Assessing the current and future risk of ballast-sourced species invasions in Canada's eastern Arctic under a climate change scenario

By

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Submitted in partial fulfillment of the requirements for the degree
of
Master of Marine Management

at

Dalhousie University
Halifax, Nova Scotia

December 2016

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LIST OF ABBREVIATIONS

AECO – Association of Arctic Expedition Cruise Operators
AEZ – Alternate Exchange Zone
AIRSS – Arctic Ice Regime Shipping System
AIS – Aquatic Invasive Species
AMS – Alternate Management System
Bcf – Billion Cubic Feet
BWE – Ballast Water Exchange
BWM – Ballast Water Management
BWMS – Ballast Water Management System
BWT – Ballast Water Treatment
CAC – Canadian Arctic Class
CAISN – Canadian Aquatic Invasive Species Network
CCIS – Canadian Council on Invasive Species
CEARA – Centre of Expertise for Aquatic Risk Assessment
Cfu – Colony Forming Unit
COTP – Captain of the Port
DFO – Department of Fisheries and Oceans
DWT – Deadweight Tonnage
EEZ – Exclusive Economic Zone
HAB – Harmful Algal Bloom
IMO – International Maritime Organization
IFAD - International Fund for Agricultural Development
IPCC – Intergovernmental Panel on Climate Change
MYI – Multi-year Ice
NAFO – Northwest Atlantic Fisheries Organization
NANPCA – National Aquatic Nuisance Prevention and Control Act
NEAS – Nunavut Eastern Arctic Shipping
NIRB – Nunavut Impact Review Board
NIS – Non-indigenous Species
NOBOB – No Ballast On Board
NORDREG – Northern Canada Vessel Traffic Zone
NPDES – National Pollutant Discharge Elimination System
NSSI – Nunavut Sealink and Supply Inc.
NTCL – Northern Transportation Company Ltd.
NWMB – Nunavut Wildlife Management Board
NWP – Northwest Passage
POLARIS – Polar Operational Limit Assessment Risk Indexing System
SLR – Sea Level Rise
SSS – Sea Surface Salinity
SST – Sea Surface Temperature
SWOT – Strengths-Weaknesses-Opportunities-Threats
TTI – Taqramut Transport Inc.
USCG – United States Coast Guard
Z/DS – Zone/Date System

ACKNOWLEDGEMENTS

I would like to thank Dr. Ronald Pelot, my academic supervisor, for guiding and advising me and providing me with many valuable opportunities. One of these such opportunities included offering me an internship in the MARIN lab, which allowed me to focus on this project as well as network with a range of professionals. Your feedback and support has truly been invaluable.

I would also like to thank Casey Hillard for his seemingly endless technological support, without which this project would not have been possible. I would also like to thank Gary Walsh, Michael Zurowski, and Dr. Colin Henein for taking the time to speak with me and provide documents to enhance my understanding of the subject matter. Finally, I would like to thank Dr. Sarah Bailey for providing me with advice and data, which thoroughly improved the quality of my data analysis.

I would like to offer a big thank you to the faculty and my fellow classmates of the Marine Affairs Program. Thank you for your continued guidance and support, which was necessary for the completion of this project and the attainment of my degree. The past 16 months of my life has been an incredibly rewarding time filled with new knowledge and friendships, and I thank you all for that.

And of course, I would like to thank my family and friends. Thank you for your support in times of difficulty, and thank you for sharing my happiness in times of progress. And most of all, thank you for allowing me to discuss this project with you when I needed an outlet, even if you had no idea what I was talking about.

Lipscombe, M.V.A. (2016). Assessing the current and future risk of ballast-sourced species invasions in Canada’s eastern Arctic under a climate change scenario [graduate project]. Halifax, NS: Dalhousie University.

ABSTRACT

The use of ballast water is an important and globally accepted method for maintaining vessel stability, as well as a major pathway for nonindigenous species (NIS) introduction. Canada has responded to this threat in the form of regulation, but existing policy may need to be adjusted to more effectively address environmental and socioeconomic changes. One area of particular interest is the eastern Canadian Arctic, where climate change in combination with growing development opportunities has resulted in an increase in marine vessel traffic volume. It is expected that this situation may lead firstly to an increasing probability of NIS introduction. Secondly, the likelihood of NIS establishment may also grow, as warming water temperatures may increase the environmental similarity between the Arctic and source ports. Due to the ecological fragility of the region, the unique relationship between the Inuit peoples and the environment, and the limited existing knowledge of the Arctic, species invasions in the eastern Canadian Arctic may have severely negative impacts. A policy analysis and risk assessment was conducted to identify ways in which Canada’s approach to ballast water management may be improved to better address this threat. Further, a projected risk assessment of the years 2055 and 2105 was conducted to predict how continued climate change may affect the risk level of ballast-mediated species invasions. It was found that though the current and predicted future risk levels are relatively low, focusing management efforts on limiting NIS introduction through improved ballast water management methods may significantly reduce the risk.

1.0 INTRODUCTION

Ballast water is used worldwide to achieve safety during vessel transit. Although this commonly accepted practice holds many benefits for ship owners and operators, it constitutes the greatest pathway for nonindigenous species (NIS) introduction (Hulme, 2009). This is a cause for concern, as invasive species may have seriously detrimental environmental and socioeconomic impacts once established (Colautti et al., 2006; Pejchar & Mooney, 2009; Ruiz et al., 1999). In response, national and international efforts have been made to manage the use of ballast water through legislation. In particular, Canada's *Ballast Water Control and Management Regulations* (SOR/2011-237) seeks to minimize the uptake or release of NIS in ballast water, or to remove or render them harmless altogether.

As alluded to, two key components of invasion are species introduction and establishment. In Canada, the eastern Arctic is experiencing an increase in the volume of vessel traffic facilitated by melting sea ice and growing development – this may increase the likelihood of NIS introduction through ballast water (Pizzolato et al., 2013). Additionally, rising water temperatures may make the region more susceptible to ballast-mediated NIS establishment (Post et al., 2009). The presence of aquatic invasive species (AIS) in the eastern Canadian Arctic could be disastrous, due to the fragility of the environment and the interconnectedness and dependence of the Inuit peoples to their natural surroundings. As a result, it is necessary to investigate the risks surrounding ballast-mediated NIS to the eastern Canadian Arctic for the purposes of protecting the environment and safe-guarding socio-economic well-being.

1.1 Ballast Water and Associated Risks

Ballast is any substance that is used onboard a vessel to regulate stability or achieve a safe weight-to-volume ratio, though water is the primary choice of ballast material (Transport Canada, 2010). Ballast water is most commonly used to replace the weight of offloaded cargo during a return voyage, but may also be regulated to reduce the amount of stress on the ship's hull, control vessel stability, improve propulsion and manoeuverability, and compensate for weight loss from fuel or water consumption (Committee on Ships' Ballast Operations, Marine Board, Commission on Engineering and Technical Systems, & Council, 1996). Ballast water may also be discharged to avoid grounding or in other emergency situations. Ballasting and deballasting occurs most frequently in ports during cargo loading and offloading, as vessels take on water from one coastal port area and discharge it at another port of call (Figure 1) (Transport Canada, 2010).

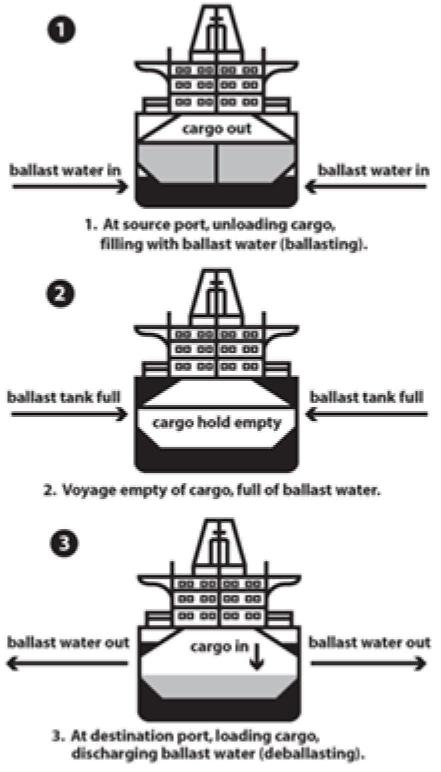


Figure 1. Mechanisms of ballast uptake and discharge (Transport Canada, 2007).

The use of ballast water is an important and globally accepted method for achieving vessel stability and safety. However, ballast water poses a serious threat to the environments where it is discharged as it has proven to be a major vector for aquatic NIS introduction. Coastal ports are home to a diverse array of bacterial, microbial, microalgal, and aquatic plant and animal species, many of which may be taken onboard along with water during ballasting and transported a far greater distance than would be possible through natural dispersal (Chan et al., 2012; Hulme, 2009). Thousands of species can be carried in a single ship's ballast water, and it is estimated that up to 10,000 NIS are transported globally each day in ballast tanks (Hulme, 2009; Transport Canada, 2010). Considering that 49.7 million tonnes of ballast water is discharged in Canadian waters annually, there is potential for a large number of NIS to be introduced (Reeves, 1999). In fact, ballast water from ocean-going vessels has been identified as one of the foremost pathways for NIS in Canadian waters (Chan et al., 2012).

Introductions of NIS into Canadian waters have caused and will continue to cause severe environmental, economic, and social impacts. Ecologically speaking, NIS may cause trophic disruptions, indigenous species displacement, and reductions in native biodiversity, which in turn create a cascade of socioeconomic problems (Ruiz et al., 1999). For example, in 2006 the sea lamprey (*Petromyzon marinus*), zebra mussel, and quagga mussel jointly cost Canadian aquaculture and aquaculture-related industries CAD$32.3 million (Colautti et al., 2006). Furthermore, considerable amounts of money are spent by different levels of government, industries, and NGOs on the management and mitigation of damage done by AIS. Human well-being is also negatively affected by the presence of NIS, as they may hinder the delivery of needed ecosystems goods and services (Pejchar & Mooney, 2009).

1.2 Ballast Water Management in Canada

In an attempt to avoid these negative impacts, the Canadian federal and provincial governments have put forth various pieces of legislation addressing invasive species. Most relevant to this project are the *Ballast Water Control and Management Regulations* (SOR/2011-237), which were introduced by Transport Canada in 2006 with the overall goal of minimizing the risks associated with AIS through the management of ballast water. Specifically, these regulations aim to limit the introduction of non-indigenous species through a preventative approach of ballast water management (BWM). The proactive nature of these Regulations is key, as it is extremely difficult to control or eradicate non-indigenous species once they have been established. However, despite the focus placed on prevention, areas of weakness within the Regulations compromise the effective limitation of NIS introduction into Canadian waters.

Firstly, the strong focus placed upon ballast water exchange (BWE) as a primary means of management challenges the overall goal of the Regulations, as it is not an effective means of removing NIS from ballast or rendering them harmless. Secondly, exemptions from management for specific voyage types granted by the Regulations leave some areas vulnerable to the introduction of NIS; vessels operating exclusively within Canadian waters are exempted from BWM, thereby leaving ports which experience a high volume of coastal domestic vessel traffic exposed to the risk of NIS introduction from other Canadian source ports. There is also a regional imbalance in the degree of protection provided by the Regulations. Freshwater ports and areas like the Great Lakes and St. Lawrence Seaway are less vulnerable to the threat of NIS introduction than marine ports, as additional requirements apply to these areas and mid-ocean BWE is more effective at eliminating freshwater organisms from ballast water.

As Canada is bordered by three coasts and is home to a diverse array of aquatic environments, it is important to consider how these policy gaps affect different regions. One area of growing concern is the Canadian Arctic, as it is a marine environment which is visited mainly by coastal domestic vessels. Rapidly occurring development and other socioeconomic changes partially facilitated by a warming climate and increased access are affecting the degree of ecological exposure of the eastern region of Canada’s Arctic to aquatic species invasions. Additionally, environmental changes are decreasing the environmental distance between origin and destination ports, thus impacting the likelihood of establishment of introduced NIS. These factors in combination result in the heightened risk of ballast-sourced species invasions.

1.3 Arctic Changes and Considerations for Ballast Water

The effects of climate change are being experienced in the Arctic more intensely than anywhere else on the planet, resulting in a rate of warming which is two to three times higher than the global average (Doney et al., 2012; Hinzman et al., 2005; Overpeck et al., 1997; Post et al., 2009). Among the many alarming environmental impacts being observed, the most concerning change involves trends in sea ice extent. Sea ice is breaking up earlier and forming later than historically recorded, leading to an increase in the length of the ice-free season. Sea ice extent is declining during all months of the year, and particularly strong negative trends have been observed in the Baffin and Hudson Bay regions of the eastern Canadian Arctic (Mudge et al., 2011; Pizzolato et al., 2013; Post et al., 2009; Stewart & Draper, 2008). Some experts expect that the Canadian Arctic will be completely ice-free in the summer by the end of this century (Engler & Pelot, 2013; Hinzman et al., 2005).

As would be expected, biological systems are responding to changes in the physical environment. Environmental changes are impacting native Arctic species in terms of range and survival, allowing opportunities for northward-moving or introduced alien species to establish themselves and colonize (Post et al., 2009). It is clear that accelerated Arctic climate changes are resulting in impacts to physical, chemical, hydrological, and biological structures, causing a system-wide response that leaves the already sensitive region and species vulnerable to disturbances.

In addition to direct impacts, Arctic climate change also has indirect environmental consequences. For example, loss of sea ice extent has direct impacts on animals that rely upon ice cover for survival, but also increases the level of accessibility to the region. With more vessels comes an increasing risk of ship-strikes, ship-sourced pollution, and ballast-mediated NIS introduction. Correlations between declining sea ice cover and growing vessel counts in the Canadian Arctic suggest that if trends continue, a significant increase in shipping can be expected through the region (Pizzolato et al., 2013).

Currently there are no known ballast-sourced AIS in the Canadian Arctic and the region is considered to be one of the least invaded realms on the planet (Chan et al., 2013). However, with increases in vessel volume and subsequent ballast discharges this may be subject to change. As the Arctic is a sensitive region which is already vulnerable to the impacts of climate change, NIS introduction could have major environmental and socio-economic consequences. The extent of these effects is unknown, as species invasions in higher latitudes are largely unstudied.

1.4 Paper Scope and Purpose

Understanding the political framework of BWM in Canada within an Arctic context given environmental and socioeconomic changes is key to providing a baseline explanation of the current level of regional protection. From there, the future threats associated with ballast-mediated NIS may be identified and management actions can be suggested. Therefore, the primary purpose of this paper is to assess the risk of ballast-mediated NIS introduction and establishment to Canada's eastern Arctic, both currently and under a climate change scenario. This will mainly be done through a vector-based risk assessment which considers environmental, political, and socio-economic factors.

While the Canadian Arctic is undergoing a variety of changes (ranging from environmental to socioeconomic), due to limited knowledge and general uncertainty surrounding polar regions, it is difficult to determine how these changes will impact the region and the Inuit peoples who rely upon the environment for their physical and cultural wellbeing. As such, it is important to understand how a warming climate and increase in vessel traffic volume in the eastern Arctic will impact the probability and consequence of ballast discharges and the resulting risk of aquatic species invasions. By conducting a risk assessment, general knowledge on the area and topic can be gained and resulting recommendations for improved management may be made.

The key problems this paper is addressing are two-fold. Firstly, it is hypothesized that the gaps in Canada's BWM Regulations hinder the achievement of their overall goals and leave particular areas more vulnerable to the threat of invasion than others. Secondly, it is posited that given the rapid rate of warming at the poles and an increase in vessel volume within the eastern Canadian Arctic, the regional risks of ballast-mediated NIS introduction and establishment will increase significantly over time. Although risk assessments have been done on Canada's Arctic ports and have found that the region is at a relatively low risk of ballast-mediated species invasions (Casas-Monroy et al., 2014), no studies projecting the *future* risks have been conducted. Overall, it is expected that policy weaknesses in combination with Arctic changes will lead to a heightened risk of species invasions.

In order to investigate the current and potential future risk of ballast-mediated species invasions to Canada's eastern Arctic, a multi-step approach was taken. Firstly, a literature review was conducted. The literature review was broken down into two main components, with the first introducing Canada's and the international regulatory approach to BWM. The second component of the literature review discussed the current status of marine vessel traffic in the Arctic, and predicted what future trends might look like. A thorough policy analysis was then conducted to further examine multiple elements of Canada's BWM legislation. Finally, a risk assessment of the introduction and establishment of NIS to Canada's eastern Arctic was performed. The first section of the risk assessment considered the current risk of the eastern Arctic's highest volume ports. The second section forecasted the future risk at these same ports for the years 2055 and 2105, taking into account trends in warming and assuming that no changes in management were made. Finally, the third component of the risk assessment forecasted the future risk of these ports for the years 2055 and 2105 under a climate change scenario, but assuming that the primary method of BWM in Canada for international vessels had shifted from BWE to ballast water treatment (BWT). From these findings, the current and future status of the eastern Canadian Arctic could be described and recommendations were made in response.

2.0 LITERATURE REVIEW

2.1 Legislative Approaches to Invasive Species Management

Canada's history of invasive species management is relatively short, but legislation has rapidly evolved in response to the threat of non-native species. In 1992 Canada ratified the UN Convention on Biodiversity, committing to preventing and eradicating the spread of invasive species. In 1995 the Canadian Biodiversity Strategy was released, calling for the development and implementation of legislation addressing invasive species. The Invasive and Alien Species Strategy for Canada was released in 2004, which outlined a plan for prevention, early detection, rapid response, and the management of the establishment or spread of invasive species. However, it was not until 2005 when AIS were specifically addressed in legislature.

Fisheries and Oceans Canada (DFO) is the federal body responsible for AIS management, and they have put forth various action plans and regulations. Two of the most prominent documents are the Canadian Action Plan to Address the Threat of Aquatic Invasive Species and the *Aquatic Invasive Species Regulations* (SOR/2015-121).

The Canadian Action Plan to Address the Threat of Aquatic Invasive Species

This Action Plan was introduced in 2005 by the Canadian Council of Fisheries and Aquaculture Ministers and the Aquatic Invasive Species Task Group as a follow-up to the Invasive Alien Species Strategy of 2004. It outlines a national AIS management approach focused on minimizing introductions of non-native species and the spread and impacts of established invasive species. Similar to the Invasive Alien Species Strategy, the Action Plan is centered on the four concepts of prevention, early detection, rapid response, and containment management.

Aquatic Invasive Species Regulations (SOR/2015-121)

Following the introduction of the Canadian Action Plan to Address the Threat of Aquatic Invasive Species it was clear that a regulatory approach for the effective management of AIS was needed. As a result, DFO developed the *Aquatic Invasive Species Regulations* (SOR/2015-121) in 2015 under the *Fisheries Act* (R.S.C., 1985, c. F-14, s. 43) to prevent introduction, spread, and establishment of AIS.

These regulations set out a list of species subject to prohibitions of importation, possession, transportation and release. In general, it is prohibited to introduce NIS to areas frequented by fish (s.10). The regulations also touch on compliance and enforcement, stating that ministers may take measures to prevent the introduction, spread and eradication of AIS by treating or destroying a member of the species, authorizing the deposition of deleterious substances, licensing fishing in an area, prohibiting specific activities, or establishing a barrier around an AIS (s.19; 22(2(a-b)); s. 25(1(a-c))).

The preventative nature of these regulations has been applauded, though other regulations are needed to manage specific vectors which contribute to the spread of AIS, such as ballast water.

2.1.1 Canadian Ballast Water Management

The *Ballast Water Control and Management Regulations* (SOR/2011-237) were established by Transport Canada in 2006 under the *Canada Shipping Act*, 2001 (S.C. 2001, c. 26). These Regulations are the first national, science-based, and legally-binding document regarding

Canada’s BWM, and have the purpose of ensuring that ballast water is managed in order to reduce the risk of AIS spread.

These Regulations apply to all Canadian vessels and all other vessels of a certain size operating in Canadian waters which are designed to carry ballast water, as well as vessels involved in oil and gas development (s.2(1(a-b)); s.2(2); s.4(3,4)). It should be noted that exceptions from the management under section 3 (a-f) apply to vessels operating only in Canadian waters or in the similar waters of the United States Great Lakes Basin or the French waters of Saint Pierre and Miquelon, or in areas of exclusive operation on the west or east coast. Furthermore, exceptions extend to search and rescue vessels and pleasure craft of a certain size, vessels with permanent ballast water in sealed tanks, and government vessels. Additionally, is not necessary to manage ballast water when doing so would jeopardize vessel stability and safety, or discharge vessel pollutants (s.4(5)).

According to the Regulations, ballast water is considered “managed” when it is exchanged in mid-ocean waters, retained onboard, treated through technology, or transferred to a reception facility (s.4(1)). Mid-ocean exchange is currently the most common form of BWM, and vessels undergoing trans-oceanic voyages must exchange ballast water in an area 200 nm from shore and 2,000 m deep before entering Canadian waters (s.6(1,2)). If a vessel does not transit through an area that meets these depth and distance requirements, exchange 50 nm from shore in an area 500 m deep is allowed; additionally, alternate exchange zones (AEZ) within Canadian waters are also located along each of Canada’s coasts for emergency situations. Special regulations apply to vessels destined for the Great Lakes with residual ballast water onboard, requiring them to either comply with the Canadian Shipping Federation’s Code of Best Practices for Ballast Water Management or undertake salt-water flushing through a mid-ocean exchange (s.5(2(a-b))). For the regulation’s standards to be met, a BWE must achieve a minimum of 95% volumetric exchange and result in ballast water with a salinity of at least 30 parts per thousand; if the exchange method is flow-through, three times the volume of the ballast tank in water must be pumped through (s.8(2,3)). Mid-ocean BWE is used to firstly reduce the presence of species in ballast water through purging, but is also used to kill freshwater AIS through osmotic shock (Ware et al., 2015).

If ballast water is treated, it must attain a viable organism and microbe content less than concentrations prescribed by the performance standards before being released in Canadian waters (Table 1). In addition to ballast water, regulations also pertain to sediment which settles out of ballast water. It is expected that the uptake of sediment will be minimized, and that sediment will be monitored and removed on a regular basis. It is necessary for sediment from outside of Canadian waters to be transferred to a land-based reception facility or deposited 200 nm from shore in an area 200 m deep (s.10(1,2)).

Table 1. The performance standards for ballast water treatment, as set out by the *Ballast Water Control and Management Regulations* (SOR/2011-237)

Acceptable Concentrations
• 10 viable organisms per cubic metre, for organism with a minimum dimension equal to or greater than 50 µ
• 10 viable organisms per millilitre, for organisms with a minimum dimension equal to or greater than 10 µ but less than 50 µ
• One colony-forming unit (cfu) of toxicogenic Vibrio cholerae (O1 and O139) per 100 mL or one cfu of that microbe per gram (wet weight) of zooplankton samples
• 250 cfu of Escherichia coli per 100 mL
• 100 cfu of intestinal enterococci per 100 mL

Section 11(1) of the regulations requires vessels to carry onboard, and adhere to, a BWM plan. This plan must set out processes and procedures for safe and effective BWM and must contain a number of required descriptions and elements. All applicable vessels are required to submit a copy of their BWM plan to the Minister (s.12). All vessels bound for a Canadian port must also submit a completed Ballast Water Reporting Form after a management process has been implemented (s.14).

If a vessel is unable to perform BWM because doing so may jeopardize vessel stability and safety, it is classified as an exceptional circumstance. In these cases, alternative measures to minimize the risk of introducing AIS including retention, exchange, release or treatment must be implemented without further compromising vessel safety (s.13(2,4,5)).

The regulations lack clear enforcement measures and penalties for noncompliance, but the *Guide to Canada's Ballast Water Control and Management Regulations, 2011* states that any vessel may be subject to inspection by Transport Canada to ensure that regulations are being followed. This could include inspection of the ballast water record book or BWM plan, or sampling of the vessel's ballast water. If found that compliance is not being met, the vessel may be required to retain ballast water onboard, conduct an exchange or discharge in a specified location, or treat ballast water with a nationally approved method. However, it should be noted that to date no treatment system has been type approved by Canada, mainly due to concerns regarding the use of such systems in cold and fresh water environments (Chan et al., 2012).

Although it is important to have national regulations regarding BWM, it is a global issue which deserves international attention. Therefore, Canada based the majority of its BWM Regulations on the International Maritime Organization's (IMO) International Convention for the Control and Management of Ship's Ballast Water and Sediment, which it ratified in 2010.

2.1.2 International Ballast Water Management

The International Convention for the Control and Management of Ship's Ballast Water and Sediment was adopted by the IMO in 2004. The Convention lays out standards and requirements to help States minimize the transfer of ballast-mediated AIS. The Convention has been ratified by

35% of the world's merchant shipping gross tonnage and will enter into force in September of 2017.

The Convention sets out BWM standards to be phased in over time, and applies to all vessels of member countries designed to carry ballast water. Most of the requirements set out in the Convention are echoed in Canada's Regulations, including the standards for BWT which are referred to as the D-2 regulations in the Convention. The Convention will eventually require that BWE be completely phased out and replaced by on-board BWT systems; however, until that is possible, mid-ocean BWE will continue to be the primary mechanism of management.

Although most requirements are shared between the Convention and Canada's Regulations, some differences exist. Unlike Canada's Regulations, the Convention sets out a framework for enforcement and violations. The procedure of ship inspection includes checking for a valid certification and Ballast Water Record Book, and potentially obtaining a sample of the ballast water (article 9.1). If it is found that requirements are not met, a more detailed inspection may be carried out and the vessel could be warned, detained or excluded. Under article 8.2, violation of the Convention by a member country within another member country's jurisdiction is prohibited, and the sanctions are to be established under the law of the nation in which the offense occurs. It is stated that sanctions should be somewhat severe, so as to discourage noncompliance (article 8.3). Parties are expected to cooperate during investigations and enforcement, and in the case of a dispute parties are expected to settle it between themselves (article 10.1; 15). If undue delay or detainment occurs, compensation for losses or damages is required under article 12.2. Although some vessels travelling along specific routes may be exempted from management (similar to in Canada), these exemptions are only granted upon the completion of a risk assessment outlined by the IMO. Additionally, the Convention strongly promotes constant monitoring by states, so as to inform vessels from where ballast water should or should not be taken up.

2.2 Arctic Shipping Trends

According to the *Arctic Waters Pollution Prevention Act* (R.S.C., 1985, c. A-12, s.2), Canada's Arctic waters include all inland waters, the territorial sea, and waters of the exclusive economic zone (EEZ) enclosed by the 60th parallel of north latitude, the 141st meridian of west longitude, and the outer limit of the EEZ. Shipping in these waters is complicated by polar conditions, and therefore various sets of both federal and international regulations govern marine vessel movement in Canada's Arctic waters. In terms of federal legislation, the *Canada Shipping Act* (S.C. 2001, c. 26) in combination with the *Arctic Waters Pollution Prevention Act* (R.S.C., 1985, c. A-12, s.2), the *Arctic Shipping Pollution Prevention Regulations* (C.R.C., c. 353), the *Coasting Trade Act* (S.C. 1992, c. 31), the *Marine Liability Act* (S.C. 2001, c. 6), the *Navigable Waters Protection Act* (R.S.C., 1985, c. N-22), and the *Marine Transportation Security Act* (S.C. 1994, c. 40) govern Arctic maritime activities. Internationally, the IMO International Code for Ships Operating in Polar Waters (the Polar Code) will apply to ship safety in Canada's Arctic. This code will come into effect on January 1, 2017, and will use a risk-based approach to protect the polar environment from shipping impacts (International Maritime Organization, 2014). The IMO has also formulated a Polar Operational Limit Assessment Risk Indexing System (POLARIS) to accompany the Polar Code. POLARIS, partially developed from Canada's Arctic Ice Regime Shipping System (AIRSS), helps plan ship routes by determining the operational limits of a vessel through the calculation of risk index outcomes (American Bureau of Shipping, 2016).

The consideration of sea ice is a critical component of marine transportation in the Arctic, and is becoming increasingly more important as patterns of ice cover respond to climate change.

Total vessel volume has increased in the Canadian Arctic by 75% since 2000, accelerating rapidly since the extreme summer sea ice minima in 2007 (Pizzolato et al., 2013). With this decrease in summer sea ice extent comes an extension of the shipping season past the traditional four-month time-frame. In some regions "shoulder seasons" may begin as early as June and continue until November (Mudge et al., 2011; Pizzolato et al., 2013). There are already a variety of shipping activities which occur in the Canadian Arctic waters, and it is expected that with a continued decline in sea ice extent vessel traffic may increase further. Specifically, there has already been a significant increase in the presence of pleasure craft, passenger vessels, government vessels and icebreakers, and bulk carriers in the Northern Canada Vessel Traffic Services (NORDREG) zone since 1990 (Pizzolato et al., 2013).

It is a common conception that with a decline in sea ice cover, more activities will be possible in the Arctic and ship traffic will increase in response. However, it is important to acknowledge that trends in Arctic ship traffic are dependent upon more than simply sea ice extent and composition. Other drivers such as geopolitics, governance, environmental awareness, infrastructure development, sector-specific demands, and economics will also impact the future of northern marine transportation (Engler & Pelot, 2013). In combination with climate change, demands such as population growth, economic development, energy consumption, competition, operational costs, and the price of oil, gas, and other commodities will determine if and how vessel traffic will increase in Canada's Arctic waters. That being said, it is clear that there is political will to facilitate Arctic shipping, as in 2015 the federal government allotted CAD$22.7 million over a period of five years to Arctic marine safety (Fisheries and Oceans Canada, 2015). Furthermore, marine transportation is more economic and energy efficient than air, road, or rail transportation. Therefore, it will most likely continue to be the preferred mode of transport in

Canada's Arctic, especially when considering the trend of declining sea ice extent.

2.2.1 Transit Shipping

2.2.1.A Current

The Northwest Passage (NWP) runs from Baffin Bay to the Bering Sea through the Canadian Arctic Archipelago, connecting European and Asian markets and the east and west coasts of North America (Borgerson, 2008). The NWP is a historically important sea route, but only began to become commonly used in the 1980's with at least one vessel making the voyage yearly. However, several vessels have begun to make the voyage annually since the Passage was completely ice-free for the first time in September of 2007 (Khon et al., 2010). Surprisingly, the majority of the voyages through the NWP are not for trans-Arctic shipping purposes; instead, the majority of ships making voyages through the NWP are Canadian Coast Guard icebreakers (33%) and small vessels or adventurers (32%), while commercial shipping vessels represent less than 2% of the traffic (Northwest Territories, 2015).

Although the NWP is shorter in distance than the Panama and Suez Canal routes for ships traveling between Europe and Asia, trans-Arctic shipping is not a common choice. Firstly, environmental changes pose a major concern. Despite loss of sea ice in the eastern mouth of the NWP, there has been an increase in the presence of drifting multi-year ice (MYI) chunks known as "growlers" throughout other sections. Growlers are extremely unpredictable and hazardous to vessels and can create chokepoints along the NWP (Engler & Pelot, 2013; Stephenson et al., 2013). It is expected that growlers and small icebergs will persist or even increase as glaciers continue to melt. As a result of these variable and dangerous conditions, the shipping season through the Arctic Archipelago is shorter than anywhere else along the NWP (or the Russia-hugging Northern Sea Route and Transpolar Sea Route, for that matter), and vessels are often forced to reduce speeds when travelling through (Stephenson et al., 2013). Though the number of vessels transiting the Passage are increasing over time, there is large year-to-year variability in vessel counts due to heavy ice years interspersed between light ice years. In 2009, seven vessels are reported to have made a full voyage through the Passage; this number soared to a record high of 30 in 2012, but was cut nearly in half just two years later due to heavy ice conditions (Engler & Pelot, 2013; Northwest Territories, 2015).

In addition to safety concerns, infrastructure also limits transit shipping through the NWP. A lack of port facilities exists in the high Canadian Arctic, and nautical charts have also been to found to be inadequate or inaccurate (Engler & Pelot, 2013; Lasserre & Pelletier, 2011). Canadian regulations only allow specific types of vessels to traverse the Passage due to ice conditions, and such vessels are expensive to construct and difficult to find. Once an adequate ship has been acquired there are operational complications to consider, such as controlling the onboard temperature in order to prevent goods from freezing. Route planning is also made more challenging by using the NWP, as ships which must adhere to a strict time schedule are at the mercy of unreliable conditions and may be required to delay arrival times (Lasserre & Pelletier, 2011). There is also the annoyance of making frequent schedule changes, as the Passage is unavailable during the winter season. Finally, the procurement and cost of insurance for vessels transiting through the NWP is an issue for many companies (Engler & Pelot, 2013; Lasserre & Pelletier, 2011). Despite reducing distance between destinations, the NWP is potentially more expensive to navigate than the Panama and Suez Canals and the Northern Sea Route due to these added complications. It appears that the present risks of shipping through the Canadian Arctic and the low navigation potential of the NWP severely limits trans-Arctic shipping through Canada's north (Stephenson et al., 2013).

2.2.1.B Future

In spite of environmental and operational challenges and a short shipping season, the NWP could result in major savings for shipping companies in time and cost if navigated successfully. For example, a trip from western Europe to the far east through the NWP would be 9,000 km shorter than using the Panama Canal, and using the NWP instead of the Suez Canal could cut 15% of the distance off of a trip from Rotterdam to Shanghai (Khon et al., 2010; Riis, 2014). It is predicted by Borgerson that a large container ship could save 20% in costs (around USD$3.5 million) each trip by using the NWP rather than the Panama Canal (2008). In addition to savings in distance, time, and costs, the NWP is an attractive alternative to the Panama and Suez Canals for mega ships as there are no size restrictions for vessels (Riis, 2014). Trans-Arctic shipping is also potentially beneficial to Canada, as it may improve development opportunities and help secure Canada's claims of Arctic sovereignty.

The general consensus is that the NWP has the potential to be profitable, but only in optimal (and rare) conditions; until then, the sea ice may be too difficult and unpredictable to manoeuver (Lasserre & Pelletier, 2011). In a survey of 98 shipping companies by Lasserre and Pelletier, only 17 companies were interested in expanding or beginning shipping in the Canadian Arctic, eight of which were already operating in the region (2011). 72% of the companies that responded stated they were not interested in Arctic shipping at all.

In addition to environmental factors, there are other variables which will impact the expansion of transit shipping in the Canadian Arctic. Global trade, the development of polar marine technology, the availability of other Arctic sea routes, and prices of oil and other commodities must also be considered (Engler & Pelot, 2013). However, if focusing primarily on accessibility, it is predicted that the NWP will open substantially by 2060 and become a viable option by the end of the 21st century, when the shipping season may be prolonged to as long as six months (Khon et al., 2010; Stephenson et al., 2013). Until then, sections of the Canadian NWP may be some of the last areas in the Arctic to be ice-covered (Engler & Pelot, 2013). This is not to say that all marine traffic in Canada's Arctic will be limited; it is forecasted that while transit traffic will not increase significantly, destination traffic will continue to become more frequent (Lasserre & Pelletier, 2011).

2.2.2 Community Re-supply

2.2.2.A Current

As a result of the increasing reliance upon community resupply for material needs, marine transportation has become an integral component for Northern community functioning. With the exception of a few perishable or urgent items arriving by air, all goods are delivered by the sea (Vannini et al., 2009). General cargo and oil tanker vessels engaging in community resupply distributed a total of 372,500 m^3 in dry cargo and 262,500 m^3 in petroleum products in 2011, and are the most common and consistent type of vessel operating in the Canadian Arctic (Engler & Pelot, 2013; Lajeunesse, 2011; Pizzolato et al., 2014; Prowse et al., 2009)

There are four systems for Arctic re-supply in the Canadian north: 1) the Athabasca Marine Supply System, 2) the Mackenzie River and West Arctic Supply System, 3) the Inside Passage and Yukon Supply System, and 4) the Eastern Arctic and Keewatin/Hudson Bay Supply System (Transport Canada, 2016). A total of five shipping companies participate in Arctic re-supply along these corridors: Northern Transportation Company Limited (NTCL), Nunavut Sealink and Supply Inc. (NSSI), Nunavut Eastern Arctic Shipping (NEAS), Taqramut Transport Inc. (TTI), Groupe Desgagnes, Fednav International Ltd., and the Woodward Group. With the exception of the Woodward Group, most of the shipments to the eastern Arctic come from Sainte-Catherine in

Quebec, though some may come from Churchill or Hay River depending on the destination. There has been a clear upsurge in resupply demand since 2007, and the current eastern Arctic sealift demand sits around 22 seasonal trips over the span of 100 days (Engler & Pelot, 2013; Transport Canada, 2016).

2.2.2.B Future

Unlike transit shipping, it is predicted that community resupply shipping will rapidly increase in the near future. The main factor influencing this sector is population growth. Canada's territories had a population of roughly 110 000 people in 2013; under a medium growth rate this number could soar to 131 000 by 2036. In Nunavut alone, an 8% increase in population growth was observed between 2006 and 2010, and the population may continue to increase to 48 451 by 2020 (Engler & Pelot, 2013). A steadily growing population will in turn lead to increased consumption, thus increasing the demand for community resupply shipping (Table 2).

Table 2. Past resupply demand vs. projected demand based on forecasted population growth (Engler and Pelot, 2013)

	2006	**2020**
Qikiqtaaluk		
Population	16,005	21,038
Dry Cargo Demand (tonnes)	35,211	46,284
Petroleum Demand (tonnes)	51,216	67,322
Kivalliq		
Population	9,266	21,181
Dry Cargo Demand (tonnes)	20,385	26,978
Petroleum Demand (tonnes)	29,651	38,979
Kitikmeot		
Population	4,741	6,232
Dry Cargo Demand (tonnes)	10,430	13,710
Petroleum Demand (tonnes)	15,171	19,942

It is projected that the amount of total inbound goods delivered to the eastern Arctic by 2020 could increase to around 2.9 million tonnes (PROLOG Canada Inc., 2011). However, much of this predicted growth is resource development driven, and by 2030 demand may fall to 1.7 million tonnes. In addition to goods needed for housing and public infrastructure projects, the eastern Arctic sealift also services the cargo requirements for mining developments; therefore, resource activity as well as population growth will impact resupply traffic.

The limitations of winter roads should also be considered, as thawing permafrost and unpredictable weather events will complicate vehicle travel and thereby increase demand for transport by sea. It is likely that as a result of sea ice loss, the season for community resupply will continue to lengthen and more frequent trips to communities will be allowed. However, considering that the majority of "ports" in the eastern Arctic are really only beaches or small craft harbours, improved port infrastructure is required to meet projected demands (Transport Canada, 2016).

2.2.3 Tourism

2.2.3.A Current

The Arctic has a long history of tourism dating back nearly two centuries. The first Arctic tourists were adventurers or pioneers, but the nature of tourists has changed over time with increased access to the previously isolated region (Snyder, 2007). Today, polar tourism is the fastest growing sector in the tourism industry, experiencing unprecedented growth since the 1990's (Stonehouse & Snyder, 2010).

There are many sub-types of tourism in the Arctic, but cruise tourism is by far the most popular. In 2007 cruise ships brought 2.5 million people to the Arctic circle; this number continues to climb, as Southeast Alaska alone brings in an average of almost one million tourists each year (Rain Coast Data, 2015; Stonehouse & Snyder, 2010). Though much more modest than its Arctic neighbours, Canadian polar tourism has also experienced a considerable upsurge of 115% from 2005 to 2013 (Dawson et al., 2014). In 2006, cruise ship numbers doubled from the previous year to 22, and reached an all time high in 2008 with 26 scheduled cruises. One of the most popular Arctic cruise ship routes is located in the eastern Canadian Arctic, running from Baffin Island to Greenland through the Davis Strait. In 2008, 14 different cruises ran through the Davis Strait to Iqaluit, Nunavut (Stewart et al., 2010).

However, despite indisputable growth in the cruise tourism sector in the Canadian Arctic since its advent, some authors have described a pattern of stabilization and even decline in more recent years. In 2010, 24 cruise ships visited Canada's Arctic; the following year this number fell to 18, and continued to decline in 2012 to only 16 scheduled expeditions (Dawson et al., 2014). The stunting of the Arctic cruise industry may ironically be partly due to the loss of sea ice. With less sea ice comes a diminished opportunity to view Arctic animals, and consequently a less authentic Arctic experience (Stewart et al., 2010). Furthermore, the presence of growlers makes navigation less predictable and poses serious safety concerns for cruise ships, as MYI is able to penetrate ship hulls (Stewart et al., 2007).

The nature of Canadian cruise tourism may also be a growth-limiting factor. Canadian cruises are typically small ships offering frequent onshore excursions to Northern communities; it is not possible to accommodate a greater number of passengers while still offering community visits due to the lack of port and community infrastructure in Canada's Eastern Arctic (Lasserre & Têtu, 2015). To put this in perspective, Canadian cruises held 149 passengers on average in 2012 in contrast to Alaskan or European cruises, which accommodate thousands of tourists each voyage. Lack of maritime infrastructure may also limit Canadian Arctic cruises, as only three ports with berths exist in the Canadian Arctic (Deception Bay, Nanisivik, and Churchill), two of which are industrial ports.

Finally, regulatory obstacles make cruise ship entry into the Arctic burdensome, challenging, and expensive. The Association of Arctic Expedition Cruise Operators (AECO) has stated that entry into Canada's Arctic with a cruise ship requires contacting more than 35 different authorities and completing over 50 applications and permits (AECO, 2015). This is supported by research done by Dawson et al., which found that in addition to international conventions, a plethora of federal, territorial, and local regulations must be adhered to (2014). Overall, it was found that Canada's Arctic cruise ship regulations are wrought with institutional complexity, capacity deficits and a lacking overseeing agency. These problems firstly act as a barrier to entry for cruise ships into Canadian waters, and secondly limit route freedom once successfully entered (Dawson et al., 2014; Lasserre & Têtu, 2015).

2.2.3.B Future

It is a common expectation that cruise ship numbers will grow as sea ice extent decreases, ice-strengthened vessels become more available, knowledge of Arctic geography increases, and technology and equipment improves. In fact, major advances are already being seen; in the summer of 2016, the luxury cruise liner Crystal Serenity was the largest ever cruise ship to transit the NWP. This voyage carried 1,800 people from Alaska to New York, making three different stops in the High Arctic along the way (Humpert, 2016).

It is also possible that tourist numbers in the Canadian Arctic will continue to climb as a result of "last-chance tourism". This theory states that tourists will be driven to vanishing or deteriorating sites in order to catch one last glimpse of it in its natural state; as climate change continues to alter the Arctic climate and ecosystems, there is a potential for a corresponding upsurge in tourism (Lemelin et al., 2010). However, such a phenomenon may only be sustained for so long until the region has been altered from its original state to a degree that is no longer appealing.

However, there are still substantial problems regarding the changing Arctic environment, the "small" nature of the Canadian Arctic cruise industry, and the regulatory obstacles which act as barriers to entry for cruise ship operators. As a result, very few tourism companies are interested in expanding their presence in the Canadian Arctic (Lasserre & Têtu, 2015). Ice conditions, world economy, and promotion by Canadian and territorial governments will determine how future Arctic tourism will look in Canada. It is predicted that the sector will see a modest growth of 1.25% during each month by 2020, and that cruises will eventually move northward into the high Arctic and NWP (Engler & Pelot, 2013; Etienne, Pelot, & Engler, 2013). Overall, it is unsure if rapid development of the Canadian eastern Arctic cruise tourism industry is likely, though currently the sector appears to be somewhat steady.

2.2.4 Resource Development

2.2.4.A Current

Resource development has been occurring in Canada's Arctic since the beginning of the 20th century. Oil and gas development first began in the Mackenzie Valley in the 1920's, and mining operations began in the Arctic in 1957 at Rankin Inlet's lead and zinc mine, and in the high Arctic in 1976 at the Nanisivik lead and zinc mine (Tetu et al., 2015). However, Canada's Arctic is still considered a frontier region (Haley et al., 2011).

In Canada, three regions have been found to have considerable oil and gas reserves: the Mackenzie River Valley, the Arctic Islands, and the Mackenzie Delta and Beaufort Sea regions (Pelletier & Lasserre, 2012). In Canada's Arctic, it is estimated that the total discovered and undiscovered oil and gas reserves add up to 8.4 billion barrels of oil and 4.3 trillion m^3 of gas, or

25% and 33% of Canada’s remaining reserves respectively (Jorgensen-Dahl, 2010). It is estimated that Nunavut alone has 523 million barrels of crude oil in proven reserves and 12,300 billions of cubic feet (Bcf) of natural gas, indicating that this region has a high potential for hydrocarbon resources (Engler & Pelot, 2013). Most of the oil and gas exploration in Canada’s Arctic is occurring in the western region, though some exploration licenses have been granted in the eastern Arctic.

In the eastern Arctic, resource development is mainly in the form of mining. Most of the minerals being mined are iron ore, nickel, and gold, but others include diamonds, copper, lead, and zinc (Engler & Pelot, 2013). By 2020, more than 25 large-scale projects are expected to be in operation in the Canadian Arctic, potentially resulting in 433 shipments in and out of Arctic ports yearly (Goldsmit et al., 2014). In the eastern Arctic specifically there are ten active mines, with only five relying upon marine transportation for exporting goods. As a result, there is only a moderate number of vessels involved in resource development traversing the eastern Arctic annually. However, at least eight mines expected to open in the near future will use Arctic shipping as a primary means of transport, signifying a potential increase in mine-related marine vessel traffic (Table 3) (Tetu et al., 2015).

2.2.4.B Future

A combination of factors will drive the development of Canada’s Arctic resources, and as a result it is hard to effectively forecast what the future will look like in terms of Arctic development. However, the high demand for natural resources, high market value, and warming Arctic are definitely increasing the interest in Northern development (Pelletier & Lasserre, 2012).

The main drivers for oil and gas development in Canada’s Arctic are oil and gas prices, other international discoveries/explorations/developments, and new or unconventional resource exploration and development. There are many obstacles specific to the Arctic that may hinder northern hydrocarbon development and it is not predicted that any oil development projects will exist in the eastern Arctic anytime in the near future (Engler & Pelot, 2013). If oil and gas development were to occur in the eastern Arctic, resources would likely be exported over land through a pipeline, though shipping may be required to deliver supplies to sites (Jorgenson-Dahl 2010; Lajeunesse, 2011).

Factors determining the development of Arctic mining include global commodity markets and prices, overall global economic conditions, existing projects and their expected lifetimes, international discoveries, regulatory regimes, access to financing, and sovereignty claims. Many challenges related to oil and gas development also apply to mining: high costs of operations and transport in the Arctic, an overall lack of infrastructure, and social opposition to environmental concerns may prevent the development of future mining projects (Engler & Pelot, 2013). However, if an increase in mining activity is to occur in the Arctic in the future, it will most likely rely heavily upon shipping for exploration, supply, and export/transport of raw materials. This is already the case for the Mary River Project.

Baffinland's Mary River Project on the northern end of Baffin Island is the largest industrial project currently underway in the Canadian Arctic, and may be one of the largest iron ore deposits in the world (Brigham, 2013; Pelletier & Lasserre, 2012). The company initially planned to transport 18 million tonnes of iron ore each year out of Steensby Inlet. Due to complications with construction of a railway from Mary River to Steensby Inlet, they instead proposed to export 4.2 million tonnes/year out of Milne Inlet. Now they are requesting to nearly triple this amount by shipping 12 million tonnes/year by 2020 (Skura, 2016). Baffinland is also proposing to ship ten months of the year, from June to March; this would equate to anywhere between 60 to 130 shipments leaving Milne Inlet each year (Jorgensen-Dahl, 2010; Skura, 2016; Etienne et al., 2013). The first outbound shipment was made in August of 2015, when 53,624 tonnes of iron were shipped to Germany via bulk carriers from Milne Inlet (Brigham, 2013). Baffinland is projected to operate for 25 years, and by 2024 they hope to be operating out of Steensby Inlet and shipping year round with 10-12 ice-class cape size vessels making around 100 round-trip voyages yearly (Megannety, 2011; Pelletier & Lasserre, 2012; Skura, 2016). This will obviously result in an increase in tankers and bulk carriers.

If Arctic resource development is to take off, the increasing unreliability of airstrips, roads, and railways as a result of permafrost thawing and climate change will lead to an intensified reliance upon sea transport (Prowse et al., 2009). Radloff & Hrebenyk (2010) predict that by 2020, several voyages relating to mining will be occurring in Canada’s Northern waters; by 2050, additional mining voyages will be occurring, as well as oil and gas development vessels. Though there is currently no “rush” occurring in the Arctic, a steady growth of resource development is expected for the region, having clear implications for marine transportation.

Table 3. Active and inactive mines which use shipping routes within the eastern Canadian Arctic (CanNor, 2013; Tetu et al., 2015)

Name	**Company**	**Product**	**Location**	**Port**	**Voyages/ 2020**	**Date**	**Production**
Active Mines							
Mary River	Baffinland	Iron ore	Qikiqtaaluk, NU	Milne Inlet/ Steensby Inlet	4-130	2015-2040	12 million tonnes/year
Meadowbank	Agnico Eagle	Gold	Kivalliq, NU	Baker Lake	0.1	2010-2018	350,000 ounces /year
Nunavik Nickel	Jilin Jien Nickel Industry Co.	Nickel, Copper	Nunavik, QC	Deception Bay	3	2013-N/A	N/A
Raglan	Glencore PLC	Nickel, Copper	Nunavik, QC	Deception Bay	2.45	1997-2039	37,000 tonnes of nickel /year
Voisey’s Bay	ValeInco	Nickel, Copper, Cobalt	Voisey’s Bay, Labrador	Edward’s Cove	20	2005-2035	50,000 tonnes nickel/year 32,000 tonnes copper/year
Inactive Mines							
Roche Bay	Savik Iron Mines Ltd.	Iron ore	Qikiqtaaluk, NU	Roche Bay	16	2017-2032	5.5 million tonnes/year
Meliadine	Agnico Eagle	Gold	Kivalliq, NU	Rankin Inlet	4	2020-2029	3-5,000 tonnes/year
Kiggavik	AREVA	Uranium	Kivalliq, NU	Churchill, Chesterfield Inlet, Baker Lake	1	2020-2045	2-4,000 tonnes/year
Izok Lake	MMG Ltd.	Zinc, Copper	Kitikmeot, NU	Grays Bay	12	2017-2029	2 million/year
Hackett River	Glencore PLC	Zinc, Silver	Kitikmeot, NU	Bathurst Inlet	5	2020-2035	250,000 tonnes of zinc/year
Hope Bay	TMAC Resources Inc.	Gold	Kitikmeot, NU	Hope Bay	N/A	2016-2036	160,000 ounces/year
Back River	Sabina Silver & Gold	Gold	Kitikmeot, NU	Bathurst Inlet	5	2019-2029	300-400,000 ounces/year
Hopes Advance	Oceanic Iron Ore Corp	Iron ore	Nunavik, QC	Pointe Breakwater	56	2017-2065	10-20 million tonnes/year
*Otelnuk Lake	Adriana Resources, Wuhan Iron & Steel Corporation	Iron ore	Nunavik, QC	Sept Iles, proposed port in Kuujjuaq	N/A	2016-2116	50 million tonnes/year
Qiqavik	True North Nickel	Gold	Nunavik, QC	Exploration Stage			
West Raglan	True North Nickel	Nickel	Nunavik, QC	Exploration Stage			

2.2.5 Fishing

2.2.5.A Current

Landings from the Arctic fishery were valued at around $79 million/year in 2013, up from $35 million in 2006. Although these values are substantially lower than those of the landings from both the east and west coasts of Canada, it is still a significant growth, especially when considering limitations in accessibility (Christie, 2012; Weber, 2015). Most of this activity is occurring in the Eastern Arctic, where commercial fishing, fish processing, and harbour construction have been occurring increasingly.

The eastern Arctic fisheries fall into Northwest Atlantic Fishery Organization (NAFO) zones 0A and 0B; zone 0A runs from just south of Cape Dyer on the eastern coast of Baffin Island northwards across Baffin Bay to the pole, and zone 0B runs south from Cape Dyer, through Cumberland Sound, and along the Davis Strait down to the northernmost tip of Labrador (Standing Senate Committee on Fisheries and Oceans, 2009). The commercial fisheries are offshore, nearshore, and inland and target mainly turbot, shrimp, and Arctic char (Indigenous and Northern Affairs Canada, 2012). Turbot is the primary fishery, and alone netted $65 million in landings in 2015. Fishing quotas are leased by Nunavut interests, usually to international companies (Indigenous and Northern Affairs Canada, 2012; Nunatsiaq News, 2011). Around 10,600 tonnes of shrimp is allotted yearly in quotas to international companies and about 3,000-4,000 is reserved for local fishery harvesting (Nunatsiaq News, 2011). In the Pond Inlet area, there is a quota of 910 kg for Arctic char (though it is unclear how much of the quota is filled) (Indigenous and Northern Affairs Canada, 2012). In the Baffin region large scale turbot fishing occurs offshore in addition to shrimp fishing to fill a quota of 9,350 tonnes; smaller scale inshore turbot and Arctic char fishing occurs in Cumberland Sound, where the quotas are 500 tonnes and 2,000 kg respectively

(Nunatsiaq News, 2011; Indigenous and Northern Affairs Canada, 2012). According to DFO, average yearly landings of turbot in Zone 0A between 2005 and 2011 were 5,864 tonnes with a value of around \$26 million. In Zone 0B, the average annual landing was 5,951 tonnes with a value of \$25 million (Fisheries and Oceans Canada, 2008). These numbers appear to be increasing, as turbot catches in Davis Strait and Baffin Bay have tripled over the past 15 years (Christie, 2012).

Pangnirtung Fisheries Ltd. is a fish processing plant which was established in 1994 in Pangnirtung. As of 2009, the plant was processing approximately 10 tonnes of Arctic char and 400 tonnes of turbot yearly and making around \$4 million in sales (Standing Senate Committee on Fisheries and Oceans, 2009; Christie, 2012). Most of the processed fish is frozen and shipped to China. In 2001, 365 tonnes of fish from offshore were delivered to the Pangnirtung fish processing plant, and this number continues to climb as fishing efforts increase (Indigenous and Northern Affairs Canada, 2012). In order to facilitate growth in the fishery and fish processing sector, a small craft harbour was constructed in Pangnirtung in 2013. There is also a smaller fish processing plant located in Iqaluit, where a deep water port is slated to open in 2020. In order to allow further expansion of this industry, more port infrastructure is required.

Despite the rapid growth of fisheries in the eastern Arctic, the activity is not yet contributing significantly to an increase in marine vessel traffic. Of 76 tracked ships in the NORDREG zone in 2011 (44 of which were successfully identified as a vessel type), only two were confirmed to be fishing vessels (Engler & Pelot, 2013). However, DFO found the volume to be a bit higher, with 10 fishing vessels on average operating in Zone 0A between 2005 and 2011 and 16 vessels in Zone 0B (Fisheries and Oceans Canada, 2008).

2.2.5.B Future

The factors which will contribute to the development of fisheries in the eastern Arctic are the distribution and abundance of the marine resources themselves, the regulatory frameworks in place, and investment in vessels and harbours (Engler & Pelot, 2013). As comparatively little is known about Arctic fish stocks, environmental awareness may drive precautionary management. Or, on the contrary, limited information may lead to resource exploitation. In this regard, governance will be key in determining how Arctic fisheries develop.

There is a current push for a deep water port in the eastern Arctic. Money has been allotted by the federal government to a port in Iqaluit, which may be in use as early as 2020. Federal funding has also been invested in a small craft harbour in Pond Inlet, and investigations are underway regarding the feasibility of a harbour in Qikiqtarjuaq. This infrastructure is desperately needed to support the growth of Nunavut's fisheries, especially considering how the territorial government has stated that the fisheries are to be a vital pillar in Nunavut's economic development plan (Christie, 2012). The federal government has responded to this plan by not only investing in harbours, but also by providing $7 million in funding in 2015 for research on new and developing fisheries – mainly turbot (Weber, 2015). In addition to expanding the turbot and Arctic char fisheries, there is potential for creating clam, scallop, and crab commercial fisheries (Indigenous and Northern Affairs Canada, 2012; Weber, 2015).

Opinions on the future of eastern Arctic fisheries differ. It is likely that similar to the extension of shipping seasons, fishery seasons will also begin to start earlier and run later. However, some experts believe that development will be slow, and may even experience a decline (Engler & Pelot, 2013). Etienne et al. (2013) project that no increase in traffic will be generated by fishing vessels by 2020. Others suggest that there is a looming commercial fishing moratorium for the eastern Arctic, comparable to what occurred in the Beaufort Sea (Christie, 2012). Still, the government of Nunavut has hope that its fisheries will continue to grow and prosper under careful management and with investment in port and vessel infrastructure.

3.0 METHODOLOGY

In order to assess the current and future vulnerability of Canada's eastern Arctic to the threat of ballast-sourced species invasions a series of analyses were performed. Firstly, a policy analysis was done to identify weaknesses and gaps within Canada's *Ballast Water Control and Management Regulations* (SOR/2011-237). Secondly, a scenario-based risk assessment was completed to describe current and project future risks to eastern Arctic ports. The purpose of this methodology is to investigate whether ballast water management needs to be improved, and if so, how this may be done.

3.1 Policy Analysis

3.1.1 SWOT Analysis

To begin, a SWOT analysis was used to critically assess Canada's *Ballast Water Control and Management Regulations* (SOR/2011-237). Specifically, the Regulation's ability to meet its overall objectives and its capacity for implementation were analyzed.

3.1.2 Matrix Analysis

Next, a matrix analysis was used to assess Canada's Regulations and the IMO Convention in terms of effectiveness and to compare the two documents. It should be noted that the Convention is composed of two sections (articles and regulations) and is accompanied by a set of guidelines, and as a result is much more comprehensive than Canada's Regulations.

During the matrix analysis, selected sections of the document in question were individually analyzed against a set of criteria. In order to assess the theoretical and practical application of the documents, the criteria were organized into four categories (coherence, implementation, ocean governance principles, and objective), which were further broken down into sub-criteria (Box 1).

For Canada's Regulations, only three sections were omitted from analysis (s.1 Interpretation, s.3 Compliance, and s.16 Repeal and Coming into Force), as they could not be effectively analyzed across all criteria due to restrictions in length or content. The IMO Convention was analyzed using two separate matrices: one for the regulations and one for the accompanying guidelines. The Convention articles were not included in this analysis, as the majority the articles were expanded upon in either the regulations or the guidelines. Only nine sections from the regulations portion of the Convention were analyzed using the matrix; the remaining regulations were omitted from the analysis, as they were expanded upon in the guidelines and were therefore indirectly analyzed. All 15 accompanying guidelines were analyzed (Table 4).

A Likert scale from 0-10 was used to describe each section's satisfaction of the criteria, with 10 representing complete fulfillment and 0 representing that the criterion was not met at all. Each section and criteria were weighted equally. The average rank for each section and criterion was calculated, as was the average for each criteria category. From these averages, the overall rank of the Regulations and Convention was calculated. Ranks were divided into groupings: rank values between 0-3 were defined as being "Unacceptable" and were given a "D" grade, rank values between 4-6 were defined as being "Less than Acceptable" and were given a "C" grade, rank values between 7-8 were defined as being "Acceptable" and were given a "B" grade, and ranks between 9-10 were defined as "Excellent" and were assigned an "A" grade. In the case of the IMO Convention, as two separate documents were examined, the rankings were averaged between the guidelines and regulations to come up with a letter grade for each section. The rankings of the regulations and guidelines were weighted equally.

Box 1. Four main categories and sub-criteria used to create policy analysis matrix.

1. Coherence:

- Clear?
  Are the regulations easy to read and comprehend?
- Consistent?
  Do the sections complement each other, or are they contradictory?
- Thorough?
  Do the regulations explain each section adequately? Is the reader left with questions?
- Sensible?
  Do these regulations make sense to readers? Are they logical?

2. Implementation:

- Feasible?
  Do the Regulations make sense in terms of practical application? Are they able to be implemented?
- Enforceable?
  Have they been or are they able to be realistically monitored and enforced?
- Consideration of risk and uncertainty?
  Do they take into account environmental and anthropogenic uncertainty or responsive alternative action?
- Efficient?
  Are actions cost-effective, timely, and sustainable?
- Regionally balanced?
  Do the regulations protect each of Canada's unique freshwater and marine ecosystems equally?

3. Ocean Governance:

- Precautionary principle?
  Do the Regulations err on the side of caution, so as to prevent unknown and harmful impacts?
- Transparency in decision making?
  Are the Regulations easy to read and accessible? Are the motivations behind each section understood?
- Obligation not to cause or transfer environmental harm?
  Do the outlined actions reflect Canada's responsibility to be an environmental steward on a global stage?
- Adaptive management?
  Are the Regulations able to be responsive to changing circumstances?
- International cooperation?
  Are these regulations compatible with international standards as well as neighbouring nation states?
- Science-based?
  Are the Regulations rooted in sound science? Is ongoing research being conducted?

4. Objective:

- Aligned with IMO convention?
  How closely do the Regulations follow the IMO Convention? Do the Regulations fall below or surpass the Convention guidelines?
- Minimize uptake and release of AIS?
  Do the Regulations provide mechanisms to effectively minimize the uptake and release of AIS?
- Remove or render AIS harmless?
  Do the Regulations provide mechanisms to effectively remove or render AIS harmless?
- Limit the Introduction of AIS?
  Is it possible to effectively reduce the introduction of AIS if the Regulations are followed properly?

Table 4. IMO Convention Regulations and Guidelines considered for the matrix analysis

Regulations	**Guidelines**
A-3 *Exceptions*	G1 *Guidelines for Sediment Reception Facilities*
A-4 *Exemptions*	G2 *Guidelines for Ballast Water Sampling*
B-2 *Ballast Water Record Book*	G3 *Guidelines for Ballast Water Management Equivalent Compliance*
B-3 *Ballast Water Management for Ships*	G4 *Guidelines for Ballast Water Management and Development of Ballast Water Management Plans*
C-2 *Warnings Concerning Ballast Water Uptake*	G5 *Guidelines for Ballast Water Reception Facilities*
D-1 *Ballast Water Exchange Standard*	G6 *Guidelines for Ballast Water Exchange*
D-2 *Ballast Water Performance Standard*	G7 *Guidelines for Risk Assessment under Regulation A-4 of the BWM Convention*
D-5 *Review of Standards by Organization*	G8 *Guidelines for Approval of Ballast Water Management Systems*
E-1 *Surveys*	G9 *Procedure for Approval of Ballast Water Management Systems that make use of Active Substances*
	G10 *Guidelines for Approval and Oversight of Prototype Ballast Water Treatment Technology Programmes*
	G11 *Guidelines for Ballast Water Exchange Design and Construction Standards*
	G12 *Guidelines on Design and Construction to Facilitate Sediment Control on Ships*
	G13 *Guidelines for Additional Measures Regarding Ballast Water Management Including Emergency Situations*
	G14 *Guidelines on Designation of Areas for Ballast Water Exchange*
	G15 *Guidelines for Port State Control under the BWM Convention*

3.1.3 Inter-Country Analysis

An inter-country analysis was conducted to compare Canada's Regulations to the policies of the U.S. and Norway. The U.S. was chosen as it is Canada's closest neighbour and their ballast water regulations were developed around the same time as Canada's, but unlike Canada they have not ratified the IMO Convention. Norway was selected because their BWM policy is relatively new and they have ratified the IMO Convention. The same matrix framework as previously introduced was used to aid in the comparison of these three documents.

3.1.4 Stakeholder Analysis

A stakeholder analysis adapted from the International Fund for Agricultural Development (IFAD) (2003) was conducted in order to identify primary, secondary, and tertiary stakeholders. The specific issue that was used to drive this analysis was the increased risk of ballast-sourced AIS introduction in the eastern Arctic as the climate warms and the volume of vessel traffic grows. Primary stakeholders were defined as those whose livelihoods are directly impacted by the issue, while secondary stakeholders are those whose livelihoods are indirectly impacted by the issue. Finally, tertiary stakeholders are those who simply have an interest in or influence over the issue. Specifically, this analysis was used to describe the different stakeholder's nature of interest in the issue and their level of power, and how the issue is expected to impact each stakeholder group.

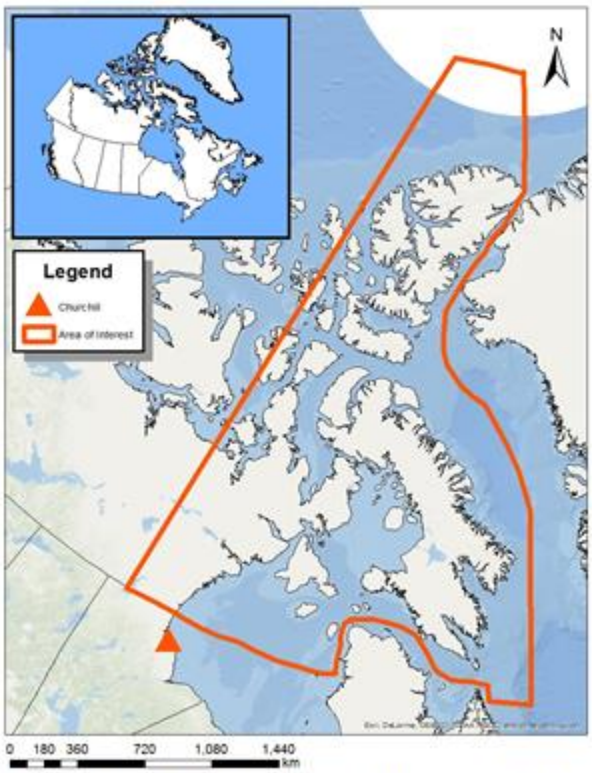


Figure 2. Boundary of the Area of Interest, including the port of Churchill

3.2 Risk Assessment

3.2.1 Study Location

The Area of Interest (AOI) was the eastern Canadian Arctic, specifically the territory of Nunavut within the region encompassing 60ºN to 85ºN, and 60ºW to 100ºW (Figure 2). Additionally, the port of Churchill was included in this analysis. Only vessel traffic data within this area were considered for the assessment.

3.2.2 Risk Assessment

Addressing risk comprises three main components: risk assessment, risk management, and risk communication. This report will focus upon risk assessment, which involves the assignment of probabilities and consequences to the effect of an activity or event. Risk assessment may be used to characterize the likelihood of species introduction, establishment, and spread, as well as the severity of associated impacts. By doing so, risk assessments may help inform decisions regarding vectors of introduction, allocation of managerial resources, and methods of control (Andersen et al., 2004; Underschultz, 2007).

Risk assessments regarding species invasions typically begin by stating the specific problem and nature of the assessment and identifying sources of risk by examining species ecology (if applicable) and pathways of introduction. In this case, the specific problem is the increasing risk of aquatic species invasions in the eastern Canadian Arctic given a warming climate and increased vessel traffic, with the source of risk being ballast water (Underschultz, 2007). The final overall risk level comes from combining the probability and consequence values.

DFO is the federal lead for AIS management, and is therefore responsible for conducting related risk assessments. The Centre of Expertise for Aquatic Risk Assessment (CEARA) was formed by DFO for the ultimate purpose of estimating the risk presented by AIS to various components of Canada's aquatic ecosystems. This risk assessment model used in this report was partially based off of the National Detailed-Level Risk Assessment Guidelines provided by CEARA. However, it should be noted that these Guidelines are mainly aimed towards species-specific risk assessment, and as a result their approach was modified. For example, only the stages of introduction and establishment were considered for this assessment, with introduction representing the probability component of the risk equation, and establishment the consequence.

It should also be noted that no single invasion model has been universally adopted. For the purpose of this paper, ballast-sourced invasions were presumed to occur in three stages (introduction, establishment, and impact) and six sub-stages (uptake, transfer, release, colonization, spread, and impact) (Figure 3). Again, only the first two stages and four sub-stages were included in the assessment as it is difficult to quantify later steps in a vector-based risk assessment approach.

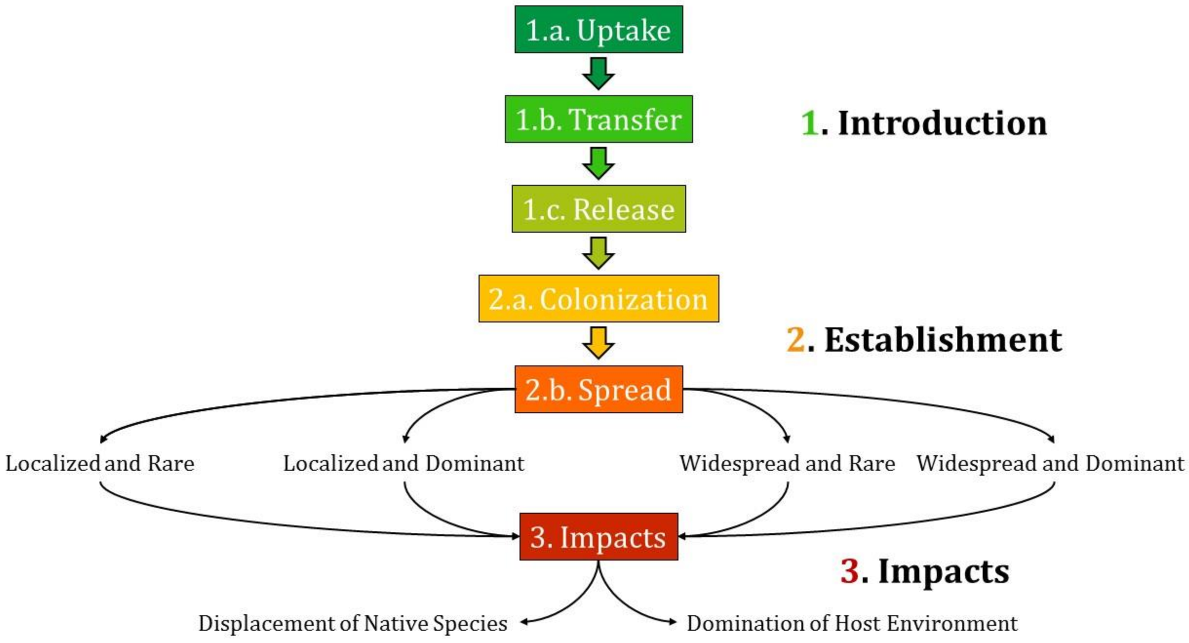


Figure 3. Stages of invasion relevant to this paper

In this assessment, a series of factors were used to describe the relationship between ballast water and both the introduction and establishment stages. Probability of introduction (P_I) was expressed as a product of uptake (P_U), transfer (P_T), and release (P_R) events, while consequence of establishment (C_E) was considered to be a product of survival (C_S) and colonization (C_C). Further, P_U is dependent upon whether uptake of ballast occurs, how much ballast is taken up, and the nature of the species composition of the source port; for example, ports with low species abundance and diversity will have a lower probability of NIS uptake. P_T is a product of whether or not ballast water management occurs, and the "age" of the ballast water, as the likelihood of NIS survival decreases with voyage length (Verna et al., 2016). P_R is effected by whether discharge of ballast water occurs, and the amount of ballast water that is being released, as the greater the volume released the greater the chance that NIS will be discharged. C_S depends upon the degree of environmental similarity between the source and destination ports, as well as the estimated propagule pressure of the ballast water; the more species rich the source port is, the greater the number of individuals of a species released during a discharge event, thus increasing the consequence of a population of a species establishing (Lockwood et al., 2009). Finally, C_C is a product of the number of known AIS from the source port and the estimated colonization pressure of the ballast water. If a source port is known to host many AIS, it suggests that NIS taken up at this port may able to establish in other donor ports given the opportunity (Ware et al., 2014). In regards to colonization pressure, the greater the diversity of the source port, the greater the likelihood that a species will be introduced that is able to establish (Lockwood et al., 2009) (Figure 4).

RISK = PROBABILITY X CONSEQUENCE
PROBABILITY OF INTRODUCTION = **PINTRODUCTION**
CONSEQUENCE OF ESTABLISHMENT = **CESTABLISHMENT**

RISK = PINTRODUCTION X CESTABLISHMENT

PINTRODUCTION = PUPTAKE X PTRANSFER X PRELEASE
PUPTAKE = UPTAKE EVENT X AMOUNT TAKEN UP X SPECIES COMPOSITION
PTRANSFER = MANAGEMENT EVENT X BALLAST AGE
PRELEASE = DISCHARGE EVENT X AMOUNT DISCHARGED

CESTABLISHMENT = CSURVIVAL X CCOLONIZATION
CSURVIVAL = ENVIRONMENTAL DISTANCE X PROPAGULE PRESSURE
CCOLONIZATION = KNOWN AIS X COLONIZATION PRESSURE

Figure 4. Risk model equation used for this assessment

All values entered into the model formula were first converted into ranks. All ranks for variables excepting uptake, management, and discharge events ranged from one to five, and were assigned by finding the greatest value for each variable and dividing it into five equal bins (Appendix 2). Ranking designation for the excepted events will be explained later.

Using Automatic Identification System ship monitoring data, the top three most visited Arctic ports within the AOI in the year 2015 were identified. From this data as well as information obtained from DFO synthesizing ballast reporting forms, an account of vessel activity was compiled for each port, taking into consideration the vessel names and types which stopped there, their estimated time of arrival, and port history of each vessel for up to two months. However, unless information was available on ballast water source location, only the ports visited immediately before the destination ports were considered in this assessment. The number of stops, vessels, and vessel types, and the months during which vessels arrived were analyzed. Using

Hadley Centre Global Sea Ice and Sea Surface Temperature (HadISST) and NOAA World Ocean Database data, the average sea surface temperature (SST) and sea surface salinity (SSS) were found for each destination port and origin port (Appendix 3).

Following this preliminary analysis, it was concluded that only merchant vessels would be considered for the risk assessment (bulk carriers, cargo ships, oil tankers), as they are the only types of vessels found to regularly discharge ballast within the AOI. Additionally, only ports where ballast discharge events occurred were included; these ports were found to be Milne Inlet and Churchill. The voyages which fit these criteria were then codified (Table 5). The voyages to each port of interest were codified based on the specific destination port and chronological order of arrival; for example, the first vessel to visit Milne Inlet in 2015 is referred to as M1, while the first vessel to visit Churchill is C2.

Table 5. Codified list of voyages considered for assessment. "M" signifies vessels travelling to Milne Inlet, while "C" signifies vessels destined for Churchill.

Code	Vessel Type	Origin	Destination
M1	Bulk Carrier	Iskenderun	Milne Inlet
M2	Bulk Carrier	Willhelmshaven	Milne Inlet
M3	Bulk Carrier	Immingham	Milne Inlet
M4	Bulk Carrier	Tuzla	Milne Inlet
M5	Bulk Carrier	Port Talbot	Milne Inlet
M6	Bulk Carrier	San Ciprian	Milne Inlet
M7	Bulk Carrier	Dunkirk	Milne Inlet
M8	Bulk Carrier	Dunkirk	Milne Inlet
M9	General Cargo	Ile-Aux-Coudres	Milne Inlet
M10	General Cargo	Iqaluit	Milne Inlet
M11	Bulk Carrier	Ijmuiden	Milne Inlet
M12	Bulk Carrier	Rotterdam	Milne Inlet
M13	Bulk Carrier	Aughinish	Milne Inlet
M14	General Cargo	Arctic Bay	Milne Inlet
M15	Oil Tanker	Ste. Catherine	Milne Inlet
M16	Bulk Carrier	Bremen	Milne Inlet
M17	Bulk Carrier	Gijon	Milne Inlet
C1	General Cargo	Arviat	Churchill
C2	General Cargo	Hall Beach	Churchill
C3	Bulk Carrier	Oran	Churchill
C4	Bulk Carrier	Baltimore	Churchill
C5	Bulk Carrier	Ghent	Churchill
C6	Bulk Carrier	Rankin Inlet	Churchill
C7	General Cargo	Casablanca	Churchill
C8	Bulk Carrier	Setubal	Churchill

3.2.3 Current Risk Assessment

3.2.3.A Probability of Introduction

Once the northern destination ports were chosen and the origin ports were identified, the probability of introduction for each vessel trip was assessed. First, based upon the vessel type and activity it was determined whether or not ballast water would be taken up at the origin port. If it was determined that no ballast would be taken on, this vessel trip was assigned a zero for P_U and was not further considered for assessment. If uptake was determined to occur, that port was considered to be a source port and the vessel trip was assigned a value of one. The amount of ballast water uptake was estimated based upon the deadweight tonnage (DWT) of the vessel in question, as for tankers the ballast capacity is typically 40% of the DWT and 20% of the DWT for general cargo vessels (David, 2015). The amount of ballast water uptake was assumed to be the entire ballast capacity for the sake of consistency. The species diversity of the source port was estimated based upon it's latitudinal coordinates and average SST, as marine species diversity is thought to have some correlation with latitude and temperature (Paul et al., 2016; Tittensor et al., 2010). The species richness of a port was estimated based upon a study done by Tittensor et al. (2010) on global marine species richness. The species diversity and richness ranks were averaged to describe the species composition of the source port.

It was assumed that all international voyages underwent BWM in the form of a mid-ocean exchange, and that coastal vessels did not undergo any form of management between the source and destination ports. For voyages where no management was determined to occur, the value of one was given for a management event. When deballasting, it is common for about 5-10% of the ballast water to remain onboard as residual, though sometimes this amount can be as high as 15% (Transport Canada, 2010). This was taken into account by applying a correction factor of 0.1 to correspond to a 90% effectiveness rate for voyages which underwent BWE from saline ports.

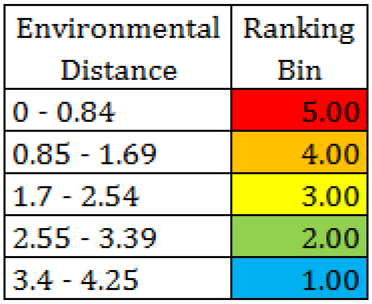
However, for voyages which underwent BWE from freshwater ports a correction factor of 0.01 was given to correspond to the associated 99% effectiveness rate of mid-ocean exchange at elimination freshwater organisms (Chan et al., 2013). Ballast water age was calculated from the date reported for ballast uptake and vessel arrival; if this information was not available, the age of ballast water was determined using the estimated arrival dates at source and destination ports from the Automatic Identification System data. It should be noted that these estimations are unlikely to be completely accurate, however no alternative means of prediction were possible.

If ballast reporting form data was not available for specific vessels which were expected to have taken up ballast water at the previous port of call and loaded cargo at a destination port, it was assumed that ballast water was discharged at the destination port. Therefore, those voyages were assigned a value of one for a discharge event. In such cases where discharge volumes were unavailable, the amount of ballast water discharged was assumed to be 33% of the amount of cargo loaded or 80% of the ship's DWT (David, 2015).

3.2.3.B Consequence of Establishment

Next, the consequence of establishment for each voyage was quantified. The standardized Euclidean distance between each destination and source port was calculated to describe the environmental similarity between ports, with a higher degree of environmental similarity corresponding to a greater consequence of establishment. SST and SSS were the variables used to determine environmental similarity, with equal weight given to both variables. In order to sort Euclidean distance into ranking bins, the greatest distance between any source port and an eastern Arctic port of interest was calculated and considered the maximum distance. This was found to be between Tuzla and Pond Inlet, with a value of 4.25. From this value, five equal ranking bins were created (Figure 5). Species diversity estimations were once again used to express propagation pressure.

The number of known AIS at each source port was estimated using regional information from a study done by Molnar et al. (2008). Species richness estimations were also used again to express colonization pressure.



Environmental Distance	Ranking Bin
0 - 0.84	5.00
0.85 - 1.69	4.00
1.7 - 2.54	3.00
2.55 - 3.39	2.00
3.4 - 4.25	1.00

Figure 5. Ranking scheme of environmental distances between source and destination ports

3.2.3.C Current Risk Calculation

The probability of introduction and consequence of establishment values for each voyage were multiplied to find the final risk value.

3.2.4 Projected Risk Assessment

In response to uncertainty surrounding the future status of both Milne Inlet and the port of Churchill, future forecasting represents the hypothetical situation that both ports will be operating in the years 2055 and 2105 at the same level they were in 2015. This is important to mention, as the port of Churchill has ceased operations as of August, 2016. Additionally, the project life expectancy of the Baffinland iron ore mine is less than 30 years, meaning that in 2055 or 2105 bulk carriers may not be operating in Milne Inlet and the volume of ballast discharge may be substantially reduced. However, the mine may be open past the expected life span due to the magnitude of the iron ore deposit (M. Zurowski, personal communication, October 25, 2016). Alternatively, it is also possible that Baffinland will be shipping the majority of its resources out of another port in 2055 instead of Milne Inlet.

A conservative approach was taken in regards to estimating the future *volume* of vessel traffic in these ports. The volume of vessel traffic for the years 2055 and 2105 were not adjusted from 2015 levels for two main reasons. Firstly, the volume of vessel traffic is largely a factor of the destination port capacity. For example, although the production at Baffinland may allow for more iron ore to be extracted over a shorter period of time, the frequency of export is limited by the port infrastructure of Milne Inlet (M. Zurowski, personal communication, October 25, 2016). Therefore, unless improvements are made to the port itself, it is not likely that the volume of vessels arriving at the port will increase significantly. Secondly, it is uncertain how climate change will impact the navigability of the eastern Arctic. Many studies assert that contrary to popular belief, warming temperatures will make Arctic shipping more complicated and hazardous due to drifting multi-year ice and unpredictable conditions (Engler & Pelot, 2013; Stephenson et al., 2013). Although conditions may be more favourable by 2105, it is possible that the shipping season length and vessel volumes may not have changed much by 2055. This factor also impacted the forecasting of ballast age, as it is uncertain how the navigability of the eastern Arctic will impact voyage length; as a result, the estimates of ballast age for 2055 and 2105 were left consistent with 2015 values.

Under these assumptions, a projected risk assessment was done for the years 2055 and 2105 at Milne Inlet and Churchill under a “Business as Usual” scenario and an “Improved Management Framework” scenario.

Steps for calculating the probability of introduction and consequence of establishment were repeated for the future assessment. The uptake events, amount of ballast taken up, ballast age, discharge events, and amount of ballast discharged for each voyage were not altered. The species richness and amount of known AIS from the source port were also left unchanged, however this was due to lack of reliable forecasts regarding these variables. Finally, the species diversity and environmental distance were adjusted using forecasted SST and SSS measures and observed rates of physical environmental change (Appendix 4) (Belkin, 2009; Jeffries et al., 2015).

For the Business as Usual risk scenario, the management events were left unchanged. For the Improved Management Framework scenario, it was assumed that BWT would be the primary form of management, and a conservative correction factor of 0.01 was applied to international voyages, as BWT should effectively treat 99.9% of NIS in ballast tanks (M. Zurowski, personal communication, October 25, 2016). However, coastal vessels were assumed to continue to not undergo any form of management.

3.2.5 Final Risk Assessment

Once all introduction and establishment probabilities and overall risk values were calculated for all the voyages to Churchill and Milne Inlet for all of the scenarios (five in total), all final values were compiled and standardized. The highest probability of introduction, highest probability of establishment, and highest resulting risk value scores were considered the maximum values for the formation of the P_I, C_E, and overall risk bins respectively.

Five risk matrices were created to illustrate each scenario, with introduction being considered the probability and establishment the consequence. The average risk value for each port during each scenario was calculated, as was the cumulative risk. Finally, a series of two sample t-tests assuming unequal variances ($\alpha = 0.05$) were run in order to determine if there were significant differences in the risk level of a port between time periods as well as management regimes.

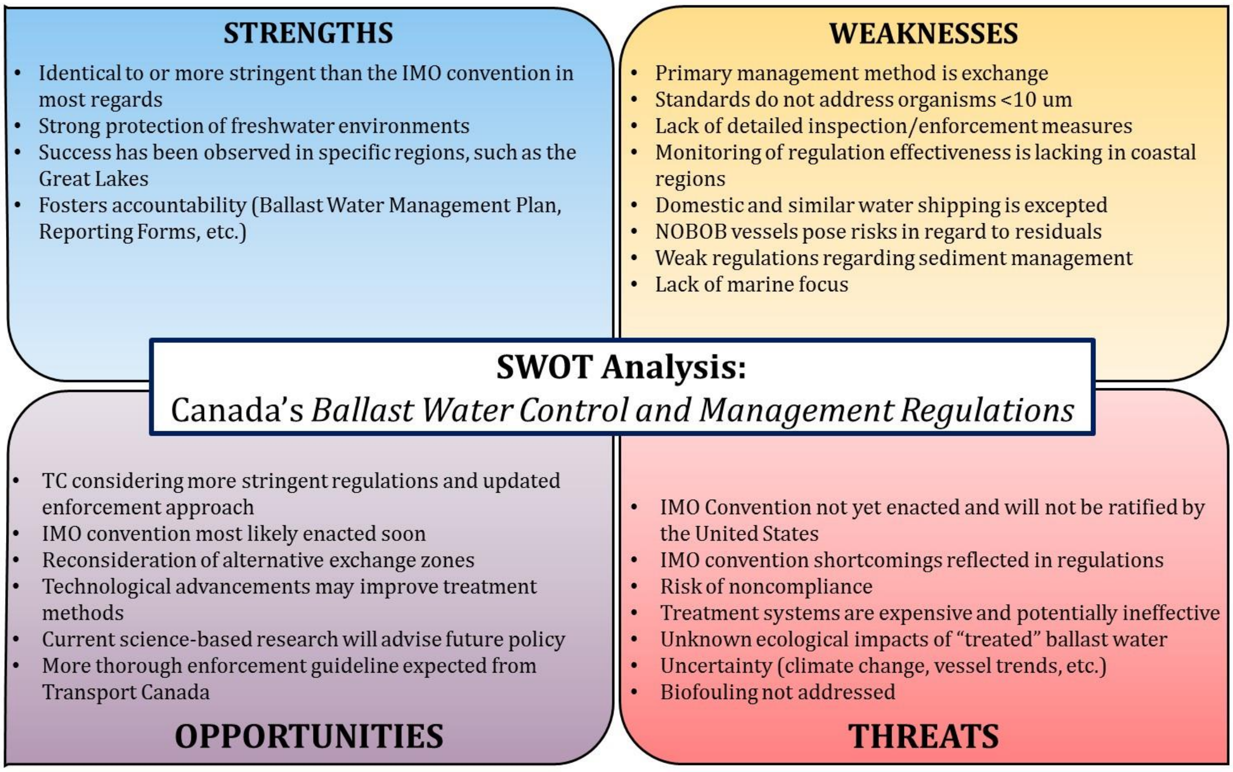
4.0 RESULTS

4.1 Policy Analysis

4.1.1 SWOT

From the SWOT analysis, it was found that many strengths and opportunities exist within Canada's Regulations, but they are countered by a number of weaknesses and threats (Figure 6).

As a result, the ability of Canada's policy to meet its overall objectives of minimizing the uptake and release of non-indigenous aquatic species or alternatively removing or rendering them harmless is compromised.



SWOT Analysis:
Canada's *Ballast Water Control and Management Regulations*

STRENGTHS

- Identical to or more stringent than the IMO convention in most regards
- Strong protection of freshwater environments
- Success has been observed in specific regions, such as the Great Lakes
- Fosters accountability (Ballast Water Management Plan, Reporting Forms, etc.)

WEAKNESSES

- Primary management method is exchange
- Standards do not address organisms <10 um
- Lack of detailed inspection/enforcement measures
- Monitoring of regulation effectiveness is lacking in coastal regions
- Domestic and similar water shipping is excepted
- NOBOB vessels pose risks in regard to residuals
- Weak regulations regarding sediment management
- Lack of marine focus

OPPORTUNITIES

- TC considering more stringent regulations and updated enforcement approach
- IMO convention most likely enacted soon
- Reconsideration of alternative exchange zones
- Technological advancements may improve treatment methods
- Current science-based research will advise future policy
- More thorough enforcement guideline expected from Transport Canada

THREATS

- IMO Convention not yet enacted and will not be ratified by the United States
- IMO convention shortcomings reflected in regulations
- Risk of noncompliance
- Treatment systems are expensive and potentially ineffective
- Unknown ecological impacts of "treated" ballast water
- Uncertainty (climate change, vessel trends, etc.)
- Biofouling not addressed

Figure 6. SWOT Analysis of Canada's Ballast Control and Management Regulations (SOR/2011-237)

The strengths of Canada's Regulations lie in its close alignment with the IMO Convention, stringent BWE requirements, strong protective measures regarding freshwater ports and environments, and fostering of accountability among ship operators through the required provision of various documents. However, the Regulations effectiveness at achieving objectives are weakened by the lack of attention placed on BWT as a means of management, unclear enforcement and monitoring measures, exceptions for various vessels (such as domestic vessels), inconsistent requirements regarding sediment management, and regional imbalances leaving some areas less protected than others from the threat of ballast-mediated AIS. Additionally, neither Canada nor the U.S. has approved any BWT systems.

Opportunities for improvement lie mainly in Transport Canada's wish to introduce more stringent regulations, the enforcement of the IMO Convention in September of 2017, and the continuing advances in technology and research. The effectiveness of Canada's Regulations may be threatened by the fact that the U.S. shows no interest in ratifying the IMO Convention and have enacted their own considerably different BWM requirements. In addition, non-compliance may also be an area of potential threat. Costs, difficulties of installation in existing vessels, issues meeting performance standards, and other inherent challenges associated with treatment systems may also prove to be a major obstacle for the future improvement of Canada's BWM, and this could be further complicated by predicted climate changes.

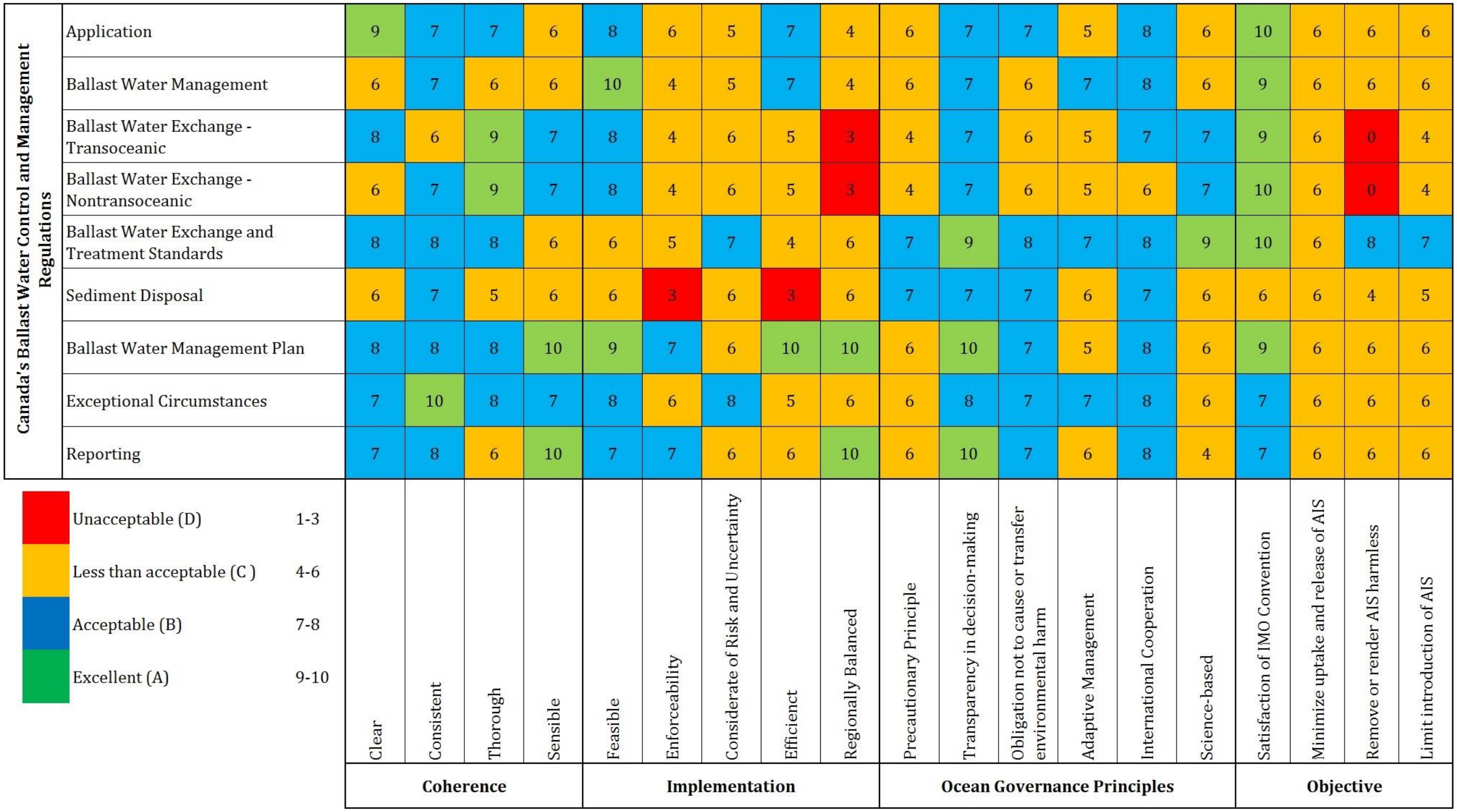
4.1.2 Matrix Analysis

In the matrix analysis of Canada's Regulations, the most common ranking was "Less than Acceptable", representing 48.5% (n=83 of the cells) of the results. "Acceptable" was the second most common, representing 36% (n=61). "Excellent" values were assigned to 12% (n=21), and "Unacceptable" rankings represented only 3.5% of the results (n=6) (Figure 7).

The Regulations were assigned an overall grade of C (Table 6). The coherence of the regulations was found to be acceptable, scoring a B grade (average ranking of 7.3). Though the regulations were quite consistent throughout the document, some sections were vague and lacked clarity. Actual implementation of the regulations was given a C- grade (average ranking of 6.1). It was found that though many of the sections were acceptably feasible and thus able to be implemented, enforcement measures were either lacking or challenging to apply, and lack of focus on geographical balance left many regions exposed to heightened risk. The regulations scored a

C+ in terms of meeting the selected Ocean Governance Principles. The regulations both rely upon and effectively incorporate aspects of international cooperation and are commended for their overall emphasis on transparency; however, the precautionary principle has not been applied effectively and more adaptive management strategies must be integrated. Finally, the overall ability of the regulations to meet the objectives scored a C- (average ranking of 6.2). Despite close alignment with the IMO Convention guidelines, the Regulations provide many exceptions which impact the minimization of contaminated ballast water release, and fail to focus on removing or rendering ballast-sourced AIS harmless. These flaws impact the overall effectiveness of reducing the introduction and establishment of AIS. It should be noted that if the objective criteria of alignment with the IMO Convention was removed, then the objective grade would change to a D (average ranking of 5.4), and the overall grade would change to a C- (average ranking of 6.4).

In the matrix analysis of the IMO Convention, the most common ranking was “Acceptable” (7-8), representing 46.2% of the results. “Less than Acceptable” was the second most common, representing 29.5%. “Excellent” values were assigned to 20% of the cells, and “Unacceptable” rankings represented only 4.3% of the results (Appendix 4).



Canada's Ballast Water Control and Management Regulations	Coherence				Implementation					Ocean Governance Principles						Objective			
	Clear	Consistent	Thorough	Sensible	Feasible	Enforceability	Considerate of Risk and Uncertainty	Efficient	Regionally Balanced	Precautionary Principle	Transparency in decision-making	Obligation not to cause or transfer environmental harm	Adaptive Management	International Cooperation	Science-based	Satisfaction of IMO Convention	Minimize uptake and release of AIS	Remove or render AIS harmless	Limit introduction of AIS
Application	9	7	7	6	8	6	5	7	4	6	7	7	5	8	6	10	6	6	6
Ballast Water Management	6	7	6	6	10	4	5	7	4	6	7	6	7	8	6	9	6	6	6
Ballast Water Exchange - Transoceanic	8	6	9	7	8	4	6	5	3	4	7	6	5	7	7	9	6	0	4
Ballast Water Exchange - Nontransoceanic	6	7	9	7	8	4	6	5	3	4	7	6	5	6	7	10	6	0	4
Ballast Water Exchange and Treatment Standards	8	8	8	6	6	5	7	4	6	7	9	8	7	8	9	10	6	8	7
Sediment Disposal	6	7	5	6	6	3	6	3	6	7	7	7	6	7	6	6	6	4	5
Ballast Water Management Plan	8	8	8	10	9	7	6	10	10	6	10	7	5	8	6	9	6	6	6
Exceptional Circumstances	7	10	8	7	8	6	8	5	6	6	8	7	7	8	6	7	6	6	6
Reporting	7	8	6	10	7	7	6	6	10	6	10	7	6	8	4	7	6	6	6

🟥	Unacceptable (D)	1-3
🟨	Less than acceptable (C)	4-6
🟦	Acceptable (B)	7-8
🟩	Excellent (A)	9-10

Figure 7. Matrix analysis of Canada's *Ballast Water Control and Management Regulations* (SOR/2011-237)

Table 6. Canada’s Regulations report card

	Average Ranking	Grade
Coherence	7.3	**B**
Clear	7.2	
Consistent	7.6	
Thorough	7.3	
Sensible	7.2	
Implementation	6.1	**C-**
Feasible	7.8	
Enforceability	4.8	
Considerate of Risk & Uncertainty	6.1	
Efficient	6.1	
Regionally Balanced	5.7	
Ocean Governance Principles	6.7	**C+**
Precautionary Principle	5.8	
Transparency in Decision Making	8.0	
Obligation Not to Cause or Transfer Harm	6.8	
Adaptive Management	5.9	
International Cooperation	7.6	
Science-based	6.3	
Objective	6.2	**C-**
Satisfaction of IMO Convention	8.6	
Minimize AIS Uptake & Release	6.0	
Remove or Render AIS Harmless	4.7	
Reduce AIS Introduction & Establishment	5.6	
Overall Grade	6.6	**C**

The Convention was assigned an overall grade of B- (Table 7). It was found that the overall coherence of the document was strong, and the regulations and guidelines were quite consistent with each other and the articles; as a result, the coherence of the Convention scored a B+. However, overall implementation of the convention is impacted by the inability to effectively enforce regulations. Additionally, efficiency of management processes and balance of environmental protection was found to be lacking. The implementation category of the Convention scored a C. Most of the selected ocean governance principles were satisfied, and a clear emphasis was placed upon providing transparency in decision making. This category was assigned a B+, but could be improved upon in future by ensuring that all aspects are created to be precautionary and adaptive. Unfortunately, the weakest part of the convention is the achievement of the overall objectives to ultimately reduce the threat of AIS introduction and establishment, which scored a weak D+. Specifically, few of the regulations and guidelines place an adequate focus on the removal or destruction of AIS.

Exceptions to the convention weaken the overall document as they compromise the attainment of the objectives and lack a precautionary nature. The BWE standard regulation (D-1) and the Guidelines for Ballast Water Exchange Design and Construction Standards (G11) were also identified as issues, as they are difficult to enforce and they do not address the removal or destruction of AIS at all. However, the ballast water performance standards (D-2) are applauded as being transparent and science-based with a clear commitment to not causing or transferring environmental harm. The guidelines and procedures for approving BWM systems (G8, G9) were also found to be quite science-based and adaptive, resulting in the potential for an effective reduction in the introduction of AIS.

Table 7. The IMO Convention Report Card

	Average Ranking	**Grade**
Coherence	7.7	**B+**
Clarity Consistency Thoroughness Sensibility	7.3 8.7 7.5 7.3	
Implementation	6.6	**C**
Feasibility Enforceability Consideration of Risk & Uncertainty Efficiency Balance	7.1 5.6 7.7 6.2 6.5	
Ocean Governance Principles	7.7	**B+**
Precautionary Principle Transparency in Decision Making Obligation Not to Cause or Transfer Harm Adaptive Management International Cooperation Science-based	7.2 8.4 7.8 7.2 7.9 7.7	
Objective	5.7	**D+**
Minimize AIS Uptake & Release Remove or Render AIS Harmless Reduce AIS Introduction & Establishment	6.7 4.3 6.1	
Overall Grade	7.1	**B-**

4.1.3 Inter-Country Analysis

It appears that the development of BWM is occurring at the same pace in Canada and the U.S., as well as internationally. However, Norway's regulations are much newer and this is reflected in the evolution of the country's policy in comparison with Canada and the U.S. (Figure 8).

In terms of accessibility, it was found that the U.S. regulations regarding BWM were challenging to find and that the legislative structure and process was difficult to comprehend. This was especially true when comparing the U.S. to Norway and Canada, as both of these countries BWM regulations were readily accessible and clear. In regards to content, all countries have the same basic regulations for the most part, though the U.S. has much more onerous requirements. Other small details differ between the U.S. regulations and countries which have ratified the IMO Convention. For example, while the Convention lays out standards which apply to "viable" organisms, the U.S. standards pertain to "living" organisms. Excluding this variation, the discharge standards of the U.S. and Convention are identical. However, the means possible to achieve these standards differ across countries. Canada and Norway allow BWMS which treat ballast water with active substances to be used, so long as these systems have been approved using the IMO-developed testing procedure. Alternatively, the U.S. only allows BWMS which use active substances if the sale and distribution of said substance is authorized under the Federal Insecticide, Fungicide and Rodenticide Act (46 CFR Part 162, Subpart 162.060-32).

All analyzed countries' regulations were deemed adequately coherent. However, unique gaps in each country's policy inhibited effective implementation of the regulations. The U.S.'s BWM requirements and implementation schedule were found to be unrealistic due to the lack of available BWMS technology. Additionally, there is very little mention in the U.S. regulations of how ballast sediment should be managed, and exempted vessels and discharge allowances in exceptional circumstances leave the U.S. marine environment vulnerable to AIS. However, unlike Canada or Norway, the U.S. actually provides basic enforcement, compliance, and penalty guidelines. It was found that all three countries struggle to effectively meet the outlined objectives of minimizing the uptake and release of AIS, and removing or rendering AIS harmless in order to limit introduction. Norway and Canada specifically fall short in meeting these objectives due to the heavy reliance placed upon BWE as a primary means of management. Although the U.S. places a greater focus on moving towards BWT, no type-approved BWMS exist. This means that either AMS is allowed or exemptions are granted; exemptions do little to protect the marine environment, and as AMS technology is only approved for five years after the scheduled implementation date, vessels will have to partake in multiple costly and time-consuming management system installations over a short time.

Ultimately, the U.S. was found to be closer at meeting objectives than Canada or Norway, as the U.S. has placed a stronger focus on removing or rendering AIS harmless rather than simply minimizing their uptake and release. However, unrealistic timelines and rigid requirements threaten both the effectiveness and adaptiveness of the U.S. regulations. Norway ranked comparatively low in terms of implementation and objectives, though the intention to address ocean governance principles was clear. It is concluded that in terms of effectiveness, Canada sits somewhere between the U.S. and Norway (Table 8).

It should be noted that the U.S. regulations are already in force, while the IMO Convention has yet to be enacted, thus potentially impacting the effectiveness of Norway and Canada's policies. Further, Norway has a relatively new BWM policy; it is a short document, with few additional measures that extend beyond IMO’s requirements. Though clearly and concisely written, there appears to be a considerable amount left out.

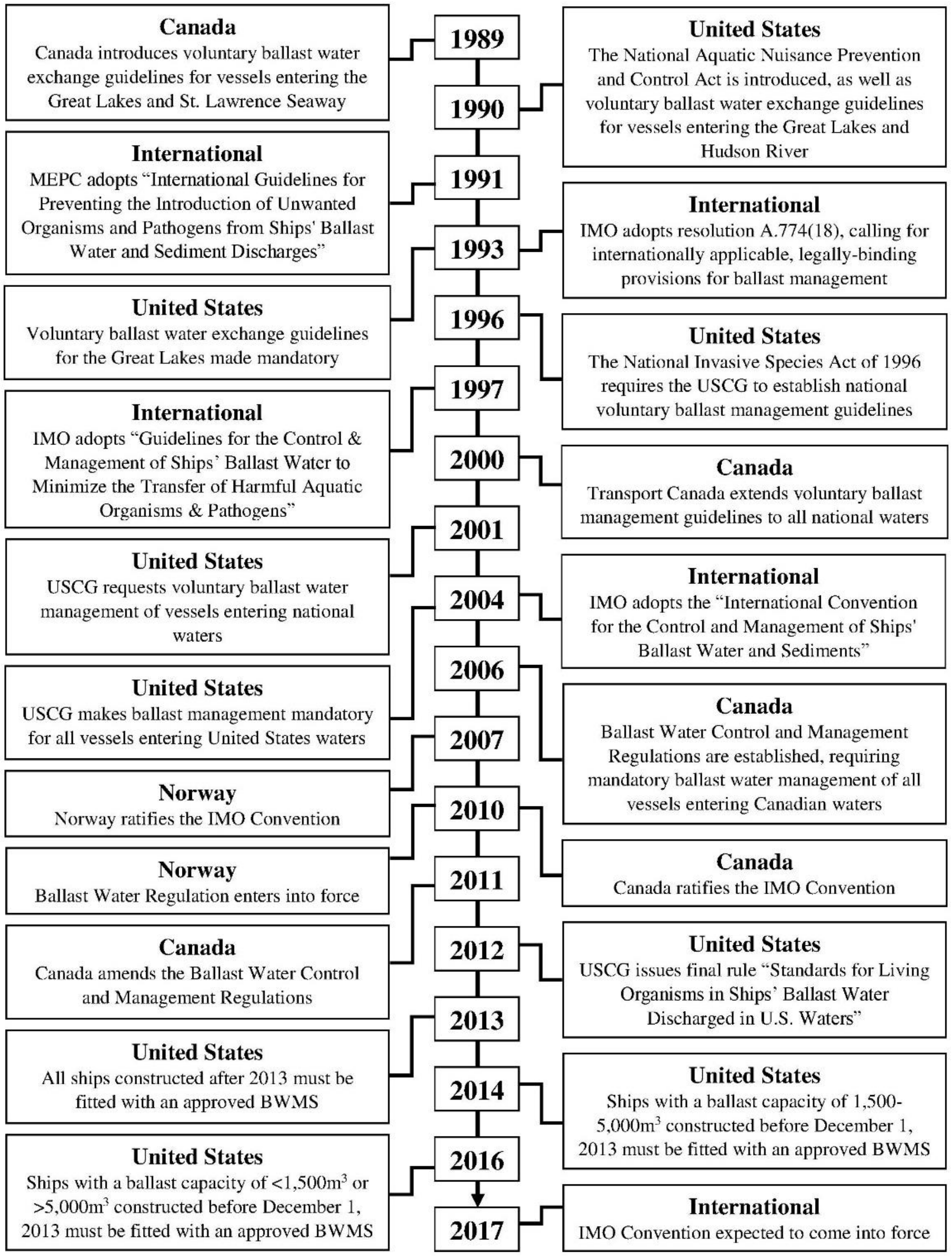


Figure 8. Timeline of the evolution of Canada’s, the U.S.’s, Norway’s, and International policy regarding ballast water management

Table 8. Inter-country comparison of BWM legislation (Lloyd's Register, 2014).

	Canada	**United States**	**Norway**
Authority	Transport Canada	USCG	Norwegian Maritime Directorate
Enforcement Date	2006	2012	2010
Affected Vessels	All Canadian vessels everywhere and foreign vessels in Canadian waters designed to carry ballast water. Exempted vessels include: - Vessels on location and engaged in drilling for, producing, conserving, or processing oil or gas - Vessels operating exclusively in Canadian waters - Vessels operating in the similar waters of the United States Great Lakes Basin or the French waters of Saint Pierre and Miquelon - Vessels operating in areas of exclusive operation - Vessels engaged in search and rescue operations that are less than 50 m in length and have a maximum ballast water capacity of 8 m^3 - Pleasure crafts that are less than 50 m in length and have a maximum ballast water capacity of 8 m^3 - Vessels that carry permanent ballast water in sealed tanks - Vessels owned or operated by a state and used only in government non-commercial service.	All non-recreational U.S. and foreign vessels equipped with ballast tanks operating in U.S. waters Vessels exempted from all requirements include: - Department of Defense, Armed Forces, and Coast Guard vessels - Warship, naval auxiliary, or other foreign state government non-commercial vessels Vessels exempted from management requirements, reporting and recordkeeping include: - Crude oil tankers engaged in coastwise trade Vessels exempted from management requirements and recordkeeping include: - Vessels operating exclusively between ports or places within a single COTP Zone Exemptions from management requirements cover: - Seagoing vessels operating in more than a single COTP Zone, not operating outside the EEZ, and are ≤1,600 gross register tons or equal to 3000 gross tons - Non-seagoing vessels - Vessels operating in more than a single COPT Zone that take on and discharge ballast water exclusively in a single COTP Zone	All ships in Norwegian territorial waters and EEZ constructed to carry ballast water, including submersible vessels and mobile offshore units. Exempted vessels include: - Ships trading exclusively in Norwegian territorial waters and EEZ - Ships with permanent ballast water in sealed tanks - Crafts of less than 50 m in length with a maximum ballast capacity of 8 m^3 used solely for recreation, competition, or search and rescue. However, these crafts shall exchange ballast water outside port waters and as far from the coast as possible.
Management Methods	1. Ballast water exchange 200 nm from shore in an area at least 2,000 m deep for transoceanic vessels, or 50 nm from shore in an area at least 500 m deep for non-transoceanic vessels. Designated alternate exchange areas may be used if needed. 2. Ballast water treatment 3. Transfer of ballast water or sediment to a reception facility 4. Retention of ballast water onboard	1. Install and operate an approved BWMS by the scheduled implementation date 2. Use only water from a U.S. public water system 3. Perform complete ballast water exchange 200 nm from shore before discharging ballast water into U.S. waters 4. Do not discharge ballast water into U.S. waters 5. Discharge to a facility onshore or another vessel Additionally, all vessels must: - Clean ballast tanks regularly to remove sediments - Discharge only minimal amount of ballast water essential for operation while in U.S. waters	1. Exchange untreated ballast water 200 nm from shore in an area at least 200 m deep. If not possible, then 200 nm from shore in an area at least 50 m deep. Alternate exchange areas are provided. At the very least, exchange must occur outside of Norwegian territorial waters 2. Ballast water treatment with technology approved in accordance with the IMO guidelines 3. Ballast water discharge to a reception facility The Norwegian Maritime Authority may impose more stringent ballast water management regulations

		• Rinse anchors and anchor chains upon retrieval • Remove fouling organisms from vessel regularly • Train all personnel involved on ballast water management procedures • When discharging to a reception facility, discharge only to facilities with an NPDES permit	under special circumstances with an increased risk of AIS introduction.
Uptake Control	Not mentioned	Vessels are required to avoid discharging or uptaking ballast water in areas within marine sanctuaries, marine preserves, marine parks, or coral reefs. Additionally, vessels must minimize uptaking ballast water in the following areas: • Areas known to have populations of harmful organisms or pathogens • Areas near sewage outfalls • Areas where tidal flushing is poor at times, or when a tidal stream is turbid • In darkness • Where propellers may stir up the sediment • Areas with pods of whales, convergence zones, and boundaries of major currents	Ships discharging ballast water that was taken onboard from outside a given region or from another area within a given region than the area in which it is to be discharged shall manage water through one of the three options outlined.
Standards	Ballast water exchange must achieve at least 95% volumetric exchange and a salinity of 30 ppt. For flow-through tanks, three times the volume of each tank is required. Treated ballast water must attain a viable organism & indicator microbe content less than • 10 viable organisms per cubic metre, for organisms with a minimum dimension ≥ 50 u • 10 viable organisms per mL, for organisms with a minimum dimension ≥ 10 u but < 50 u • One cfu of toxicogenic *Vibrio cholera* (O1 and O139) per 100 mL or one cfu of that microbe per gram (wet weight) of zooplankton samples • 250 cfu of *Escherichia coli* per 100 mL • 100 cfu of intestinal enterococci per 100 mL	Vessels with an approved BWMS must meet the following discharge standards: • Fewer than 10 viable organisms per cubic metre, for organisms with a minimum dimension ≥ 50 u • Fewer than 10 viable organisms per mL, for organisms with a minimum dimension ≥ 10 u but < 50 u • Less than 1 cfu of toxicogenic *Vibrio cholera* (O1 and O139) per 100 mL • Fewer than 250 cfu of *Escherichia coli* per 100 mL • Fewer than 100 cfu of intestinal enterococci per 100 mL	Ballast water exchange must achieve at least 95% volumetric exchange or pump three times the volume of each ballast tank. Treated ballast water must attain a viable organism & indicator microbe content less than: • 10 viable organisms per cubic metre, for organisms with a minimum dimension ≥ 50 u • 10 viable organisms per mL for organisms with a minimum dimension ≥ 10 u but < 50 u • One cfu of toxicogenic *Vibrio cholera* (O1 and O139) per 100 mL or one cfu of that microbe per gram (wet weight) of zooplankton samples • 250 cfu of *Escherichia coli* per 100 mL • 100 cfu of intestinal enterococci per 100 mL

Compliance	The authorized representative/master of a Canadian or foreign vessel, or owner/operator of a pleasure craft must ensure that • All management requirements are met • The ballast water management plan meets the requirements and is submitted to the Minister and carried out • The vessel does not enter Canada's territorial sea if management requirements are not met unless the Minister is notified 96 hours prior to entry and provided with updates • Alternative measures are determined and implemented if management requirements cannot be met • A completed Ballast Water Reporting Form is submitted to the Minister following a management process for vessels bound for Canadian waters and kept onboard for 24 months.	Applicable vessels are expected to have a type-approved BWMS installed and operational by the dates provided by the implementation schedule. If this is not possible, the authorized representative or master of the vessel must request for an extension of compliance date or be using an approved AMS. The authorized representative/master of a vessel must provide the COTP with access to the vessel in order to take samples, examine documents, and make other inquiries to assess compliance. The authorized representative/master must provide records to the COTP upon request. Vessels with BWMS are subject to Coast Guard inspection, and must have sampling ports at each overboard discharge point.	In the event of accidental ballast water discharge or ingress resulting from damage to the vessel, crew members are expected to take all reasonable precautions to prevent or minimize discharge. Log books shall be safe-kept onboard so as to be readily available for inspection.
Enforcement	Not mentioned	When multiple entities are responsible for compliance with a requirement, each entity is jointly liable for a violation of the requirement. A person who violates these regulations is liable for a civil penalty up to $35,000. Each day of a continuing violation constitutes a separate violation. A person knowingly violating the regulations is guilty of a class C felony.	Not mentioned
Reporting Requirements	Ballast Water Reporting Forms must be submitted through email before entering Canadian waters and kept onboard 24 months following submission. Forms must include: • Vessel information • Voyage information • Ballast water usage and capacity • Ballast water management • Ballast water history (source, management practices, proposed discharge) • Residual ballast and sediment • Title and signature	All applicable vessels that operate within more than one COPT Zone must submit a ballast water report to the National Ballast Information Clearinghouse (NIBC) electronically. Reports should include: • Vessel information • Voyage information • Ballast water information • Ballast water tank information • Information on ballast tanks to be discharged (tank design, ballast source, management details) • Certificate of accurate information Vessels operating exclusively within one COTP Zone must submit Annual Ballast Water Summary Reports on vessel information, ballast information, and operational information to the NIBC.	No reporting is necessary, but a record book or deck log book must be kept. The book should include ship information (name, IMO number, gross tonnage, flag, total ballast water capacity) and each ballast water management operation, and should be written in the working language of the ship (as well as in English). Books should be kept onboard three years after the last entry has been made, and then two years in the company's control. Entries should be made when: • Ballast is taken onboard • Ballast is circulated or treated • Ballast is discharged to the sea • Ballast is discharged to a facility • Exceptional uptake or discharges of ballast occurs Entries should include: • Date, time and location of operation

			• Estimated volume managed • Whether the management plan has been implemented • Signature of the officer in charge
Management Plan	A Ballast Water Management Plan must be onboard and submitted to the Minister, and must contain: • The vessel's ballast water management processes • The management procedures that the crew follow • The crew's and vessel's safety procedures • Sediment disposal procedures • The procedures for coordinating ballast water release with authorities • The procedures for completing and submitting the Reporting Form • A description of the ballast water system • Evidence of tank boundary structure stability for flow-through exchange systems • A list of exchange sequences accounting for vessel design and problems for sequential exchange systems • A description of operational limits • An identification of the officer onboard responsible for carrying out procedures	The authorized representative/master of a vessel is required to maintain a ballast water management plan developed specifically for that vessel which includes: • Detailed safety procedures • Actions for implementing management requirements • Fouling maintenance and sediment removal procedures • Procedures for coordinating management strategies with Coast Guard authorities • Identification of the officer in charge of plan implementation • Reporting requirements and procedures for destination ports in the U.S. • A translation of the plan into English, French, or Spanish if the vessel's working language is another language.	Each ship shall have a ballast water and sediments management plan onboard specific to that particular vessel. The plan should provide a description of the actions to be taken to implement the ballast water management requirements and include an identification of the officers in charge of plan implementation. The plan should be written in the working language of the ship, and also be translated into either English, Spanish, or French if the working language is none of those. The plan must be approved in accordance with IMO guidelines.
Exceptional Circumstances	Ballast water need not be managed if the uptake or release of ballast water is necessary for ensuring vessel safety, saving life, avoiding the discharge of a pollutant, or if release occurs as a result of vessel damage upon navigational accident. Upon inability to manage ballast water due to safety reasons, the master of the vessel must give the Minister 96 hours' notice prior to entering the territorial sea and implement alternative measures including either ballast water retention, exchange, release, or treatment.	If a vessel is unable to meet management requirements because its voyage does not exceed 200 nm or due to safety reasons: • It is allowed to discharge ballast water in areas other than the Great Lakes and the Hudson River. • The vessel must discharge only the amount of ballast water operationally necessary to ensure safety. • However, such a discharge will not be allowed if the vessel is required to have an approved BWMS. If the installed BWMS fails: • The problem must be reported to the nearest COTP. • Vessels will be allowed to employ one of the other management methods outlined above. • If other management methods are unable to be employed due to safety concerns, the vessel will be allowed to discharge ballast water in areas other the Great Lakes and the Hudson River. • The vessel must discharge only the amount of ballast water operationally necessary to ensure safety.	Requirements do not apply in the event of an accidental discharge or ingress resulting from damage to the vessel. Requirements do not apply in the event of emergencies when the uptake and discharge of ballast water is necessary to the safety of the ship or those onboard. Additionally, the Norwegian Maritime Authority may grant exemptions from the requirements in individual cases if special reasons justifiable in terms of safety are given. Ballast water treatment requirements do not apply to ships that are testing new ballast water technology during the first five years after installation, or during the first five years after approved ballast water technology should have been installed.
Ratification of IMO	Yes, in 2010	No	Yes, in 2007

4.1.4 Stakeholder Analysis

It was found that only two groups in the AOI are directly impacted by the issue of ballast-mediated AIS introduction and establishment, namely Inuit peoples and the eastern Arctic fisheries. This finding is based largely around the assumption that AIS introduction has the potential to disrupt the ecosystem, impacting marine wildlife that is important in terms of survival, culture, and the economy. Two groups were found to be indirectly impacted by the issue: the tourism industry and other polar states. Northern cruises partially rely upon the presence of Arctic wildlife to attract tourists. If the ecosystem is disturbed by AIS and animals like polar bears or whales are negatively impacted, then demand for tourism may decline. Other polar states may be at risk of secondary invasions if AIS are introduced to the eastern Canadian Arctic, as the waters of northern Canada are transited by both domestic and international vessels and AIS have the ability to disperse easily.

The tertiary stakeholder group was the most frequently represented category, as the majority of identified stakeholders were not found to be impacted by the issue but instead had an interest in or influence over the issue (Figure 9). The tertiary stakeholder groups include the shipping industry, the Nunavut territorial governments, federal government departments, NGOs, and the IMO. The shipping industry would have both an interest in and influence over the issue, as their operations may affect the issue and consequent regulations may in turn impact their operations. The majority of the Nunavut territorial governments (Regional Inuit Associations, the Nunavut Wildlife Management Board (NWMB), and the Nunavut Department of Environment) merely have an interest in the issue, as protecting the interest of Inuit peoples and resources such as wildlife and fisheries falls within their mandates. However, the Nunavut Department of Economic Development and Transportation may have an influence over the introduction of ballast-sourced

AIS as they are responsible for stimulating developments which may strengthen the territorial economy as well as ensuring the safe and effective movement of goods. The Nunavut Impact Review Board may also have some influence, as they must consider the issue of ballast-sourced AIS when assessing proposed development projects and associated risks. As ballast water and AIS are federally managed, federal government departments have more power over the issue compared to territorial government bodies. Transport Canada has influence over the issue, as they are responsible for ensuring safe, efficient, and ecologically sound transportation and have legislative authority over BWM. DFO also has a degree of influence; in addition to being in charge of managing fisheries and safeguarding Canada's waters, they are also responsible for AIS management. Environment and Climate Change Canada and Natural Resources Canada have an interest in the issue, as they are responsible for protecting the environment in the face of climate change and promoting responsible development of resources, respectively. With the exception of research vessels which may on rare occasions have the potential to introduce AIS, NGO's merely have an interest in the issue. University researchers and organizations such as the Canadian Aquatic Invasive Species Network (CAISN) and the Canadian Council on Invasive Species (CCIS) are interested in collecting information on AIS in order to provide results which will enhance management. In the long term, this data may eventually have influence, but initially these stakeholders just have an interest in the issue. Finally, the IMO has both an interest in and influence over the issue. Their mandate is to ensure safe and secure international shipping and prevent marine vessel pollution, and their convention on BWM has the potential to reduce the risk of ballast-sourced AIS introduction.

The primary stakeholders, though experiencing potentially high levels of impact, have very little power or influence over the issue. Similarly, the secondary stakeholders were also found to have low levels of power over the increasing risk of AIS introductions. Conversely, it was found that many tertiary stakeholders who were likely to experience a minimal impact as a result of the issue had a considerably greater amount of influence over the primary and secondary stakeholder groups (Table 9). Territorial and federal government departments typically had high levels of importance, while NGO groups had lower levels of both importance and power. The IMO was the only stakeholder group found to have high importance and power while also experiencing high potential impact level.

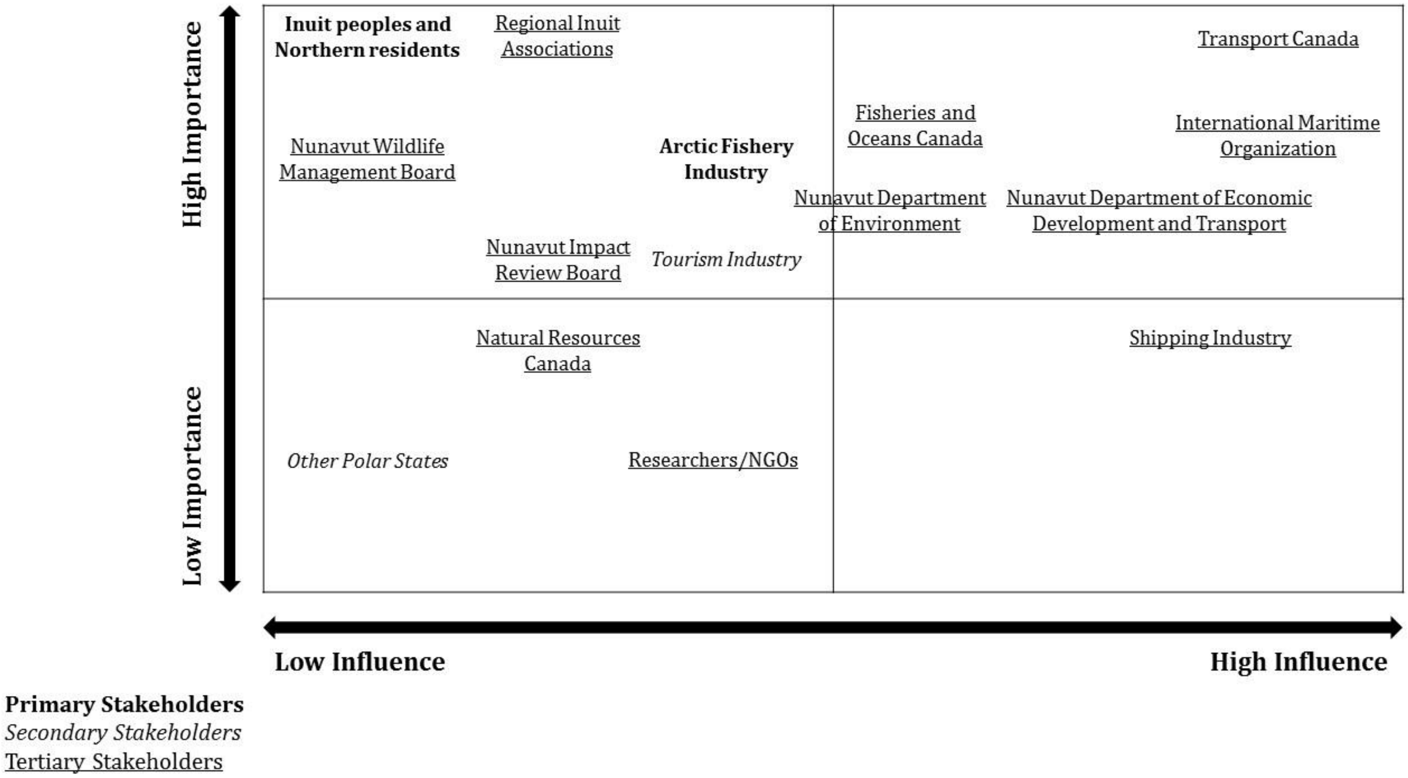


Figure 9. Identification and categorization of primary, secondary, and tertiary stakeholders

Table 9. The nature of stakeholder groups' interest in the issue of ballast-mediated species invasions in the eastern Canadian Arctic, as well as the potential impact the issue may have on them as a group.

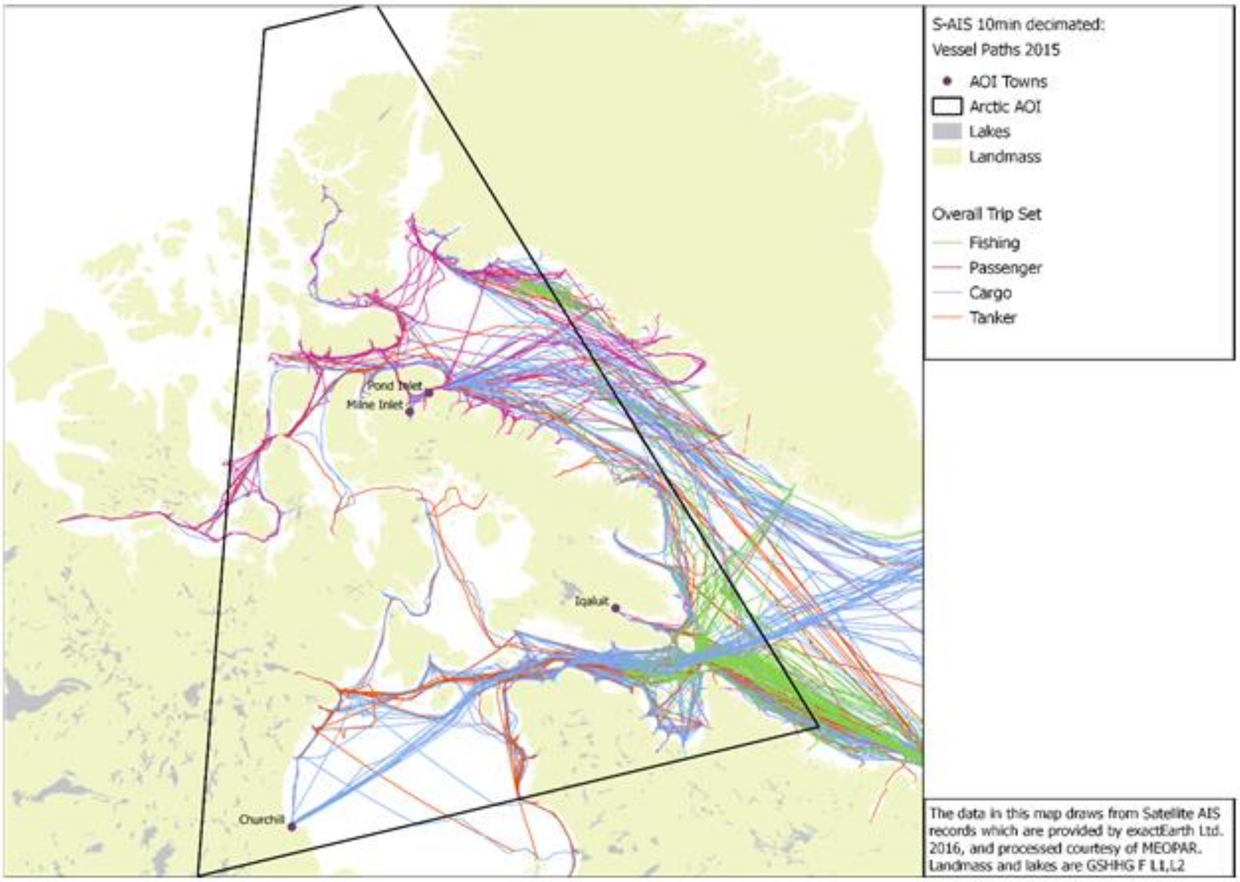
Stakeholder Group	Nature of Interest in Issue	Potential Impact
Primary Stakeholders		
Inuit	Aquatic invasive species (AIS) could disrupt the ecosystem and displace or negatively affect species which are integral to food security or income, or are culturally important.	High
Fishery Industry	AIS could displace or negatively affect economically important fish stocks. Fishing vessels themselves may transfer AIS, and therefore may be impacted by policy decisions regarding ballast water.	Medium
Secondary Stakeholders		
Tourism Industry	AIS could displace/negatively affect wildlife species which attract tourists to Arctic cruises. Policy decisions may impact where cruise ships go and how they operate, as they may transfer AIS.	Low-Medium
Polar States	Due to ease of dispersal of aquatic species, increased introduction of AIS to the eastern Canadian Arctic may mean increased risk of secondary invasions for nearby polar states.	Medium-High
Tertiary Stakeholders		
Shipping Companies	Ship traffic is the direct cause of ballast-sourced AIS introductions, therefore the shipping industry (transit, resupply, tourism, fishing, resource development, etc.) has great influence over the issue. Resulting policy decisions may impact the shipping industry.	Medium
Regional Inuit Associations	The eastern Arctic regional associations represent the interests of the Inuit peoples. They work to safeguard Inuit rights, promote wellbeing, preserve culture, manage land, and protect wildlife and the environment. Therefore, they have an interest in the issue as well as the developments stimulating Arctic marine traffic.	Medium
Nunavut Wildlife Management Board (NWMB)	The NWMB's main concern is wildlife conservation. They work within a terrestrial and marine capacity, and therefore their interest would lie in how introduced AIS would impact marine wildlife.	Low-Medium
Nunavut Department of Environment	The Nunavut Department of Environment is responsible for preserving natural and cultural resources. Specifically, the department deals with wildlife management, fisheries, and general environmental protection. Therefore, they would be interested in minimizing AIS introduction to fulfil their mandate.	Medium

Nunavut Department of Economic Development and Transportation	This department aims to stimulate and strengthen the territory's economy and ensure the safe and effective movement of goods. Therefore, they may have an influence in increasing the introduction of AIS by facilitating developments and an increase in vessel traffic.	Medium
Nunavut Impact Review Board (NIRB)	The NIRB is responsible for assessing the potential impacts of proposed projects. This would include considering ballast water discharge from shipping related to development, and assessing the subsequent risk of AIS.	Low-Medium
Transport Canada	Transport Canada is responsible for promoting safe, efficient, and environmentally-responsible transportation policies and programs. Transport Canada has both an interest in and influence over this issue, as the department introduced legislation outlining ballast management methods in order to minimize the risk of AIS introduction.	Medium
Fisheries and Oceans Canada (DFO)	DFO is the lead federal role in managing fisheries and safeguarding waters. They also have a lead role in managing AIS. As a result, they have introduced multiple pieces of legislation dealing with AIS and offered suggestions to Transport Canada.	High
Environment and Climate Change Canada	This department is responsible for preserving all aspects of the natural environment, including water resources. Though this department may have little influence over this issue, they have an interest in protecting the Arctic environment from AIS introduction.	Low-Medium
Natural Resources Canada	This department promotes the responsible development of Canada's Natural Resources – including energy and minerals. This means that they have an interest in making sure that an increase in vessel traffic related to development does not lead to AIS introductions.	Low
University Researchers	Much research is being done already in the Arctic by universities. However, many knowledge gaps still exist and by investigating this issue, information could be revealed regarding Arctic changes, vessel trends, and the Arctic ecosystem in general. Research vessels may also contribute to the introduction of AIS.	Low-Medium
Canadian Aquatic Invasive Species Network (CAISN)	CAISN is developing early detection and rapid response measures, with an overall goal of enhancing AIS prediction, management, and monitoring. They hope to compile a profile of AIS in Canadian waters, and therefore have an interest in introductions of AIS into Arctic waters.	High
Canadian Council on Invasive Species (CCIS)	The main mandate of the CCIS is to manage invasive species so as to reduce the associated threats and impacts. They prioritize early detection. Their interest in the issue would be to step in *after* the introduction of an AIS has been detected, to implement a management strategy.	Medium-High
International Maritime Organization (IMO)	The IMO is responsible for the safety and security of international shipping and the prevention of marine pollution. IMO has implemented guidelines and conventions regarding AIS, as they are considered a form of pollution.	High

4.2 Risk Assessment

While not technically ports, for the purpose of this discussion, ship destinations within the AOI will be referred to as ports herein. 32 Arctic ports within the AOI were destination ports in 2015, totalling 265 stops (not including fishing vessels). The top three most visited ports were chosen to be ports of interest in this study: Iqaluit (27 stops), Milne Inlet (21 stops), and Pond Inlet (20 stops). In addition to these three ports, the port of Churchill was also chosen to be a port of interest in this study due to findings of previous risk assessments, though it only ranked as the 11th most visited eastern Arctic port in 2015 (8 stops) (Figure 10). The degree of exposure of the four ports of interest to ballast-mediated NIS introductions can be expressed as a factor of the number of stops by vessels, which totalled 75 for all four ports combined. Excluding fishing vessels, seven types of vessels visited the ports of interest in 2015, the most common being general cargo (23 stops), passenger (19 stops), and bulk carriers (18) (Figure 11; Figure 12). Arrival dates at the ports of interest ranged from July to November, with exposure being greatest during the month of August (35 stops) (Figure 13).

Following this vessel analysis, Iqaluit and Pond Inlet were removed from further assessment due to the nature of vessel activity which occurs at these ports; mainly passenger ships or general cargo vessels and tankers dropping off supplies visit these ports, and therefore no regular ballast discharges occur at Iqaluit and Pond Inlet. Additionally, only general cargo, bulk carrier, and oil tanker vessel types were considered for the assessment, due to the low likelihood and poor predictability of ballast discharge from the other types of identified vessels.



The data in this map draws from Satellite AIS records which are provided by exactEarth Ltd. 2016, and processed courtesy of MEOPAR. Landmass and lakes are GSHHG F L1,L2

Figure 10. Selected destination ports for assessment and vessel traffic paths within the Area of Interest

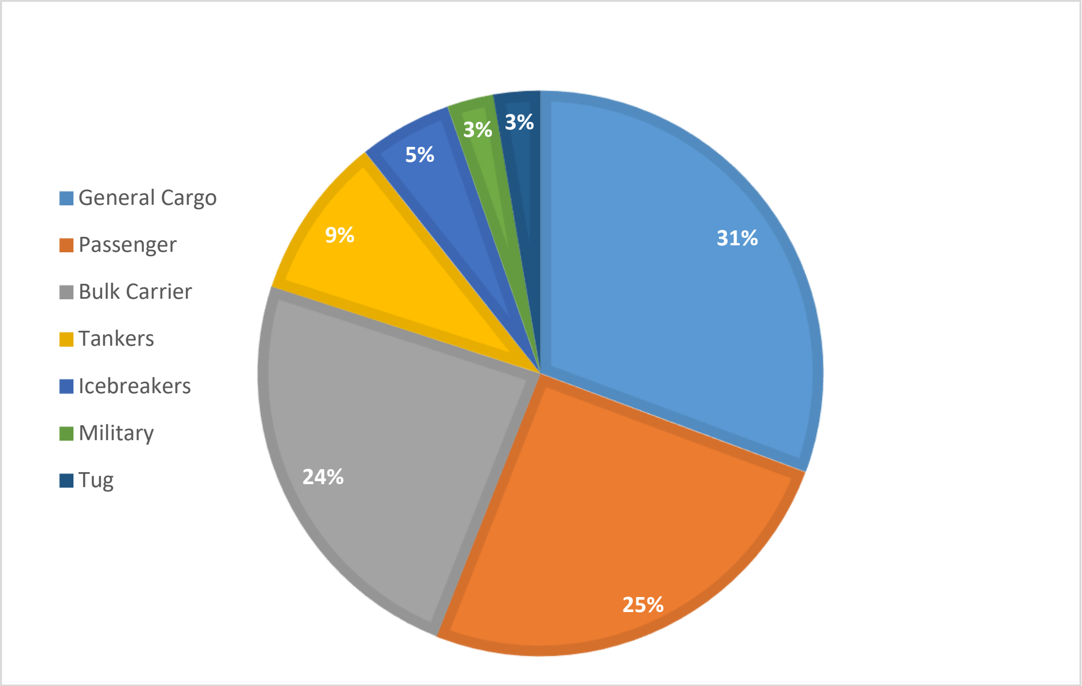


Figure 11. Percentage of vessel types by stops in the top three most visited eastern Arctic ports and the port of Churchill in 2015

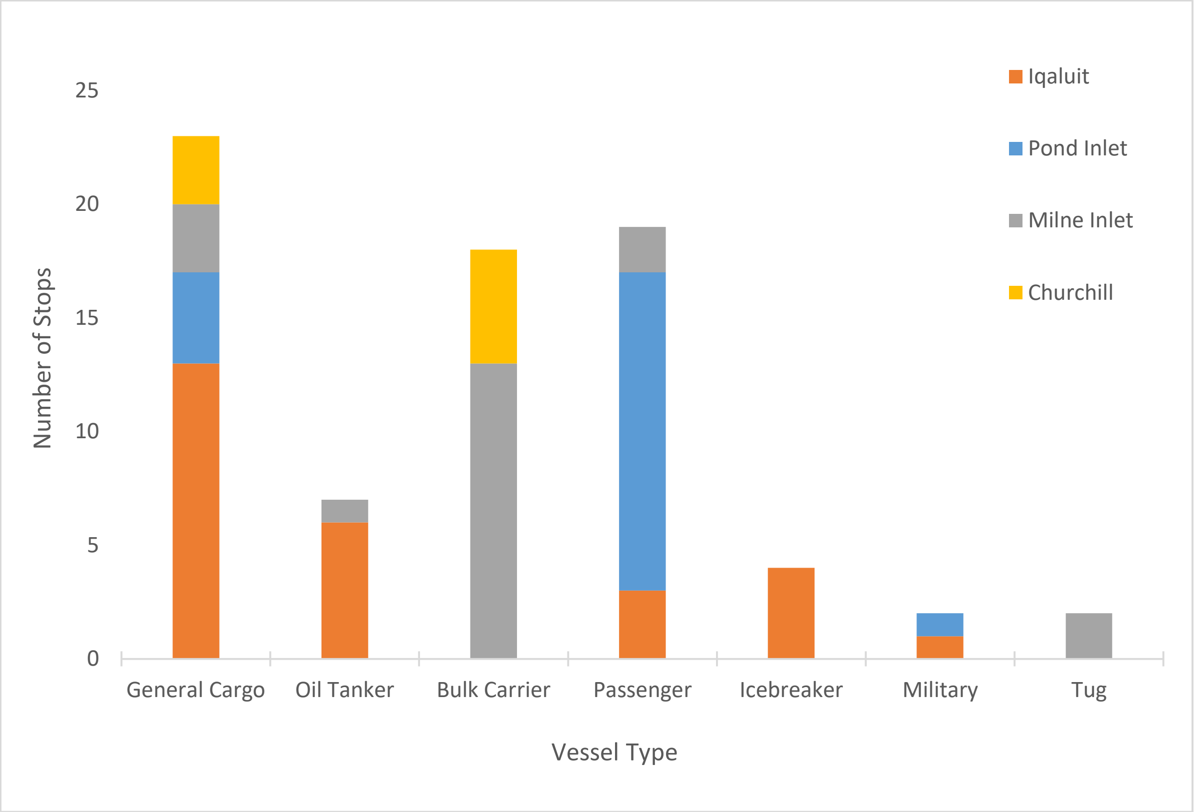


Figure 12. Number of stops by vessel type in the top three most visited eastern Arctic ports and the port of Churchill in 2015

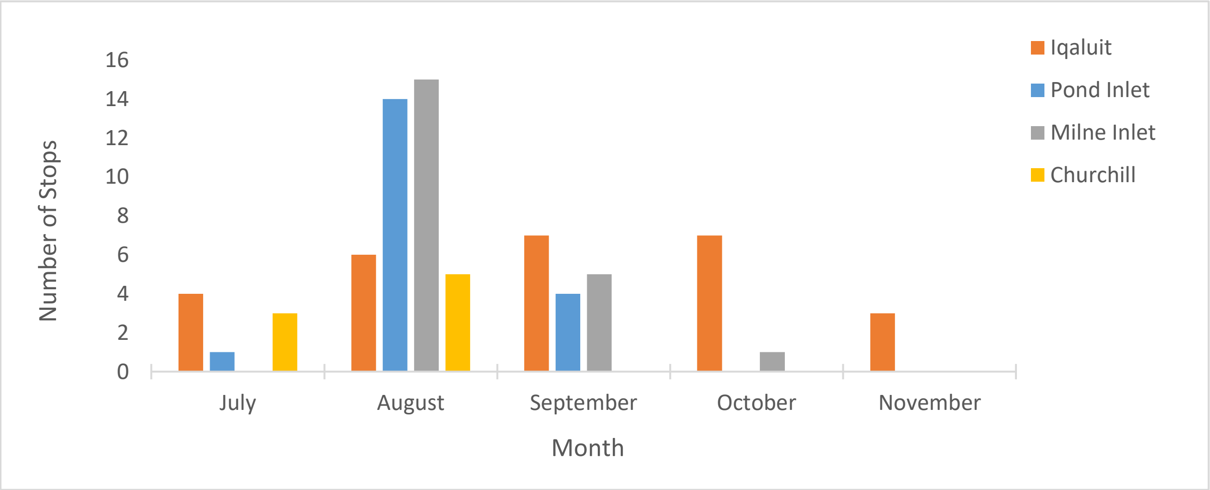
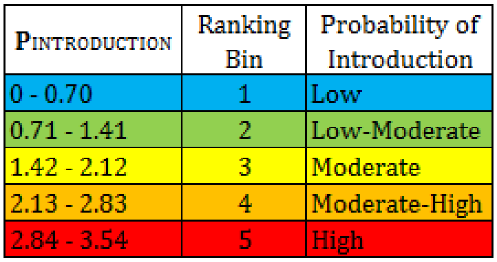


Figure 13. Number of stops by month in the top three most visited eastern Arctic ports and the port of Churchill in 2015

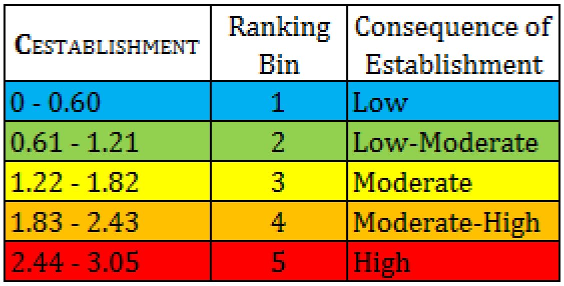
4.2.1 Current Risk Assessment



PINTRODUCTION	Ranking Bin	Probability of Introduction
0 - 0.70	1	Low
0.71 - 1.41	2	Low-Moderate
1.42 - 2.12	3	Moderate
2.13 - 2.83	4	Moderate-High
2.84 - 3.54	5	High

Figure 14. Ranking scheme for probability of introduction.

As mentioned, the probability of introduction for each voyage was determined using multiple factors and was assigned using a ranking bin; these ranks were then used to describe the probability of ballast-mediated NIS introduction for each voyage (Figure 14). The average ranking of the probability of introduction at Milne Inlet in 2015 was moderately likely (PINTRODUCTION=1.49). M17 and M12 were both found to have a highly likely probability of introduction, though M17 had the greatest probability (PINTRODUCTION=3.54) (refer to Table 5 on page 43 for a description of the coding scheme). Voyages M9, M10, M14, and M15 had the lowest calculated probability of introduction (PINTRODUCTION=0), and were ranked as having an unlikely probability of introduction along with M5 and M16. The average ranking of the probability of introduction into Churchill in 2015 was found to have a low-moderate likelihood (PINTRODUCTION=0.79). The voyages with the highest probability of introduction at this port were C1 and C6 (PINTRODUCTION=1.09), which scored a low-moderate likelihood along with C2 and C4. The lowest ranking voyage for the probability of introduction to Churchill was C5 (PINTRODUCTION=0.44), scoring a rank of unlikely. C8, C3, and C7, though having a greater probability of introduction than C5, also ranked as unlikely.

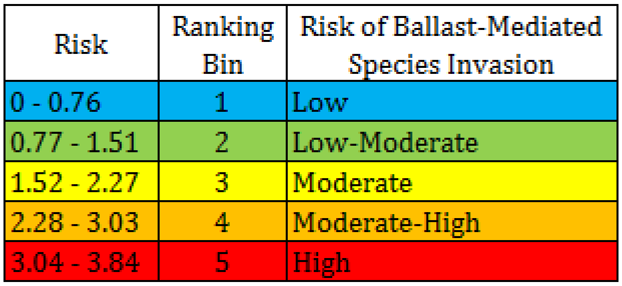


CESTABLISHMENT	Ranking Bin	Consequence of Establishment
0 - 0.60	1	Low
0.61 - 1.21	2	Low-Moderate
1.22 - 1.82	3	Moderate
1.83 - 2.43	4	Moderate-High
2.44 - 3.05	5	High

Figure 15. Ranking scheme for consequence of establishment

Similar to probability of introduction, the consequence of establishment was described for each voyage using a ranking bin (Figure 15). The average ranking of the consequence of establishment in Milne Inlet in 2015 was moderate (CESTABLISHMENT=1.29). The voyage with the greatest consequence of establishment was M13

($C_{\text{ESTABLISHMENT}}$=2.61). The voyages with the lowest probability of introduction (M9, M10, M14, M15) also had the lowest consequence of establishment ($C_{\text{ESTABLISHMENT}}$=0), as did M4. The average ranking of the consequence of establishment in Churchill in 2015 was low-moderate ($C_{\text{ESTABLISHMENT}}$=0.61). The voyage with the single greatest consequence of establishment was C4 ($C_{\text{ESTABLISHMENT}}$=1.63), ranking a high consequence of establishment along with C8. The voyages with the lowest consequence of establishment were three general cargo vessels arriving from other eastern Arctic source ports (C1, C2, C6). C3 and C7 had a higher consequence of establishment than these three vessels, but also ranked as low.



Risk	Ranking Bin	Risk of Ballast-Mediated Species Invasion
0 - 0.76	1	Low
0.77 - 1.51	2	Low-Moderate
1.52 - 2.27	3	Moderate
2.28 - 3.03	4	Moderate-High
3.04 - 3.84	5	High

Figure 16 Ranking scheme for overall risk

The total amount of ballast water estimated to have been discharged in Milne Inlet in 2015 was approximately 302,425 m^3. The overall risk for each voyage was calculated by multiplying the probability of introduction with the consequence of establishment, and a ranking bin systems was used to describe the overall risk of ballast-mediated species invasion associated with each voyage (Figure 16). The overall cumulative risk of ballast- mediated species invasions at Milne Inlet across all vessels was over six times greater than the cumulative risk at Churchill (Figure 17). However, the average overall risk ranking for Milne Inlet was only low-moderate (1.14). The voyage deemed as the highest risk at Milne Inlet and in the entire assessment for 2015 was M12, with an overall

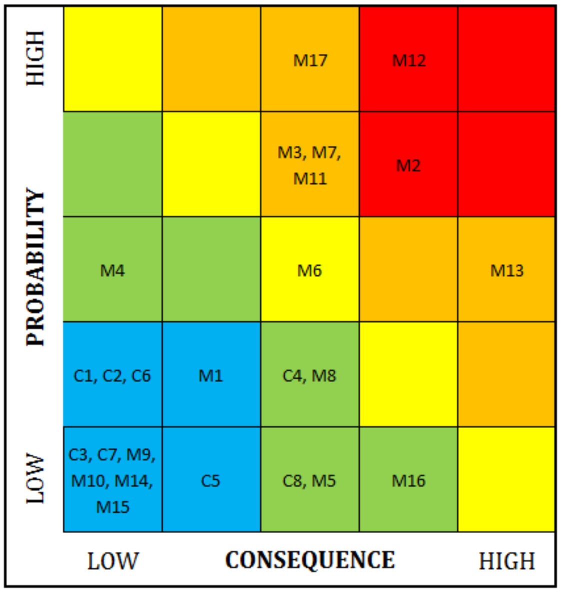


Figure 17. Risk matrix for Milne Inlet and Churchill for 2015

moderate-high risk level (2.71). Voyages M9, M10, M14, M15 represented the lowest risk (0). The total amount of ballast water estimated to have been discharged at the port of Churchill in 2015 was approximately 76,000 m^3, only around a quarter of the amount discharged at Milne Inlet. The average risk at the port of Churchill was found to be low (0.19). The highest risk voyage at Churchill was C4, ranking as still only having an overall low risk level (0.61).

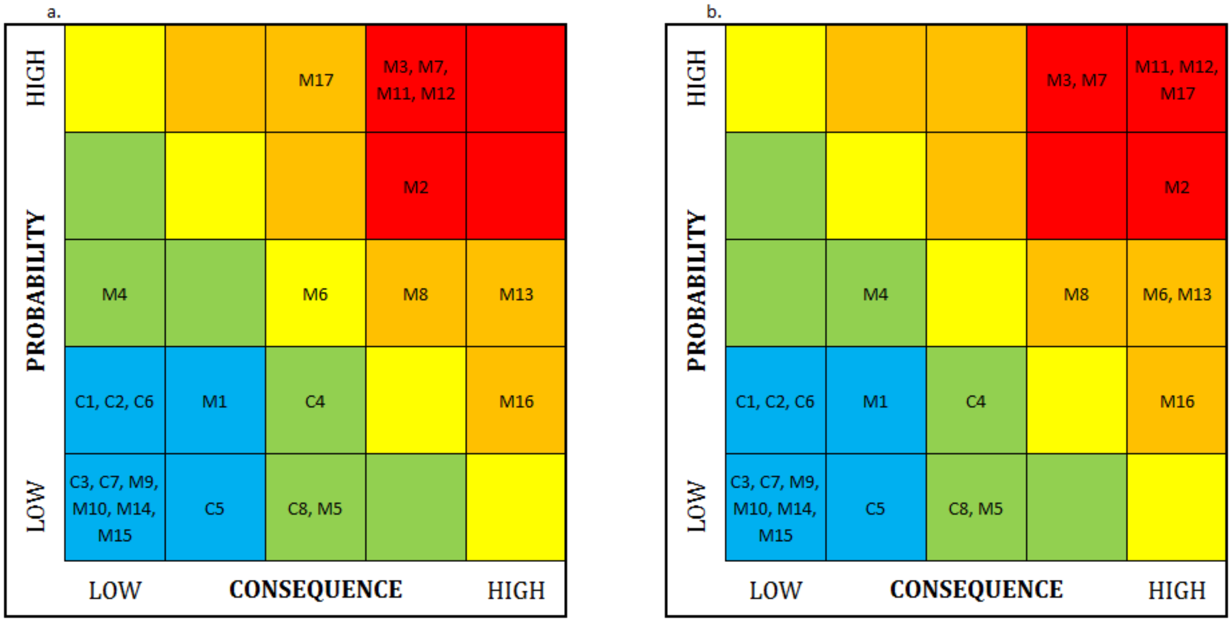
4.2.2 Future Risk Assessment: Business as Usual

Under this scenario, the average overall risk of ballast-mediated species invasion at Milne Inlet in 2055 is estimated to continue to be low-moderate (1.35), with the cumulative risk increasing just under 20% (Figure 15.a). M2 would now be considered the greatest risk voyage at this port with an overall high risk level (2.81), due to the magnitude in the increase of the voyage's probability of introduction and consequence of establishment. Although M2 would not experience a significant enough increase to affect its ranking position, many other voyages would experience both an increase in probability of introduction and consequence of establishment (M3, M7, M8, M11, M12, and M16).

The average overall risk at the port of Churchill would still be low in 2055 (0.21), with the cumulative risk only increasing just over 7% (Figure 15.a). C4 would continue to be the greatest risk voyage at this port with a moderate ranking (0.61), and C2 would continue to be the lowest risk voyage (0.04).

By 2105, the average overall risk level at Milne Inlet is projected to rise to moderate (1.65), with the cumulative risk increasing just under 45% from 2015 levels. The voyage with the greatest overall risk is predicted to be M17 (3.84), scoring a rank of high risk along with M2, M11 and M12. Between 2055 and 2015 under this scenario, many voyages are expected to experience significant increases in regards to consequence of establishment (Figure 15.b). There is predicted to be no change in regards to the voyage of least risk.

The average overall risk at Churchill during 2105 would be low (0.21), and the voyages of greatest and least risk at the port of Churchill are not expected to change between 2055 and 2105. Generally, no changes regarding the risk level of ballast-mediated species invasion are predicted to occur at the port of Churchill between 2055 and 2105.



a.

PROBABILITY	LOW		CONSEQUENCE		HIGH
HIGH			M17	M3, M7, M11, M12	
				M2	
PROBABILITY	M4		M6	M8	M13
	C1, C2, C6	M1	C4		M16
LOW	C3, C7, M9, M10, M14, M15	C5	C8, M5		

b.

PROBABILITY	LOW		CONSEQUENCE		HIGH
HIGH				M3, M7	M11, M12, M17
					M2
PROBABILITY		M4		M8	M6, M13
	C1, C2, C6	M1	C4		M16
LOW	C3, C7, M9, M10, M14, M15	C5	C8, M5		

Figure 18.a Business as Usual scenario risk matrix for Milne Inlet and Churchill in the year 2055
Figure 18.b Business as Usual scenario risk matric for Milne Inlet and Churchill in the year 2105

The change in the overall risk at Milne Inlet between 2015 and 2055 under a Business as Usual Framework is not expected to be significant (p=0.29), nor will the change between 2015 and 2105 (p=0.13). This is also the case for the port of Churchill (p=0.43; p=0.43).

4.2.3 Future Risk Assessment: Improved Management Framework

Under an improved ballast water management regime, the expected overall risk will decrease significantly at Milne Inlet between 2015 and 2055 ($p<0.001$) (Figure 16.a). The average overall risk is expected to be low in 2055 (0.15), dropping almost 90% from 2015 risk levels. It is expected that all voyages will have a low probability of introduction, though M13, and M16 are predicted to have high consequence of establishment levels (3.05 and 2.71, respectively). Similar to the 2055 under a Business as Usual scenario, M2 will have the greatest overall risk level – though it will only be ranked as low (0.28).

The overall risk level is expected to significantly decrease at the port of Churchill between 2015 and 2055 under an improved management regime as well (p=0.038). The overall average risk level will still be low (0.04), with a cumulative risk almost 80% lower than 2015 levels. It is expected that all voyages will have a low probability of introduction, excepting voyages from source ports within Canada's waters (C1, C2, C7). It is predicted that C4 and C8 will have the greatest risk of establishment, ranking as moderate (1.63 each). Similar to the Business as Usual scenario in 2055, C4 will maintain the greatest overall risk level, though again it will only be ranked as low.

Compared to predicted Business as Usual risk levels for 2055, risk is expected to decrease significantly at both Milne Inlet (p=<0.001) and the port of Churchill (p=0.032) under an Improved Management Framework scenario in 2055.

Under an improved ballast water management regime, the expected overall risk will decrease significantly at Milne Inlet between 2015 and 2105 (p<0.001) (Figure 16.b). The average overall risk is not expected to change from the predicted Improved Management Framework 2055 level, though the average risk level will increase slightly (0.18). Although all voyages will maintain their low probability of introduction, voyages M2, M6, M11, M12, M13, M16 and M17 are expected to have high consequence of establishment levels. Similar to the Business as Usual scenario for 2105, M17 will have the greatest overall risk level, though it will only rank as low (0.38).

The overall risk level is not expected to increase between 2055 and 2105 under an Improved Management Framework at the port of Churchill, but will still be lower than the 2015 risk levels. There is not expected to be any change to the probability of establishment levels or consequence of establishment.

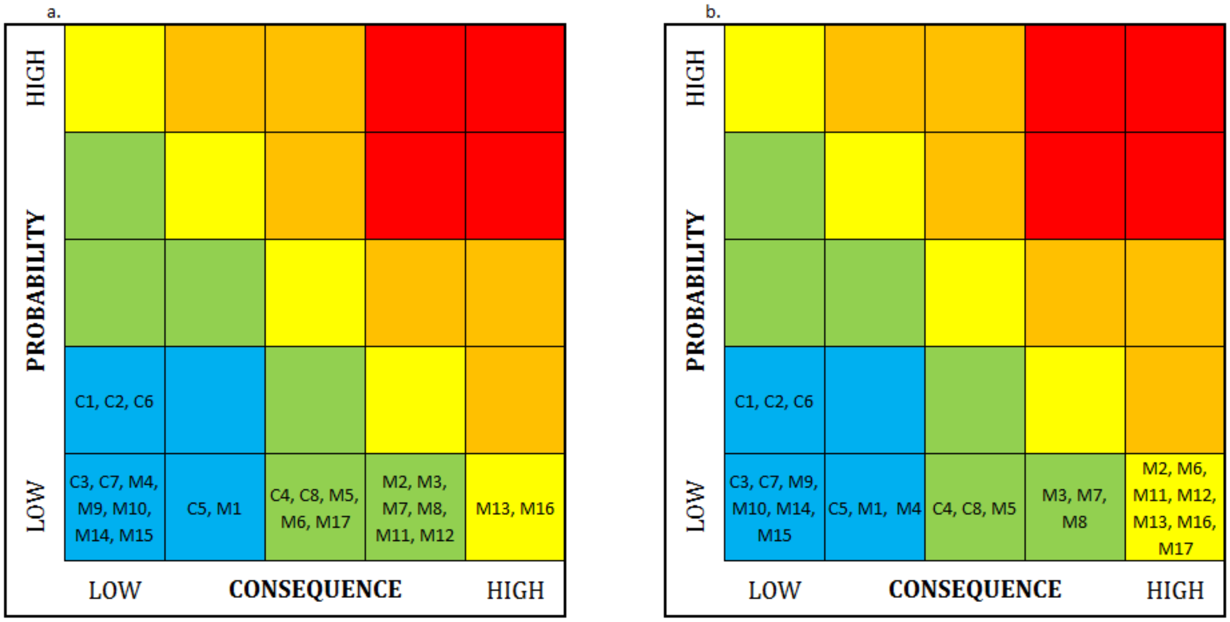


Figure 19.a Improved Management Framework risk matrix for Milne Inlet and Churchill during the year 2055
Figure 19.b Improved Management Framework risk matrix for Milne Inlet and Churchill during the year 2105

Compared to 2105 levels under the Business as Usual scenario, both Milne Inlet and Churchill are expected to experience significant decreases in risk levels ($p<0.001$; $p=0.032$).

5.0 DISCUSSION

5.1 Canadian Ballast Water Management

Canada’s legislative history with BWM is relatively short, but has evolved rapidly since the discussion of ballast-mediated AIS first formally began in 1992. Though great strides have been made over time, it is argued in this paper that improvements still need to be made in order to better protect Canada’s aquatic environments.

There are many merits to Canada's current BWM Regulations. Firstly, the close alignment of Canada's Regulations with international conventions suggests that understanding and compliance of regulations will be strengthened. There has also been evidence of the effectiveness of Canada's approach, as no new AIS have been observed in the Great Lakes since the introduction of the Regulations in 2006 (Fisheries and Oceans Canada, 2011).

However, many issues are associated with Canada's primary BWM approach of mid-ocean exchange; BWE does not fully eliminate AIS from tanks, as although it requires a 95% volumetric exchange this does not mean that 95% of organisms are being targeted, as organisms are not evenly distributed in ballast water. Additionally, BWE may not effectively treat euryhaline species or organisms in resting stages and is not always a feasible option for ship operators (International Association for Great Lakes Research, 2002). In addition to prioritizing potentially ineffective BWM methods, the Regulations also grant full exemption from management to vessels under various situations. In doing so, the Regulations potentially ignore ecologically sensitive areas and may also facilitate primary or secondary AIS introductions. There is also regional imbalance within the Regulation; great emphasis is placed upon protecting freshwater environments such as the Great Lakes and St. Lawrence Seaway, but a lacking marine focus leaves many ports vulnerable to the risk of AIS introduction.

Although not currently being used as a management method in Canada, BWT is an option for BWM presented in the Regulations; however, gaps exist within the policy in regards to BWT which could complicate its introduction as a management method as well as its effectiveness. For example, the performance standards for BWT do not address organisms less than 10 um, which is a potential issue as algal species smaller than this size have been known to form harmful algal blooms (HABs). Most alarmingly, in some cases BWT systems have proven to be unable to meet the performance standards set out by both the IMO Convention and Canada's Regulations (World Shipping Council, 2016). Systems have been found to have difficulty treating low salinity and low temperature water, which are common characteristics of Canada's aquatic ecosystems (Transport Canada, 2015; Jing et al., 2012). This is not only an ecological issue, but also an economic issue, as ship owners are responsible for covering the cost of a type-approved system, even if is found to be ineffective following installation.

Furthermore, it has become clear that inspection targets are not being met. According to a report done by the Office of the Auditor General of Canada, a quarter of all vessels entering Canada's east and west coasts are to be inspected; however, in 2007 only 7% of vessels were inspected on the west coast (2008). Even if inspection occurs consistently, there is no guarantee that it will be met with compliance; 36% of vessels entering the Great Lakes and St. Lawrence Seaway between June and December of 2006 were issued instruction letters for noncompliance (Office of the Auditor General of Canada, 2008). Additionally, it is difficult to ensure that ballast management is being conducted correctly even if "compliance" appears to be occurring; in 2007, 93% of vessels entering Canadian waters on the east coast submitted reporting forms, but many of them were incomplete and therefore may not have accurately reflected management practices (Office of the Auditor General of Canada, 2008).

The risks posed by these gaps and shortcomings may become magnified in the future. Climate changes are expected to naturally increase invasion rates, and human actions may further accelerate this phenomenon. This is an area of major concern in Canada, as previously inaccessible or inhospitable areas such as the Arctic are now experiencing increases in vessel traffic and water temperatures. The introduction and establishment of AIS in the Arctic has potentially disastrous ecological, social, and economic impacts due to the sensitivity of the environment, the deep ties the Inuit peoples have to their natural surroundings, and the inequitable power distribution that exists regarding this issue.

5.2 Eastern Arctic Risk Assessment

In previous risk assessments, the Arctic has been found to be at low risk of ballast-sourced species invasions (Casas-Monroy et al., 2014). This is largely due to the relatively low amount of ballast water discharged in Arctic ports and low suitability of Arctic environments for NIS. However, the most recent risk assessment was done in 2014, before the Baffinland iron ore mine began shipments out of Milne Inlet. Further, no previous studies of Canadian Arctic ports have attempted to do future risk projections. Due to the changing environmental and socioeconomic conditions in the Arctic, conducting a projected risk assessment was thought to be useful. In order to provide context and baseline data, a more recent current risk assessment was first conducted.

5.2.1 The Current Risk

Of the four original ports of interest, only Milne Inlet and Churchill were considered for the risk assessment. This was a result of Iqaluit and Pond Inlet experiencing strictly resupply, passenger, icebreaker, and military vessel traffic – all of which would not normally discharge ballast water during a call at either of these ports. However, this is not to say that Iqaluit and Pond Inlet are at no risk of AIS introduction, as discharge may occur as a result of an accident or other exceptional circumstances. Conversely, Milne Inlet experienced frequent ballast discharge events by bulk carriers picking up iron ore from the Baffinland mine, and several bulk carriers loading grain and general cargo vessels loading goods for resupply purposes discharged ballast in the port of Churchill.

In general, the current risk associated with ballast-mediated species invasion in the eastern Arctic is considered to be low-moderate. The majority of vessels operating in this region are general cargo or passenger vessels which do not routinely discharge ballast water at destination ports within the AOI. Although high risk discharge events do occur, the "riskiest" port in this assessment was only found to be at an average overall low-moderate risk level. These conclusions are consistent with other studies, which have found that the Arctic is presently at a relatively minimal risk of ship-sourced AIS introduction and establishment (Casas-Monroy et al., 2014; Chan et al., 2012; Chan et al., 2014; Chan et al., 2015). However, other risk assessments have ranked Churchill at a greater invasion risk than any other Arctic port, including Milne Inlet (Chan et al., 2012). The reason for this disparity may be that at the time of that study Churchill was operating at a normal level, though the port ceased operations in August, 2016 and was likely not functioning at normal capacity in 2015. Furthermore, the Baffinland mine was not yet shipping out of Milne Inlet during the study by Chan et al.; now the cumulative risk at Milne Inlet is much higher than Churchill's due to the amount and size of vessels which arrive at the port.

In terms of NIS introduction, length of voyage time and capacity of ballast tank seemed to be the determining factors. Voyages which ranked as having the greatest consequence of establishment were those which came from source ports with at least moderate levels of propagule pressure, colonization pressure, and known AIS, and a moderate-high level of environmental similarity. In Milne Inlet the voyage which had the greatest probability of introduction also posed the greatest overall risk, though in Churchill the voyage which had the greatest consequence of establishment posed the greatest overall risk; this may suggest that neither introduction or establishment alone is the main indicator of risk.

The risk categorization of voyages within this assessment differed from the findings of a study done by Chan et al. (2012). In their assessment, it was found that coastal domestic source ports contribute the highest risk to Arctic destination ports. This discrepancy is most likely due to the consideration of different factors, such as ballast capacity and source port species composition. Alternatively, this study's findings are more complementary to those of an assessment completed by Casas-Monroy et al. (2014). In their assessment, it was found that international transoceanic vessels have the greatest per-event introduction potential, suggesting that if the volume of these vessel types were to increase so would the overall risk value of a port.

5.2.2 The Future Risk

The overall risk level to Milne Inlet or Churchill is not expected to change by the year 2055 under a Business as Usual scenario given the assumptions of future conditions, though Milne Inlet is expected to experience a moderate risk of ballast-mediate species invasions by 2105. The consequence of establishment of many voyages is expected to increase over time due to heightened environmental similarity between source and destination ports. Although vessel volume was not adjusted in this assessment from current levels, if Baffinland continues to ship out of Milne Inlet throughout its project life it is likely that the shipping and ballast discharge volume at Milne Inlet will significantly increase by 2055. For example, in 2016 the number of discharge events more than doubled from 17 in the previous year to 38, and the expected cumulative discharge increased by a factor of three (M. Zurowski, personal communication, October 25, 2016).

It is likely that an improved management framework will be in place by the year 2055, as BWT is to be phased in as the principal means of BWM under the IMO Convention. Following the enactment of the Convention in September, 2017 all new ships are to be built with an onboard treatment system, and all existing ships are to be fitted with a treatment system during their first dry-dock. This of course will have a significant impact on the risk of ballast-mediated NIS, and is expected to result in an overall low risk to both the port of Churchill and Milne Inlet by 2055 and 2105. However, improved management is only considered to have a direct impact on the probability of introduction; many voyages are estimated to continue experiencing increases in consequence, and by 2105 almost half of the voyages to Milne Inlet will have a moderate-high or higher consequence of establishment. Additionally, BWT will only be required of international vessels and therefore does not impact the risk level of domestic voyages. As a result, BWT will be more effective at reducing the risks of ballast-mediated AIS at some ports than others. For example, improved management is expected to have less of an effect on the port of Churchill due to the number of discharge events there by domestic vessels.

5.3 Implications for Vessel Types

In regards to general vessel trends, very few types of vessels are expected to pose threats to the eastern Arctic in terms of AIS introduction. It is unlikely that transit shipping will increase significantly by 2055 due to unpredictable ice conditions within the eastern Arctic Archipelago region of the NWP, though the volume of transit vessels may grow by the end of the century (Stephenson et al., 2013). However, these vessels are not likely to discharge ballast at any Arctic ports as they will typically be destined for ports in either Asia or Europe. General cargo resupply vessels are the most common types of vessels operating in the eastern Arctic, and are predicted to increase in volume as northern community populations grow. Despite this increase in volume, the increase in risk is not expected to rise as these vessels are delivering supplies and not likely to discharge ballast water over the course of their journey. However, an increase in traffic volume does result in the increase in probability that an exceptional circumstance or accident may occur, leading to unintentional discharge of ballast. It is uncertain how tourism will develop in the eastern Arctic, though it is expected that the volume of passenger vessels will remain steady. However, current and expected future tourism is expected to have little impact on the risk of AIS introduction, as cruise ships would not discharge ballast unless picking up cargo or fuel – both of which are unlikely to occur in eastern Arctic ports. In the instance that Arctic fisheries become a viable industry, fishing vessels themselves will contribute little to ballast-mediated AIS risks. However, the growth of this industry could result in the construction or improvement or port infrastructure, facilitating other types of vessel arrivals. Additionally, increased input to the Pangnirtung fish processing plant could increase the risk of AIS introduction, as the product is typically exported by sea and vessels picking up cargo at this port would likely discharge ballast before loading.

Of all the types of vessel traffic currently occurring in the eastern Arctic, the greatest sources of risk are those engaging in resource development activities. There are a number of inactive mines slated to begin operation in the near future, some of which may be operational in 2055. Radloff & Hrebenyk (2010) predict that by 2020, several voyages relating to mining will be occurring in Canada's Northern waters; by 2050, additional mining voyages will be occurring, as well as oil and gas development vessels. It is too early to predict what the resource development climate will be like in the eastern Arctic in 2105. The development of resources in Canada's North is highly dependent on multiple factors, and though access is a key component it is not the primary determinant. Instead, level of demand and market value will control if and how much development occurs within Canada's eastern Arctic in future (Etienne et al., 2013).

5.4 Unexpected Findings, Limitations, & Future Research

Interestingly it was found that although Canada's policy ranked low at being able to protect eastern Arctic waters from ship-sourced non-indigenous species invasions, the Arctic remains at a low risk level. It is expected that as the Arctic warms, and under the assumption that development continues and increases, policy gaps will become more apparent and improved management methods will be necessary; this will hopefully be addressed by the required fitting of treatment systems under the IMO Convention. It was also unexpected to find that some of the Arctic's highest volume ports (Iqaluit and Pond Inlet) were at minimal risk, while Churchill which ranked 11th in terms of density of vessel volume ranked as having some risk. Further, the degree of environmental change predicted to occur both regionally and globally by 2105 was expected to have a greater effect on the environmental similarity between ports, and therefore risk of AIS, than was actually found. It was surprising that the risk of ballast-mediated species invasions at the port of Churchill did not change considerably throughout this analysis, though this may be due to the relatively low salinity at Churchill and the source ports maintaining uniform species diversity levels despite climate change impacts. This may also suggest that if other Arctic ports continue to experience "freshening" due to melting ice, they may become more environmentally dissimilar to marine source ports over time despite rising water temperatures, thus decreasing the consequence of establishment of introduced NIS.

Selecting destination ports of interest for assessment based on the density of vessel traffic rather than the type of vessel traffic which occurs there may have been a confounding variable in this study. As a result of only two ports being at a predictable level of risk, the sample size was limited and the ability to compare ranks was constrained. Inaccessibility of data complicated the accuracy of the assessment, as the specific ballast water information and voyage length had to be estimated for a few voyages. It should also be noted that using the data from 2016 for Milne Inlet may have been a better representation of the risk level due to increased output from the Baffinland iron ore mine, but 2015 data was used in order for a more consistent comparison with other Arctic ports. Additionally, considerable difficulty was encountered in terms of forecasting future conditions. Gaps in data made predicting some variables impossible, such as species richness and number of known AIS in source ports. There is also high uncertainty surrounding the forecasting of future Arctic development, vessel trends, and navigability.

In future, additional variables could be considered for more comprehensive risk assessments. These could include physical characteristics such as pH, oxygen level, and ice cover in addition to water temperature and salinity. It would also be interesting to include environmental quality as an indicator, as disturbed or impacted environments have proven to be especially vulnerable to species invasions (Cohen, 1998). However, this is difficult to quantify. Other studies could be done on the risks posed by Arctic ports as *source* ports, and more specifically sources of secondary invasion to other Arctic ports. Hull-fouling should also be explored, as previous studies have found that the eastern Arctic is more vulnerable to species invasions associated with this vector (Chan et al., 2012; Chan et al., 2015). There are also unintentional environmental impacts associated with management strategies aimed at limiting non-indigenous species introduction that could be investigated within an Arctic scope, including the use of anti-fouling paint and chemical methods of ballast treatment.

5.5 Implications and Significance

The principal implication of this study is that although there are gaps within Canada's BWM framework, the eastern Arctic remains at low-moderate risk. Though this may become more of a problem in future, immediate action in this region does not appear to be necessary. However, from a national perspective it is imperative that improved methods of BWM be developed and adopted, and that the reliance upon BWE be shifted to BWT. Transport Canada has discussed the introduction of more stringent regulations, proposing that salt water flushing occur in empty ballast tanks before entering Canadian waters, vessels with onboard BWT system be required to meet both treatment and exchange standards, and that the location of AEZs be reconsidered (Fisheries and Oceans Canada, 2015; Transport Canada, 2012). In future, the fitting of BWT systems may be enough to diminish the risk of AIS of international vessels, though this method, as well as the changes proposed by Transport Canada, do nothing to address the probability of introduction associated with domestic vessels. Consequently, future policy efforts may be directed at this type of vessel traffic.

Additionally, this study brings up an interesting question of *perceived* risk – if northern residents are concerned about the introduction of AIS and the impacts they may have, some form of action is needed. Now that multiple risk assessments of ballast-mediated species invasions have been conducted within the eastern Canadian Arctic, a risk management component in combination with stakeholder input should be used to implement action. Though it is typical for policy makers and managers to hold public consultations with stakeholder groups, it is clear in this case that consultations are not sufficient and that primary stakeholder groups should have a greater degree of power. In future, efforts should be made to accommodate the most impacted stakeholder groups into the decision and policy making process, possibly through a co-management approach. The issue of AIS is not just one of ecological risk, but also social and economic risk and these factors must be considered in more depth.

In general, little can be done in regards to controlling the consequence of establishment of introduced NIS from a marine management perspective, as increased environmental similarity as a result of climate change is a globally scaled issue. However, the probability of NIS introduction is a product of factors which can be controlled, and therefore management efforts should be focused on treating this component of the risk source.

The topic of ship-sourced AIS in the Arctic is a subject which must continue to be monitored due to the sensitivity of the environment and the highly interactive and interdependent relationship between social, economic, and environmental spheres in this region. Furthermore, impacts associated with aquatic species invasions are not restricted to a local scale, but can have international and even global implications. Conducting preliminary assessments such as the one done in this paper helps ensure the wise use of resources and improves the efficiency of management approaches.

6.0 RECOMMENDATIONS

6.1 Shift from BWE to BWT

As discussed, little can be done to control the environmental impacts of climate change which may increase the consequence of establishment of NIS. Therefore, an effort should be made to limit NIS introduction in the first place. Focus must be placed on creating type-approved treatment systems to begin the phase-in of BWT as the main BWM strategy. Government incentives could be given to stimulate and accelerate the introduction of effective technology, and research should be done on the unintended ecological effects of different treatment systems. It is imperative that Canada have a selection of type-approved BWT systems, especially with the enactment of the IMO Convention of September, 2017. It is also important that emphasis be placed upon creating systems which can be used in harsh environments, such as Canada's Arctic.

6.2 Address risks of coastal domestic vessels

As of now, vessels which operate exclusively within Canada's waters are exempted from BWM, and therefore have an increased probability of introducing NIS. Although many vessels entering the Arctic undergo voluntary BWE in an AEZ, there needs to be a legal framework in place to protect the eastern Arctic from domestic AIS introductions. There does not appear to be much risk posed by other eastern Arctic source ports, so focus should be placed upon targeting vessels arriving at Arctic destination ports from domestic non-Arctic source ports. If BWE is chosen to be the best option for domestic vessel BWM, then the location of the Arctic AEZs should be reassessed.

6.3 Target highest risk pathways

Assessments such as the one done in this study are useful for identifying the pathways of greatest risk. For example, in the case of Milne Inlet the highest risk pathways were voyages with the shortest length from environmentally-similar ports with high levels of species diversity. In contrast, in Churchill environmental similarity had little impact on overall risk. By analyzing vessel trends at individual ports, it is possible to focus inspection or management efforts on specific pathways so as to maximize efficiency while minimizing risk. For identified high risk pathways a combination of both exchange and treatment may be deemed necessary, while low risk pathways may be sufficiently addressed by only BWE.

6.4 Address alternative ship-sourced pathways of invasion

Much research has been done on the risk of ballast water as a vector for AIS introduction in Canada and the Arctic. Most of these studies as well as this one have found that the eastern Canadian Arctic is at a relatively low risk of ballast-mediated species invasions, currently and in the future. However, hull-fouling has been identified as a source of greater risk. More research should be done to understand this source of risk and to provide management solutions. Similar to ballast water management, legislation should be introduced which addresses hull-fouling management.

6.5 Focus on the social component of risk

Of the research done on ballast-mediated AIS in the Arctic, mostly all of it has to do with the ecological aspect of the issue. However, the Canadian Arctic is a unique place in terms of social structure and the nature of the relationship between environment and individual or community. Now that a solid foundation has been created from scientific research, more attention needs to be paid to addressing the socioeconomic components of this subject. This could involve social science research in order to understand the Inuit perspective on the issue, as well as stakeholder consultation and involvement. Though ballast water management is under federal jurisdiction, it may be wise in this situation to devolve some degree of managerial responsibility to regional governments regarding local requirements and enforcement, as currently the most impacted stakeholders have the least amount of power.

7.0 CONCLUSION

This study found that the current risk of ballast-mediated AIS introduction and establishment at Canada's most visited eastern Arctic ports is relatively low, and asserts that the risk will be moderate at highest in future, under both a Business as Usual management scenario as well an Improved Management Framework.

Despite increasing levels of vessel traffic and environmental similarity between connected ports facilitated by climate change, the actual number of vessels discharging ballast water in eastern Arctic ports is currently low and will most likely stay at this level unless a considerable spike in resource development occurs. However, individual high risk discharge events do occur, and there is a trend towards increasing consequence of magnitude of discharge events as time goes on due to the increasing environmental similarity of eastern Arctic ports to source ports as a result of climate change. In order to counteract this impact on the overall risk, moves should be made towards decreasing the probability of AIS introduction through more progressive and effective management approaches. Specifically, it is suggested that an effort should be made towards accelerating the phase-in of BWT as a primary means of management, and that the Regulations be amended to require management of domestic vessels travelling to the Arctic.

It is important to address the issue of ballast-mediated AIS in the context of Canada’s Arctic, as this is a problem with ecological, social, and economic implications that is expected to only increase in severity as the environmental and socioeconomic climate of the region continues to evolve.

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APPENDIX 1: FORMATION OF BINS

Uptake Event	Rank
Yes	1
No	0

Amount Taken Up (tonnes)	Rank
0 – 6,094	1
6,050 – 12,189	2
12,190 – 18,284	3
18,285 – 24,329	4
24,830 – 30,475	5

Species Diversity = ($\text{Rank}_{\text{Latitude}}$ + Rank_{SST}) / 2			
Latitude	$\text{Rank}_{\text{Latitude}}$	SST	Rank_{SST}
60º - 90ºN	1	1.0 – 5.9	1
60º - 90ºS	2	6.0 – 11.9	2
30ºS – 30ºN	3	12.0 – 17.9	3
30º - 60º N	4	18.0 – 23.9	4
30º - 60ºS	5	24.0 – 30.0	5

Species Richness	Rank
0 – 0.153	1
0.154 – 0.307	2
0.308 – 0.461	3
0.462 – 0.615	4
0.616 – 0.770	5

Management Event	Rank
No	1
BWE from saline port	0.1
BWE from freshwater port	0.01
BWT	0.01

Ballast Age (days)	Rank
1 – 3	1
4 – 6	2

7 – 9	3
10 – 12	4
12 +	5
Discharge Event	Rank
Yes	1
No	0
Amount Discharged (tonnes)	Rank
0 – 4,929	1
4,930 – 9,879	2
9,880 – 14,789	3
14,790 – 19,719	4
19,720 – 24,650	5
Environmental Distance	Rank
3.40 – 4.25	1
2.55 – 3.39	2
1.70 – 2.54	3
0.85 – 1.69	4
0 – 0.84	5
Known AIS	Rank
0 – 11.19	1
11.20 – 22.39	2
22.40 – 33.59	3
33.60 – 44.79	4
44.80 – 56.00	5

	Risk	**Probability of Introduction**	**Consequence of Establishment**
1.00	0 – 0.76	0 – 0.70	0 – 0.60
2.00	0.77 – 1.51	0.71 – 1.41	0.61 – 1.21
3.00	1.52 – 2.27	1.42 – 2.12	1.21 – 1.82
4.00	2.28 – 3.03	2.13 – 2.83	1.83 – 2.43
5.00	3.04 – 3.84	2.84 – 3.54	2.44 – 3.05

APPENDIX 2: AVERAGE SST AND SSS FOR SOURCE AND DESTINATION PORTS

	SSS (ºC)	SSS (psu)
AKULIVIK	0.4	28.8
ARCTIC BAY	-0.2	30
ARVIAT	1.41	31
AUGHINISH	11.62	35.25
AUPALUK	0.46	31.32
BALTIMORE	14.56	36
BREEVORT	-0.97	32.5
BREMEN	11.29	33
CAPE DORSET	-0.73	32
CAPE DYER	-0.48	32
CARTWRIGHT	1.57	32
CASABLANCA	20.05	36.4
CHESTERFIELD INLET	0.61	31.5
CHURCHILL	2	31
CLYDE RIVER	-0.48	32.4
COME BY CHANCE	4.86	32
CORAL HARBOR	-2	31.78
DECEPTION_BAY	0.15	32.13
DUNKIRK	11.87	34.5
GEORGE RIVER	0.13	31.94
GHENT	11	34
GIJON	15.98	35.65
GRAND ANSE	12.93	28
HALL BEACH	-0.19	31.5
HELICOPTER ISLAND	0.92	31
IGLOOLIK	-0.37	32.5
IJMUIDEN	11.68	33.87
ILE-AUX-COUDRES	7	31.5
IMMINGHAM	10.73	34.95
INUKJUAK	0.55	28
IQALUIT	0.31	32
ISKENDERUN	21.9	34.84
IVUJIVIK	1.57	32
KANGIQSUALAJUAQ	0.27	32.15
KANGIQSUJUAQ	0.27	32.15

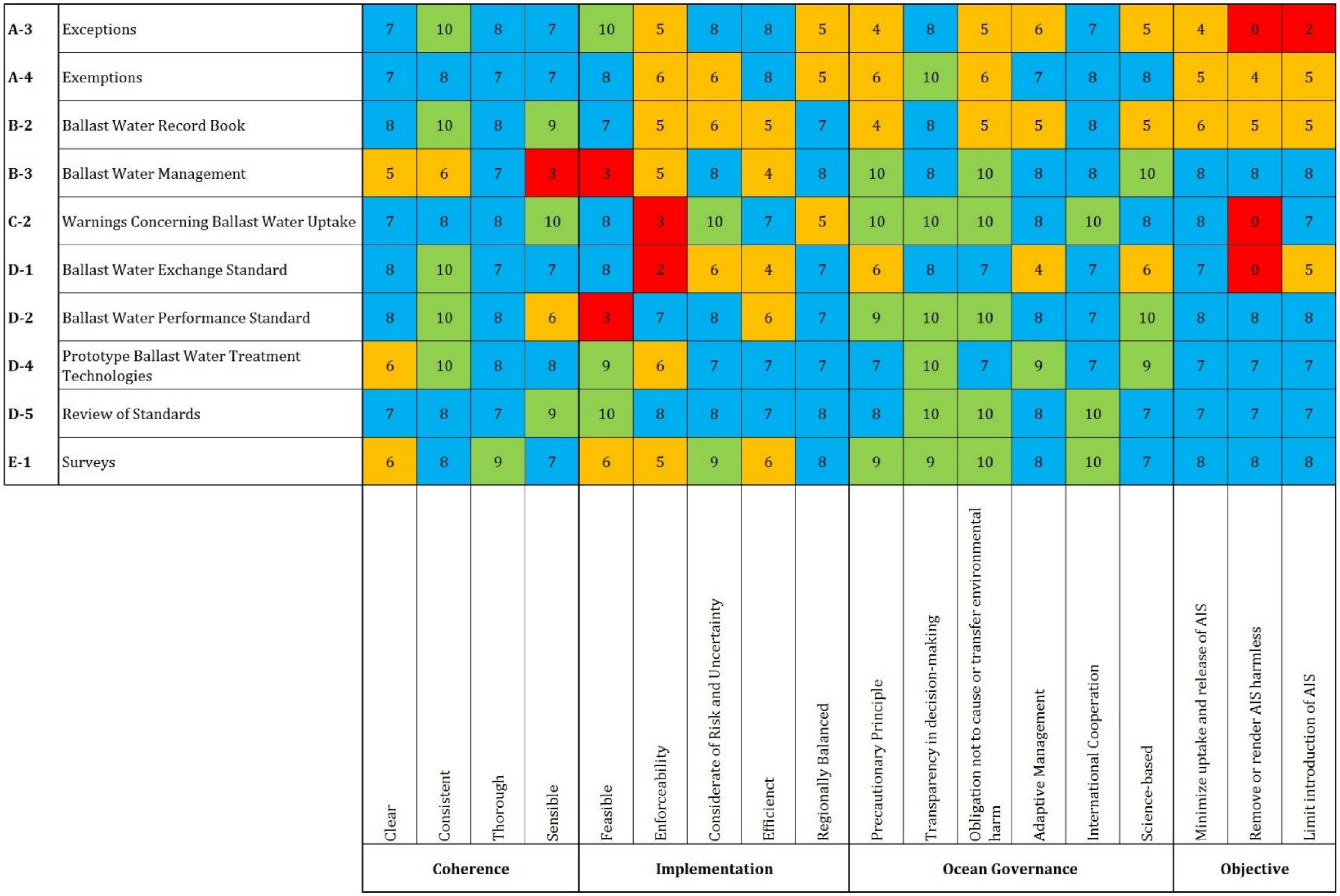
KANGIRSUK	0.19	32
KIMMIRUT	0.31	32.2
KUUJUAQ	0.62	31.32
MILNE INLET	-0.17	32
ORAN	20.11	37
PANGNIRTUNG	-0.83	31.5
POND INLET	-0.05	32.76
PUVIRNITUQ	0.04	28.8
QIKIQTARJUAQ	-0.76	31.65
QUAQTAQ	0.31	32.2
RANKIN INLET	0.92	31.54
REPULSE BAY	-1.23	31
RESOLUTE BAY	-0.91	31.8
ROTTERDAM	12.4	33.5
SALUIT	0.24	32
SAN CIPRIAN	15.8	35.7
SANIKILUAQ	0.77	28.3
SETUBAL	17.7	36
TALBOT	12.41	35
TASIUJAQ	0.79	31
TUZLA	22	38
UMIUJAQ	1.44	27.87
WHALE_ COVE	0.92	31.5
WILHELMSHAVEN	11.2	32

APPENDIX 3: FORECASTED MEAN SST VALUES

	2015	2055	2105
AKULIVIK	0.40	2.40	4.90
ARCTIC BAY	-0.20	1.8	4.3
ARVIAT	1.41	3.41	5.91
AUGHINISH	11.62	13.1	14.95
AUPALUK	0.46	2.46	4.96
BALTIMORE	14.56	15.76	17.26
BREEVORT	-0.97	1.03	3.53
BREMEN	11.29	13.47	16.2
CAPE DORSET	-0.73	1.27	3.77
CAPE DYER	-0.48	1.52	4.02
CARTWRIGHT	1.57	3.57	6.07
CASABLANCA	20.05	21.05	22.3
CHESTERFIELD INLET	0.61	2.61	5.11
CHURCHILL	2.00	4.00	6.50
CLYDE RIVER	-0.48	1.52	4.02
COME BY CHANCE	4.86	6.86	9.36
CORAL HARBOR	-2.00	0.00	2.50
DECEPTION_BAY	0.15	2.15	4.65
DUNKIRK	11.87	13.07	14.57
GEORGE RIVER	0.13	2.13	4.63
GHENT	11.00	13.18	15.91
GIJON	15.98	16.86	17.96
GRAND ANSE	12.93	14.93	17.43
HALL BEACH	-0.19	1.81	4.31
HELICOPTER ISLAND	0.92	2.92	5.42
IGLOOLIK	-0.37	1.63	4.13
IJMUIDEN	11.68	13.86	16.59
ILE-AUX-COUDRES	7.00	9	11.5
IMMINGHAM	10.73	12.91	15.64
INUKJUAK	0.55	2.55	5.05
IQALUIT	0.31	2.24	4.74
ISKENDERUN	21.90	24.5	27.75
IVUJIVIK	1.57	3.57	6.07
KANGIQSUALAJUAQ	0.27	2.27	4.77
KANGIQSUJUAQ	0.27	2.27	4.77
KANGIRSUK	0.19	2.19	4.69

KIMMIRUT	0.31	2.31	4.81
KUUJUAQ	0.62	2.62	5.12
MILNE INLET	-0.17	1.83	4.33
ORAN	20.11	21.29	22.77
PANGNIRTUNG	-0.83	1.17	3.67
POND INLET	-0.05	1.95	4.45
PUVIRNITUQ	0.04	2.04	4.54
QIKIQTARJUAQ	-0.76	1.24	3.74
QUAQTAQ	0.31	2.31	4.81
RANKIN INLET	0.92	2.92	5.42
REPULSE BAY	-1.23	0.77	3.27
RESOLUTE BAY	-0.91	1.09	3.59
ROTTERDAM	12.40	14.58	17.31
SALUIT	0.24	2.24	4.74
SAN CIPRIAN	15.80	16.68	17.78
SANIKILUAQ	0.77	2.77	5.27
SETUBAL	17.70	19.7	22.2
TALBOT	12.41	14.41	16.91
TASIUJAQ	0.79	2.79	5.29
TUZLA	22.00	24.6	27.85
UMIUJAQ	1.44	3.44	5.94
WHALE COVE	0.92	2.92	5.42
WILHELMSHAVEN	11.20	13.38	16.11

APPENDIX 4: IMO CONVENTION MATRIX ANALYSIS



		Coherence				Implementation					Ocean Governance						Objective		
		Clear	Consistent	Thorough	Sensible	Feasible	Enforceability	Considerate of Risk and Uncertainty	Efficient	Regionally Balanced	Precautionary Principle	Transparency in decision-making	Obligation not to cause or transfer environmental harm	Adaptive Management	International Cooperation	Science-based	Minimize uptake and release of AIS	Remove or render AIS harmless	Limit introduction of AIS
A-3	Exceptions	7	10	8	7	10	5	8	8	5	4	8	5	6	7	5	4	0	2
A-4	Exemptions	7	8	7	7	8	6	6	8	5	6	10	6	7	8	8	5	4	5
B-2	Ballast Water Record Book	8	10	8	9	7	5	6	5	7	4	8	5	5	8	5	6	5	5
B-3	Ballast Water Management	5	6	7	3	3	5	8	4	8	10	8	10	8	8	10	8	8	8
C-2	Warnings Concerning Ballast Water Uptake	7	8	8	10	8	3	10	7	5	10	10	10	8	10	8	8	0	7
D-1	Ballast Water Exchange Standard	8	10	7	7	8	2	6	4	7	6	8	7	4	7	6	7	0	5
D-2	Ballast Water Performance Standard	8	10	8	6	3	7	8	6	7	9	10	10	8	7	10	8	8	8
D-4	Prototype Ballast Water Treatment Technologies	6	10	8	8	9	6	7	7	7	7	10	7	9	7	9	7	7	7
D-5	Review of Standards	7	8	7	9	10	8	8	7	8	8	10	10	8	10	7	7	7	7
E-1	Surveys	6	8	9	7	6	5	9	6	8	9	9	10	8	10	7	8	8	8

		Clear	Consistent	Thorough	Sensible	Feasible	Enforceability	Considerate of Risk and Uncertainty	Efficient	Regionally Balanced	Precautionary Principle	Transparency in decision-making	Obligation not to cause or transfer environmental harm	Adaptive Management	International Cooperation	Science-based	Minimize uptake and release of AIS	Remove or render AIS harmless	Limit introduction of AIS
G1	Sediment Reception Facilities	7	7	4	6	6	5	8	5	6	10	8	9	6	7	7	7	7	7
G2	Ballast Water Sampling	8	9	9	7	6	6	7	5	7	6	7	7	9	9	10	5	7	6
G3	Equivalent Compliance	7	10	6	7	7	3	9	6	4	7	6	9	5	5	6	9	0	5
G4	Ballast Water Management & Ballast Water Management Plans	9	10	8	8	8	6	7	7	9	8	10	8	8	6	7	7	5	6
G5	Ballast Water Reception Facilities	7	7	6	7	6	5	8	7	6	10	8	9	6	7	7	7	7	8
G6	Ballast Water Exchange	8	9	7	8	8	5	9	5	6	5	6	5	5	6	7	6	0	4
G7	Risk Assessment	8	10	9	10	5	7	10	6	6	8	10	8	9	10	10	7	0	6
G8	Approval of Ballast Water Management Systems	7	10	9	6	7	8	7	4	6	9	9	10	9	8	10	7	8	8
G9	Approval of Ballast Water Management Systems Using Active Substances	7	7	7	8	8	8	8	7	8	8	8	9	9	7	10	7	8	8
G10	Prototype Ballast Water Treatment Technology	6	7	8	5	6	7	8	8	7	6	7	7	9	7	8	6	6	6
G11	Ballast Water Exchange Design and Construction Standards	6	6	5	6	6	3	7	6	8	4	5	4	6	6	6	6	0	4
G12	Design and Construction for Sediment Control	8	9	7	8	8	7	6	9	6	6	6	7	6	6	7	6	0	4
G13	Additional Measures	8	10	7	7	8	6	9	6	6	9	9	10	8	10	7	8	6	8
G14	Designatin of Areas for Ballast Water Exchange	8	9	7	8	7	5	6	7	4	5	9	5	7	9	9	6	0	4
G15	Port State Control	10	10	9	8	8	8	8	6	5	6	8	8	6	10	6	6	5	6
		Coherence				**Implementation**					**Ocean Governance**						**Objective**		