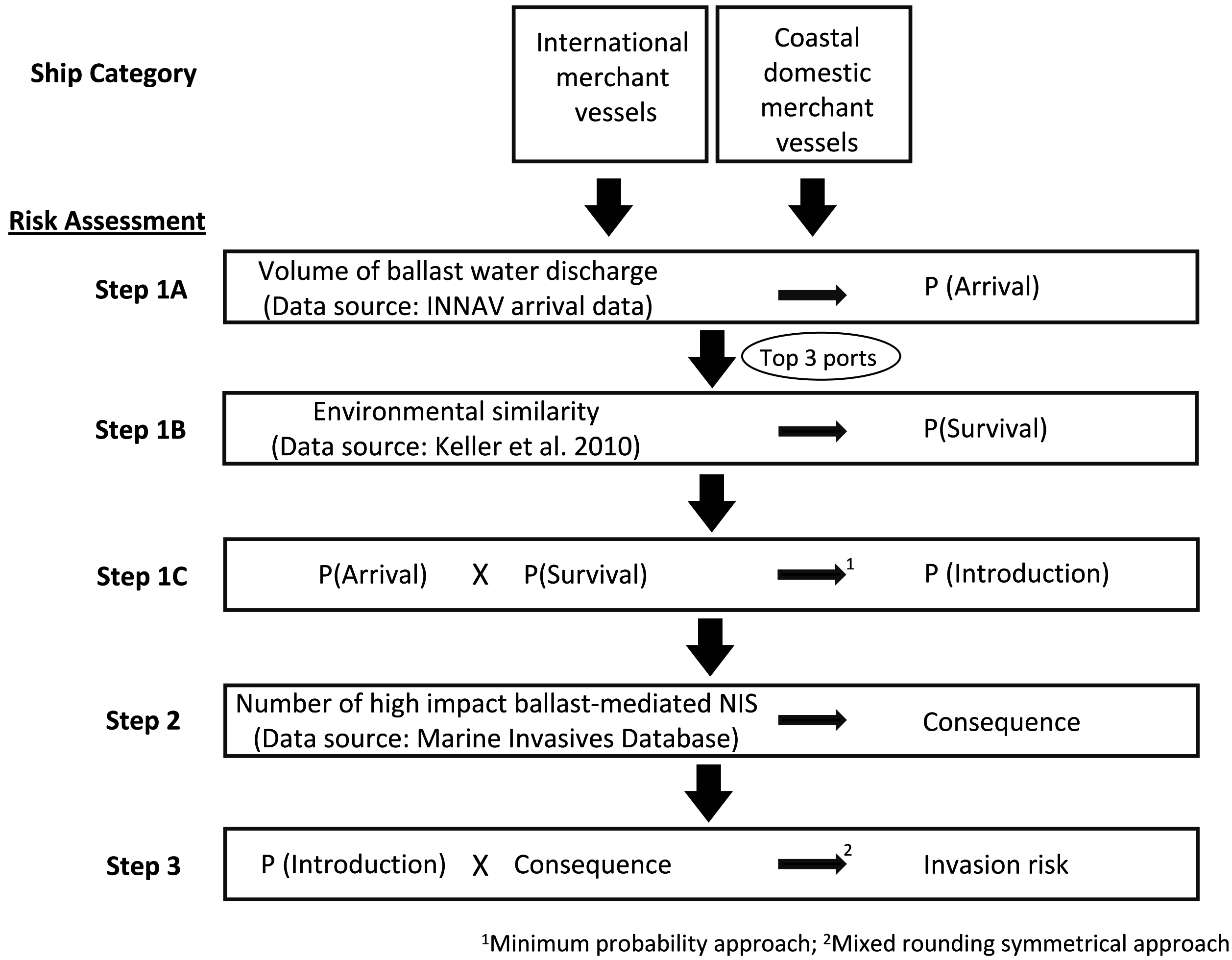


Figure 4. Flow chart illustrating steps for risk assessment of ballast-mediated invasions. A filtering approach was used after Step 1A to prioritize the risk assessment to the top three Arctic ports for each ship category.

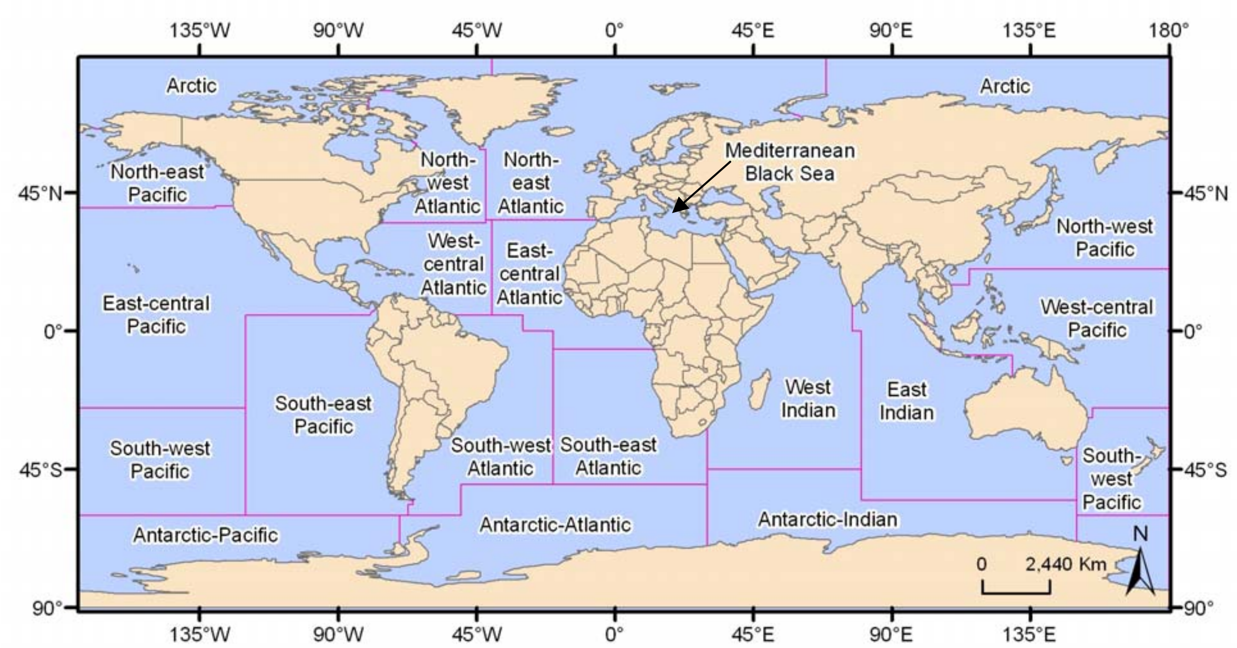


Figure 5. Map illustrating regions of ballast water origin, following the ocean areas designated by the Food and Agriculture Organization of the United Nations (FAO).

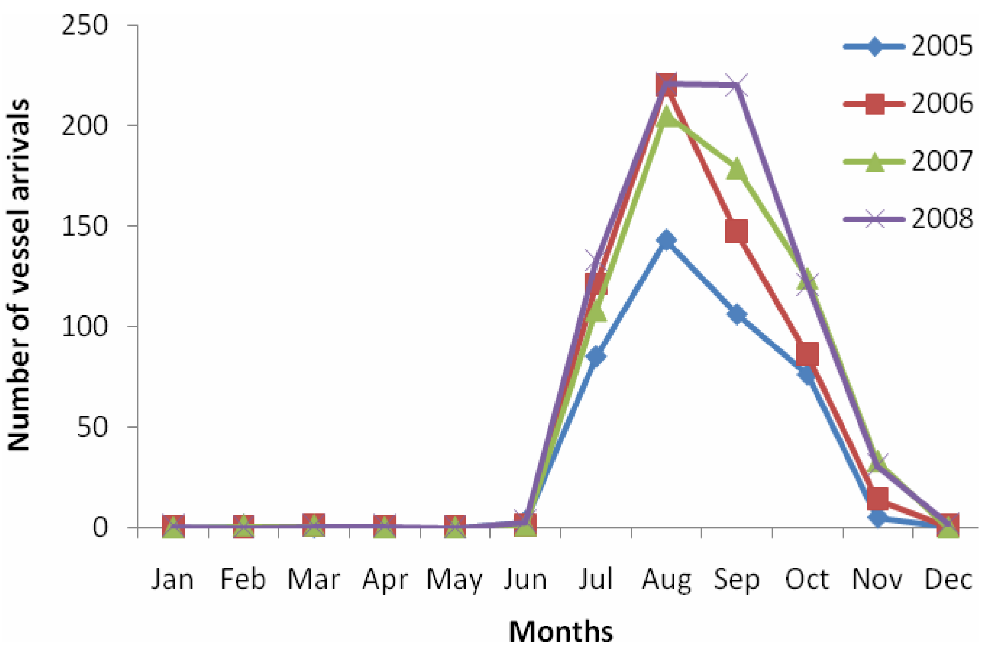


Figure 6. Number of vessel arrivals at Canadian Arctic ports by month.

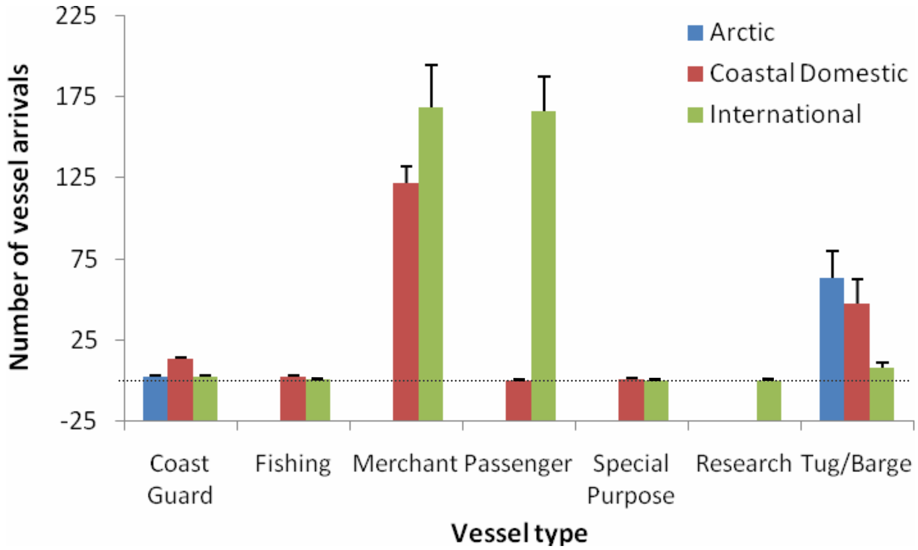


Figure 7. Mean (+ S.E.M.) annual number of vessel arrivals by vessel type and transit route. The x-axis has been lowered to differentiate zero (no bar presented) from values close to zero.

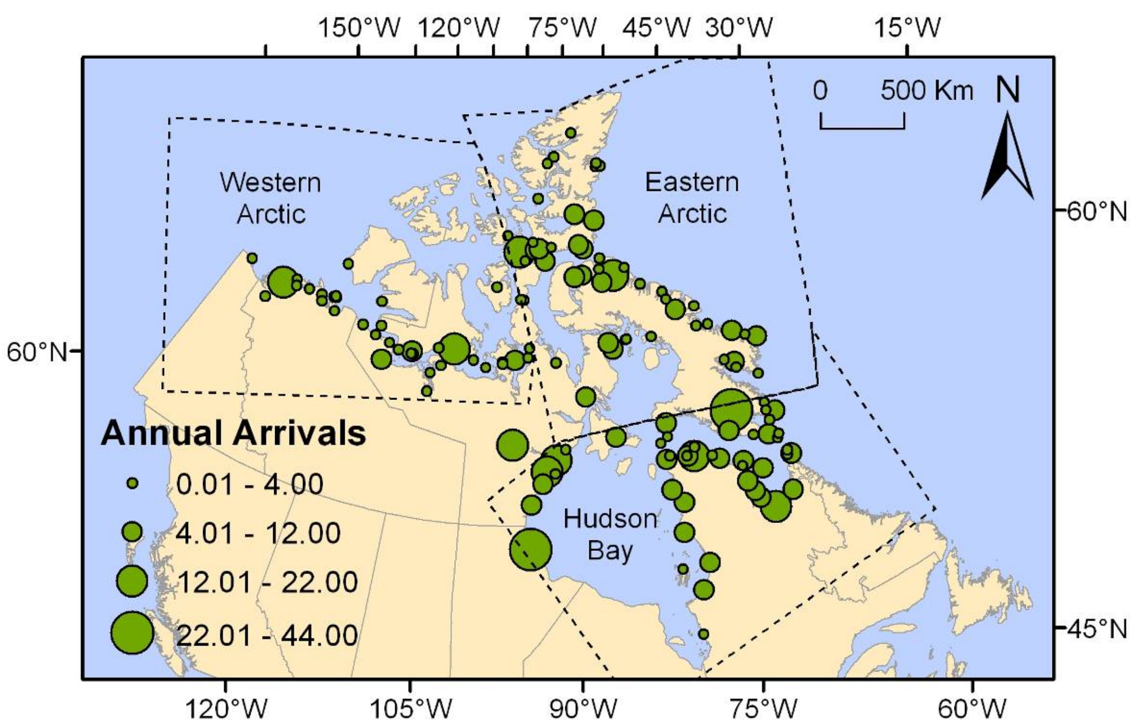


Figure 8. Map illustrating the spatial distribution of vessel arrivals in the Canadian Arctic by region: Western Arctic, Eastern Arctic and Hudson Bay. Dashed-line polygons outline the boundary of the Arctic regions, following Canadian Ice Service (2009).

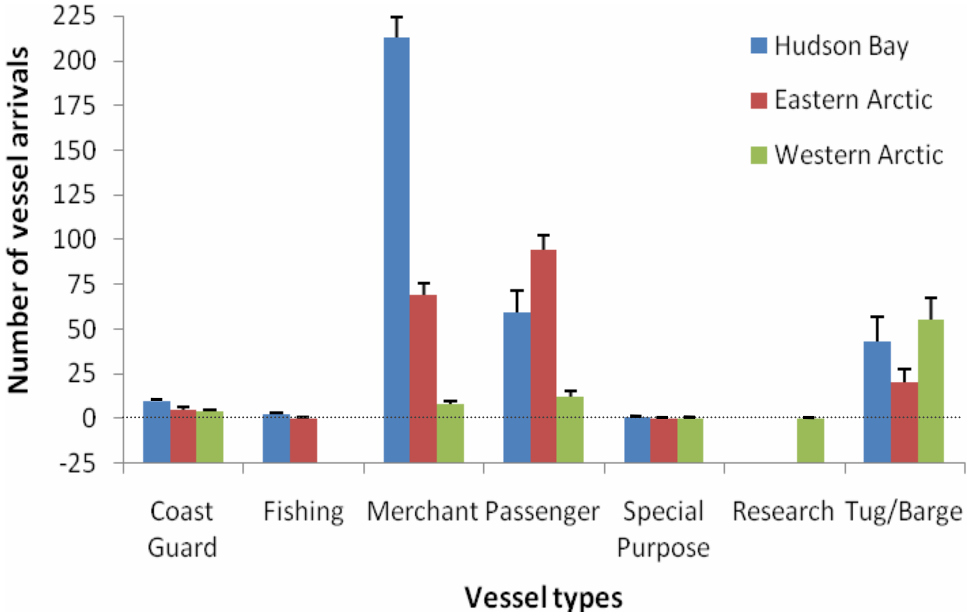


Figure 9. Mean (+ S.E.M.) annual number of vessel arrivals by vessel type and Arctic region. The x-axis has been lowered to differentiate zero (no bar presented) from values close to zero.

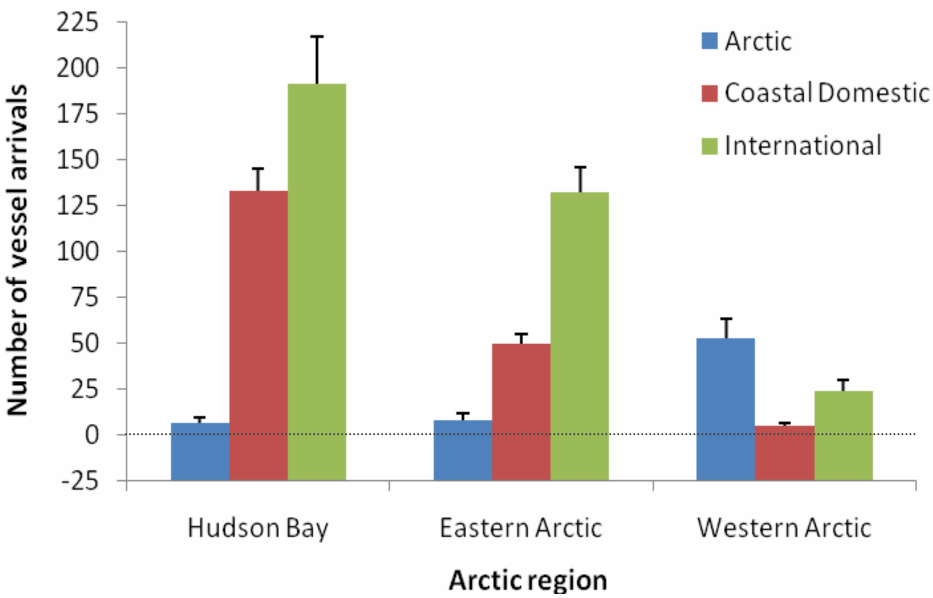


Figure 10. Mean (+ S.E.M.) annual number of vessel arrivals by vessel operational region and Arctic region. The x-axis has been lowered to differentiate zero (no bar presented) from values close to zero.

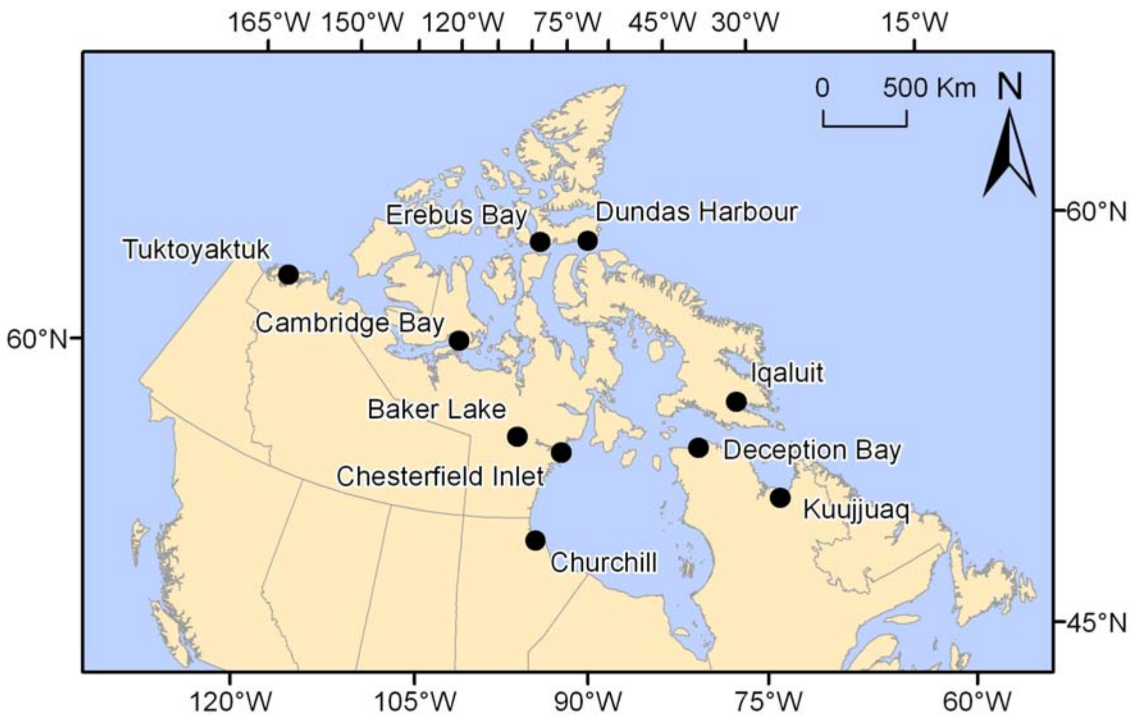


Figure 11. Map illustrating locations of all top Arctic ports based on the number of vessel arrivals for all vessel categories.

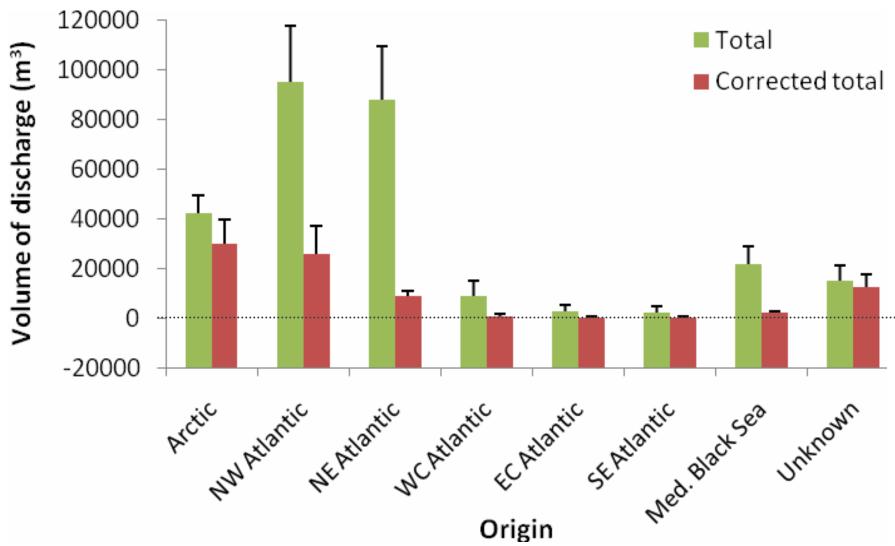


Figure 12. Mean (+ S.E.M.) annual total and corrected total volume of ballast water discharge by origin. Corrected totals account for reduced propagule supply due to ballast water exchange. The x-axis has been lowered to differentiate zero (no bar presented) from values close to zero.

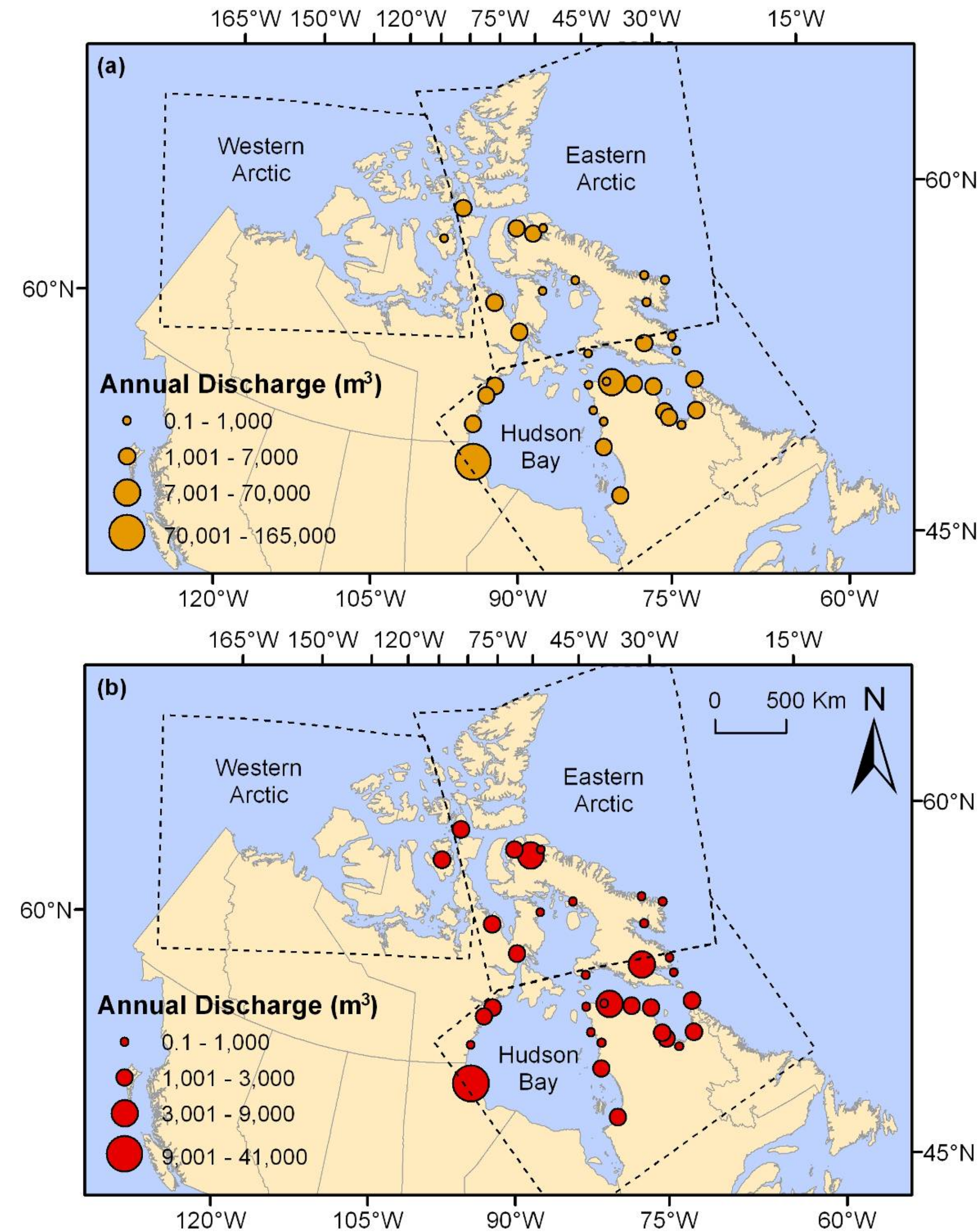


Figure 13. Map illustrating spatial patterns of (a) annual ballast water discharges and (b) a combination of direct and foreign exchanged (with correction factor applied) ballast water discharges in the Canadian Arctic by the three Arctic regions: Hudson Bay, Eastern Arctic and Western Arctic. Dotted-line polygons outline the boundary of the Arctic regions, following Canadian Ice Services (2009).

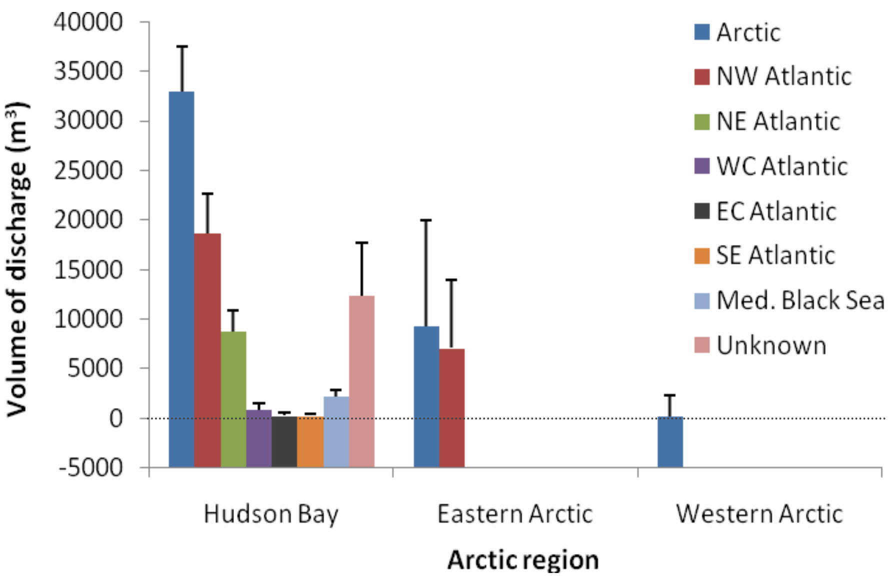


Figure 14. Mean (+ S.E.M.) annual discharge volume of direct and foreign exchanged (with correction factor applied) ballast water (m^3) by Arctic region and origin. The x-axis has been lowered to differentiate zero (no bar presented) from values close to zero.

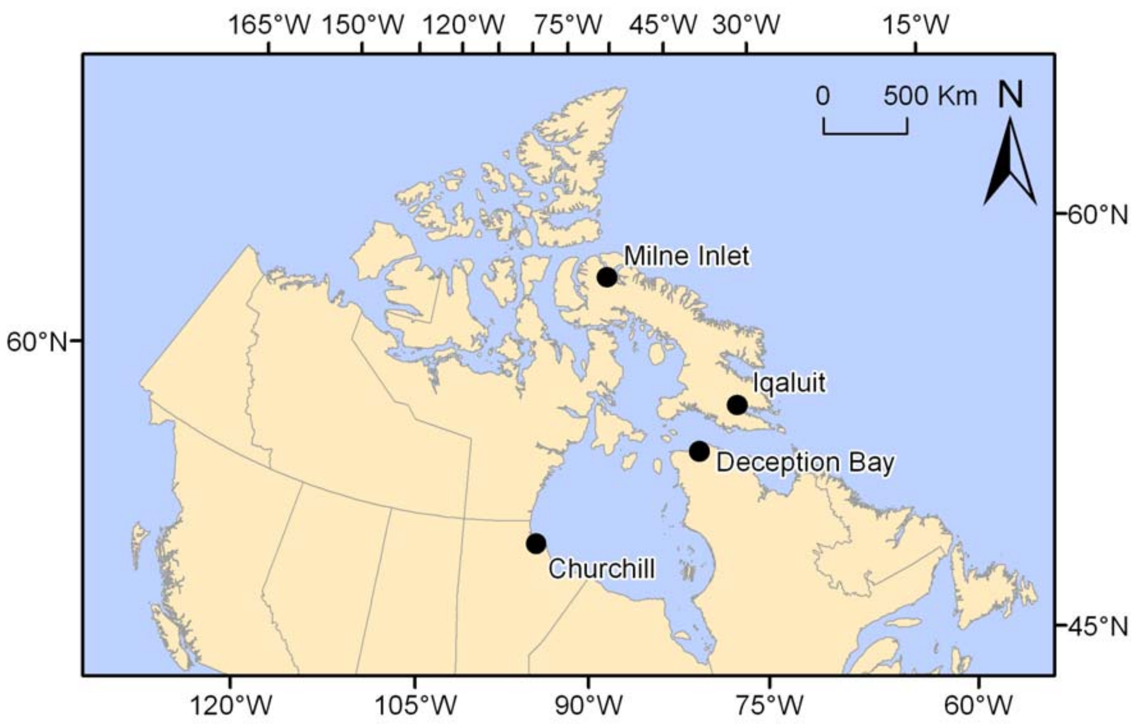


Figure 15. Map illustrating locations of all top Arctic ports based on the annual average volume of ballast water discharged by all merchant vessels; correction factors were applied to account for reduction in propagule supply due to ballast water exchange.

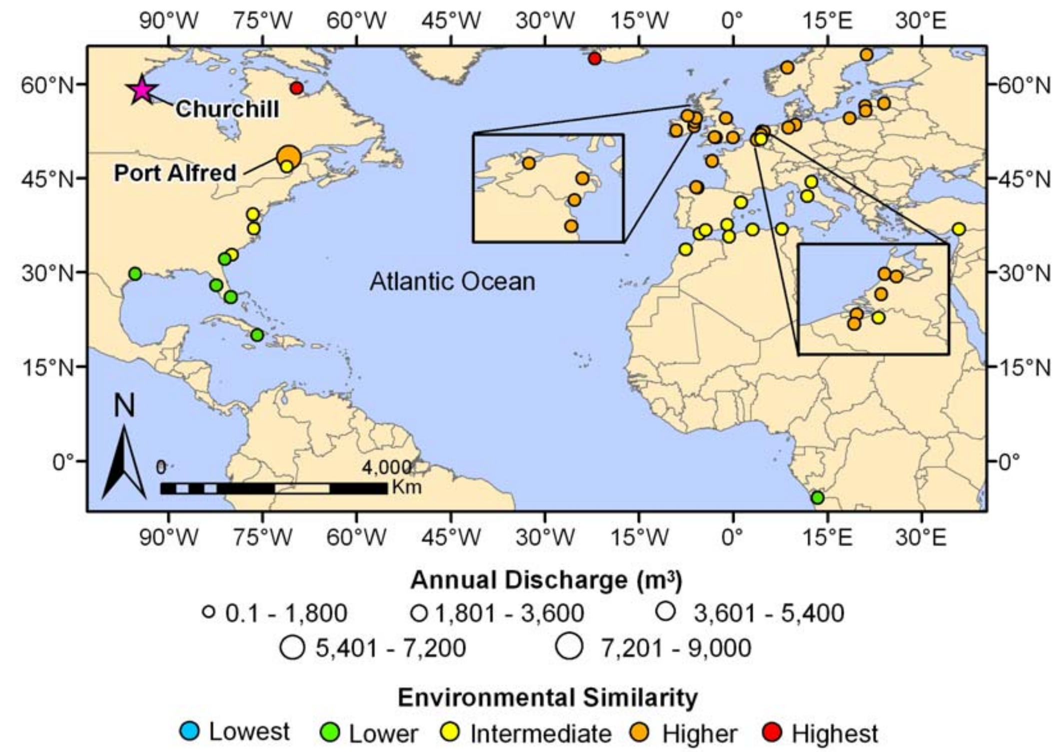


Figure 16. Map illustrating propagule supply and environmental similarity between Churchill and source ports connected via international merchant vessel ballast water discharges.

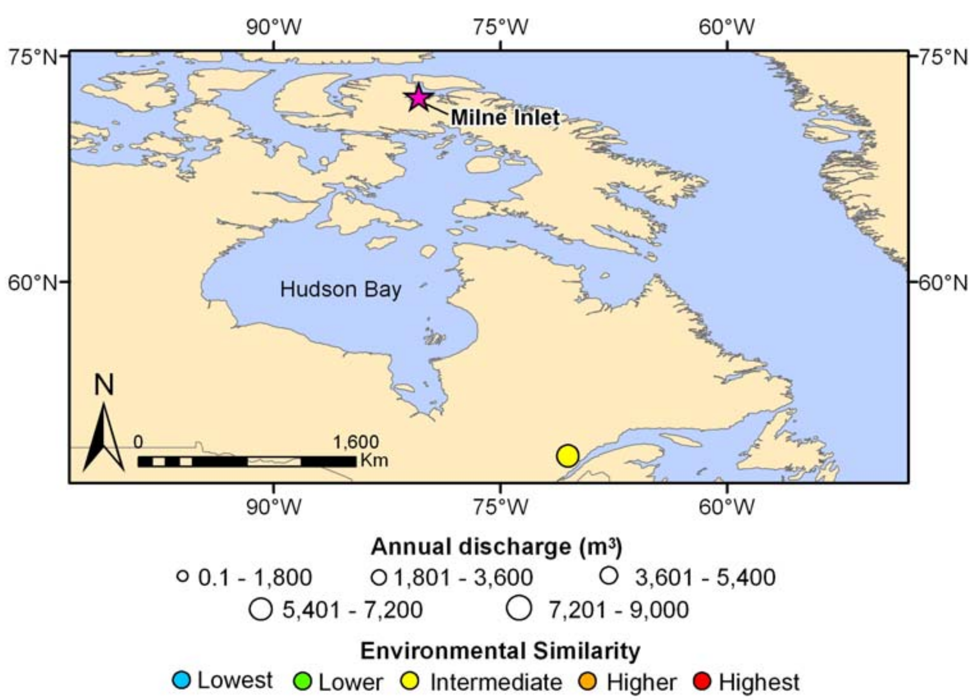


Figure 17. Map illustrating propagule supply and environmental similarity between Milne Inlet and source ports connected via international merchant vessel ballast water discharges.

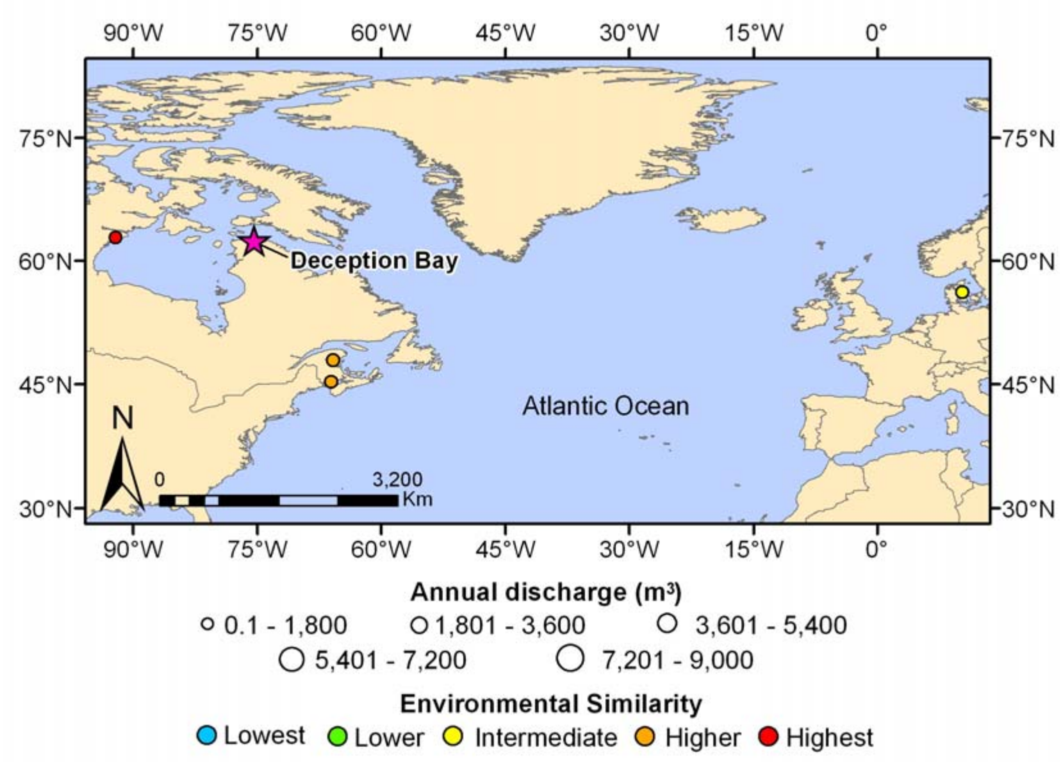


Figure 18. Map illustrating propagule supply and environmental similarity between Deception Bay and source ports connected via international merchant vessel ballast water discharges.

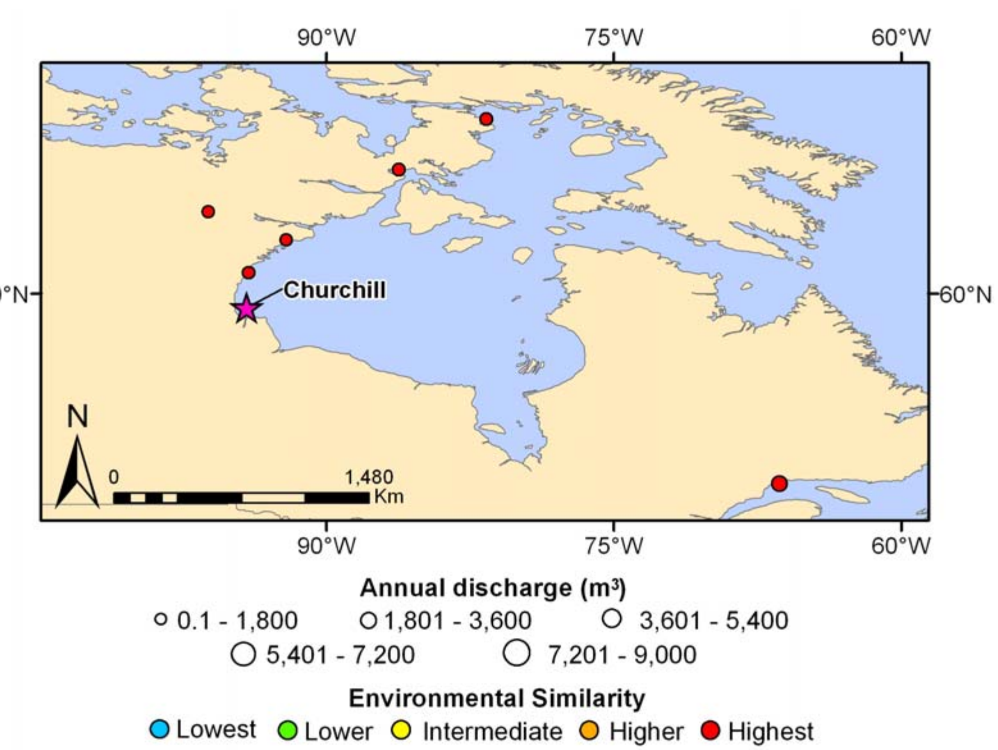


Figure 19. Map illustrating propagule supply and environmental similarity between Churchill and source ports connected via coastal domestic merchant vessel ballast water discharges.

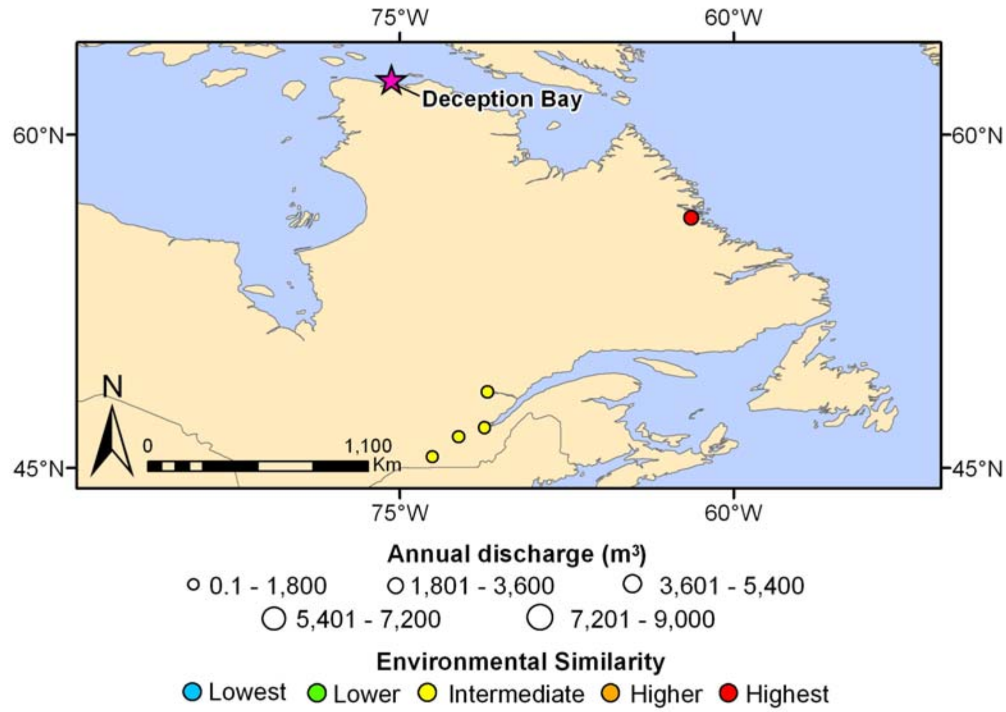


Figure 20. Map illustrating propagule supply and environmental similarity between Deception Bay and source ports connected via coastal domestic merchant vessel ballast water discharges.

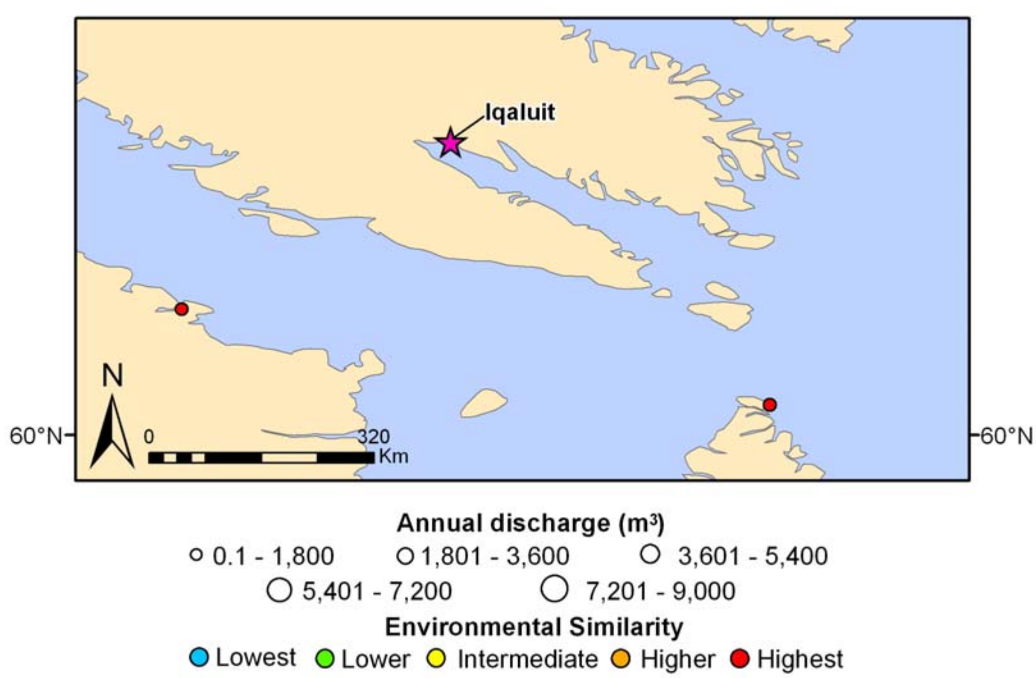


Figure 21. Map illustrating propagule supply and environmental similarity between Iqaluit and source ports connected via coastal domestic merchant vessel ballast water discharges.

APPENDICES

Appendix A. List of global ports that have highest environmental similarity to Churchill. NIS originating from these ports have the highest potential for survival if introduced at Churchill.

Global Ports	Country	Latitude	Longitude	Environmental Distance
Punta Loyola	ARG	-51.60	-69.02	0.88
Punta Quilla	ARG	-50.12	-68.41	1.28
Rio Grande	ARG	-53.79	-67.70	0.64
San Julian	ARG	-49.25	-67.67	0.92
Santa Cruz	ARG	-50.13	-68.38	1.28
Ushuaia	ARG	-54.80	-68.23	0.69
Crozet Island	ATF	-46.33	51.50	0.59
Port aux Francais	ATF	-49.35	70.20	0.60
Macquarie Island	AUS	-54.58	158.97	0.63
Argentia	CAN	47.30	-53.98	0.99
Arviat	CAN	61.10	-94.07	0.51
Aupaluk	CAN	59.35	-69.60	1.26
Baker Lake	CAN	64.29	-96.18	0.75
Bamberton	CAN	48.58	-123.52	1.24
Bay Bulls	CAN	47.30	-52.73	0.91
Bay de Verde	CAN	48.08	-52.90	0.88
Bay Roberts	CAN	47.57	-53.22	1.04
Beaver Cove	CAN	50.53	-126.85	0.97
Belledune	CAN	47.92	-65.85	1.17
Blanc Sablon	CAN	51.42	-57.13	0.84
Bonavista	CAN	48.65	-53.12	0.88
Bridgewater	CAN	44.37	-64.50	1.28
Burin	CAN	47.03	-55.17	1.02
Butchers Cove	CAN	48.83	-54.00	1.01
Butterfly Bay	CAN	62.98	-64.80	0.97
Cape Dyer	CAN	66.67	-61.42	1.38
Cape Hooper	CAN	68.43	-66.78	1.10
Caraquet	CAN	47.80	-65.02	1.24
Cartwright	CAN	53.70	-57.02	1.09
Catalina	CAN	48.52	-53.07	0.88
Charles Island Harbour	CAN	62.65	-74.33	1.11
Chemainus	CAN	48.92	-123.70	1.40
Chesterfield Inlet	CAN	63.37	-90.87	0.50
Chevery Harbour	CAN	50.45	-59.62	0.81
Churchill	CAN	58.78	-94.22	0.00
Clarks Harbour	CAN	43.42	-65.63	1.00
Clyde River	CAN	69.83	-70.37	1.09
Comeau Bay	CAN	49.22	-68.15	0.59
Constance Bank	CAN	48.35	-123.37	1.18
Coral Harbour	CAN	64.19	-83.26	1.05
Cowichan Bay	CAN	48.75	-123.60	1.40
Crofton	CAN	48.87	-123.63	1.40
Deception Bay	CAN	62.17	-74.70	1.11
Dildo	CAN	47.57	-53.57	1.00
Englee Harbour	CAN	50.72	-56.12	0.83

Englewood	CAN	50.53	-126.87	0.97
Esquimalt	CAN	48.43	-123.43	1.18
Flowers Cove	CAN	51.28	-56.75	0.78
Fortune	CAN	47.07	-55.83	1.01
Fox Harbour	CAN	52.33	-55.67	0.71
Hall Beach	CAN	68.80	-76.17	0.69
Harbour Grace	CAN	47.68	-53.22	1.04
Havre St. Pierre	CAN	50.23	-63.60	1.39
Hawkes Bay	CAN	50.62	-57.17	1.38
Herschel Island	CAN	69.57	-139.00	0.84
Hopedale	CAN	55.45	-60.20	0.74
Igloolik	CAN	69.17	-81.68	1.30
Ile-aux-Coudres	CAN	47.42	-70.39	0.60
Inukjuak	CAN	58.47	-78.13	0.26
Iqaluit	CAN	63.75	-68.53	0.69
Ivujivik	CAN	62.42	-77.90	0.78
Jedway	CAN	52.30	-131.22	1.39
Kangiqsualujjuaq	CAN	58.60	-65.93	1.36
Kekerten Island	CAN	65.70	-65.82	0.87
Killinek	CAN	60.38	-64.43	1.13
Kimmirut	CAN	62.80	-69.83	0.99
Kugluktuk	CAN	67.80	-115.20	0.94
Kuujjuaq	CAN	58.15	-68.30	0.99
Kuujjuaraapik	CAN	55.28	-77.75	0.66
La Have	CAN	44.28	-64.35	1.28
La Scie	CAN	49.97	-55.58	0.78
L'Anse-au-Loup	CAN	51.52	-56.83	0.95
Les Mechins	CAN	49.02	-66.98	0.85
Lewisporte	CAN	49.25	-55.05	0.85
Little Cornwallis Island	CAN	75.38	-96.95	0.73
Long Harbour	CAN	47.45	-53.82	0.99
Long Pond	CAN	47.52	-52.97	0.93
Longstaff Bluff	CAN	68.90	-75.20	0.69
Lower Cove	CAN	48.52	-59.10	1.33
Lower Island Cove	CAN	48.00	-52.98	0.87
Lower Savage Island	CAN	61.80	-65.75	1.19
Lunenburg	CAN	44.37	-64.30	1.28
Main Brook	CAN	51.18	-56.02	1.38
Margaretsville	CAN	45.05	-65.07	1.00
Marystown	CAN	47.17	-55.15	1.02
Masset	CAN	54.00	-132.15	1.08
Matane	CAN	48.85	-67.53	0.67
Melville Island	CAN	75.50	-112.00	0.73
Milne Inlet	CAN	72.43	-80.53	1.25
Mont Louis	CAN	49.23	-65.73	0.99
Monumental Island port	CAN	62.77	-63.85	0.96
Nain	CAN	56.53	-61.70	0.86
New Harbour	CAN	44.47	-64.08	1.34
Okak Harbour	CAN	57.58	-61.92	0.92
Pangnirtung	CAN	66.08	-65.75	0.70

Perce	CAN	48.50	-64.22	1.12
Plumper Sound	CAN	48.77	-123.20	1.26
Pointe au Pic	CAN	47.62	-70.13	0.60
Pointe Noire	CAN	50.17	-66.47	1.03
Pond Inlet	CAN	72.63	-78.28	1.21
Port de Grave	CAN	47.60	-53.20	1.04
Port Edward	CAN	54.23	-130.30	1.25
Port Hardy	CAN	50.72	-127.48	1.13
Port Hope Simpson	CAN	52.55	-56.30	1.24
Port McNeill	CAN	50.60	-127.08	1.05
Port Saunders	CAN	50.63	-57.30	0.91
Port Simpson	CAN	54.58	-130.42	0.97
Port Union	CAN	48.50	-53.08	0.88
Portneuf	CAN	48.62	-69.08	0.23
Prince Rupert	CAN	54.32	-130.37	1.29
Puvirnituq	CAN	60.00	-77.25	0.19
Quaqtaq	CAN	61.04	-69.63	1.15
Ramea Island	CAN	47.52	-57.42	1.36
Rankin Inlet	CAN	62.83	-92.11	0.48
Repulse Bay	CAN	66.52	-86.24	1.18
Resolute	CAN	74.68	-94.87	0.72
Resolution Island	CAN	61.38	-65.00	1.08
Rigolet	CAN	54.18	-58.42	1.08
Rimouski	CAN	48.48	-68.52	0.49
Riverport	CAN	44.28	-64.33	1.28
Riviere du Loup	CAN	47.85	-69.57	0.32
Saglek	CAN	58.54	-63.02	1.03
Salluit	CAN	62.30	-75.38	1.11
Sanikiluaq	CAN	56.60	-79.20	0.70
Sept-Iles	CAN	50.10	-66.38	1.03
Shelburne	CAN	43.67	-65.32	1.07
Shippegan	CAN	47.75	-64.70	1.25
Sidney	CAN	48.65	-123.38	1.24
Squamish	CAN	49.68	-123.17	1.23
St. Anthony	CAN	51.37	-55.58	0.70
St. Augustin	CAN	51.22	-58.65	0.81
St. Barbe Harbour	CAN	51.20	-56.77	1.30
St. John's	CAN	47.56	-52.71	0.93
Sugluk Island Harbour	CAN	62.30	-75.45	1.11
Tadoussac	CAN	48.13	-69.72	0.30
Tasiujaq	CAN	58.90	-69.33	1.26
Tilt Cove	CAN	49.88	-55.62	0.78
Tuktoyaktuk	CAN	69.43	-133.05	0.97
Twillingate	CAN	49.68	-54.75	0.83
Ucluelet	CAN	48.92	-125.57	1.36
Umiujak	CAN	56.57	-76.50	0.86
Valleyfield Harbour	CAN	49.12	-53.61	1.01
Victoria	CAN	48.42	-123.38	1.18
Voisey Bay	CAN	56.25	-61.92	0.95
Wabana	CAN	47.63	-52.92	0.93

Kangiqsujuaq	CAN	61.60	-71.97	1.05
Walrus Island	CAN	63.90	-89.58	0.62
Wemindji New Post	CAN	53.00	-78.82	0.52
Whale Cove	CAN	62.18	-92.61	0.48
Winisk	CAN	55.28	-85.23	0.87
Witless Bay	CAN	47.28	-52.77	0.91
Cabo Negro	CHL	-52.95	-70.78	1.12
Caleta Clarencia	CHL	-52.90	-70.15	1.19
Chacabuco	CHL	-45.47	-72.83	1.10
Gregorio	CHL	-52.63	-70.18	1.04
Guarello	CHL	-50.35	-75.33	1.13
Porvenir	CHL	-53.28	-70.37	1.16
Puerto Aisen	CHL	-45.38	-72.68	1.28
Puerto Cisnes	CHL	-44.73	-72.70	1.35
Puerto Eden	CHL	-49.15	-74.45	1.31
Puerto Melinka	CHL	-43.90	-73.73	1.35
Puerto Natales	CHL	-51.72	-72.52	1.16
Puerto Percy	CHL	-52.92	-70.28	1.11
Puerto Quellon	CHL	-43.15	-73.62	1.36
Puerto Williams	CHL	-54.93	-67.62	0.73
Punta Arenas	CHL	-53.17	-70.90	0.69
Punta Delgada	CHL	-52.45	-69.53	1.28
Grytviken	FLK	-54.28	-36.50	0.59
Mare Harbour	FLK	-51.92	-58.47	0.93
Stanley Harbour	FLK	-51.68	-57.83	0.82
Dalur	FRO	61.77	-6.67	0.96
Fuglafjordur	FRO	62.25	-6.82	1.02
Gota	FRO	62.18	-6.70	1.01
Hosvik	FRO	62.15	-6.93	1.02
Hvalba	FRO	61.60	-6.95	0.99
Hvalvik	FRO	62.18	-7.00	0.97
Klaksvik	FRO	62.23	-6.58	1.01
Kollafjordur	FRO	62.12	-6.90	1.02
Midvagur	FRO	62.03	-7.18	1.07
Nordskali	FRO	62.20	-6.98	0.97
Runavik	FRO	62.10	-6.72	1.01
Saltangara	FRO	62.12	-6.70	1.01
Sandvagur	FRO	62.05	-7.13	1.04
Skalafjordur	FRO	62.20	-6.85	0.97
Skali	FRO	62.15	-6.77	1.01
Skopun	FRO	61.90	-6.87	0.96
Sorvagur	FRO	62.08	-7.42	1.03
Strendur	FRO	62.12	-6.75	1.01
Streymnes	FRO	62.18	-7.02	0.97
Toftir	FRO	62.08	-6.72	1.01
Torshavn	FRO	62.00	-6.75	1.01
Tvoroyri	FRO	61.55	-6.80	0.99
Vagur	FRO	61.47	-6.80	1.04
Vestmanna	FRO	62.15	-7.17	1.07
Aberlady Bay	GBR	56.02	-2.85	1.16

Alnwick	GBR	55.40	-1.70	1.32
Ballycastle	GBR	55.22	-6.23	1.38
Ballylumford	GBR	54.83	-5.78	1.36
Baltasound	GBR	60.75	-0.83	1.29
Bangor	GBR	54.67	-5.67	1.37
Berwick-upon-Tweed	GBR	55.77	-2.00	1.28
Blyth	GBR	55.12	-1.48	1.33
Bressay	GBR	60.13	-1.08	1.27
Broadford	GBR	57.23	-5.90	1.19
Brodick	GBR	55.57	-5.10	1.32
Bruichladdich	GBR	55.77	-6.37	1.38
Burray	GBR	58.85	-2.90	1.22
Campbeltown	GBR	55.42	-5.58	1.34
Colonsay	GBR	56.05	-6.18	1.37
Craignure	GBR	56.47	-5.70	1.35
Cullivoe	GBR	60.70	-1.00	1.29
Dundee	GBR	56.47	-2.97	1.16
Dunvegan	GBR	57.45	-6.58	1.33
Eyemouth	GBR	55.87	-2.08	1.16
Fraserburgh	GBR	57.68	-2.00	1.18
Girvan	GBR	55.25	-4.87	1.34
Glencripesdale	GBR	56.67	-5.82	1.39
Glensanda	GBR	56.57	-5.53	1.36
Hartlepool	GBR	54.70	-1.20	1.33
Kilkeel	GBR	54.07	-6.00	1.39
Kilroot	GBR	54.72	-5.75	1.37
Kinlochbervie	GBR	58.45	-5.03	1.30
Kirkwall	GBR	59.00	-2.98	1.23
Kishorn	GBR	57.38	-5.60	1.37
Kylesku	GBR	58.25	-5.02	1.28
Lamlash	GBR	55.53	-5.07	1.32
Largo Bay	GBR	56.22	-2.93	1.16
Larne	GBR	54.85	-5.78	1.36
Lerwick	GBR	60.15	-1.13	1.27
Loch Carnan	GBR	57.33	-7.25	1.39
Lochinver	GBR	58.15	-5.25	1.40
Lochmaddy	GBR	57.60	-7.13	1.39
Lyness	GBR	58.83	-3.18	1.22
Magheramorne	GBR	54.82	-5.77	1.36
Methil	GBR	56.18	-3.00	1.16
Mid Yell Voe	GBR	60.60	-1.07	1.28
Montrose	GBR	56.70	-2.47	1.15
Mull of Galloway	GBR	54.63	-4.85	1.38
North Shields	GBR	55.02	-1.43	1.33
North Sunderland	GBR	55.58	-1.65	1.33
Peterhead	GBR	57.50	-1.78	1.18
Port Ellen	GBR	55.62	-6.22	1.36
Portavogie	GBR	54.45	-5.43	1.38
Portpatrick	GBR	54.85	-5.12	1.36
Portree	GBR	57.40	-6.18	1.25

Redcar	GBR	54.62	-1.07	1.33
Sanday	GBR	59.22	-2.50	1.22
Sandhaven	GBR	57.68	-2.02	1.18
Sandwick	GBR	60.00	-1.23	1.26
Scalloway	GBR	60.13	-1.27	1.27
Seaham	GBR	54.83	-1.32	1.32
Seaton Sluice	GBR	55.08	-1.47	1.33
Shapinsay	GBR	59.05	-2.85	1.23
South Shields	GBR	55.00	-1.43	1.33
St. Margaret's Hope	GBR	58.83	-2.95	1.22
St. Monans	GBR	56.20	-2.77	1.16
Stornoway	GBR	58.20	-6.38	1.39
Stranraer	GBR	54.92	-5.03	1.36
Stromness	GBR	58.97	-3.30	1.22
Stronsay	GBR	59.12	-2.62	1.22
Sullom Voe	GBR	60.45	-1.33	1.33
Sunderland	GBR	54.92	-1.37	1.32
Tayport	GBR	56.45	-2.88	1.16
Tofts Voe	GBR	60.50	-1.18	1.28
Tyne	GBR	55.00	-1.43	1.33
Ullapool	GBR	57.90	-5.17	1.30
Vidlin Voe	GBR	60.38	-1.13	1.25
Warkworth	GBR	55.33	-1.57	1.32
Wick	GBR	58.43	-3.08	1.19
Aappilattoq	GRL	60.17	-44.28	0.63
Aasiaat	GRL	68.72	-52.88	0.82
Alluitsup Paa	GRL	60.47	-45.57	1.10
Ammassalik	GRL	65.58	-37.50	1.10
Aputiteq	GRL	67.80	-32.22	0.94
Daneborg	GRL	74.30	-20.25	0.80
Danmarkshavn	GRL	76.77	-18.75	0.83
Dundas	GRL	76.55	-68.82	0.81
Fiskenaesset	GRL	63.08	-50.68	0.55
Ikkatseq	GRL	65.63	-37.95	0.65
Ilulissat	GRL	69.22	-51.10	0.83
Ivittuut	GRL	61.20	-48.17	0.56
Kangaamiut	GRL	65.82	-53.30	0.99
Kangerluarsoruseq	GRL	63.70	-51.55	0.84
Kangilinnguit	GRL	61.20	-48.10	0.64
Kirkespirdalen	GRL	60.32	-44.93	0.60
Kulusuk	GRL	65.53	-37.25	1.08
Kuummiut	GRL	65.87	-37.00	0.67
Maniitsoq	GRL	65.42	-52.90	0.87
Marmorilik	GRL	71.13	-51.28	0.78
Mesters Vig	GRL	72.15	-23.75	0.88
Moriusaq	GRL	76.73	69.60	1.37
Nanortalik	GRL	60.13	-45.25	1.05
Narsaq	GRL	60.90	-45.98	0.93
Narsaq Kujalleq	GRL	60.00	-44.67	0.63
Narsarsuaq	GRL	61.15	-45.43	0.95

Nerlerit Innat	GRL	70.73	-22.63	0.88
Nuuk	GRL	64.17	-51.73	0.86
Paamiut	GRL	62.00	-49.67	1.38
Pituffik	GRL	76.55	-68.87	0.87
Qaanaaq	GRL	77.47	-69.22	0.93
Qaqortoq	GRL	60.72	-46.03	1.08
Qasigiannguit	GRL	68.82	-51.18	0.77
Qeqertarsuaq	GRL	69.25	-53.55	0.80
Qutdleq	GRL	62.52	-42.22	0.93
Qutdligssat	GRL	70.07	-52.83	0.84
Savissivik	GRL	76.03	-64.85	1.25
Siorapaluk	GRL	77.78	-70.70	0.92
Sisimiut	GRL	66.95	-53.68	0.82
Skjoldungen	GRL	63.23	-41.45	0.63
Tasiusaq	GRL	73.37	-56.07	0.93
Thule Air Base	GRL	76.55	-68.82	0.81
Tovqussaq	GRL	64.87	-52.20	0.61
Umivik	GRL	64.25	-40.83	0.75
Upernavik	GRL	72.78	-56.15	0.91
Uummannaq	GRL	70.68	-52.13	0.80
Zackenberg	GRL	74.47	-20.63	0.83
Akranes	ISL	64.32	-22.08	0.93
Akureyri	ISL	65.68	-18.05	0.81
Bakkafjordur	ISL	66.05	-14.75	0.60
Bildudalur	ISL	65.68	-23.60	0.67
Blonduos	ISL	65.67	-20.30	0.76
Bolungavik	ISL	66.17	-23.23	0.61
Bordeyri	ISL	65.22	-21.15	0.74
Borgarnes	ISL	64.53	-21.92	0.74
Breidhdalsvik	ISL	64.73	-13.98	0.66
Budir	ISL	64.93	-13.80	0.65
Dalvik	ISL	65.97	-18.52	0.70
Djupavik	ISL	65.95	-21.57	0.28
Djupivogur	ISL	64.67	-14.25	0.75
Dyrholaey	ISL	63.40	-19.13	1.03
Eskifjordur	ISL	65.08	-13.98	0.61
Eyrarbakki	ISL	63.87	-21.15	0.98
Flatey	ISL	65.37	-22.92	0.59
Flateyri	ISL	66.05	-23.48	0.65
Gardabaer	ISL	64.07	-21.93	0.97
Grafaros	ISL	65.55	-19.40	0.93
Grenivik	ISL	65.95	-18.20	0.75
Grindavik	ISL	63.83	-22.43	1.06
Grundarfjordur	ISL	64.92	-23.22	0.75
Grundartangi	ISL	64.35	-21.78	0.55
Gufunes	ISL	64.15	-21.82	0.91
Hafnarfjordur	ISL	64.07	-21.92	0.97
Helguvik	ISL	64.38	-21.47	0.71
Hellisandur	ISL	64.90	-23.90	0.87
Hesteyri	ISL	66.35	-22.85	0.65

Hjalteyri	ISL	65.85	-18.20	0.75
Hofdhakaupstadur	ISL	65.83	-20.32	0.74
Hofn	ISL	64.27	-15.22	0.93
Hofsos	ISL	65.88	-19.40	0.79
Holmavik	ISL	65.70	-21.68	0.69
Hrafneyri	ISL	64.38	-21.53	0.72
Hrisey	ISL	66.03	-18.42	0.60
Husavik	ISL	66.05	-17.37	0.61
Hvaleyri	ISL	64.33	-21.73	0.56
Hvammstangi	ISL	65.40	-20.95	0.69
Isafjordur	ISL	66.08	-23.10	0.61
Keflavik	ISL	64.00	-22.55	0.93
Kopasker	ISL	66.28	-16.45	0.73
Kopavogur	ISL	64.10	-21.88	0.97
Korsnes	ISL	64.12	-21.90	0.97
Kroksfjardarnes	ISL	65.45	-21.93	0.74
Krossanes	ISL	65.70	-18.12	0.75
Midsandur	ISL	64.40	-21.47	0.71
Neskaupstadur	ISL	65.15	-13.68	0.58
Njardhvik	ISL	65.58	-13.85	0.58
Nordurfjordur	ISL	66.03	-21.57	0.60
Olafsfjordur	ISL	66.08	-18.63	0.60
Olafsvik	ISL	64.90	-23.72	0.73
Patrekshofn	ISL	65.58	-23.98	0.77
Raufarhofn	ISL	66.45	-15.90	0.68
Reykholar	ISL	65.45	-22.22	0.73
Reykjanes	ISL	63.80	-22.70	0.91
Reykjavik	ISL	64.15	-21.95	0.97
Rifshofn	ISL	64.88	-23.67	0.73
Sandgerdhi	ISL	64.05	-22.72	0.93
Sandur	ISL	64.92	-23.82	0.74
Saudarkrokur	ISL	65.75	-19.60	0.59
Seydhisfjordur	ISL	65.25	-13.92	0.21
Siglufjordur	ISL	66.20	-18.87	0.69
Stodhvarfjordur	ISL	64.83	-13.83	0.65
Stokkseyri	ISL	63.83	-21.08	1.03
Straumsvik	ISL	64.05	-22.05	0.94
Stykkisholmur	ISL	65.07	-22.68	0.60
Sudhureyri	ISL	66.13	-23.53	0.62
Svalbardhseyri	ISL	65.75	-18.10	0.75
Thingeyri	ISL	65.87	-23.48	0.67
Thorlakshofn	ISL	63.85	-21.33	0.92
Thorshofn	ISL	66.20	-15.33	0.66
Vestmannaeyjar	ISL	63.43	-20.27	1.08
Vopnafjordur	ISL	65.75	-14.82	0.62
Nemuro	JPN	43.33	145.58	1.35
Aaheim	NOR	62.05	5.52	1.04
Aakrehamn	NOR	59.25	5.17	1.29
Aalesund	NOR	62.47	6.17	1.20
Abelvaer	NOR	64.73	11.17	1.12

Andenes	NOR	69.32	16.13	0.87
Askvoll	NOR	61.35	5.07	1.30
Aukra	NOR	62.78	6.97	1.16
Averoy	NOR	63.12	7.67	1.14
Ballangen	NOR	68.37	16.93	1.23
Ballstad	NOR	68.07	13.53	1.09
Batsfjord	NOR	70.63	29.73	0.81
Bekkjarvik	NOR	60.00	5.22	1.24
Bergneset	NOR	68.80	16.00	0.87
Bergsfjord	NOR	70.25	21.80	0.72
Berlevaag	NOR	70.85	29.10	0.79
Billefjord	NOR	70.37	25.10	0.63
Bjugn	NOR	63.77	9.73	1.04
Bodo	NOR	67.28	14.38	0.88
Bokn	NOR	59.22	5.45	1.28
Borkenes	NOR	68.77	16.18	0.68
Bovagen	NOR	60.70	4.93	1.23
Brattvag	NOR	62.60	6.45	1.14
Brekstad	NOR	63.68	9.67	1.06
Bremanger	NOR	61.85	4.95	1.34
Brettesnes	NOR	68.23	14.87	0.86
Bronnoysund	NOR	65.47	12.22	1.11
Deknepoll	NOR	61.92	5.13	1.24
Dryna	NOR	62.63	6.53	1.21
Dyroy	NOR	68.82	14.82	0.85
Elnesvagen	NOR	62.85	7.15	1.21
Elvalandet	NOR	64.57	11.42	1.23
Espevaer	NOR	59.58	5.15	1.28
Fagervika	NOR	66.12	12.85	1.17
Fedje	NOR	60.75	4.73	1.23
Festoy	NOR	62.37	6.33	1.19
Fevag	NOR	63.67	9.83	1.03
Finnfjord	NOR	70.82	23.08	0.71
Fiskarstranda	NOR	62.43	6.27	1.12
Floro	NOR	61.60	5.03	1.20
Foresvik	NOR	59.22	5.43	1.28
Fosnavaag	NOR	62.35	5.63	1.22
Glomfjord	NOR	66.82	13.62	1.03
Gravdal	NOR	68.12	13.55	1.09
Gurskebotn	NOR	62.22	5.65	1.26
Gursken	NOR	62.23	5.55	1.22
Halsa	NOR	66.75	13.57	1.05
Hammerfest	NOR	70.67	23.67	0.68
Hareid	NOR	62.37	6.03	1.10
Harstad	NOR	68.80	16.55	0.84
Hasvik	NOR	70.48	22.15	0.70
Haugesund	NOR	59.42	5.27	1.40
Haugsholmen	NOR	62.17	5.40	1.21
Havoysund	NOR	70.98	24.58	0.69
Hekkelstrand	NOR	68.40	16.83	1.23

Hellestrand	NOR	61.33	5.12	1.33
Henningsvaer	NOR	68.15	14.22	0.89
Hestvika	NOR	63.57	9.17	1.13
Hilleren	NOR	60.17	5.08	1.23
Hitra	NOR	63.43	8.42	1.13
Hjorungavaag	NOR	62.35	6.08	1.10
Holmedal	NOR	61.35	5.18	1.36
Hommelsto	NOR	65.53	12.33	1.12
Honningsvaag	NOR	70.98	25.98	0.67
Husoy	NOR	61.02	4.70	1.21
Ikornnes	NOR	62.38	6.52	1.36
Innhavet	NOR	67.97	15.93	1.34
Jelsa	NOR	59.33	6.03	1.32
Jovik	NOR	69.60	19.83	0.88
Kaafjord	NOR	69.58	20.52	0.84
Kalvaag	NOR	61.77	4.88	1.22
Karlsoy	NOR	70.00	19.90	0.86
Kirkenes	NOR	69.73	30.05	0.76
Kjelstraum	NOR	60.80	4.95	1.23
Kjopsvik	NOR	68.08	16.38	1.08
Kollsnes	NOR	60.57	4.83	1.23
Kolvereid	NOR	64.88	11.58	1.10
Kristiansund	NOR	63.12	7.73	1.14
Langevag	NOR	62.43	6.25	1.12
Larsnes	NOR	62.20	5.65	1.26
Lauvsnes	NOR	64.50	10.90	1.13
Leirpollen	NOR	70.38	25.52	1.04
Lillebukt	NOR	70.33	22.50	0.85
Lodingen	NOR	68.42	16.00	0.86
Lysoysund	NOR	63.88	9.88	1.13
Maaloy	NOR	61.92	5.12	1.24
Marnes	NOR	67.13	14.08	0.88
Mastrevik	NOR	60.80	4.97	1.23
Mehamn	NOR	71.00	27.83	0.66
Melbu	NOR	68.50	14.80	0.92
Midsund	NOR	62.70	6.70	1.18
Mjosund	NOR	63.23	8.50	1.09
Molde	NOR	62.73	7.17	1.12
Moltustranda	NOR	62.30	5.65	1.22
More	NOR	62.47	6.15	1.20
Myre	NOR	69.08	15.95	0.88
Nesna	NOR	66.20	13.02	1.19
North Cape	NOR	71.17	25.77	0.67
Nusfjord	NOR	68.03	13.35	0.92
Oksfjord	NOR	70.23	22.30	0.69
Ottersoy	NOR	64.85	11.28	1.12
Ramsund	NOR	68.48	16.52	0.81
Ramsvika	NOR	62.93	7.40	1.09
Randaberg	NOR	59.00	5.63	1.28
Raudeberg	NOR	61.98	5.10	1.22

Repparfjord	NOR	70.43	24.25	1.02
Risnes	NOR	61.15	5.17	1.28
Rorvik	NOR	64.87	11.27	1.12
Salthella	NOR	60.00	5.12	1.24
Sandnessjoen	NOR	66.02	12.63	0.87
Sandstad	NOR	63.52	9.07	1.03
Selje	NOR	62.05	5.37	1.21
Skaland	NOR	69.45	17.30	0.92
Skudeneshavn	NOR	59.13	5.27	1.28
Solevaag	NOR	62.40	6.33	1.19
Sortland	NOR	68.70	15.43	0.90
Sovik	NOR	65.92	12.43	1.07
Spjelkavik	NOR	62.45	6.37	1.14
Stamsund	NOR	68.12	13.85	0.93
Stokksund	NOR	64.03	10.03	1.14
Stokmarknes	NOR	68.57	14.92	1.01
Storasund	NOR	59.38	5.27	1.40
Straumen	NOR	63.33	8.10	1.14
Sture	NOR	60.62	4.85	1.23
Svolvaer	NOR	68.23	14.57	1.01
Tau	NOR	59.07	5.93	1.28
Tjeldbergodden	NOR	63.42	8.70	1.04
Tjorvaag	NOR	62.28	5.75	1.22
Tomrefjord	NOR	62.63	6.68	0.98
Tovik	NOR	68.67	16.90	0.90
Tromso	NOR	69.65	18.97	1.25
Ulsteinvik	NOR	62.35	5.85	1.22
Uthaug	NOR	63.73	9.60	1.12
Vadso	NOR	70.07	29.73	0.90
Vardo	NOR	70.38	31.10	0.61
Vats	NOR	59.48	5.75	1.24
Vestnes	NOR	62.63	7.07	1.13
Vigsnes	NOR	59.40	5.13	1.29
Vikholmen	NOR	66.20	12.97	1.22
Voksa	NOR	62.23	5.45	1.21
Aleksandrovsk-Sakhalinskiy	RUS	50.88	142.12	0.93
Amderma	RUS	69.73	61.58	1.08
Anadyr	RUS	64.73	177.53	1.02
Belomorsk	RUS	64.53	34.82	0.68
Belyy Island	RUS	73.52	70.80	0.72
Beringovskiy	RUS	63.13	179.50	0.61
Burevestnik	RUS	44.95	147.62	1.36
Cape Shmidta	RUS	68.88	-179.47	1.15
De Kastri	RUS	51.47	140.78	1.38
Dikson	RUS	73.50	80.40	0.97
Egvekinot	RUS	66.33	-179.03	0.71
Kamenka	RUS	65.88	44.18	1.25
Kem	RUS	65.00	34.78	0.73
Keret	RUS	66.28	33.57	0.91
Kolguyev Island	RUS	68.77	49.23	1.10

Magadan	RUS	59.63	150.83	1.02
Mezen	RUS	65.85	44.25	1.25
Nabil	RUS	51.70	143.30	0.64
Novyy Port	RUS	67.68	73.10	0.75
Okhotsk	RUS	59.35	143.17	1.35
Ossora	RUS	59.27	163.13	1.06
Pechenga	RUS	69.55	31.17	0.90
Petropavlovsk-Kamchatskiy	RUS	53.02	158.63	1.16
Pevek	RUS	69.72	170.30	0.77
Poronaysk	RUS	49.22	143.12	1.18
Preobrazhenskoye	RUS	54.87	167.67	0.59
Provideniya	RUS	64.42	-173.25	0.68
Severo Kurilsk	RUS	50.68	156.12	0.83
Severodvinsk	RUS	64.58	39.78	0.78
Severomorsk	RUS	69.08	33.45	1.32
Umba	RUS	66.67	34.30	1.33
Ust-Kamchatsk	RUS	56.22	162.48	0.83
Ust-Kara	RUS	69.20	65.00	1.09
Ust-Khayruzovo	RUS	57.08	156.83	1.37
Ust-Penzhino	RUS	62.50	165.15	1.28
Varandey	RUS	68.82	58.00	0.72
Varnek	RUS	69.90	60.02	0.99
Vitino	RUS	66.90	32.33	1.39
Yuzhno Kurilsk	RUS	44.05	145.80	1.29
Advent Bay	SJM	78.25	15.58	0.80
Barents Island	SJM	78.58	21.83	0.82
Barentsburg	SJM	78.08	14.22	0.90
Bear Island	SJM	74.50	19.20	1.00
Longyearbyen	SJM	78.25	15.58	0.80
Ny Alesund	SJM	78.92	11.93	0.85
St. Pierre	SPM	46.82	-56.17	1.05
Adak	USA	51.85	-176.65	0.51
Afognak	USA	58.00	-152.83	1.14
Akutan	USA	54.13	-165.75	0.50
Anacortes	USA	48.52	-122.62	1.03
Angoon	USA	57.48	-134.57	1.05
Barrow	USA	71.32	-156.72	1.12
Bartlett Cove	USA	58.47	-135.82	1.29
Bethel	USA	60.80	-161.77	0.66
Bremerton	USA	47.57	-122.62	1.16
Castle Island	USA	56.65	-133.17	1.13
Chatham	USA	57.52	-134.95	0.77
Chenega	USA	60.27	-148.07	1.00
Chignik	USA	56.30	-158.40	0.88
Cold Bay	USA	55.18	-162.70	0.88
Cordova	USA	60.55	-145.77	1.14
Craig	USA	55.47	-133.15	1.20
Dutch Harbour	USA	53.90	-166.53	0.78
Eastport	USA	44.90	-66.98	0.83
False Pass	USA	54.83	-163.40	0.58

Friday Harbour	USA	48.53	-123.00	1.10
Gambell	USA	63.77	-171.72	0.72
Gustavus	USA	58.40	-135.73	1.29
Haines	USA	59.23	-135.45	1.32
Hawk Inlet	USA	58.10	-134.73	0.97
Homer	USA	59.63	-151.50	0.78
Hoonah	USA	58.12	-135.43	0.78
Hydaburg	USA	55.20	-132.82	0.97
Icy Strait Point	USA	58.10	-135.60	1.05
Juneau	USA	58.30	-134.42	0.86
Kake	USA	56.92	-133.87	0.60
Kaktovik	USA	70.13	-143.83	1.14
Kenai	USA	60.55	-151.27	1.00
Ketchikan	USA	55.35	-131.65	1.24
King Cove	USA	55.03	-162.32	0.79
Kiska Harbour	USA	51.98	177.57	0.52
Klawock	USA	55.55	-133.10	1.29
Kodiak	USA	57.78	-152.40	0.72
Manchester	USA	47.55	-122.53	0.96
March Point	USA	48.50	-122.57	1.03
Metlakatla	USA	55.13	-131.57	0.97
Naknek	USA	58.73	-157.03	1.12
Nikishka	USA	60.73	-151.30	0.79
Nikiski	USA	60.68	-151.38	0.73
Nome	USA	64.52	-165.42	0.86
Orca	USA	60.58	-145.72	1.20
Pelican	USA	57.95	-136.22	1.03
Petersburg	USA	56.82	-132.95	1.13
Port Lions	USA	57.87	-152.88	1.14
Prudhoe Bay	USA	70.33	-148.33	1.10
Red Dog	USA	67.58	-164.05	0.91
Sand Point	USA	55.32	-160.48	0.67
Sandy Point	USA	48.82	-122.78	1.17
Seldovia	USA	59.43	-151.72	0.88
Seward	USA	60.12	-149.43	1.07
Sitka	USA	57.05	-135.33	1.09
Skagway	USA	59.45	-135.32	0.80
St. Lawrence Island	USA	63.00	-169.50	0.68
St. Michael	USA	63.47	-162.02	1.09
St. Paul	USA	57.12	-170.27	0.50
Susitna	USA	61.47	-150.50	1.35
Tatitlek	USA	60.85	-146.68	1.23
Tenakee Springs	USA	57.78	-135.22	0.99
Togiak	USA	59.08	-160.50	1.06
Tolstoi Bay	USA	55.67	-132.52	1.01
Tyonek	USA	61.07	-151.15	1.16
Unalaska	USA	53.85	-166.52	0.53
Valdez	USA	61.13	-146.35	0.98
Wainwright	USA	70.65	-160.17	1.10
Whittier	USA	60.78	-148.67	0.90

Wrangell	USA	56.47	-132.37	1.16
Yakutat	USA	59.55	-139.75	1.11

Appendix B. List of global ports that have highest environmental similarity to Milne Inlet. NIS originating from these ports have the highest potential for survival if introduced at Milne Inlet.

Global Ports	Country	Latitude	Longitude	Environmental Distance
Bowman Island	ATA	-65.50	103.42	0.44
Casey	ATA	-66.28	110.53	0.47
Commonwealth Bay	ATA	-67.00	142.00	0.56
Davis	ATA	-68.58	77.97	0.28
Dumont d'Urville	ATA	-66.67	140.02	0.56
Mawson	ATA	-67.60	62.87	0.29
McMurdo	ATA	-77.85	166.60	0.49
Molodezhnaya	ATA	-67.67	45.83	0.48
Port Lockroy	ATA	-64.82	-63.52	0.27
Crozet Island	ATF	-46.33	51.50	1.13
Port aux Francais	ATF	-49.35	70.20	1.14
Macquarie Island	AUS	-54.58	158.97	1.16
Arviat	CAN	61.10	-94.07	1.16
Aupaluk	CAN	59.35	-69.60	0.17
Baker Lake	CAN	64.29	-96.18	0.65
Broughton Island	CAN	67.56	-64.08	0.30
Butterfly Bay	CAN	62.98	-64.80	0.39
Cambridge Bay	CAN	69.18	-105.06	0.44
Cape Dorset	CAN	64.31	-76.70	0.25
Cape Dyer	CAN	66.67	-61.42	0.23
Cape Hooper	CAN	68.43	-66.78	0.19
Charles Island Harbour	CAN	62.65	-74.33	0.24
Chesterfield Inlet/Igluligaarjuk	CAN	63.37	-90.87	1.00
Churchill	CAN	58.78	-94.22	1.25
Clyde River	CAN	69.83	-70.37	0.19
Coral Harbour	CAN	64.19	-83.26	0.35
Deception Bay	CAN	62.17	-74.70	0.24
Fox Harbour	CAN	52.33	-55.67	0.87
Hall Beach	CAN	68.80	-76.17	1.20
Herschel Island	CAN	69.57	-139.00	0.72
Hopedale	CAN	55.45	-60.20	0.87
Igloolik	CAN	69.17	-81.68	0.21
Inukjuak	CAN	58.47	-78.13	1.14
Iqaluit	CAN	63.75	-68.53	1.16
Ivujivik	CAN	62.42	-77.90	0.55
Kangiqsualujjuaq	CAN	58.60	-65.93	0.15
Kekerten Island	CAN	65.70	-65.82	0.48
Killinek	CAN	60.38	-64.43	0.21
Kimmirut	CAN	62.80	-69.83	0.31
Kugaaruk	CAN	68.53	-89.83	0.37
Kugluktuk	CAN	67.80	-115.20	0.40
Kuujjuaraapik	CAN	55.28	-77.75	0.79
Little Cornwallis Island	CAN	75.38	-96.95	0.76

Longstaff Bluff	CAN	68.90	-75.20	1.20
Lower Savage Island	CAN	61.80	-65.75	0.14
Melville Island	CAN	75.50	-112.00	0.71
Milne Inlet	CAN	72.43	-80.53	0.00
Monumental Island port	CAN	62.77	-63.85	0.39
Nain	CAN	56.53	-61.70	0.68
Okak Harbour	CAN	57.58	-61.92	0.43
Pangnirtung	CAN	66.08	-65.75	0.91
Pond Inlet/Mittimatalik	CAN	72.63	-78.28	0.07
Portneuf	CAN	48.62	-69.08	1.13
Puvirnituq	CAN	60.00	-77.25	1.18
Quaqtaq	CAN	61.04	-69.63	0.18
Rankin Inlet	CAN	62.83	-92.11	1.22
Repulse Bay	CAN	66.52	-86.24	0.22
Resolute	CAN	74.68	-94.87	0.78
Resolution Island	CAN	61.38	-65.00	0.26
Riviere du Loup	CAN	47.85	-69.57	1.28
Saglek	CAN	58.54	-63.02	0.31
Salluit	CAN	62.30	-75.38	0.24
Sanikiluaq	CAN	56.60	-79.20	0.67
Sugluk Island Harbour	CAN	62.30	-75.45	0.24
Tadoussac	CAN	48.13	-69.72	1.21
Tasiujaq	CAN	58.90	-69.33	0.17
Umiuja	CAN	56.57	-76.50	0.55
Voisey Bay	CAN	56.25	-61.92	0.51
Kangiqsujuaq	CAN	61.60	-71.97	0.25
Walrus Island	CAN	63.90	-89.58	0.77
Wemindji New Post	CAN	53.00	-78.82	1.15
Whale Cove	CAN	62.18	-92.61	1.12
Winisk	CAN	55.28	-85.23	0.59
Grytviken	FLK	-54.28	-36.50	1.00
Deception Island	GBR	-62.95	-60.63	0.28
Scotia Bay	GBR	-60.72	-44.63	0.32
Aasiaat	GRL	68.72	-52.88	0.80
Alluitsup Paa	GRL	60.47	-45.57	0.25
Ammassalik	GRL	65.58	-37.50	0.31
Aputiteq	GRL	67.80	-32.22	0.58
Daneborg	GRL	74.30	-20.25	0.69
Danmarkshavn	GRL	76.77	-18.75	0.65
Dundas	GRL	76.55	-68.82	0.82
Fiskenaesset	GRL	63.08	-50.68	1.26
Ikkatseq	GRL	65.63	-37.95	1.03
Ilulissat	GRL	69.22	-51.10	0.70
Ivittuut	GRL	61.20	-48.17	1.33
Kangaamiut	GRL	65.82	-53.30	0.47
Kangerluarsoruseq	GRL	63.70	-51.55	0.51
Kirkespirdalen	GRL	60.32	-44.93	1.30
Kulusuk	GRL	65.53	-37.25	0.32
Kuummiut	GRL	65.87	-37.00	0.94
Maniitsoq	GRL	65.42	-52.90	0.56

Marmorilik	GRL	71.13	-51.28	0.83
Mesters Vig	GRL	72.15	-23.75	0.50
Moriusaq	GRL	76.73	69.60	0.27
Nanortalik	GRL	60.13	-45.25	0.32
Nerlerit Innat	GRL	70.73	-22.63	0.65
Nuuk	GRL	64.17	-51.73	0.51
Paamiut	GRL	62.00	-49.67	0.19
Pituffik	GRL	76.55	-68.87	0.65
Qaanaaq	GRL	77.47	-69.22	0.52
Qaqortoq	GRL	60.72	-46.03	0.25
Qasigiannguit	GRL	68.82	-51.18	1.39
Qeqertarsuaq	GRL	69.25	-53.55	0.78
Qutdleq	GRL	62.52	-42.22	0.45
Qutdligssat	GRL	70.07	-52.83	0.71
Savissivik	GRL	76.03	-64.85	0.26
Siorapaluk	GRL	77.78	-70.70	0.53
Sisimiut	GRL	66.95	-53.68	0.61
Skjoldungen	GRL	63.23	-41.45	1.09
Tasiusaq	GRL	73.37	-56.07	0.58
Thule Air Base	GRL	76.55	-68.82	0.82
Tovqussaq	GRL	64.87	-52.20	1.22
Umivik	GRL	64.25	-40.83	0.85
Upernavik	GRL	72.78	-56.15	0.58
Uummannaq	GRL	70.68	-52.13	0.71
Zackenberg	GRL	74.47	-20.63	0.64
Bakkafjordur	ISL	66.05	-14.75	1.22
Bolungavik	ISL	66.17	-23.23	1.33
Breidhdalsvik	ISL	64.73	-13.98	1.00
Budir	ISL	64.93	-13.80	1.00
Djupavik	ISL	65.95	-21.57	1.39
Eskifjordur	ISL	65.08	-13.98	1.29
Flatey	ISL	65.37	-22.92	1.18
Flateyri	ISL	66.05	-23.48	1.39
Hrisey	ISL	66.03	-18.42	1.31
Husavik	ISL	66.05	-17.37	1.34
Isafjordur	ISL	66.08	-23.10	1.33
Neskaupstadur	ISL	65.15	-13.68	1.23
Njardhvik	ISL	65.58	-13.85	1.32
Nordurfjordur	ISL	66.03	-21.57	1.18
Olafsfjordur	ISL	66.08	-18.63	1.30
Saudarkrokur	ISL	65.75	-19.60	1.25
Seydhisfjordur	ISL	65.25	-13.92	1.35
Stodhvarfjordur	ISL	64.83	-13.83	1.00
Stykkisholmur	ISL	65.07	-22.68	1.09
Sudhureyri	ISL	66.13	-23.53	1.35
Vopnafjordur	ISL	65.75	-14.82	1.31
Amderma	RUS	69.73	61.58	0.37
Belyy Island	RUS	73.52	70.80	1.18
Beringovskiy	RUS	63.13	179.50	1.15
Cape Shmidta	RUS	68.88	-179.47	0.30

Chikhacheva	RUS	72.28	146.88	1.01
Dikson	RUS	73.50	80.40	1.37
Egvekinot	RUS	66.33	-179.03	1.17
Nabil	RUS	51.70	143.30	1.39
Novyy Port	RUS	67.68	73.10	1.13
Provideniya	RUS	64.42	-173.25	1.20
Varandey	RUS	68.82	58.00	1.00
Advent Bay	SJM	78.25	15.58	0.93
Barents Island	SJM	78.58	21.83	0.82
Barentsburg	SJM	78.08	14.22	0.56
Bear Island	SJM	74.50	19.20	0.45
Longyearbyen	SJM	78.25	15.58	0.93
Ny Alesund	SJM	78.92	11.93	0.81
Adak	USA	51.85	-176.65	1.34
Barrow	USA	71.32	-156.72	0.37
Gambell	USA	63.77	-171.72	0.96
Kaktovik	USA	70.13	-143.83	0.48
Kiska Harbour	USA	51.98	177.57	1.39
Prudhoe Bay	USA	70.33	-148.33	0.44
St. Lawrence Island	USA	63.00	-169.50	1.36
St. Paul	USA	57.12	-170.27	1.30
Wainwright	USA	70.65	-160.17	0.37

Appendix C. List of global ports that have highest environmental similarity to Deception Bay. NIS originating from these ports have the highest potential for survival if introduced at Deception Bay.

Global Port	Country	Latitude	Longitude	Environmental Distance
Bowman Island	ATA	-65.50	103.42	0.55
Casey	ATA	-66.28	110.53	0.60
Commonwealth Bay	ATA	-67.00	142.00	0.71
Davis	ATA	-68.58	77.97	0.39
Dumont d'Urville	ATA	-66.67	140.02	0.71
Mawson	ATA	-67.60	62.87	0.40
McMurdo	ATA	-77.85	166.60	0.62
Molodezhnaya	ATA	-67.67	45.83	0.62
Port Lockroy	ATA	-64.82	-63.52	0.33
Crozet Island	ATF	-46.33	51.50	1.01
Port aux Francais	ATF	-49.35	70.20	1.01
Macquarie Island	AUS	-54.58	158.97	1.05
Arviat	CAN	61.10	-94.07	1.12
Aupaluk	CAN	59.35	-69.60	0.19
Baker Lake	CAN	64.29	-96.18	0.66
Broughton Island	CAN	67.56	-64.08	0.42
Butterfly Bay	CAN	62.98	-64.80	0.30
Cambridge Ba	CAN	69.18	-105.06	0.60
Cape Dorset/Kingait	CAN	64.31	-76.70	0.36
Cape Dyer	CAN	66.67	-61.42	0.29
Cape Hooper	CAN	68.43	-66.78	0.09
Charles Island Harbour	CAN	62.65	-74.33	0.00

Chesterfield Inlet	CAN	63.37	-90.87	0.95
Churchill	CAN	58.78	-94.22	1.11
Clyde River	CAN	69.83	-70.37	0.12
Comeau Bay	CAN	49.22	-68.15	1.36
Coral Harbour	CAN	64.19	-83.26	0.19
Deception Bay	CAN	62.17	-74.70	0.00
Flowers Cove	CAN	51.28	-56.75	1.39
Fox Harbour	CAN	52.33	-55.67	0.65
Hall Beach	CAN	68.80	-76.17	1.00
Herschel Island	CAN	69.57	-139.00	0.60
Hopedale	CAN	55.45	-60.20	0.64
Igloolik	CAN	69.17	-81.68	0.43
Inukjuak	CAN	58.47	-78.13	0.97
Iqaluit	CAN	63.75	-68.53	0.95
Ivujivik	CAN	62.42	-77.90	0.36
Kangiqsualujjuaq	CAN	58.60	-65.93	0.29
Kekerten Island	CAN	65.70	-65.82	0.29
Killinek	CAN	60.38	-64.43	0.21
Kimmirut	CAN	62.80	-69.83	0.15
Kugluktuk	CAN	67.80	-115.20	0.22
Kuujjuaraapik	CAN	55.28	-77.75	0.65
Little Cornwallis Island	CAN	75.38	-96.95	0.57
Longstaff Bluff	CAN	68.90	-75.20	1.00
Lower Savage Island	CAN	61.80	-65.75	0.16
Melville Island	CAN	75.50	-112.00	0.55
Milne Inlet	CAN	72.43	-80.53	0.24
Monumental Island port	CAN	62.77	-63.85	0.30
Nain	CAN	56.53	-61.70	0.45
Okak Harbour	CAN	57.58	-61.92	0.28
Pangnirtung	CAN	66.08	-65.75	0.70
Pelly Bay	CAN	68.53	-89.83	0.55
Pond Inlet	CAN	72.63	-78.28	0.18
Portneuf	CAN	48.62	-69.08	0.97
Puvirnituq	CAN	60.00	-77.25	1.02
Quaqtaq	CAN	61.04	-69.63	0.07
Rankin Inlet	CAN	62.83	-92.11	1.16
Repulse Bay	CAN	66.52	-86.24	0.37
Resolute	CAN	74.68	-94.87	0.58
Resolution Island	CAN	61.38	-65.00	0.22
Rimouski	CAN	48.48	-68.52	1.22
Riviere du Loup	CAN	47.85	-69.57	1.11
Saglek	CAN	58.54	-63.02	0.23
Salluit	CAN	62.30	-75.38	0.00
SanikiluaqIslands	CAN	56.60	-79.20	0.48
St. Anthony	CAN	51.37	-55.58	1.21
Sugluk Island Harbour	CAN	62.30	-75.45	0.00
Tadoussac	CAN	48.13	-69.72	1.04
Tasiujaq	CAN	58.90	-69.33	0.19
Umiujak	CAN	56.57	-76.50	0.40
Voisey Bay	CAN	56.25	-61.92	0.27

Kangiqsujuaq	CAN	61.60	-71.97	0.09
Walrus Island	CAN	63.90	-89.58	0.74
Wemindji New Post	CAN	53.00	-78.82	1.00
Whale Cove	CAN	62.18	-92.61	1.06
Winisk	CAN	55.28	-85.23	0.37
Grytviken	FLK	-54.28	-36.50	0.84
Deception Island	GBR	-62.95	-60.63	0.34
Scotia Bay	GBR	-60.72	-44.63	0.40
Aappilattoq	GRL	60.17	-44.28	1.23
Aasiaat	GRL	68.72	-52.88	0.56
Alluitsup Paa	GRL	60.47	-45.57	0.13
Ammassalik	GRL	65.58	-37.50	0.35
Aputiteq	GRL	67.80	-32.22	0.34
Daneborg	GRL	74.30	-20.25	0.49
Danmarkshavn	GRL	76.77	-18.75	0.45
Dundas	GRL	76.55	-68.82	0.61
Fiskenaesset	GRL	63.08	-50.68	1.05
Ikkatseq	GRL	65.63	-37.95	0.82
Ilulissat	GRL	69.22	-51.10	0.47
Ivittuut	GRL	61.20	-48.17	1.13
Kangaamiut	GRL	65.82	-53.30	0.23
Kangerluarsoruseq	GRL	63.70	-51.55	0.33
Kangilinnguit	GRL	61.20	-48.10	1.36
Kirkespirdalen	GRL	60.32	-44.93	1.10
Kulusuk	GRL	65.53	-37.25	0.34
Kuummiut	GRL	65.87	-37.00	0.73
Maniitsoq	GRL	65.42	-52.90	0.34
Marmorilik	GRL	71.13	-51.28	0.62
Mesters Vig	GRL	72.15	-23.75	0.32
Moriusaq	GRL	76.73	69.60	0.34
Nanortalik	GRL	60.13	-45.25	0.18
Narsaq Kujalleq	GRL	60.00	-44.67	1.24
Nerlerit Innat	GRL	70.73	-22.63	0.44
Nuuk	GRL	64.17	-51.73	0.30
Paamiut	GRL	62.00	-49.67	0.29
Pituffik	GRL	76.55	-68.87	0.44
Qaanaaq	GRL	77.47	-69.22	0.32
Qaqortoq	GRL	60.72	-46.03	0.10
Qasigiannguit	GRL	68.82	-51.18	1.18
Qeqertarsuaq	GRL	69.25	-53.55	0.57
Qutdleq	GRL	62.52	-42.22	0.25
Qutdligssat	GRL	70.07	-52.83	0.48
Savissivik	GRL	76.03	-64.85	0.15
Siorapaluk	GRL	77.78	-70.70	0.33
Sisimiut	GRL	66.95	-53.68	0.40
Skjoldungen	GRL	63.23	-41.45	0.88
Tasiusaq	GRL	73.37	-56.07	0.34
Thule Air Base	GRL	76.55	-68.82	0.61
Tovqussaq	GRL	64.87	-52.20	1.01
Umivik	GRL	64.25	-40.83	0.63

Upernavik	GRL	72.78	-56.15	0.35
Uummannaq	GRL	70.68	-52.13	0.48
Zackenberg	GRL	74.47	-20.63	0.44
Bakkafjordur	ISL	66.05	-14.75	1.04
Bildudalur	ISL	65.68	-23.60	1.30
Bolungavik	ISL	66.17	-23.23	1.17
Breidhdalsvik	ISL	64.73	-13.98	0.87
Budir	ISL	64.93	-13.80	0.86
Dalvik	ISL	65.97	-18.52	1.29
Djupavik	ISL	65.95	-21.57	1.22
Eskifjordur	ISL	65.08	-13.98	1.11
Flatey	ISL	65.37	-22.92	0.99
Flateyri	ISL	66.05	-23.48	1.20
Hesteyri	ISL	66.35	-22.85	1.23
Hofdhakaupstadur	ISL	65.83	-20.32	1.39
Holmavik	ISL	65.70	-21.68	1.34
Hrisey	ISL	66.03	-18.42	1.15
Husavik	ISL	66.05	-17.37	1.17
Hvammstangi	ISL	65.40	-20.95	1.30
Isafjordur	ISL	66.08	-23.10	1.17
Kopasker	ISL	66.28	-16.45	1.40
Neskaupstadur	ISL	65.15	-13.68	1.06
Njardhvik	ISL	65.58	-13.85	1.15
Nordurfjordur	ISL	66.03	-21.57	1.01
Olafsfjordur	ISL	66.08	-18.63	1.14
Raufarhofn	ISL	66.45	-15.90	1.32
Saudarkrokur	ISL	65.75	-19.60	1.09
Seydhisfjordur	ISL	65.25	-13.92	1.21
Siglufjordur	ISL	66.20	-18.87	1.25
Stodhvarfjordur	ISL	64.83	-13.83	0.86
Stykkisholmur	ISL	65.07	-22.68	0.90
Sudhureyri	ISL	66.13	-23.53	1.19
Thingeyri	ISL	65.87	-23.48	1.27
Thorshofn	ISL	66.20	-15.33	1.31
Vopnafjordur	ISL	65.75	-14.82	1.13
Batsfjord	NOR	70.63	29.73	1.36
Berlevaag	NOR	70.85	29.10	1.36
Billefjord	NOR	70.37	25.10	1.29
Hammerfest	NOR	70.67	23.67	1.37
Havoysund	NOR	70.98	24.58	1.38
Honningsvaag	NOR	70.98	25.98	1.36
Mehamn	NOR	71.00	27.83	1.33
North Cape	NOR	71.17	25.77	1.36
Oksfjord	NOR	70.23	22.30	1.39
Vardo	NOR	70.38	31.10	1.25
Amderma	RUS	69.73	61.58	0.17
Belyy Island	RUS	73.52	70.80	1.02
Beringovskiy	RUS	63.13	179.50	0.93
Cape Shmidta	RUS	68.88	-179.47	0.14
Chikhacheva	RUS	72.28	146.88	1.07

Dikson	RUS	73.50	80.40	1.27
Egvekinot	RUS	66.33	-179.03	0.96
Nabil	RUS	51.70	143.30	1.22
Novyy Port	RUS	67.68	73.10	0.98
Pevek	RUS	69.72	170.30	1.33
Preobrazhenskoye	RUS	54.87	167.67	1.30
Provideniya	RUS	64.42	-173.25	0.99
Ust-Kamchatsk	RUS	56.22	162.48	1.40
Varandey	RUS	68.82	58.00	0.77
Advent Bay	SJM	78.25	15.58	0.72
Barents Island	SJM	78.58	21.83	0.59
Barentsburg	SJM	78.08	14.22	0.36
Bear Island	SJM	74.50	19.20	0.31
Longyearbyen	SJM	78.25	15.58	0.72
Ny Alesund	SJM	78.92	11.93	0.60
Adak	USA	51.85	-176.65	1.20
Akutan	USA	54.13	-165.75	1.29
Barrow	USA	71.32	-156.72	0.24
Bethel	USA	60.80	-161.77	1.31
Gambell	USA	63.77	-171.72	0.73
Kaktovik	USA	70.13	-143.83	0.46
Kiska Harbour	USA	51.98	177.57	1.23
Prudhoe Bay	USA	70.33	-148.33	0.33
St. Lawrence Island	USA	63.00	-169.50	1.14
St. Paul	USA	57.12	-170.27	1.11
Unalaska	USA	53.85	-166.52	1.30
Wainwright	USA	70.65	-160.17	0.23

Appendix D. List of global ports that have highest environmental similarity to Iqaluit. NIS originating from these ports have the highest potential for survival if introduced at Iqaluit.

Global Port	Country	Latitude	Longitude	Environmental Distance
Punta Loyola	ARG	-51.60	-69.02	1.27
Rio Grande	ARG	-53.79	-67.70	0.95
San Julian	ARG	-49.25	-67.67	1.25
Ushuaia	ARG	-54.80	-68.23	0.94
Davis	ATA	-68.58	77.97	1.32
Mawson	ATA	-67.60	62.87	1.32
Port Lockroy	ATA	-64.82	-63.52	1.25
Crozet Island	ATF	-46.33	51.50	0.84
Port aux Francais	ATF	-49.35	70.20	0.84
Macquarie Island	AUS	-54.58	158.97	0.89
Argentia	CAN	47.30	-53.98	1.01
Arviat	CAN	61.10	-94.07	1.03
Aupaluk	CAN	59.35	-69.60	1.11
Baker Lake	CAN	64.29	-96.18	1.00
Bay Bulls	CAN	47.30	-52.73	0.86
Bay de Verde	CAN	48.08	-52.90	0.83
Bay Roberts	CAN	47.57	-53.22	1.09
Belledune	CAN	47.92	-65.85	1.29

Blanc Sablon	CAN	51.42	-57.13	0.72
Bonavista	CAN	48.65	-53.12	0.85
Broughton Island	CAN	67.56	-64.08	1.32
Burin	CAN	47.03	-55.17	1.02
Butchers Cove	CAN	48.83	-54.00	1.04
Butterfly Bay	CAN	62.98	-64.80	0.87
Cape Dorset	CAN	64.31	-76.70	1.28
Cape Dyer	CAN	66.67	-61.42	1.20
Cape Hooper	CAN	68.43	-66.78	0.98
Caraquet	CAN	47.80	-65.02	1.36
Cartwright	CAN	53.70	-57.02	0.97
Catalina	CAN	48.52	-53.07	0.85
Charles Island Harbour	CAN	62.65	-74.33	0.95
Chesterfield Inlet	CAN	63.37	-90.87	0.95
Chevery Harbour	CAN	50.45	-59.62	0.83
Churchill	CAN	58.78	-94.22	0.69
Clarks Harbour	CAN	43.42	-65.63	1.25
Clyde River	CAN	69.83	-70.37	0.98
Comeau Bay	CAN	49.22	-68.15	0.64
Coral Harbour	CAN	64.19	-83.26	0.91
Deception Bay	CAN	62.17	-74.70	0.95
Dildo	CAN	47.57	-53.57	1.05
Englee Harbour	CAN	50.72	-56.12	0.76
Flowers Cove	CAN	51.28	-56.75	0.64
Fortune	CAN	47.07	-55.83	1.03
Fox Harbour	CAN	52.33	-55.67	0.43
Hall Beach	CAN	68.80	-76.17	0.05
Harbour Grace	CAN	47.68	-53.22	1.09
Havre St. Pierre	CAN	50.23	-63.60	1.33
Herschel Island	CAN	69.57	-139.00	0.77
Hopedale	CAN	55.45	-60.20	0.43
Igloolik	CAN	69.17	-81.68	1.29
Ile-aux-Coudres	CAN	47.42	-70.39	0.85
Inukjuak	CAN	58.47	-78.13	0.50
Iqaluit	CAN	63.75	-68.53	0.00
Ivujivik	CAN	62.42	-77.90	0.71
Kangiqsualujjuaq	CAN	58.60	-65.93	1.22
Kangiqsujuaq	CAN	61.60	-71.97	0.91
Kekerten Island	CAN	65.70	-65.82	0.68
Killinek	CAN	60.38	-64.43	1.03
Kimmirut	CAN	62.80	-69.83	0.86
Kugluktuk	CAN	67.80	-115.20	0.80
Kuujjuaq	CAN	58.15	-68.30	0.70
Kuujjuaraapik	CAN	55.28	-77.75	0.72
La Scie	CAN	49.97	-55.58	0.64
L'Anse-au-Loup	CAN	51.52	-56.83	0.84
Les Mechins	CAN	49.02	-66.98	0.84
Lewisporte	CAN	49.25	-55.05	0.82
Little Cornwallis Island	CAN	75.38	-96.95	0.40
Long Harbour	CAN	47.45	-53.82	1.01

Long Pond	CAN	47.52	-52.97	0.91
Longstaff Bluff	CAN	68.90	-75.20	0.05
Lower Cove	CAN	48.52	-59.10	1.34
Lower Island Cove	CAN	48.00	-52.98	0.83
Lower Savage Island	CAN	61.80	-65.75	1.06
Main Brook	CAN	51.18	-56.02	1.31
Margaretsville	CAN	45.05	-65.07	1.20
Marystown	CAN	47.17	-55.15	1.02
Matane	CAN	48.85	-67.53	0.70
Melville Island	CAN	75.50	-112.00	0.55
Milne Inlet	CAN	72.43	-80.53	1.16
Mont Louis	CAN	49.23	-65.73	1.01
Monumental Island port	CAN	62.77	-63.85	0.86
Nain	CAN	56.53	-61.70	0.58
Okak Harbour	CAN	57.58	-61.92	0.83
Pangnirtung	CAN	66.08	-65.75	0.25
Perce	CAN	48.50	-64.22	1.21
Pointe au Pic	CAN	47.62	-70.13	0.85
Pointe Noire	CAN	50.17	-66.47	0.99
Pond Inlet	CAN	72.63	-78.28	1.09
Port de Grave	CAN	47.60	-53.20	1.09
Port Saunders	CAN	50.63	-57.30	0.85
Port Simpson	CAN	54.58	-130.42	1.39
Port Union	CAN	48.50	-53.08	0.85
Portneuf	CAN	48.62	-69.08	0.57
Puvirnituq	CAN	60.00	-77.25	0.54
Quaqtaq	CAN	61.04	-69.63	1.00
Ramea Island	CAN	47.52	-57.42	1.36
Rankin Inlet/Kangiqliniq	CAN	62.83	-92.11	1.04
Repulse Bay/Aivilik	CAN	66.52	-86.24	1.16
Resolute	CAN	74.68	-94.87	0.39
Resolution Island	CAN	61.38	-65.00	0.98
Rigolet	CAN	54.18	-58.42	1.16
Rimouski	CAN	48.48	-68.52	0.56
Riviere du Loup	CAN	47.85	-69.57	0.62
Saglek	CAN	58.54	-63.02	0.94
Salluit	CAN	62.30	-75.38	0.95
Sanikiluaq	CAN	56.60	-79.20	0.61
Sept-Iles	CAN	50.10	-66.38	0.99
Shelburne	CAN	43.67	-65.32	1.32
Shippegan	CAN	47.75	-64.70	1.36
St. Anthony	CAN	51.37	-55.58	0.46
St. Augustin	CAN	51.22	-58.65	0.83
St. Barbe Harbour	CAN	51.20	-56.77	1.24
St. John's	CAN	47.56	-52.71	0.89
Sugluk Island Harbour	CAN	62.30	-75.45	0.95
Tadoussac	CAN	48.13	-69.72	0.58
Tasiujaq	CAN	58.90	-69.33	1.11
Tilt Cove	CAN	49.88	-55.62	0.64
Tuktoyaktuk	CAN	69.43	-133.05	1.13

Twillingate	CAN	49.68	-54.75	0.77
Umiujak	CAN	56.57	-76.50	0.79
Valleyfield Harbour	CAN	49.12	-53.61	1.04
Voisey Bay	CAN	56.25	-61.92	0.73
Wabana	CAN	47.63	-52.92	0.91
Walrus Island	CAN	63.90	-89.58	0.91
Wemindji New Post	CAN	53.00	-78.82	0.72
Whale Cove	CAN	62.18	-92.61	0.99
Winisk	CAN	55.28	-85.23	0.66
Witless Bay	CAN	47.28	-52.77	0.86
Puerto Williams	CHL	-54.93	-67.62	0.98
Punta Arenas	CHL	-53.17	-70.90	1.09
Grytviken	FLK	-54.28	-36.50	0.66
Mare Harbour	FLK	-51.92	-58.47	1.22
Stanley Harbour	FLK	-51.68	-57.83	1.14
Dalur	FRO	61.77	-6.67	1.28
Fuglafjordur	FRO	62.25	-6.82	1.35
Gota	FRO	62.18	-6.70	1.34
Hosvik	FRO	62.15	-6.93	1.26
Hvalba	FRO	61.60	-6.95	1.33
Hvalvik	FRO	62.18	-7.00	1.20
Klaksvik	FRO	62.23	-6.58	1.33
Kollafjordur	FRO	62.12	-6.90	1.26
Midvagur	FRO	62.03	-7.18	1.32
Nordskali	FRO	62.20	-6.98	1.20
Runavik	FRO	62.10	-6.72	1.34
Saltangara	FRO	62.12	-6.70	1.34
Sandvagur	FRO	62.05	-7.13	1.28
Skalafjordur	FRO	62.20	-6.85	1.20
Skali	FRO	62.15	-6.77	1.34
Skopun	FRO	61.90	-6.87	1.29
Sorvagur	FRO	62.08	-7.42	1.37
Strendur	FRO	62.12	-6.75	1.34
Streymnes	FRO	62.18	-7.02	1.20
Toftir	FRO	62.08	-6.72	1.34
Torshavn	FRO	62.00	-6.75	1.34
Tvoroyri	FRO	61.55	-6.80	1.33
Vagur	FRO	61.47	-6.80	1.38
Vestmanna	FRO	62.15	-7.17	1.32
Deception Island	GBR	-62.95	-60.63	1.26
Scotia Bay	GBR	-60.72	-44.63	1.31
Aappilattoq	GRL	60.17	-44.28	0.58
Aasiaat	GRL	68.72	-52.88	0.52
Alluitsup Paa	GRL	60.47	-45.57	1.00
Ammassalik	GRL	65.58	-37.50	1.10
Aputiteq	GRL	67.80	-32.22	0.70
Daneborg	GRL	74.30	-20.25	0.47
Danmarkshavn	GRL	76.77	-18.75	0.51
Dundas	GRL	76.55	-68.82	0.38
Fiskenaesset	GRL	63.08	-50.68	0.39

Ikkatseq	GRL	65.63	-37.95	0.32
Ilulissat	GRL	69.22	-51.10	0.57
Ivittuut	GRL	61.20	-48.17	0.44
Kangaamiut	GRL	65.82	-53.30	0.77
Kangerluarsoruseq	GRL	63.70	-51.55	0.74
Kangilinnguit	GRL	61.20	-48.10	0.63
Kirkespirdalen	GRL	60.32	-44.93	0.45
Kulusuk	GRL	65.53	-37.25	1.07
Kuummiut	GRL	65.87	-37.00	0.35
Maniitsoq	GRL	65.42	-52.90	0.68
Marmorilik	GRL	71.13	-51.28	0.36
Mesters Vig	GRL	72.15	-23.75	0.66
Moriusaq	GRL	76.73	69.60	1.21
Nanortalik	GRL	60.13	-45.25	0.95
Narsaq	GRL	60.90	-45.98	1.23
Narsaq Kujalleq	GRL	60.00	-44.67	0.59
Narsarsuaq	GRL	61.15	-45.43	1.22
Nerlerit Innat	GRL	70.73	-22.63	0.55
Nuuk	GRL	64.17	-51.73	0.70
Paamiut	GRL	62.00	-49.67	1.23
Pituffik	GRL	76.55	-68.87	0.54
Qaanaaq	GRL	77.47	-69.22	0.66
Qaqortoq	GRL	60.72	-46.03	0.97
Qasigiannguit	GRL	68.82	-51.18	0.31
Qeqertarsuaq	GRL	69.25	-53.55	0.42
Qutdleq	GRL	62.52	-42.22	0.77
Qutdligssat	GRL	70.07	-52.83	0.56
Savissivik	GRL	76.03	-64.85	1.05
Siorapaluk	GRL	77.78	-70.70	0.65
Sisimiut	GRL	66.95	-53.68	0.64
Skjoldungen	GRL	63.23	-41.45	0.37
Tasiusaq	GRL	73.37	-56.07	0.67
Thule Air Base	GRL	76.55	-68.82	0.38
Tovqussaq	GRL	64.87	-52.20	0.31
Umivik	GRL	64.25	-40.83	0.43
Upernavik	GRL	72.78	-56.15	0.67
Uummannaq	GRL	70.68	-52.13	0.54
Zackenberg	GRL	74.47	-20.63	0.52
Akranes	ISL	64.32	-22.08	1.16
Akureyri	ISL	65.68	-18.05	1.19
Bakkafjordur	ISL	66.05	-14.75	0.62
Bildudalur	ISL	65.68	-23.60	0.69
Blonduos	ISL	65.67	-20.30	0.74
Bolungavik	ISL	66.17	-23.23	0.76
Bordeyri	ISL	65.22	-21.15	0.75
Borgarnes	ISL	64.53	-21.92	1.12
Breidhdalsvik	ISL	64.73	-13.98	0.76
Budir	ISL	64.93	-13.80	0.75
Dalvik	ISL	65.97	-18.52	0.63
Djupavik	ISL	65.95	-21.57	0.61

Djupivogur	ISL	64.67	-14.25	1.02
Dyrholaey	ISL	63.40	-19.13	1.17
Eskifjordur	ISL	65.08	-13.98	0.63
Eyrarbakki	ISL	63.87	-21.15	1.07
Flatey	ISL	65.37	-22.92	0.61
Flateyri	ISL	66.05	-23.48	0.62
Gardabaer	ISL	64.07	-21.93	1.09
Grafaros	ISL	65.55	-19.40	1.31
Grenivik	ISL	65.95	-18.20	0.73
Grindavik	ISL	63.83	-22.43	1.22
Grundarfjordur	ISL	64.92	-23.22	0.83
Grundartangi	ISL	64.35	-21.78	0.91
Gufunes	ISL	64.15	-21.82	1.00
Hafnarfjordur	ISL	64.07	-21.92	1.09
Helguvik	ISL	64.38	-21.47	1.10
Hellisandur	ISL	64.90	-23.90	0.99
Hesteyri	ISL	66.35	-22.85	0.64
Hjalteyri	ISL	65.85	-18.20	0.73
Hofdhakaupstadur	ISL	65.83	-20.32	0.71
Hofn	ISL	64.27	-15.22	1.07
Hofsos	ISL	65.88	-19.40	0.79
Holmavik	ISL	65.70	-21.68	0.69
Hrafneyri	ISL	64.38	-21.53	1.12
Hrisey	ISL	66.03	-18.42	0.73
Husavik	ISL	66.05	-17.37	0.70
Hvaleyri	ISL	64.33	-21.73	0.93
Hvammstangi	ISL	65.40	-20.95	0.64
Isafjordur	ISL	66.08	-23.10	0.76
Keflavik	ISL	64.00	-22.55	1.19
Kopasker	ISL	66.28	-16.45	0.73
Kopavogur	ISL	64.10	-21.88	1.09
Korsnes	ISL	64.12	-21.90	1.09
Kroksfjardarnes	ISL	65.45	-21.93	0.79
Krossanes	ISL	65.70	-18.12	1.12
Midsandur	ISL	64.40	-21.47	1.10
Neskaupstadur	ISL	65.15	-13.68	0.67
Njardhvik	ISL	65.58	-13.85	0.72
Nordurfjordur	ISL	66.03	-21.57	0.69
Olafsfjordur	ISL	66.08	-18.63	0.72
Olafsvik	ISL	64.90	-23.72	0.79
Patrekshofn	ISL	65.58	-23.98	0.81
Raufarhofn	ISL	66.45	-15.90	0.71
Reykholar	ISL	65.45	-22.22	0.77
Reykjanes	ISL	63.80	-22.70	1.19
Reykjavik	ISL	64.15	-21.95	1.09
Rifshofn	ISL	64.88	-23.67	0.79
Sandgerdhi	ISL	64.05	-22.72	1.19
Sandur	ISL	64.92	-23.82	0.80
Saudarkrokur	ISL	65.75	-19.60	0.71
Seydhisfjordur	ISL	65.25	-13.92	0.74

Siglufjordur	ISL	66.20	-18.87	0.62
Stodhvarfjordur	ISL	64.83	-13.83	0.75
Stokkseyri	ISL	63.83	-21.08	1.11
Straumsvik	ISL	64.05	-22.05	1.18
Stykkisholmur	ISL	65.07	-22.68	0.56
Sudhureyri	ISL	66.13	-23.53	0.77
Svalbardhseyri	ISL	65.75	-18.10	1.12
Thingeyri	ISL	65.87	-23.48	0.67
Thorlakshofn	ISL	63.85	-21.33	1.00
Thorshofn	ISL	66.20	-15.33	0.72
Vestmannaeyjar	ISL	63.43	-20.27	1.40
Vopnafjordur	ISL	65.75	-14.82	0.60
Nemuro	JPN	43.33	145.58	1.40
Andenes	NOR	69.32	16.13	1.12
Ballstad	NOR	68.07	13.53	1.23
Batsfjord	NOR	70.63	29.73	0.63
Bergneset	NOR	68.80	16.00	1.11
Bergsfjord	NOR	70.25	21.80	0.97
Berlevaag	NOR	70.85	29.10	0.62
Billefjord	NOR	70.37	25.10	0.86
Bodo	NOR	67.28	14.38	1.10
Borkenes	NOR	68.77	16.18	1.12
Brettesnes	NOR	68.23	14.87	1.07
Dyroy	NOR	68.82	14.82	1.07
Fevag	NOR	63.67	9.83	1.36
Finnfjord	NOR	70.82	23.08	0.95
Gravdal	NOR	68.12	13.55	1.23
Hammerfest	NOR	70.67	23.67	0.92
Harstad	NOR	68.80	16.55	1.07
Hasvik	NOR	70.48	22.15	0.94
Havoysund	NOR	70.98	24.58	0.93
Henningsvaer	NOR	68.15	14.22	1.13
Honningsvaag	NOR	70.98	25.98	0.90
Jovik	NOR	69.60	19.83	1.09
Kaafjord	NOR	69.58	20.52	0.99
Karlsoy	NOR	70.00	19.90	0.77
Kirkenes	NOR	69.73	30.05	1.26
Leirpollen	NOR	70.38	25.52	0.87
Lillebukt	NOR	70.33	22.50	0.65
Lodingen	NOR	68.42	16.00	1.09
Marnes	NOR	67.13	14.08	1.11
Mehamn	NOR	71.00	27.83	0.87
Melbu	NOR	68.50	14.80	0.98
Midsund	NOR	62.70	6.70	1.37
Myre	NOR	69.08	15.95	1.13
North Cape	NOR	71.17	25.77	0.90
Nusfjord	NOR	68.03	13.35	1.18
Oksfjord	NOR	70.23	22.30	0.92
Ramsund	NOR	68.48	16.52	1.31
Repparfjord	NOR	70.43	24.25	1.25

Sandnessjoen	NOR	66.02	12.63	1.14
Skaland	NOR	69.45	17.30	0.85
Sortland	NOR	68.70	15.43	1.14
Sovik	NOR	65.92	12.43	1.37
Stamsund	NOR	68.12	13.85	1.18
Stokmarknes	NOR	68.57	14.92	1.10
Svolvaer	NOR	68.23	14.57	1.10
Tomrefjord	NOR	62.63	6.68	1.34
Tovik	NOR	68.67	16.90	0.74
Vadso	NOR	70.07	29.73	0.72
Vardo	NOR	70.38	31.10	0.77
Agnevo	RUS	50.52	142.07	1.39
Aleksandrovsk-Sakhalinskiy	RUS	50.88	142.12	0.85
Amderma	RUS	69.73	61.58	0.85
Anadyr	RUS	64.73	177.53	0.75
Belomorsk	RUS	64.53	34.82	0.79
Belyy Island	RUS	73.52	70.80	0.62
Beringovskiy	RUS	63.13	179.50	0.38
Boshnyakovo	RUS	49.58	142.20	1.30
Burevestnik	RUS	44.95	147.62	1.38
Cape Shmidta	RUS	68.88	-179.47	0.97
De Kastri	RUS	51.47	140.78	1.37
Dikson	RUS	73.50	80.40	1.05
Egvekinot	RUS	66.33	-179.03	0.05
Kamenka	RUS	65.88	44.18	1.16
Kem	RUS	65.00	34.78	0.84
Keret	RUS	66.28	33.57	1.02
Kolguyev Island	RUS	68.77	49.23	0.82
Magadan	RUS	59.63	150.83	0.71
Mezen	RUS	65.85	44.25	1.16
Nabil	RUS	51.70	143.30	0.71
Novyy Port	RUS	67.68	73.10	0.70
Okhotsk	RUS	59.35	143.17	1.08
Ossora	RUS	59.27	163.13	0.81
Pechenga	RUS	69.55	31.17	1.08
Petropavlovsk-Kamchatskiy	RUS	53.02	158.63	1.11
Pevek	RUS	69.72	170.30	0.41
Pogranichnoye	RUS	50.37	143.72	1.38
Poronaysk	RUS	49.22	143.12	1.16
Preobrazhenskoye	RUS	54.87	167.67	0.69
Provideniya	RUS	64.42	-173.25	0.14
Severo Kurilsk	RUS	50.68	156.12	0.72
Severodvinsk	RUS	64.58	39.78	0.97
Umba	RUS	66.67	34.30	1.35
Ust-Kamchatsk	RUS	56.22	162.48	0.65
Ust-Kara	RUS	69.20	65.00	0.74
Ust-Penzhino	RUS	62.50	165.15	0.98
Varandey	RUS	68.82	58.00	0.37
Varnek	RUS	69.90	60.02	0.62
Yuzhno Kurilsk	RUS	44.05	145.80	1.32

Advent Bay	SJM	78.25	15.58	0.32
Barents Island	SJM	78.58	21.83	0.51
Barentsburg	SJM	78.08	14.22	0.72
Bear Island	SJM	74.50	19.20	0.87
Longyearbyen	SJM	78.25	15.58	0.32
Ny Alesund	SJM	78.92	11.93	0.45
St. Pierre	SPM	46.82	-56.17	1.06
Adak	USA	51.85	-176.65	0.79
Afognak	USA	58.00	-152.83	1.23
Akutan	USA	54.13	-165.75	0.82
Angoon	USA	57.48	-134.57	1.27
Barrow	USA	71.32	-156.72	0.93
Bethel	USA	60.80	-161.77	0.59
Castle Island	USA	56.65	-133.17	1.38
Chatham	USA	57.52	-134.95	1.10
Chenega	USA	60.27	-148.07	1.28
Chignik	USA	56.30	-158.40	0.88
Cold Bay	USA	55.18	-162.70	1.01
Cordova	USA	60.55	-145.77	1.35
Dutch Harbour	USA	53.90	-166.53	0.94
Eastport	USA	44.90	-66.98	1.11
False Pass	USA	54.83	-163.40	0.88
Gambell	USA	63.77	-171.72	0.40
Hawk Inlet	USA	58.10	-134.73	1.15
Homer	USA	59.63	-151.50	1.10
Hoonah	USA	58.12	-135.43	1.11
Hydaburg	USA	55.20	-132.82	1.36
Icy Strait Point	USA	58.10	-135.60	1.24
Juneau	USA	58.30	-134.42	1.02
Kake	USA	56.92	-133.87	1.03
Kaktovik	USA	70.13	-143.83	1.04
Kenai	USA	60.55	-151.27	1.02
King Cove	USA	55.03	-162.32	0.90
Kiska Harbour	USA	51.98	177.57	0.78
Kodiak	USA	57.78	-152.40	0.94
Metlakatla	USA	55.13	-131.57	1.36
Naknek	USA	58.73	-157.03	1.05
Nikishka	USA	60.73	-151.30	1.12
Nikiski	USA	60.68	-151.38	1.10
Nome	USA	64.52	-165.42	0.61
Pelican	USA	57.95	-136.22	1.37
Petersburg	USA	56.82	-132.95	1.35
Port Lions	USA	57.87	-152.88	1.23
Prudhoe Bay	USA	70.33	-148.33	0.92
Red Dog	USA	67.58	-164.05	0.55
Sand Point	USA	55.32	-160.48	0.95
Seldovia	USA	59.43	-151.72	0.91
Seward	USA	60.12	-149.43	1.13
Sitka	USA	57.05	-135.33	1.30
Skagway	USA	59.45	-135.32	0.80

St. Lawrence Island	USA	63.00	-169.50	0.26
St. Michael	USA	63.47	-162.02	0.95
St. Paul	USA	57.12	-170.27	0.58
Tatitlek	USA	60.85	-146.68	1.23
Tenakee Springs	USA	57.78	-135.22	1.20
Togiak	USA	59.08	-160.50	0.92
Tolstoi Bay	USA	55.67	-132.52	1.39
Tyonek	USA	61.07	-151.15	1.19
Unalaska	USA	53.85	-166.52	0.85
Valdez	USA	61.13	-146.35	0.89
Wainwright	USA	70.65	-160.17	0.91
Whittier	USA	60.78	-148.67	0.87
Wrangell	USA	56.47	-132.37	1.39
Yakutat	USA	59.55	-139.75	1.18

Appendix E. High impact fouling NIS established at ports directly connected to major Arctic ports.

Species	Taxonomic Group	Ports									
		BL[1]	CB[2]	CH[3]	CI[4]	DB[5]	DH[6]	EB[7]	IQ[8]	KU[9]	TU[10]
Acartia tonsa	Crustacean			X		X					
Acrothamnion preissii	Plant			X							
Aglaothamnion halliae	Algae			X		X					
Anadara inaequivalvis	Mollusc			X							
Antithamnionella ternifolia	Algae			X		X					
Asparagopsis armata	Plant			X							
Balanus improvisus	Crustacean			X							
Balanus trigonus	Crustacean			X							
Botryllus schlosseri	Tunicate			X		X					
Botryllus violaceus	Tunicate			X		X			X		
Brachidontes pharaonis	Mollusc			X							
Caulerpa racemosa var. cylindracea	Plant			X							
Cerithium scabridum	Mollusc			X							
Ciona intestinalis	Tunicate			X		X					
Cladophora sericea	Algae	X	X	X	X	X			X	X	X
Codium fragile ssp tomentosoides	Algae	X		X	X	X			X	X	
Codium webbiana	Algae			X		X					
Corbula gibba	Mollusc			X		X					
Cordylophora caspia	Cnidarian			X		X			X		
Crassostrea gigas	Mollusc			X		X					
Crepidula fornicata	Mollusc			X		X					
Didemnum cf. lahillei	Ascidian			X		X					
Didemnum vexillum	Ascidian					X					
Dreissena polymorpha	Mollusc	X		X	X	X			X	X	
Drymonema dalmatinum	Cnidarian			X							
Elminius modestus	Crustacean			X		X					
Eriocheir sinensis	Crustacean			X		X					
Ficopomatus enigmaticus	Annelid			X		X					
Fucus evanescens	Algae			X		X					
Hemimysis anomala	Crustacean			X							
Hydroides elegans	Echinoderms			X		X					
Hydroides ezoensis	Annelid			X		X					
Hypnea musciformis	Algae			X							

Lophocladia lallemandii	Algae			X							
Lyrodus medilobatus	Mollusc			X							
Maeotias marginata	Cnidarian			X		X					
Membranipora membranacea	Bryozoan			X		X					
Mya arenaria	Mollusc			X		X					
Mytella charruana	Mollusc			X							
Mytilicola orientalis	Annelid			X							
Perna viridis	Mollusc			X							
Phyllorhiza punctata	Cnidarian			X							
Polyandrocarpa zorritensis	Tunicate			X							
Polydora ciliata	Annelid			X		X			X		
Polydora cornuta	Annelid			X							
Polysiphonia morrowii	Algae			X							
Pontogammarus robustoides	Crustacean			X							
Pseudopolydora paucibranchiata	Annelid			X							
Rapana venosa	Mollusc			X							
Rhithropanopeus harrisii	Crustacean			X		X					
Sargassum muticum	Algae			X		X					
Sphaeroma terebrans	Crustacean			X							
Spirorbis marioni	Annelid			X							
Styela clava	Tunicate	X		X	X	X			X	X	
Stypopodium schimperi	Algae			X							
Synidotea laevidorsalis	Crustacean			X							
Teredo bartschi	Mollusc			X							
Tricellaria inopinata	Bryozoan			X		X					
Undaria pinnatifida	Plant			X		X					
Victorella pavida	Bryozoan			X		X					
Xenostrobus securis	Mollusc			X							

Abbreviations: Baker Lake[1]; Cambridge Bay[2]; Churchill[3]; Chesterfield Inlet[4]; Deception Bay[5]; Dundas Harbour[6]; Erebus Bay[7;] Iqaluit[8]; Kuujjuaq[9]; Tuktoyaktuk[10]

Appendix F. High impact ballast-mediated NIS established at ports directly connected to major Arctic ports.

Species	Higher Taxa	Ports			
		CH[1]	DB[2]	IQ[3]	MI[4]
Acartia tonsa	Crustacean	X	X		
Acrothamnion preissii	Plant	X			
Aglaothamnion halliae	Algae	X	X		
Alepes djedaba	Fish	X			
Alexandrium catenella	Algae	X			
Alexandrium minutum	Algae	X			
Alexandrium ostenfeldii	Algae	X	X		X
Alexandrium peruvianum	Algae	X			
Alexandrium taylori	Algae	X			
Anadara inaequivalvis	Mollusc	X			
Asparagopsis armata	Plant	X			
Balanus improvisus	Crustacean	X			
Botryllus schlosseri	Tunicate	X	X		
Botryllus violaceus	Tunicate	X	X		
Brachidontes pharaonis	Mollusc	X			
Callinectes sapidus	Crustacean	X	X		
Carcinus maenas	Crustacean	X	X		
Caulerpa racemosa var. cylindracea	Plant	X			
Caulerpa taxifolia	Plant	X			
Cercopagis pengoi	Crustacean	X	X		
Chara connivens	Algae	X	X		
Charybdis hellerii	Crustacean	X			
Chattonella aff verruculosa	Algae	X	X		
Codium webbiana	Algae	X	X		
Corbula gibba	Mollusc	X	X		
Cordylophora caspia	Cnidarian	X	X		
Coscinodiscus wailesii	Diatom	X	X		
Crepidula fornicata	Mollusc	X	X		
Dasya baillouviana	Algae	X	X		
Didemnum cf. lahillei	Ascidian	X	X		
Dreissena polymorpha	Mollusc	X	X	X	X
Dyspanopeus sayi	Crustacean	X			
Elminius modestus	Crustacean	X	X		
Eriocheir sinensis	Crustacean	X	X		
Ficopomatus enigmaticus	Annelid	X	X		
Gammarus tigrinus	Crustacean	X	X		
Garveia Franciscana	Cnidarian	X			
Hemigrapsus penicillatus	Crustacean	X			
Hemigrapsus sanguineus	Crustacean	X	X		
Hemimysis anomala	Crustacean	X			
Heterosiphonia japonica	Algae	X	X		
Hydroides ezoensis	Annelid	X	X		
Lithoglyphus naticoides	Mollusc	X			
Littorina littorea	Mollusc	X	X		
Lophocladia lallemandii	Algae	X			
Maeotias marginata	Cnidarian	X	X		

Marenzelleria neglecta	Annelid	X	X		
Marenzelleria viridis	Annelid	X	X		
Membranipora membranacea	Bryozoan	X	X		
Moerisia lyonsi	Cnidarian	X			
Musculista senhousia	Mollusc	X			
Mya arenaria	Mollusc	X	X		
Mytella charruana	Mollusc	X			
Mytilopsis leucophaeata	Mollusc	X			
Neogobius melanostomus	Fish	X			
Ostreopsis ovata	Algae	X			
Percnon gibbesi	Crustacean	X			
Perna perna	Mollusc	X			
Perna viridis	Mollusc	X			
Phyllorhiza punctata	Cnidarian	X			
Polyandrocarpa zorritensis	Tunicate	X			
Polydora ciliata	Annelid	X	X		
Polydora cornuta	Annelid	X			
Polysiphonia morrowii	Algae	X			
Pontogammarus robustoides	Crustacean	X			
Prorocentrum minimum	Diatom	X	X		
Pseudobacciger harengulae	Annelid	X	X		
Pseudopolydora paucibranchiata	Annelid	X			
Rapana venosa	Mollusc	X			
Rhithropanopeus harrisii	Crustacean	X	X		
Rhopilema nomadica	Cnidarian	X			
Sargassum muticum	Algae	X	X		
Spartina anglica	Plant	X	X		
Strombus persicus	Mollusc	X			
Styela clava	Tunicate	X	X		X
Theora lubrica	Mollusc	X			
Undaria pinnatifida	Plant	X	X		
Xenostrobus securis	Mollusc	X			

Abbreviations: Churchill[1]; Deception Bay[2]; Iqaluit[3]; Milne Inlet[4]