The Development of Ballast Water Management in Canada: A Critical Analysis of the Journey

By

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LIST OF ABBREVIATIONS

AIS	Aquatic Invasive Species
BOB	Ballast on Board
BW	Brackish Water
BWE	Ballast Water Exchange
BWMC	IMO 2004 *International Convention for the Control and Management of Ships' Ballast Water and Sediments*
CBD	Convention on Biological Diversity
CCG	Canadian Coast Guard
CMAC	Canada's Marine Advisory Council
CWA	*Clean Water Act*
DFO	Fisheries and Oceans Canada
EC	Environment Canada
ECAREG	Eastern Canada Vessel Traffic Services Zone
EEZ	Exclusive Economic Zone
EPA	Environmental Protection Agency
FW	Fresh Water
GLFC	Great Lakes Fishery Commission
GLR	Great Lakes Region
GLWQA	*Great Lakes Water Quality Agreement*
HAB	Harmful Algal Bloom
IMO	International Maritime Organization
MCTSC	Marine Communication and Traffic Services Centre
MEPC	IMO Marine Environment Protection Committee
MOE	Mid-Ocean Exchange
NANPCA	*Non-Indigenous Nuisance Prevention and Control Act*
NIS	Non-Indigenous Species
NISA	*National Invasive Species Act*
NOBOB	No Ballast On-Board
NS	Nova Scotia
PSU	Practical Salinity Units
SW	Salt Water
TC	Transport Canada
US	United States
USCG	United States Coast Guard
USFWS	United States Fish and Wildlife Service
VPA	Vancouver Port Authority
VPC	Vancouver Port Corporation

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ABSTRACT

Non-indigenous species (NIS) and aquatic invasive species (AIS) create significant risks when introduced to foreign ecosystems. One of the many vectors facilitating the transport of NIS is ballast water, and as commercial shipping increases globally so too does the use of ballast water. Despite Canadian regulations and international guidelines put forth by the International Maritime Organization, ballast water has facilitated the introduction of several NIS to Canada. This paper seeks to analyze the development of, and identify gaps in, Canadian ballast water management, in the context of marine ecosystems. Although large-scale ballast water management in Canada began in the late 1980s, many management gaps have persevered through time, and put Canada's coasts at risk of NIS introduction. Such management gaps include: intracoastal shipping; salinity issues associated with mid-ocean exchange and euryhaline species; vessels reporting 'No-Ballast On Board'; lack of monitoring, and; issues surrounding political will. Additionally, ballast water regulations for the Canadian Arctic have not been thoroughly considered which represents a significant management gap, especially since the Arctic will continue to see an increase in warming and subsequently, commercial shipping in the future. Relevant case studies of ballast water-mediated introductions to marine ecosystems are also explored, including: European green crabs (*Carcinus maenas*) to Newfoundland; Chinese mitten crabs (*Eriocheir sinensis*) to the St. Lawrence River, and; copepods to the Pacific Northwest. Several recommendations for Canadian ballast water management are generated in order to protect Canada's vulnerable marine ecosystems for generations to come.

Keywords: ballast water management (BWM); ballast water exchange (BWE); non-indigenous species (NIS); aquatic invasive species (AIS); Canadian policy; marine ecosystems.

1.0 INTRODUCTION

"Invasions of new species by ships may in future severely obscure the picture of natural dispersion of marine invertebrates" (Thorson, 1961, p. 458).

1.1 Non-Indigenous Species and Aquatic Invasive Species

The Convention on Biological Diversity (CBD) defines non-indigenous species (NIS) as species introduced outside their natural past or present range, which might survive and subsequently reproduce, and that may or may not cause harm to native ecosystems (CBD, 1992). Aquatic invasive species (AIS) are a distinct subset of NIS: AIS are one of the most significant threats to global biodiversity, and are a leading cause of animal extinctions worldwide (Sala et al., 2000; Clavero and Garcia-Berthou, 2005). The Government of Canada defines AIS as alien species that become established in a new region and that disrupt the balance of the ecosystem, ultimately causing irreversible damage to the environment (CCFAM, 2004). AIS have the capacity to change community structure, alter food webs, displace native species, diminish fisheries, and alter major ecosystem processes such as nutrient cycling (Molnar et al., 2008). In addition to altering ecosystems, AIS are capable of damaging man-made systems, fouling structures such as ship hulls, piers, and buoys, and clogging intake pipes (Molnar et al., 2008).

Although some NIS disperse naturally, anthropogenic-mediated invasions are prevalent: thousands of NIS have been transported globally by humans (Ruiz et al., 1997; Cohen and Carlton, 1998; Roman and Darling, 2007). One of many ways that NIS can be transported is via ballast water, which is one of the leading vectors for transporting and introducing species (Ruiz et al., 1997; Bax et al., 2003; Holeck et al.¸ 2004; Roman and Darling, 2007).

1.2 A Brief History of Ballast Water

In the past, a variety of materials have been utilized to control a ship's stability and trim (i.e., tilt of the vessel): for centuries, rocks and sand collected from nearby seashores were used, thus facilitating the transport of associated benthic marine organisms living in the dry ballast (Carlton, 1985; Davidson and Simkanin, 2012). In the late 1870s, iron-hulled ships became established, and the use of ballast water instead of solid ballast became common practice (Carlton, 1985; Davidson and Simkanin, 2012). Planktonic species suspended in the ballast water and benthic species and cysts in the sediments of the ballast tanks were now transferable across the globe, but it took several decades for the significance of this practice to be documented and understood (Davidson and Simkanin, 2012).

It is currently common practice for commercial vessels to pump ballast water into ballast holding tanks of ships for stability and trim (Wonham et al., 2001). Today, ballast water has mediated the transfer and introduction of at least one third of documented marine invasions around the world (Hewitt and Campbell, 2010). A variety of management strategies, on both a national and an international scale have been developed to address the problem of NIS transport via ballast water. Despite Canadian ballast water management beginning in the early 1980s, ballast water-mediated introductions still occur today, indicating that current management strategies are not wholly effective.

1.3 Purpose and Scope of This Paper

The purpose of this project is to review and analyze the development of ballast water regulation and management in Canada, from its inception in the early 1980s to its current status. Ballast water management in Canada initially predominantly focused on the Great Lakes Region (GLR), as indicated in Canada's initial ballast water management guidelines (see section 3.3.3;

Locke et al., 1991). This paper, however, will focus on evaluating the implementation of these management strategies in marine ecosystems. This will be conducted by assessing major developments and legislation in accordance with relevant international policies (specifically United States (US) and International Maritime Organization (IMO)). By analyzing the timeline of events, management gaps will be identified, and relevant recommendations for consideration in future ballast water management policy development will be generated, to help ensure that Canada's coasts are protected for generations to come.

Canada is currently in the process of implementing new international ballast water standards, as a result of the 2010 ratification of the IMO's 2004 Ballast Water Management Convention (BWMC; see sections 3.3.8 and 3.4.2). These ballast management guidelines were not available from the office of the Minister of Transport at the time that this document was being prepared. Therefore, this evaluation is limited to publicly available documents on past and current ballast management legislation and guidelines, and will not speculate on Canada's future implementation of ballast water discharge standards outlined in the IMO's BWMC, yet to be ratified on a global scale (see section 3.4.2).

2.0 METHODOLOGY

2.1 Methods and Sub-Questions

The literature for this project was obtained from a variety of different sources. The Web of Science database was primarily used to locate relevant primary literature. A network of current and former scientists and policy analysts from Fisheries and Oceans Canada (DFO), Transport Canada (TC), and Canadian Coast Guard (CCG) was utilized to locate grey literature, and otherwise difficult to obtain documents and notices. All of the aforementioned literature was analyzed to determine Canada's current ballast water management status, and to generate detailed historical ballast water management timelines.

Although the primary goal of this research was to analyze the evolution of ballast water management in Canada, a variety of sub-questions were generated to further assist this goal. The sub-questions that this project strives to address are:

1. What is the purpose and history of ballast water use?
2. How are NIS and AIS introduced via ballast water problematic?
3. What are the predominant NIS and AIS transport vectors?
4. What are the differences between freshwater and saltwater ballast water management?
5. What is the international history (e.g., US, IMO) of ballast water management as relevant to Canadian policy?
6. What issues are historically and currently associated with Canadian ballast water management?
7. What recommendations and future considerations are associated with Canadian ballast water management?

3.0 LITERATURE REVIEW

3.1 Transport Vectors

Vectors that facilitate the transport of NIS to non-native regions can be classified as either primary or secondary pathways (Lacoursiere-Roussel et al., 2012). Primary pathways mediate the transport and initial introduction of organisms from native to non-native habitats and would not be possible via natural mechanisms, such as larval dispersal (e.g., Wonham et al., 2001; Puth and Post, 2005; DiBacco et al., 2012). Primary introductions are usually followed by secondary dispersal as most species spread from its primary location of introduction (DiBacco et al., 2012). Secondary spread transpires post-establishment via natural (e.g., larval dispersal) or human-mediated vectors (e.g., hull-fouling). Secondary vectors can be the same as or different from vectors that mediate primary introductions (Murray et al., 2014).

This section (3.1) reviews transport vectors that mediate and facilitate the primary and secondary spread of aquatic NIS to and within Canada. The *Canadian Action Plan to Address the Threat of Aquatic Invasive Species* identifies the following seven pathways for the introduction and spread of AIS (CCFAM, 2004).

3.1.1 Ship-Mediated

Ship mediated introductions of NIS occur when vessels inadvertently transport species that are capable of surviving in ballast water, or that are attached to the hulls of ships arriving from foreign ports (CCFAM, 2004; Hulme et al., 2008). Many types of vessels are capable of transporting NIS, including, but not limited to, commercial vessels, naval vessels and cruise ships (CCFAM, 2004). As such, most documented introductions of marine and freshwater NIS, including invasive species, have been attributed to ship-mediated introductions, although there are additional ship-based vectors that facilitate the transport of NIS (e.g., dry ballast, cargo and packing materials) (Mills et al., 1993; Fofonoff et al., 2003; Ricciardi, 2006; Molnar et al., 2008; Lacoursiere-Roussel et al., 2012).

There are several different estimates demonstrating the prevalence of ship-mediated introductions. Molnar et al. (2008) found that 69% of marine invasive species were introduced via the shipping vector: 31% were transported via ballast water alone, 39% were transported via hull-fouling alone, and 31% were transported by either hull-fouling or ballast water. Fofonoff et al. (2003) found that of the confirmed non-native species of algae and invertebrates introduced to North America, shipping was a possible vector for the introduction in 79.5% of cases. Finally, of the mobile (organisms capable of self-induced movement) biota introduced via shipping since 1900, 48% were introduced by ballast water alone, while a further 39% were attributed to either ballast water or hull-fouling vectors (Fofonoff et al., 2003).

Although study estimates vary, ballast water is consistently the largest source of historically introduced AIS in Canada (CCFAM, 2004). Many other studies have cited ballast water as the most common pathway for introduction on a global scale, including: Ruiz et al., 1997; Bax et al. 2003; Holeck et al., 2004; DiBacco et al., 2012, and; Pam et al., 2013.

3.1.2 Recreational Boating

The recreational boating pathway consists of both in-water and land-based transport of all non-transoceanic vessels, which are part of the shipping pathway (e.g., commercial vessels, naval vessels, cruise ships) (CCFAM, 2004). Watercraft such as yachts, canoes, motorboats, and any associated equipment (e.g., trailers) are all part of this pathway. There are few regulations targeted at recreational boaters to prevent the spread of NIS, which is not indicative of the relative importance of the recreational boating pathway (CCFAM, 2004; Kelly et al., 2013).

Recreational boating is thought to be one of the most important secondary vectors for the spread of invasive organisms worldwide (Minchin et al., 2006; Kelly et al., 2013). For instance, invasive algae have been shown to be prone to entanglement on the propeller or anchor line of boats, whereas bivalves, such as zebra (*Dreissena polymorpha*) and quagga mussels (*Dreissena rostriformis bugensis*), often foul boating equipment, hulls, or entangled algae (Ricciardi et al., 1995; Kelly et al., 2013). Given that the successful short-term overland dispersal of zebra mussels is highly probable, and that zebra mussels can survive out of water for up to approximately 15 days, the recreational boating pathway poses a significant risk for the unwanted introduction of new species (McMahon and Payne, 1992; Ricciardi et al., 1995).

3.1.3 Live Bait

The use of live bait to catch fish by both recreational and commercial anglers defines this pathway (CCFAM, 2004). Non-native bait species can be spread via bait buckets or harvest gear, and can be spread either intentionally or unintentionally (CCFAM, 2004). In addition, dead bait may mediate the potential transfer of parasites or other diseases that can become invasive when introduced to a new habitat (CCFAM, 2004).

Anglers and live bait have long been implicated as an invasion pathway (Litvak and Mandrak, 1993; Drake and Mandrak, 2014). Although many jurisdictions prohibit the release of bait, anglers often release leftover bait into nearby waters (Litvak and Mandrak, 1993). In 2006, over 103 million bait fish were sold to anglers in Ontario alone, thus the use of live bait as a vector for NIS has been identified as a significant issue (OMNR, 2006).

3.1.4 Aquarium Trade

The *Canadian Action Plan to Address the Threat of Aquatic Invasive Species* defines the aquarium trade pathway as the unintentional or intentional release of aquatic organisms (i.e., invertebrates, fish, plants) for use in ornamental pools, aquariums, or water gardens (CCFAM, 2004). The world aquarium and aquatic ornamental trade is a multi-billion dollar per year industry, and this trend shows no sign of diminishing: ten years ago, it was predicted that, on a global scale, the industry will grow annually by 14% (Padilla and Williams, 2004; Katsanevakis et al., 2013).

Hobbyists in the aquarium trade are important vectors to consider regarding the introduction of NIS; in many cases, hobbyists may be uniformed or the species in question may be misidentified, further exacerbating the spread of AIS (Kay and Hoyle, 2001). The aquarium trade industry is largely unregulated, and is a significant source of invasive species: globally, over 150 AIS (mostly fish) in natural ecosystems have been documented to come from the aquarium trade (Padilla and Williams, 2004).

3.1.5 Live Food Fish

The live food fish vector refers to any aquatic organism (i.e. finned fish, shellfish) transferred within or imported to Canada for human consumption (CCFAM, 2004; Kerr et al., 2005). There is a long history in British Columbia and on the Canadian Atlantic coast of live fish being shipped to both national and international markets (CCFAM, 2004). In Ontario alone, over 1 million kg of live marine invertebrates and over 700,000 kg of live freshwater fish are imported annually (Kerr et al., 2005). These activities are regulated by the federal *Fish Inspection Act* and are monitored by the Canadian Food Inspection Agency; however with these quantities, the risk of introduction of unwanted organisms (e.g., NIS, AIS) still exists (Kerr et al., 2005).

There are many issues associated with live food fish. For instance, sterility is not a requirement for the live food fish industry, and there are minimal regulations in place regarding the disposal of holding water and packing materials, which may contain invasive pathogens, gametes, or fertilized eggs (Kerr et al., 2005). Additionally, both live and dead unsold food fish may be released by the transporter, resulting in the further risk of non-native species becoming invasive (Kerr et al., 2005). As an example, it has been suggested that the primary introduction of the European green crab (*Carcinus maenas*) to San Francisco Bay on the west coast of the US likely occurred via shipments of live food fish from the east coast (CCFAM, 2004).

3.1.6 Canals and Water Diversions

The canal and water diversion pathway consists of channels that are used for commercial shipping or water diversion (CCFAM, 2004). Canals are man-made, artificial connections that allow for movement across physical barriers both within (intra-basin) and between (inter-basin) watersheds (Kerr et al., 2005). Currently, the Canadian Government is opposed to any inter-basin canal or water diversion projects, as it may result in the introduction of NIS to Canadian waters (CCFAM, 2004).

The role of canals and water diversions in the introduction of NIS should not be underestimated. For instance, the construction of the Welland Canal in 1829 allowed sea lampreys (*Petromyzon marinus*) to bypass Niagara Falls and gain access to the Upper Great Lakes (Lawrie, 1970; Mills et al., 1993). Despite strict regulations by the Canadian Government, it is predicted that the construction of canals and water diversions will continue to facilitate the movement of AIS in North America (Mills et al., 2000).

3.1.7 Unauthorized Introductions

The unauthorized introductions pathway refers to the transfer or introduction of any fish, shellfish, or plant that is not authorized by a federal, provincial, or territorial agency (CCFAM, 2004). The majority of introductions in Canada are anthropogenic and unauthorized, suggesting that the risk of aquatic invasions between ecosystems is a risk that requires adequate management, including raising awareness among citizens that are uninformed of the potential ecological and commercial problems associated with the introduction of NIS to native ecosystems (Dextrase and Mandrak, 2006).

3.2 Historical Invasions

AIS can invade on many spatial scales, with varying social, economic, and environmental consequences. The following section will explore historical examples of invasions on different spatial scales, including continental (Ponto-Caspian region), regional (Laurentian Great Lakes), and local perspectives (Nova Scotia, Canada).

3.2.1 A Continental Perspective – Ponto-Caspian Region

Within the past 70 years, jellyfish and related species have posed a problem as invaders, particularly species such as the comb jelly (ctenophore), *Mnemiopsis leidyi* (Purcell, 2012). *M. leidyi* has successfully invaded many water bodies in the Ponto-Caspian region, including the Black Sea (1980s), Caspian Sea (1999), North Sea (2006), Baltic Sea (2006), and recently, the Mediterranean Sea (2009) (Kube et al., 2007; Boero et al., 2009; Kim et al., 2013).

The primary vector for introduction of *M. leidyi* to the Black Sea is thought to be ballast water (Shiganova, 1998; Ghabooli et al., 2013). At the peak of its invasion in the Black Sea in 1989, there were over 300 individuals per meter^3 of water; this resulted in significant economic losses to local fisheries, and a loss of several thousand local fishing jobs (Knowler, 2005; Kube, et al., 2007). Estimates of economic losses vary widely, and range from $16.7 million to $309 million per year (Caddy, 1992; Knowler, 2005). In addition to local losses of employment, there are many other social consequences of *M. leidyi* or jellyfish invasions, including: increased injuries among bathers, enhanced negative perception of ocean ecosystems, and decreased recreational usage of the oceans (Purcell et al., 2007; Richardson et al., 2009; Gershwin et al, 2010).

Environmentally, the impacts of a *M. leidyi* or jellyfish invasion may include ecosystem degradation and a loss of biodiversity (Mills, 2001; Brotz et al., 2012). Additionally, oxygen requirements following massive die-offs and subsequent decomposition characteristic of population explosions may surpass ambient oxygen levels available in the region, and result in hypoxic or even anoxic conditions, thereby further impacting aerobic species and environments (Pitt et al., 2009).

Table 1 – Summary of some social, environmental, and economic impacts that the ctenophore *Mnemiopsis leidyi* and jellyfish invasions have had on human populations.

Social	**Environmental**	**Economic**
Loss of power/blackouts (Gershwin, 2013)	Ecosystem degradation (Brotz *et al.*, 2012)	Nuclear or power plant shutdowns (Gershwin, 2013; Richardson *et al.*, 2009)
Injury or death (Richardson *et al.*, 2009)	Loss of biodiversity – monoculture of species (Mills, 2001)	Desalination plant closures (Gershwin, 2013)
Increased fear/negative perception of oceans (Gershwin *et al.*, 2010)	Hypoxic or anoxic conditions during decomposition (Pitt *et al.*, 2009)	Loss in tourist revenue (Richardson *et al.*, 2009)
Decreased recreational use of oceans (Purcell *et al.*, 2007)		Loss in fisheries revenue (Richardson *et al.*, 2009)

3.2.2 A Regional Perspective – Laurentian Great Lakes

It is estimated that the Laurentian GLR contains over 139 NIS, many of which have become invasive, such as: *Petromyzon marinus* (sea lamprey), Dreissena *polymorpha* (zebra mussels), *Dreissena rostriformis bugensis* (quagga mussels), and *Neogobius melanostomus* (round gobies) (Vanderploeg et al., 2002; Beeton, 2002). Perhaps the most infamous of these invaders has been the zebra mussel, which was likely introduced to the GLR via ballast water discharge containing veligers sometime in 1986 or 1987, or as early as 1985 (Hebert et al., 1989; Griffiths et al., 1991; Mackie, 1991). Zebra mussels were first seen in Lake St. Clair (Windsor, Ontario) in June 1988: by September 1990, they were found in all the Great Lakes (Griffiths et al., 1991; Vanderploeg et al., 2002).

Zebra mussels are thought to have invaded an empty or underutilized niche within the GLR, and colonized benthic and littoral environments alike (Vanderploeg et al., 2002). The rate at which zebra mussels invaded was swift, and caused significant environmental changes;

namely, a reduction of nutrients in the surrounding water effectively clarified the water column and thereby changed the structure and function of the surrounding ecosystem (Mackie, 1991; Sousa et al., 2014). In addition, there continue to be severe socio-economic impacts from the zebra mussel invasion, including: fouling of commercial fishing gear; hull fouling of commercial and recreational boats, resulting in reduced sailing efficiency; beaches lined with dead shells, resulting in bather injuries; and reduced flow rates in water intake pipes (Mackie, 1991). Since their introduction to the GLR, zebra mussels have caused upwards of $138 million per year in damage to human infrastructure alone (Lodge and Finnoff, 2008; Bailey et al., 2011a; Rothlisberger et al., 2012).

3.2.3 A Local Perspective –Nova Scotia, Canada

Tunicates are sessile, filter-feeding animals that live as either solitary individuals or colonies attached to natural (e.g. rocks) or manmade (e.g. piers) substrates (Howes et al., 2007; Pearse et al., 2010). In recent years, Atlantic Canadian provinces have experienced a significant increase in several invasive tunicate species. DFO has identified clubbed tunicate (*Styela clava*), golden star tunicate (*Botryllus schlosseri*), vase tunicate (*Ciona intestinalis*), and violet tunicate (*Botrylloides violaceus*) as AIS (Sephton et al., 2011; Moore et al., in press). Perhaps one of the most notorious species of invasive tunicates in Nova Scotia (NS) is the cryptogenic (of unknown origin) vase tunicate, *C. intestinalis*. Invasive *C. intestinalis* in NS and across the world was not recognized as having an impact until recently, primarily due to an increase in dispersion via ship fouling and ballast water transfer (Lambert and Lambert, 1998; Carver et al., 2006).

In NS, one of the primary concerns associated with invasive tunicates is their impact on the shellfish aquaculture industry: extensive aquaculture fouling (e.g., on aquaculture gear and shellfish) by *C. intestinalis* was first reported in 1997 in Lunenburg, and the problem continued in 1998-1999 (Carver et al., 2003; Vercaemer et al., 2011). While economic losses associated with tunicate fouling (and other invasive species) in NS's aquaculture industry are not publically available, stakeholders are concerned that tunicate invasions will have an impact on aquaculture (DFO, 2006). In addition to economic concerns, tunicate invasions create significant environmental impacts, such as increased amounts of fecal matter on the benthos leading to the development of hypoxic conditions, and thus the deterioration of benthic communities (Carver et al., 2006). Additionally, tunicate invasions may displace native species and enhance trophic competition by depleting available food resources, and negatively impact populations of microzooplankton, such as ciliates or planktonic bivalve larvae (Jorgensen et al., 1984; Bingham and Walters, 1989; Petersen and Riisgaard, 1992).

3.3 A Canadian Historical Perspective of Ballast Water Management

A brief analysis of the historically published AIS literature indicates that the Laurentian GLR are far more highly studied than any of Canada's marine ecosystems. Based on the invasion history of the GLR (see section 3.2.2), it is logical that, initially, policies regarding AIS and ballast water management were targeted at invasions in the GLR: indeed, sources cite that 55-70% of invasions in the GLR since 1959 are attributable to the release of ballast water (Ricciardi, 2006; DFO, 2011a). In the approximately 25 years that have passed since zebra mussels invaded the GLR (Mills et al., 1993; Ricciardi and Rasmussen, 1998), however, ballast water and AIS management still seems to be targeted at the GLR with less emphasis on coastal marine systems, as will be discussed in the following sections. A detailed, amalgamated timeline of Canadian, American, and IMO policies (as relevant to Canadian ballast water management) can be found in the Appendix of this paper.

3.3.1 Early Attempts at Ballast Water Management

In 1982, CCG issued Notice to Mariners #995, which prevented ships bound for Mines Seleine's pier in the Grande Entrée Lagoon of the Magdalen Islands from discharging ballast water obtained in high risk areas (Gosselin et al., 1995; Gauthier and Steel, 1996; Claudi and Ravishankar, 2006). High risk areas were specifically identified within the Notice, and included regions such as: Bay of Fundy, west of the eastern tip of Anticosti Island, and waters within five nautical miles of the Canadian shoreline (NOTMAR, 1982).

Notice to Mariners #995 was issued to prevent the introduction of toxic phytoplankton to bays containing mussel aquaculture farms in the Grande Entrée Lagoon (Claudi and Ravishankar, 2006). This notice was renewed on a yearly basis and prohibited ships from discharging ballast water within 10 nautical miles of the islands (Gosselin *et al.*, 1995; Claudi and Ravishankar, 2006).

A review of available literature indicates that this was Canada's first localized attempt at ballast water management. Due to the ever-present threat of AIS in ballast water, over time, ballast water management efforts would become more pronounced and applied at a larger scale.

3.3.2 The Impetus for Large-Scale Canadian Ballast Water Management

The introduction of AIS to inland waters of Canada, specifically to the GLR, has been facilitated by the completion of several engineering projects. The completion of these projects (e.g., Welland Canal (1829), locks in Sault Ste. Marie (1855), canal system in the St. Lawrence River (1847)) dissolved the natural barriers between Canadian and American waters (Mills et al., 1993). The most notable engineering example was the opening of the St. Lawrence Seaway in 1959, which allowed vessels to travel from the Atlantic Ocean across the Great Lakes, to the western side of Lake Superior (Ashworth, 1986; Mills et al., 1993; Ricciardi, 2006; DFO, 2011a). The opening of the St. Lawrence Seaway resulted in transoceanic ships traveling to major cities and distribution centres located throughout the GLR, and a dramatic increase in the amount of ballast water released and transported throughout the Great Lakes (Mills et al., 1993). Many transoceanic vessels entering the GLR not carrying cargo (or partial loads) were ballasted, which required discharging ballast water picked up from the previous port(s) of call before loading new cargo (Holeck et al., 2004). In 1990, it was estimated that transoceanic vessels pumped at least 719,473 tonnes of ballast water into the St. Lawrence Seaway alone (Locke et al., 1991). In addition to transoceanic vessels, by the late 1980s, domestic ships in the GLR were releasing more than 50 million tonnes of ballast water, aiding in the primary introduction and secondary spread of NIS or AIS (Wiley and Claudi, 2002). Significant introductions of note include the zebra mussel, *Dreissena polymorpha* (see section 3.2.2), the spiny water flea, *Bythotrephes longimanus* (formerly *Bythotrephes cederstroemii*), and the Eurasian ruffe, *Gymnocephalus cernuus* (IJC/GLFC, 1990; Locke et al., 1991; Mills et al., 1993).

Recognizing the socioeconomic and environmental damages being caused to the GLR by AIS, Canada, along with the US and Australia, approached the IMO's Marine Environmental Protection Committee (MEPC) in 1988 to raise the issue of global ballast water management (see section 3.4.2; Wiley and Claudi, 2002). Their concerns were legitimized in 1991 when the IMO adopted voluntary *Guidelines for Preventing the Introduction of Unwanted Organisms and Pathogens from Ships' Ballast Water and Sediment Discharges* (MEPC 50(31)) (see 3.4.2; IMO, 1991; Wiley and Claudi, 2002). Canada's influence in the development of early ballast water management guidelines is evidenced by the fact that these initial guidelines were based on Canada's newly instated 1989 voluntary ballast water guidelines (see section 3.3.3; TC, 2007).

3.3.3 *Voluntary Guidelines for the Control of Ballast Water Discharges from Ships Proceeding to the St. Lawrence River and Great Lakes*

The *Voluntary Guidelines for the Control of Ballast Water Discharges from Ships Proceeding to the St. Lawrence River and Great Lakes* (hereafter referred to as *Voluntary Guidelines*) was Canada's first large-scale attempt at mitigating the introduction of AIS via ballast water. The objective of these *Voluntary Guidelines* was to protect the waters of the GLR from "non-native fish and other aquatic organisms, that can be harmful to the balance of nature that now exists" (Locke et al., 1991, p. 47). The *Voluntary Guidelines* were developed by CCG in consultation with DFO, Environment Canada (EC), United States Coast Guard (USCG), Great Lakes Fishery Commission (GLFC), and Canadian and American commercial fishing representatives, and were released on 1 May 1989. The responsibility of distributing and promoting these guidelines to transoceanic vessels entering Canadian waters fell to the CCG. In this case, 'transoceanic' refers to those vessels destined for the GLR that have "left the North American continental shelf [i.e. Canada's Exclusive Economic Zone (EEZ)] on their inbound voyage" (Locke et al., 1991, p. 48).

The *Voluntary Guidelines* were the first to promote mid-ocean ballast water exchange (MOE) as a means to protect the Great Lakes ecosystem from the introduction of non-indigenous organisms. Specifically, the *Voluntary Guidelines* were the first to recommend that ballast water exchange (BWE) occur beyond the continental shelf or beyond the effects of freshwater currents. BWE was considered the most viable method for mitigating AIS impacts at the time largely because the open ocean contained fewer organisms than coastal regions, and because marine organisms picked up during MOE were unlikely to survive in freshwater systems like the GLR following deballasting (Reeves, 2000; DFO, 2014).

The *Voluntary Guidelines* applied to all transoceanic ships traveling the Eastern Canada Vessel Traffic Services Zone (ECAREG) that were destined for the St. Lawrence Seaway and the GLR. Vessels carrying ballast water were requested to provide the location and depth where BWE was performed, or the location where ballast water was taken on. Additionally, vessels were requested to exchange water as far from shore as was practical, and in waters deeper than 2000m. Where this was not possible, or where ships did not leave the continental shelf of North America, exchange could be conducted in the Laurentian Channel, in waters at least 340m deep. Exchange should have been completed prior to passing 64°W, or otherwise as far east as is possible. It is worth noting that the safety of the vessel and its operators remained of the utmost importance, and that the *Voluntary Guidelines* should not have been utilized if safety was an issue.

During BWE, water pumps were run until they lost suction, thereby ensuring that ballast tanks were as empty as possible. Although ballast sediments were not officially managed at the time, disposal of sediment from transoceanic ships in land-based facilities was encouraged.

Despite the fact that these guidelines were voluntary, there was a $50,000 fine under the *Canada Shipping Act* for refusal to provide information pertaining to BWE, or for providing information indicating false compliance on the Ballast Water Exchange Report Form (Locke et al., 1991). A study conducted shortly after the implementation of the *Voluntary Guidelines* found that compliance by ocean-going vessels was 89% by 1990, indicating that the *Voluntary Guidelines* were being utilized by the majority of vessels shortly after their release (Locke et al., 1991). A follow-up study a year later revealed that the rate of ocean-going vessels not in compliance was similar, rising slightly from 12% by 1990 to 14% by 1991 (Locke et al., 1993).

Canada's *Voluntary Guidelines* provided a basis on which both the IMO and the US based their strategies for ballast water management. It is worth noting that from the onset of ballast water management in Canada there were management gaps that persevered through time. For example, the *Voluntary Guidelines* introduced the early idea of exception/exemption zones: ships that did not leave the continental shelf of North America were not required to exchange their ballast water. This principle endures even in today's ballast water management regulations, despite concerns about this aspect of the regulations (Lavoie et al., 1999; Hines et al., 2004; Niimi, 2004; Simkanin et al., 2009; DiBacco et al., 2012; DFO 2014): as such, it is examined in further detail in section 4.1.1.

3.3.4 The 1990s

Many critical changes occurred over the course of the 1990s that would eventually allow for ballast water management to become both statutory and a national initiative. These changes are outlined in the following sections.

3.3.4.1 Boundary Changes – 1990-1991

A subtle change occurred to the *Voluntary Guidelines* between 1990 and 1991. In 1990, only the regions upriver of the St. Lawrence Seaway (slightly south of Montreal) were protected by the *Voluntary Guidelines*. By 1991, however, areas upriver of Quebec City were under protection by the *Voluntary Guidelines* (Locke et al., 1993): the rationale behind this boundary shift is obscure and largely undocumented. In 1990, however, at least 27 ships released ballast water in the St. Lawrence River and Montreal Harbour combined, and at least eight of these vessels released ballast water that was not in compliance with the *Voluntary Guidelines* (Locke et al., 1993). These findings indicate that some vessels had not performed MOE and were still releasing ballast water potentially containing NIS, which could contaminate the St. Lawrence River and nearby Great Lakes. By expanding the area protected under the *Voluntary Guidelines* from Montreal to Quebec City, it can be speculated that the boundary change occurred to further protect the St. Lawrence Seaway and GLR from invasions by NIS.

3.3.4.2 Port of Vancouver – 1997

In 1997, the Vancouver Port Corporation (VPC), renamed the Vancouver Port Authority (VPA) in 1999 (Ircha, 1999; Yarnell, 1999), developed a mandatory BWE program (hereafter referred to as *Standing Orders*) for all ballasted ships destined to arrive at the Port of Vancouver (Levings, 1999; Lloyd's Register, 2014). The 1997 *Standing Orders* stated that ships intending to deballast within the Port of Vancouver must inform the VPA if they have performed MOE, and complete and submit an associated ballast reporting form. MOE must have occurred in waters deeper than 2000m and at least 95% of water held in the ballast tanks must have been replaced with mid-ocean water, or ballast water must have been exchanged three times if a flow-through exchange process was used (Levings, 1999). If MOE had not occurred, deballasting was not allowed within VPA waters. If deballasting was necessary in VPA waters and MOE had not occurred, the vessel was required to return to sea or to an alternate backup location to deballast, subject to any safety concerns of the ship's Captain (Levings, 1999). In addition to reviewing the ballast reporting forms, the VPA was responsible for sampling ballast tanks for salinity and biota in an attempt to confirm that MOE had occurred. If ballast water had a salinity of >25 psu (practical salinity units) or if ballast water samples revealed more oceanic copepods (calanoids) than bottom-dwelling copepods (harpacticoids), MOE was confirmed (Levings, 1999). Using copepods as biological indicators of MOE was unique to the VPA, but at the time, it had not been sufficiently investigated and thus its reliability was unknown (Levings, 1999). Despite the progressive nature of the VPA's *Standing Orders*, the task of sorting, identifying, and counting copepods as indicators of MOE was onerous, and the VPA experienced significant difficulties implementing the aforementioned procedures (C. Levings, pers. comm.).

There were a number of ships exempt from the BWE requirements in the *Standing Orders*. Those ships included: vessels discharging less than 1,000 tons of ballast water; vessels arriving from north of Cape Mendocino, California, if ballast water originated from that region; vessels caught in poor weather and unable to exchange safely in waters deeper than 2000m, and; vessels that had other specific safety concerns (Levings, 1999; Lloyd's Register, 2014). Vessels traveling from north of Cape Mendocino were exempt from performing BWE, as Cape Mendocino was considered to be a biogeographic barrier to the natural dispersion of species (Simkanin et al., 2009).

At the time, the 1997 VPA *Standing Orders* were considered to represent one of the most progressive policies for ballast water and AIS risk management of marine systems in the world (Levings, 1999). The protocols were soon adopted by Fraser Port and the Port of Nanaimo, and were eventually incorporated into drafts of the Canadian national guidelines, which were released in 2000 (Levings, 1999; TC, 2000).

3.3.4.3 Bill C-15: Amending *Canada Shipping Act* – 1998

House of Commons Bill C-15 was initially proposed in 1997 to amend the *Canada Shipping Act*. Bill C-15 received Royal Assent 11 June 1998, and Governor in Council authority on 31 October 1998 (Wiley and Claudi, 2002). Bill C-15 was a significant piece of legislation, as it amended Section 657 of *Canada Shipping Act: Regulations Relating to Pollution*. According to the newly amended *Canada Shipping Act*, the Governor in Council may: "make regulations respecting the protection of the marine environment, including regulations… respecting the control and management of ballast water" (Canada Shipping Act, 2001, p. 101). In short, the enactment of Bill C-15 meant that Canada now had authority to implement statutory regulations regarding ballast water management (Wiley and Claudi, 2002). This enactment echoed the US' authority to implement statutory regulations, and was a significant step forward in the quest to protect not only the GLR, but all of Canada's coasts from AIS via ballast water management.

3.3.4.4 Ballast Water Management Working Group – 1998

On 4 November 1998, mere days after Bill C-15 received Governor-in-Council authority, a working group on ballast water management was established under the Standing Committee on the Environment, a subsection of Canada's Marine Advisory Council (CMAC) (Wiley, 2000; Wiley and Claudi, 2002). The CMAC is TC's nationwide consultative body for marine issues, and has representation from several different sectors, including the federal government (e.g., TC, DFO, EC, CCG), the transportation industry, environmental groups, and other relevant marine stakeholders (Wiley and Claudi, 2002; Capt. M. Balaban, pers. comm.). In particular, the ballast water working group targeted members with backgrounds in government, industry, and environmental sciences (Wiley, 2000).

As a team, the working group mapped out Canada's future ballast water management strategies. Ultimately, the working group intended to "provide a scientifically based regulatory environment that will, to the greatest extent possible, prevent future introductions of aquatic alien species from the ballast water of ships" (Wiley and Claudi, 2002, p. 238). The working group's first step was to compile data collected from 10 years of experience with the Canadian *Voluntary Guidelines*, and extend that regime to the east, west, and Arctic coasts of Canada (Wiley and Claudi, 2002). Next, regional working groups were created to determine how ballast water management was to be implemented across Canada, as shipping patterns, geography, and oceanography varied between regions (Wiley and Claudi, 2002). Ultimately, this facilitated the creation of nationwide, non-statutory ballast water guidelines (TC, 2000).

3.3.5 *Guidelines for the Control of Ballast Water Discharge from Ships in Waters under Canadian Jurisdiction* (TP 13617)

The *Guidelines for the Control of Ballast Water Discharge from Ships in Waters under Canadian Jurisdiction* (hereafter referred to as *Ballast Water Guidelines*) were released on 1 September 2000. These new *Ballast Water Guidelines* applied to all vessels subject to Vessel Traffic Services, and revoked and replaced the 1989 *Voluntary Guidelines* (TC, 2000). The *Ballast Water Guidelines* were non-statutory, and were developed by TC and DFO with the support of the CMAC, and in consultation with ship owners, environmental organizations, government departments, and the USCG. The purpose of the *Ballast Water Guidelines* was to protect waters that fall under Canadian jurisdiction from pathogens and non-indigenous aquatic organisms that can be potentially harmful to existing ecosystems (TC, 2000). The *Ballast Water Guidelines* were designed to minimize the probability of future introductions via ballast water, while protecting the safety of ships (TC, 2000). As with all previous ballast water management guidelines, any recommended actions by the *Ballast Water Guidelines* must not compromise the safety of vessels and crew.

The 2000 *Ballast Water Guidelines* were consistent with several international guidelines. On a global scale, the *Ballast Water Guidelines* were designed to implement, in waters under Canadian jurisdiction, the 1997 resolution of the IMO (A.868 (20)): *Guidelines for the Control and Management of Ships' Ballast Water to Minimize the Transfer of Harmful Aquatic Organisms and Pathogens* (see section 3.4.2 and Appendix). On a more regional scale, all vessels destined for the GLR were still required to comply with the US' mandatory ballast water program (see section 3.4.1 and Appendix). Additionally, according to the 1972 Great Lakes Water Quality Agreement (GLWQA), American and Canadian regulations must be compatible; thus, the 2000 *Ballast Water Guidelines* were developed to be consistent with existing US legislation (Wiley and Claudi, 2002; TC, 2012).

As per the *Ballast Water Guidelines*, every vessel carrying ballast water was required to have a ballast water management plan specific to the ship. When developing ballast water management plans, the Model Ballast Water Management Plan, developed by the International Chamber of Shipping and the International Association of Independent Tanker Owners, was considered to be an appropriate reference document (TC, 2000).

There were several reporting requirements for vessels destined to Canadian ports. For instance, the vessel's Captain was required to fully complete a ballast water report form, and provide information, as requested, to the Marine Communication and Traffic Services Centre (MCTSC). If the ballast water report form was not fully completed, the Captain was required to provide MCTSC with the following information: whether a ballast water report form had been submitted to the proper authorities, and whether ballast water was being carried (TC, 2000). If ballast water was being carried, the Captain was obliged to provide further information, including: whether the vessel had an appropriate ballast water management plan, whether the plan had been reviewed by the flag State, and whether ballast water management had occurred prior to entering Canada's EEZ. In order to monitor compliance and quality of information provided, ships could be boarded and samples could be collected. Additionally, at the time, ongoing research was being conducted on the effectiveness of ballast water management; thus, ships could be boarded and samples could be collected for scientific analysis (TC, 2000). While the tests conducted on collected samples are not specified in the *Ballast Water Guidelines*, samples were in part collected for the future development of Canadian ballast water management (TC, 2000).

The 2000 *Ballast Water Guidelines* list four options for ballast water management, including BWE, non-release of ballast water, discharge to reception facilities, or alternative methods (TC, 2000). Non-release of ballast water occurred when ballast water was retained onboard, and discharge to reception facilities could occur only if a facility was available for use (TC, 2000). If a vessel's Captain chose to undergo BWE, exchange was required to occur where water depths were more than 2000m, or, in exceptional circumstances, in an alternative exchange zone (see next paragraph). For BWE, ships could undergo sequential exchange, whereby all ballast water is discharged and ballast tanks are subsequently refilled, or flow-through exchange, whereby three times the tank volume is pumped through the tanks concurrently discharging and refilling tanks (TC, 2000). For the alternative methods option, specific methods are not provided in the *Ballast Water Guidelines*, but it is indicated that any method utilized must be at least as effective as BWE, non-release, or discharge to reception facilities (TC, 2000): how it was to be determined if an alternative method was equally as effective, is not described in the *Ballast Water Guidelines.*

Ballast tank sediment disposal is briefly considered under the *Ballast Water Guidelines*: disposal of ballast tank sediments as a result of 'cleaning' ballast tanks should have been carried out outside of Canada's EEZ. In waters under Canadian jurisdiction, ballast sediments from transoceanic ships should have been disposed of in land facilities. Interestingly, the *Ballast Water Guidelines* do not specify what 'cleaning' the tanks is: if 'cleaning' simply refers to BWE (either sequential or flow-through), then this management practice may not have eradicated or even lowered the risk of transferring live organisms in sediments.

In the Annexes of the *Ballast Water Guidelines*, there are regional specifications for ships traveling to Canada's west coast, GLR, Arctic, or east coast. For vessels proceeding to the Ports of Vancouver, Nanaimo, or Fraser River on Canada's west coast, ships must comply with both the *Ballast Water Guidelines* and the local *Standing Orders* (described in section 3.3.4.2 above). A number of exemptions for Canada's west coast are also listed: ships arriving from British Columbia, Alaska, or the west coast of the US north of Cape Mendocino, or vessels discharging less than 1,000 metric tonnes of ballast water were exempt from the *Ballast Water Guidelines* (TC, 2000). For the GLR and St. Lawrence River, for ships not exiting the continental shelf of North America, exchange could occur in the Laurentian Channel, in waters deeper than 300m (TC, 2000). The issue of exemption zones for non-transoceanic vessels is a significant gap in ballast water management, even today, and therefore will be more fully discussed in section 4.1.1. The Annex also clarifies that there was a mandatory Great Lakes and St. Lawrence River ballast regime for the US (see section 3.4.1), and thus joint boarding by TC and USCG representatives in Montreal could occur. Finally, on the east coast, ballast water management information provided to MCTSC could be verified on a random basis, onboard the vessel. At the time the *Ballast Water Guidelines* were published, there were no listed exemptions for ships traveling to the east coast.

Alternative exchange zones for each region in Canada (west coast, GLR, Arctic, and east coast) were listed in each respective Annex, in case ships were incapable of performing MOE for safety reasons. For the west coast, ships could exchange in the outgoing current of the Juan de Fuca Strait. For the GLR, ships could exchange in the Laurentian Channel, in waters deeper than 300m. For the Arctic (north of 60° latitude), alternative exchange zones were listed as the Hudson Strait and Lancaster Sound, in waters deeper than 300m. For the east coast, as of 1

September 2000 when the *Ballast Water Guidelines* were published, no alternative BWE zone had been identified.

3.3.6 Code of Best Practices for Ballast Water Management – Shipping Federation of Canada

On 28 September 2000, the Shipping Federation of Canada released the *Code of Best Practices for Ballast Water Management* (hereafter referred to as the *Code*). The non-statutory *Code* recognized that ballast water is the primary vector for the spread of AIS in the GLR, and encouraged all vessels entering the Great Lakes to commit to the *Code* (SFC, 2000). The *Code* encouraged vessels to conduct ballast water management whenever practical, and to undergo management even if it is not required for the port of arrival. As per the *Code*, frequent BWE is thought to reduce the amount of sediment present in the ballast tanks (SFC, 2000). The *Code* also encouraged: regular inspection of the ballast tanks; a commitment to US legislation; recordkeeping to verify compliance; a commitment to the precautionary approach; disposal of sediments; support of scientific research and analysis; cooperation in the development of treatment systems; and global, integrated ballast water management (SFC, 2000).

3.3.7 *Ballast Water Control and Management Regulations*

The *Ballast Water Control and Management Regulations* (SOR/2006-129; hereafter referred to as *Ballast Water Regulations*) came into effect on 8 June 2006 (TC, 2006). On 27 October 2011, an updated version of these regulations, SOR/2011-237, repealed and replaced SOR/2006-129 (TC, 2011). Although SOR/2006-129 has been repealed and replaced, there have been no significant policy changes between the two versions (see http://www.gazette.gc.ca/rp-pr/p2/2011/2011-11-09/html/sor-dors237-eng.html#REF1). Due to the lack of changes, the

Ballast Water Regulations will be analyzed with an emphasis on the latter (SOR/2011-237), Canada's current regulations for ballast water management.

The intent of the *Ballast Water Regulations* is to: "require ships to manage ballast water in such a manner as to reduce the potential of [damaging] invasions" (TC, 2006, p. 712). The *Ballast Water Regulations* are the first nationally relevant, legally-binding document produced for Canadian ballast water management. Thus, items that once might have been considered arbitrary are now defined. For example, the *Ballast Water Regulations* define several phrases that were previously not defined, such as the 'Great Lakes Basin', and 'release' in respect to ballast water. The *Ballast Water Regulations* apply to all Canadian vessels worldwide that are designed or constructed to carry ballast water, and also to all non-Canadian vessels operating in waters under Canadian jurisdiction (TC, 2011). In addition, the *Ballast Water Regulations* apply to vessels that drill for, produce, conserve, or process oil and gas, as per the *Canada Oil and Gas Operations Act*.

According to the *Ballast Water Regulations*, ballast water is considered to be managed if it is treated, exchanged, transferred to a reception facility, or retained on board the vessel (TC, 2011). Ballast water taken on board a vessel from waters outside of Canadian jurisdiction must be managed to minimize and remove potentially dangerous organisms. As with the previous sets of guidelines, however, there are several exceptions associated with the *Ballast Water Regulations*. For example, the *Ballast Water Regulations* do not apply with respect to: vessels operating exclusively in waters under Canadian jurisdiction; those actively engaged search and rescue vessels or pleasure craft that are less than 50m in overall length, and that have a ballast capacity of less than $8m^3$; vessels with permanent ballast in sealed tanks; or government owned and operated non-commercial vessels (TC, 2011).

As with previous guidelines, there are several exemption zones for ballast water management, in which vessels travelling from particular areas are not required to exchange ballast water. Specifically, ballast water that is taken on board in the Great Lakes under American jurisdiction, or in Saint Pierre or Miquelon islands under French jurisdiction is not subject to the *Ballast Water Regulations* (TC, 2011). There are also areas of exemption for ships traveling exclusively within regions on both the west and east coast of North America. For example, vessels operating exclusively north of Cape Blanco, Oregon, on the west coast, and exclusively north of Cape Cod, Massachusetts, on the east coast need not manage ballast (TC, 2011). Interestingly, on the west coast, the range of the exemption zone shifted north from Cape Mendocino (as per the 2000 *Ballast Water Guidelines*) to Cape Blanco (as per the 2006 and 2011 *Ballast Water Regulations*). The exemption zone has been shortened by approximately 350km, yet the rationale behind this shift was not documented in the regulations nor communicated to the public. It has been shown that these zones of exemption create significant gaps in management: for example, recent studies have demonstrated that ballast water taken onboard in regions exempt from the *Ballast Water Regulations* may still be harmful to waters under Canadian jurisdiction (Briski et al., 2012; DiBacco et al., 2012) since they represent a secondary source for the introduction and spread of NIS. This is a significant management gap that will be more fully explored in section 4.1.1.

For vessels that are destined to the GLR and that have residual ballast taken on outside of waters under Canadian jurisdiction, they must either: comply with *Code of Best Practices for Ballast Water Management* as published by the Canadian Shipping Federation (see section 3.3.6), or undertake MOE at least 200 nm from Canadian shores (TC, 2011). In the *Ballast Water Regulations*, MOE is described as three separate steps: 1) addition of mid-ocean water to tanks containing residual ballast water; 2) mixing of the mid-ocean water with any residual ballast water or sediments; and 3) release of the mixed water, and uptake of new ballast water so that any residual water or sediment exceeds a salinity of 30 psu (TC, 2011).

If ballast water cannot be managed according to *Ballast Water Regulations*, alternative exchange zones are listed, where ships may exchange ballast water. When the 2000 *Ballast Water Guidelines* were released, no alternative exchange zone had been declared for the east coast. The *Ballast Water Regulations*, however, list alternative exchange zones for all of Canada's coasts. On the east coast, for example, alternative BWE may occur south of 43°30' north latitude, in waters deeper than 1000m (TC, 2011). Additionally, in the Arctic, alternative exchange zones are in the Hudson Strait, east of 70°W in waters deeper than 300m, or in in Lancaster Sound, east of 80°W in waters deeper than 300m (TC, 2011). Recent studies, however, indicate that there are still several unknowns associated with shipping and ballast water management in the Arctic (e.g., lack of baseline data); this issue will be explored in more detail in section 4.1.6.

As with the 2000 *Ballast Water Guidelines*, a number of exchange and treatment standards are listed in the *Ballast Water Regulations*. At least 95% volumetric exchange must occur, and a salinity of at least 30 psu must be achieved if exchange occurs more than 50nm from shore. For flow-through exchange, pumping three times the volume of each ballast tank is considered the equivalent of 95% exchange (TC, 2011). One of the largest differences to the *Ballast Water Regulations* from the *Ballast Water Guidelines* is the inclusion of treatment standards as an option for ballast water management. The treatment allows for: 10 viable organisms per cubic metre (i.e., 1000 liters), for organisms with a minimum dimension ≥50 μm; 10 viable organisms per mL, for organisms with a minimum dimension ≥10 μm but <50 μm; 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; and 100 cfu of intestinal enterococci per 100 mL (TC, 2011). Residual sediments and ballast water are also considered to be a risk, and therefore residual sediments are not to be released in waters under Canadian jurisdiction; instead, sediments should be disposed of at a land-based reception facility (TC, 2011). An extensive search reveals that no land-based reception facilities exist in Canada at time of writing.

The *Ballast Water Regulations* state that a ballast water management plan should be on board each vessel, and its processes and procedures should be followed. At a minimum, the plan must contain a detailed description of: the vessel's ballast water management processes; the ballast water management procedures the crew must follow; safety procedures; procedures to dispose of sediment; a procedure to coordinate with Canadian authorities should release occur, and; procedures for completing the Ballast Water Reporting Form (TC, 2011). The plan must also include: design specifications of the ballast system; evidence of vessel stability where a flow-through system is used; operational limits, and; identification of the officer responsible for ensuring the processes are followed (TC, 2011). The ship's Captain must submit a completed Ballast Water Reporting Form as soon as possible after a management procedure, and must retain a copy of each completed report onboard for at least 24 months.

As with all previous rules and guidelines, safety of the vessel and crew are of the utmost importance in the *Ballast Water Regulations*. Therefore, if the vessel cannot comply with its ballast water management plan such that doing so would compromise the stability or the safety of those on board the vessel, the ship must not enter Canada's territorial sea unless the Minister of Transport is notified. In consultation with the Minister, the vessel Captain must consider alternative ballast water management methods while in Canadian waters, including the retention, exchange, release, or treatment of some or all ballast water (TC, 2011).

3.3.8 Current Status and IMO D-2 Standards

In 2004, IMO released the *International Convention for the Control and Management of Ships' Ballast Water and Sediments* (BWMC; see section 3.4.2 and Appendix). One of the main requirements of the BWMC is that ships will be required to perform ballast water management to a given numeric concentration standard, termed D-2 standards. Canada ratified the BWMC in April 2010 (TC, 2012). At present, TC is deciding how to proceed with the implementation of IMO's D-2 standards. A formal discussion paper has been released (TC, 2012), and recommendations to the Minister of Transport have been made. At the time of writing, ballast management guidelines from the office of the Minister of Transport were not available; thus, Canada's next steps towards implementing numeric-based standards remain uncertain.

3.4 International History of Ballast Water Management

3.4.1 Relevant American Legislation

In 1972, the US' Environmental Protection Agency (EPA) adopted the *Clean Water Act* (CWA) to restore and maintain the chemical, physical, and biological integrity of US waters (CWA, 2002). In 1973, amendments were made to the CWA to exclude ballast water and related discharges from CWA permitting; thus, a vessel's ballast water discharges were not regulated under the CWA (Albert et al., 2013). It wasn't until 2009 that the order excluding ballast water from CWA permitting was struck down in US District Court (Albert et al., 2013).

Also in 1972, the *Great Lakes Water Quality Agreement* (GLWQA) was ratified by Canada and the US to ensure that both countries were committed to restoring and maintaining the chemical, physical, and biological integrity of the Great Lakes' waters (Krantzberg, 2012). One of the most crucial requirements of the GLWQA is that governments must have compatible regulations regarding ballast water management in the Great Lakes (Reeves, 2000; Wiley and Claudi, 2002). Thus, regulations created by one country must be consistent and enforceable with respect to the other country's policies.

In 1990, the *Non-Indigenous Aquatic Nuisance Prevention and Control Act* (NANPCA) was introduced in the US to prevent the spread of aquatic and terrestrial invasive species in the nation's waters (NANPCA, 1990). NANPCA has been described as "the cornerstone of [the US'] defense against the invasion of aquatic nuisance species in the Great Lakes" (Weathers and Reeves, 1996, p. 93). Also in 1990, the USA created voluntary BWE guidelines for ships destined to the GLR; as per the GLWQA, these guidelines were parallel with Canada's 1989 *Voluntary Guidelines* (Dextrase, 2002).

Mandatory legislation requiring mid-ocean BWE was introduced for transoceanic ships destined for the GLR in 1993, and the regulations were modeled on the 1989 Canadian *Voluntary Guidelines* (see section 3.3.3; Dextrase, 2002). Due to the GLWQA, mandatory BWE was now required for all ballasted ships travelling outside the US' EEZ that entered the GLR, regardless of whether the destination port was American or Canadian (Dextrase, 2002). Three years later, in 1996, the *National Invasive Species Act* (NISA) was introduced to "provide for ballast water management to prevent the introduction and spread of nonindigenous species into the waters of the United States" (NISA, 1996, p. 1). The USCG established a national, voluntary ballast water management program in 1999, similar to the program established by Canada one year later (see section 3.3.5; Miller et al., 2007; Albert et al., 2013). In 2004, ballast water reporting was made mandatory for all ships in US waters, and by 2005, ballast water management was required for all ships in US waters (Miller et al., 2007; TC, 2007; Albert et al., 2013).

The US has not yet ratified IMO's 2004 BWMC (IMO, 2014b), and it is unlikely that they will in the near future, as the USCG established their own concentration-based ballast water discharge limits in 2012 (Albert et al., 2013). The initial phase of standards, Phase 1 standards, were implemented in 2012 and require that vessels already subject to USCG's BWE, and coastal vessels larger than 1600 tons that do not operate outside of US or Canada's EEZ, meet the IMO's BWMC D-2 regulations. Phase 2 standards will require that vessels meet a discharge standard 1000 times more stringent than Phase 1 for certain classes of organisms, and will come into effect when additional research and technological advances support the implementation of stricter standards (Albert et al., 2013).

American legislation is further complicated because, in addition to the aforementioned federal regulations, each state can also implement regulations for ballast water management. For example, the state of California has enacted legislation requiring zero detectable organisms of all sizes, including bacteria and viruses, in ballast water discharge by 2020 (Albert et al., 2013). Therefore, any vessels undergoing BWE in California must meet all federal and state-enacted regulations.

3.4.2 Relevant IMO History

The IMO was established in 1948, as the Inter-Governmental Maritime Consultative Organization (IMO, 2014b). In the late 1980s, Canada, the US, and Australia approached IMO's MEPC with concerns regarding AIS transported in ballast water. In 1988, at the 26th meeting of MEPC, the issue of ballast water management was formally presented to the Committee. On 4 July 1991, voluntary *International Guidelines for Preventing the Introduction of Unwanted*

Aquatic Organisms and Pathogens from Ships' Ballast Water and Sediment Discharges were released (IMO, 1991). These guidelines recognized the significance of ballast water in the primary introduction of NIS, requested member states to further research the role of ballast water in facilitating the spread of AIS, and urged states to minimize the probability that ballast water will contain unwanted species (IMO, 1991). Approximately two years later, 4 November 1993, the IMO adopted resolution A.774 (18): *Guidelines for Preventing the Introduction of Unwanted Organisms and Pathogens from Ships' Ballast Water and Sediment Discharge* (IMO, 1993).

In November 1997, IMO adopted resolution A.868 (20): *Guidelines for the Control and Management of Ships' Ballast Water to Minimize the Transfer of Harmful Aquatic Organisms and Pathogens*. These guidelines were an updated version of resolution A.774 (18) and included further recommendations and procedures for best ballast water management practices, including: avoiding uptake in ports where harmful organisms dwell; cleaning ballast tanks and removing sediments regularly; avoiding unnecessary ballast water discharge; and undertaking ballast water management procedures such as MOE, non-release of ballast water, and or discharge to onshore treatment facilities (IMO, 1997). Although voluntary, A.868 (20) is the current resolution for global ballast water management (IMO, 1997).

On 13 February 2004, IMO formally adopted the *International Convention for the Control and Management of Ships' Ballast Water and Sediments* (BWMC). The objective of the BWMC is to prevent the invasion of non-native species via ships' ballast water, and is the first attempt at international, legally-binding legislation for ballast water management (IMO, 2004). Of the regulations proposed by the BWMC, the D-2 regulations appear to have garnered the most attention. D-2 regulations propose a ballast water performance standard, whereby the quality of ballast water will be held to a predetermined, numerically-based concentration standard for allowable numbers of live organisms transported in ballast tanks (IMO, 2004; see Table 2).

IMO's BWMC will enter into force 12 months after ratification by 30 States, representing at least 35% of the world shipping tonnage (Lawal, 2011; IMO, 2014b). As of 31 August 2014, 40 States have ratified the BWMC, but 35% of world merchant shipping tonnage has not yet been reached (IMO, 2014b).

Table 2 – Ballast water performance standards as per IMO BWMC Regulation D-2. Table adapted from TC, 2012.

Category		**Vessel must discharge less than**
Organisms greater than or equal to 50 μm in minimum dimension		10 viable organisms per m^3
Organisms less than 50 μm and greater than or equal to 10 μm in minimum dimension		10 viable organisms per mL
Indicator microbes (for human health purposes)	Toxicogenic *Vibrio cholerae* (O1 and O139)	1 colony forming unit (CFU) per 100 mL or 1 CFU per 1 g (wet weight) zooplankton samples
	Escherichia coli	250 CFU per 100 mL
	Intestinal *Enterococci*	100 CFU per 100 mL

4.0 DISCUSSION

4.1 Historical and Current Issues with Canada's Ballast Water Management

4.1.1 Intracoastal Shipping and its Implications

Intracoastal shipping refers to vessels that operate exclusively along the coast of North America, and commonly occurs along both the east and west coasts of Canada. Depending on the port where ballast water was taken onboard, and according to the current *Ballast Water Regulations*, these vessels may or may not be required to exchange or manage ballast water. For example, vessels are not required to manage ballast water if they operate: exclusively north of Cape Blanco, Oregon, on the west coast; exclusively north of Cape Cod, Massachusetts, on the east coast, and; exclusively between the French islands of St. Pierre and Miquelon and Canadian coasts (TC, 2011; DiBacco et al., 2012). In all these areas, ballast water management is not required largely on the basis that these regions share common waters (or “similar waters” (TC, 2011, p. 5)): namely, that they contain and are characterized by commonly shared biotic communities.

In recent years, several issues associated with intracoastal shipping (e.g., vessels operating exclusively north of Cape Blanco or Cape Cod are not required to manage ballast water, while vessels traveling to Canada from south of Cape Blanco or Cape Cod are required to perform BWE) and a lack of BWE requirements for vessels operating exclusively in similar waters have been brought forward. Many researchers have demonstrated that ballast water taken on in similar waters is a significant way to facilitate the anthropogenic secondary spread of invasive species (e.g., Lavoie et al., 1999; Niimi, 2004; Simkanin et al., 2009; DiBacco et al., 2012). Additionally, since intracoastal voyages are typically shorter than transoceanic voyages (i.e., hours or days vs. days or weeks), species in ballast tanks experience lower cumulative mortality, and thus the risk of transfer and establishment by non-native species is increased (Lavoie et al., 1999; Verling et al., 2005; Simkanin et al., 2009). The lack of ballast water management for intracoastal vessels has been recognized as a considerable gap in ballast water management (Simkanin et al., 2009; DFO 2014), and is a significant issue that needs to be addressed in Canadian ballast water management regulations (see sections 4.2.1 and 4.2.3).

4.1.2 Salinity Issues – Mid-Ocean Exchange and Euryhaline Species

MOE is the leading method in Canada and around the world for managing NIS in ballast water (Wiley and Claudi, 2002; Fofonoff et al., 2003). However, it was never intended to be a permanent solution, and in fact was considered only an interim method for managing NIS (Simard et al., 2011); this interim method has now been the dominant form of ballast water management for more than 25 years. The purpose of MOE is twofold: 1) exposing freshwater organisms to mid-ocean salinity levels is fatal, resulting in a decreased probability of survival and introduction of viable organisms, and; 2) exchanging ballast between two ecologically distinct zones (e.g., with distinctly different salinities) is expected to result in a lowered risk of introduction (Reeves, 2000; DFO, 2014). At one time, MOE was considered an effective way to minimize the introduction of NIS via ballast water, and the probability of facilitating introductions between coastal and open-ocean ecosystems had, at least initially, been described as “virtually non-existent” (Carlton et al., 1995, p. 153).

Since its adoption, several studies on the effectiveness of MOE have shown that it is not completely effective at eradicating species in ballast tanks, and that the efficacy of BWE can be highly variable as a result of the: (i) type of vessel, (ii) method of exchange, (iii) species composition, and (iv) length of voyage (Locke et al., 1993; Wonham et al., 2001; Levings et al., 2004; Briski et al., 2012). Additionally, it can be difficult to differentiate between natural mortality and efficacy of BWE (Taylor et al., 2007). For instance, Simard et al. (2011) noted that while initial efficacy of BWE ranged from 49-90% for phytoplankton and zooplankton, once natural mortality was taken into account, the actual efficacy was much lower, and ranged from 23-54%. The true efficacy of MOE is therefore less than the original efficacy of 67-86% estimated in 1990-91 (Locke et al., 1993). Additionally, it has been demonstrated that, contrary to expectations, the uptake of ballast water can actually increase, instead of decrease, the risk of introducing non-indigenous populations, particularly in marine or saline environments, during an initial period after uptake (Carver and Mallet, 2002). These results indicate that BWE alone is not capable of meeting D-2 standards outlined in the IMO’s 2004 BWMC (Briski et al., 2013).

In addition to the issues posed by MOE, euryhaline species present another category of concern. Euryhaline refers to species that have a high tolerance for a wide range of salinities

(Henry and Campoverde, 2006). Adult European green crabs, for example, can temporarily tolerate salinities ranging from 4 to 52 psu, although they prefer salinities ranging from 10 to 30 psu (Cohen et al., 1995; Grosholz and Ruiz, 2002). The wide salinity tolerances of euryhaline species in combination with the true efficacy of MOE suggests that euryhaline species pose a significant invasion threat for marine systems, as MOE may not be effective at reducing populations of NIS (Gray et al., 2005; Simard et al., 2011). Since euryhaline species are capable of surviving MOE, Canada's coasts may not be adequately protected.

Within the IMO's 1991 *Guidelines for Preventing the Introduction of Unwanted Organisms and Pathogens from Ships' Ballast Water and Sediment Discharges* (MEPC 50(31)), IMO created a risk matrix meant to demonstrate the probability of organisms surviving and reproducing in three different types of ballast water: freshwater (FW), brackish water (BW), and fully saline water (SW) (Figure 1; IMO, 1991). While IMO's 1991 guidelines do not specify the salinity ranges of FW, BW, and SW, salinity ranges are generally considered to be <0.5 psu for FW, 0.5 to 30 psu for BW, and >30 psu for SW (IMO, 1991; Paavola et al., 2005; Lomolino et al., 2010).

	DISCHARGED BALLAST		
RECEIVING WATERS	**FW**	**BW**	**SW**
FW	High	Medium	Low
BW	Medium	High	High
SW	Low	High	High

Figure 1 –Probability of organisms' survival and reproduction in freshwater (FW), brackish water (BW), and fully saline water (SW). Adapted from IMO, 1991.

Figure 1 indicates that FW ballast deposited in FW systems presents a high risk of an organism's survival, establishment and ultimately successful reproduction. Similarly, SW ballast deposited into a SW system contains a high risk of NIS being introduced. The creation of this risk matrix in 1991, long before any mandatory Canadian ballast water management regulations, raises the question of why different BWE practices were not created for FW (i.e. GLR) and SW (i.e. coastal) regions, as the risk of depositing different types of ballast water clearly varies according to the region of deposition. Studies conducted on both Canadian coasts suggest that there is a significant risk of introduction from SW ballast water discharge across all salinity-based ecosystems (Kerr, 1990; Carver and Mallet, 2002; Casas-Monroy et al., 2011; DiBacco et al., 2012). Recall that MOE as a form of ballast water management exploits salinity differences, and that one of the underlying assumptions of MOE is that exposing freshwater organisms to mid-ocean salinities level is fatal (Reeves, 2000; DFO, 2014). However, this assumption is not true for vessels traveling between SW systems, as MOE does not create a fatal salinity difference. The publication of IMO's risk matrix suggests that the risk of depositing brackish or saltwater ballast water to coastal ecosystems was known as early as 1991, yet not accounted for; as MOE is still the predominant form of ballast water management today, this risk continues.

Issues such as MOE and euryhaline species continue to be a threat to aquatic ecosystems, even after the implementation of the 2006 *Ballast Water Regulations*. Based on the aquatic invasions seen in the 1980s in the GLR, the analysis suggests that ballast water management and MOE was introduced as a way to protect the GLR from NIS. However, early publications such as the IMO's 1991 guidelines indicate that MOE is not effective for all ecosystems (IMO, 1991). Thus, MOE should be reconsidered as an effective management strategy for Canada's coasts, based on the current research presented here. The issue of the effectiveness of MOE is supported by continued invasions in Canada's marine ecosystems, such as the 2007 invasion of European green crabs in Newfoundland, and the repeated introductions of Chinese mitten crabs in the St. Lawrence River (see sections 4.2.1 and 4.2.2, respectively).

4.1.3 No Ballast On-Board (NOBOB) Vessels

In addition to intracoastal shipping and salinity issues of MOE, vessels declaring 'No Ballast On-Board' (NOBOB) and containing residual water and sediments pose a further risk to aquatic ecosystems. Historically, approximately 90% of vessels entering the GLR declare NOBOB, as they are weighed down with cargo and therefore do not require the use of ballast water (Colautti et al., 2003). It is difficult, however, to completely empty a ballast tank of all residual water and sediments. When a vessel's cargo is unloaded, the ship takes on ballast water, thereby suspending residual water and sediments in the ballast tanks: this mixture is then released at another port when the vessel deballasts and takes on new cargo (Bailey et al., 2005; Duggan et al., 2005; Ricciardi, 2006). The residual water and sediments in ballast tanks can therefore contaminate ecosystems if they harbour invasive organisms. As a group, NOBOB vessels have been characterized to have a higher invasion risk than vessels with 'Ballast On-Board' (BOB), as NOBOB vessels were not required to undergo MOE (Duggan et al., 2005): beginning with the 1989 *Voluntary Guidelines*, ships declaring NOBOB were exempt from ballast water management guidelines set up for the GLR (Locke et al., 1993). This was a significant gap in ballast water management, and left the GLR at risk of introductions via ballast water (Duggan et al., 2005).

Several studies have indicated that the residual sediments and waters of NOBOB ships put ecosystems at risk of an invasion. For example, NOBOB ships can carry harmful algal bloom (HAB) species containing toxins. Doblin et al. (2007) suggest that the ballast water of ships carrying HAB-containing toxins from infected ports should be considered high risk for at least 11 days after entering the GLR due to the presence of harmful toxin-containing organisms. In addition, Bailey et al. (2005) demonstrate that diapausing eggs can indeed hatch within the residual sediments of the ballast tanks of NOBOB ships. Although the authors concluded that the invasion risk was low, species could potentially be involved in multiple primary introductions; thus the importance of residual sediments in NOBOB ships cannot be understated (Bailey et al., 2005). Additionally, Briski et al. (2011) found that MOE does not reduce the species richness or abundance of invertebrate eggs found in ballast sediments, and that the risk of invasion via ballast sediments is highest on the east coast of Canada, as ships frequently visit shallow and sandy ports in the North and Baltic Seas prior to arrival on the Atlantic coast. Other studies have found that viable organisms live both within residual ballast waters and sediments, indicating that MOE may not completely 'clean' the tanks of ballast sediments (Duggan et al., 2005; Casas-Monroy et al., 2011; DiBacco et al., 2012).

It was not until TC's 2000 *Ballast Water Guidelines* and the concurrent Shipping Federation of Canada's *Code* that residual waters and sediments carried by ships declaring NOBOB were considered from a management perspective. The 2006 *Ballast Water Regulations*, however, do not outline strict regulations for NOBOB vessels. According to the *Ballast Water Regulations*, NOBOB vessels carrying residual amounts of ballast water and sediments need not manage them if the voluntary best practices set forth by the Shipping Federation of Canada in 2000 (e.g. the *Code*) are met, or if MOE (termed 'saltwater flushing' in the *Ballast Water Regulations*) occurs outside of Canada's EEZ (TC, 2011). Despite the recognition that residual water and sediments in ballast tanks of NOBOB vessels can contaminate ecosystems if they contain invasive organisms, there are at present no legally-binding resolutions governing

NOBOB vessels. However, the recognition of residual ballast water and sediments in Canada's current *Ballast Water Regulations* indicates that ballast water management gaps are, at minimum, being identified moving forward.

4.1.4 Lack of Monitoring

Since Canada's national *Ballast Water Guidelines* were implemented in 2000, little monitoring on the effectiveness of ballast water management on Canada's coasts has been conducted. An extensive search of publically-available literature reveals that only two studies have been conducted: one in July 2000 and the other beginning in September 2001. Despite the call for protection of Atlantic Canada's marine ecosystems from ballast water release in 1990 (Kerr, 1990), the risk of NIS release via ballast water was not addressed until 2002, when Mallet Research Services Ltd. produced a document for TC on the risk of ballast-mediated introductions to Atlantic Canada. In this study, researchers demonstrated that MOE for vessels destined for coastal ports may, contrary to expectations, increase the density of NIS in ballast water and therefore the risk of introducing NIS (Carver and Mallet, 2002). The authors speculate that the increased density of NIS in ballast water and subsequently the risk of introduction may have been a result of the location of ballast water uptake (Carver and Mallet, 2002), while other studies indicate that an uptake of fresh ballast water via MOE results in increased nutrients, oxygen, and plankton in the water, therefore facilitating the survival of NIS (Simard et al., 2011). In addition, the researchers' results suggested that: "there is a significant risk of ballast water-mediated introduction of non-indigenous as well as toxic/harmful taxa" (Carver and Mallet, 2002, p. 41). These findings indicate that not only is coastal monitoring for effectiveness scarce, but that MOE may actually put coastal ecosystems at higher risk of introductions, instead of preventing them. Despite commissioning this report, TC made the 2000 national voluntary guidelines legally binding in 2006.

4.1.5 Issues Surrounding Political Will

Traditionally, Canada and US' ballast water management policies have closely aligned, in part due to the 1972 *Great Lakes Water Quality Agreement* which states that Canada and the US must have compatible regulations regarding ballast water management in the GLR (see section 3.4.1 and Appendix; Reeves, 2000; Wiley and Claudi, 2002). In some cases, however, it seems that Canada relied on policies created by the US to regulate ballast water management, instead of developing their own mandate. For instance, *Canada Shipping Act* was amended by Bill C-15 in 1998, which allowed Canada to create mandatory ballast water management regulations: however, it was not until 2006 that Canada created legally binding *Ballast Water Regulations*. This was at least in part due to reliance on the US' 1993 mandatory ballast water regulations for the GLR. Indeed, court transcripts obtained from the Legislative Assembly of Ontario confirms this: "although we did receive authority to implement legislation in 1998… we felt that the United States' testing was, for Canada, and specifically for ports in the Great Lakes, an effective control mechanism" (Committee Transcripts, 2000). Ultimately, reliance on US regulations led to a delay of nearly 20 years of creating national ballast water management regulations, which could help protect Canada's marine systems as well as freshwater systems such as the GLR.

To date, MOE remains the prominent mechanism of ballast water management in Canada (Wiley and Claudi, 2002; Fofonoff et al., 2003). Many different onboard ballast water treatment systems are being developed and tested, yet as of 2011, no treatment systems had been approved for use in Canada (Bailey et al., 2011b). A review of primary and grey literature indicates that this is still true in 2014. IMO's 2004 BWMC, however, requires that BWE be phased out completely and replaced by onboard treatment systems by 2016 for countries that have ratified the convention (IMO, 2004; Bailey et al., 2011b). Based on Canada's progress towards implementing D-2 standards, this is problematic as Canada must implement onboard treatment systems by 2016; thus, strong political will and adequate sustained funding is required for implementation to occur on schedule.

4.1.6 Arctic Considerations

Given warming conditions, reduction in seasonal ice cover and the resultant increased vessel traffic, the Arctic is becoming more vulnerable to potential introductions of NIS (Chan et al., 2013). According to the Arctic Council (2009), the Arctic remains a relatively pristine ecosystem, with a significant number of endemic species. Marine shipping, however, is expected to grow in the Arctic as sea ice retreats, thereby threatening fragile ecosystems (Arctic Council, 2009; Chan et al., 2013). As such, management gaps in current Canadian ballast water regulations need to be addressed and closed in order to keep Arctic ecosystems intact and pristine.

Although there is less shipping in the Arctic than on the east and west coasts of Canada, ballast water discharge was 275,714m^3 per annum at several ports in 2013 (Chan et al., 2013). This number is approximately 2.5 times less than ballast water discharge in the GLR in 1990 (Locke et al., 1991), yet continues to rise (Chan et al., 2013). Most ballast water discharge in the Canadian Arctic originates from other ports in the Arctic (Chan et al., 2013), raising questions about the risks and possible consequences of intracoastal shipping in the Arctic. Recall that, according to Canada's *Ballast Water Regulations*, ships operating exclusively north of Cape Blanco on the west coast and Cape Cod on the east coast do not need to manage ballast water

(TC, 2011), yet these ships provide a serious risk for introducing NIS as a secondary vector pathway. There is no reference to intracoastal shipping in the Arctic in the current Canadian regulations, suggesting that the Arctic was likely not considered when the regulations were developed. This further suggests that domestic ships operating exclusively north of Cape Blanco or Cape Cod need not manage ballast water when proceeding to an Arctic port. It certainly suggests that ships transiting from southern Canadian waters, well-characterized by numerous invasions, are also exempt from ballast water management. This gap is enforced by similar American regulations: ships destined for Alaska from the west coast of North America (including California, Oregon, Washington, and the Pacific coast of Canada) are not required to exchange or treat ballast water prior to arrival (McGee et al., 2006). Yet, most organisms that arrive or are introduced via ballast water in Alaska originate from California and Washington, supporting the idea that intracoastal shipping is a significant source of primary and or secondary introduction (McGee et al., 2006).

The risk of invasion in the Arctic is not spatially or temporally uniform, and depends heavily on the activity type involved and the time of year (Chan et al., 2013). Based on a relative risk assessment done in 2013, Churchill (Manitoba) is at the greatest risk of invasion from the ballast water of foreign vessels, despite national ballast water regulations (Chan et al., 2013). Although many organisms remain ill-adapted to cold water regions, some species may still be able to survive and populate. For example, Japanese skeleton shrimp (*Caprella mutica*) is one species that could potentially invade Canada's Arctic (Turcotte and Sainte-Marie, 2009). Indeed, Quebec populations of the invasive *Caprella mutica* are able to survive through harsh winters, indicating that an accidental secondary spread to the Arctic might result in the species becoming established (Turcotte and Sainte-Marie, 2009). In addition, species such as European green crabs can have distinct genetic strains with different environmental characteristics and tolerances: Canada's east coast has recently been invaded by a northern European green crab genotype that is distributed throughout northern Europe, and that may be capable of surviving northern Canadian climates (Roman, 2006; C. DiBacco, pers. comm.). Furthermore, warming ocean temperatures may facilitate the spread of invaders further north, and allow them to survive in regions once too frigid.

The lack of baseline data in the Arctic is problematic. Baseline data, such as species distribution and sea ice coverage, is often unavailable, thus determining the cumulative effects of stressors such as marine invasions and climate change remains difficult (Swanzey and Southam, 2013). Despite this issue, Canada has a unique opportunity to prevent damage to its Arctic, and thus needs to reassess and close loopholes in its current ballast water management regime; section 5.0 lists several recommendations as to how this may be accomplished. Above all else, a precautionary approach is needed to ensure that Canadian Arctic ecosystems are protected from biological invasions (Chan et al., 2013). Regulations that reduce the risk from predominate vectors for NIS introductions, such a commercial vessel traffic, represent an important and attainable objective.

4.2 Case Studies of Concern

4.2.1 Green Crabs in Newfoundland

The European green crab (*Carcinus maenas*) is one of the world's most successful marine invaders (Roman, 2006; Blakeslee et al., 2010). This is in part due to the life history of the species, as well as their aggressiveness and voracious diet (Klassen and Locke, 2007). Green crabs have a two-part life cycle, which progresses from a planktonic (free-swimming) larval stage to a benthic adult stage (Klassen and Locke, 2007). Green crabs have a long planktonic life history stage of development, spending upwards of 50 days as plankton where they can disperse in coastal currents (Williams and Naylor, 1967; DeRivera et al., 2007). Additionally, fecundity is high: females can spawn up to 185,000 eggs at a time (Cohen and Carlton, 1995).

Green crabs are native to much of Europe and the North African coasts, but have invaded many other regions of the world, including: the east and west coasts of North America, South Africa, Asia, and Australia (Klassen and Locke, 2007). The first report of the green crab in North America is in the north-eastern US, and dates back to the early 19th century (Grosholz and Ruiz, 1996). In Canada, green crabs were first reported in the Digdeguash River, Passamaquoddy Bay, in 1951 (Leim, 1951). Since then, the crabs have slowly spread to every Maritime province in Atlantic Canada, and have been reported in lower numbers in British Columbia (Klassen and Locke, 2007).

Traditionally, primary introductions of green crabs are associated with commercial shipping, either via ballast water or fouling (Roman and Darling, 2007). It has been suggested that green crabs have undergone several primary introductions via shipping in eastern North America. A shift in green crab genotypes along the eastern coast of Nova Scotia is consistent with two introduction events, such that the crabs first seen in Passamaquoddy Bay are different than those in northern Nova Scotia (Roman, 2006). Roman suggests that the second primary introduction occurred either in Halifax or in Chedabucto Bay, both of which receive commercial traffic from Europe (2006). This suggestion is consistent with an introduction via commercial shipping and likely ballast water transfer of planktonic larvae.

A secondary introduction from Nova Scotia to Placentia Bay, Newfoundland, was confirmed in 2007 (DFO, 2011b). Blakeslee et al. (2010) suggest a Nova Scotian origin for green crabs in Newfoundland, instead of a direct introduction from Europe. The authors' findings are supported by oceanographic circulation patterns, whereby larvae could not be naturally dispersed from Nova Scotia to Newfoundland, which leaves domestic vessel traffic between Nova Scotian ports and Placentia Bay, which is exempt from ballast water management, as the most likely vector (Blakeslee et al., 2010).

A potential introduction of green crabs from Nova Scotia to Newfoundland via ballast water has significant implications for intracoastal shipping in Canada. Recall that vessels travelling exclusively north of Cape Cod on the east coast are not required to manage ballast water (TC, 2006; TC, 2011). The introduction of green crabs to Newfoundland illustrates that not managing ballast water on domestic voyages can have serious impacts. This is a significant management gap, and therefore Canada needs to develop ballast water management regulations that protect Canada's coasts, regardless of port of origin for any given vessel (see section 5.1).

4.2.2 Chinese Mitten Crabs in the St. Lawrence River

Chinese mitten crabs (*Eriocheir sinensis*) are another notoriously successful aquatic invader, and are on the IUCN's 100 most invasive species in the world list (Lowe et al., 2000). Mitten crabs have a complex life history, and undergo planktonic larval development (Anger, 1991). Mitten crabs are euryhaline, and optimal larval development can occur in salinities ranging from 10 to 32 psu (Anger, 1991). Like the European green crab, the larval phase is long-lasting, and occurs for approximately 43-90 days (Anger, 1991; Herborg, 2007). Mitten crabs are also catadromous: adults tend to live in low salinity waters at the heads of rivers, but require saltwater to reproduce, thus necessitating the ability of adult females to migrate long distances, up to 500 km, to spawn (Cohen and Carlton, 1997; Veilleux and de Lafontaine, 2007).

Chinese mitten crabs are endemic to the Yellow Sea in Eastern Asia, and are invasive to Western Asia, Europe, and the US (Veilleux and de Lafontaine, 2007). Mitten crabs have not become established in Canada; however, single specimens have been caught repeatedly in the GLR over the past 40 years (Tepolt et al., 2007). Many authors have concluded that ballast water is the most likely vector for primary introduction of these crabs (Cohen and Carlton, 1997; Ricciardi, 2001; Grigorovich et al., 2003). Based on genetic analyses, it is unlikely that the Chinese mitten crabs that have been found in the Great Lakes and St. Lawrence River over the years originate from a single source. Instead, it is more likely that the crabs originated from more than one European source; the episodic discovery of such individuals is consistent with repeated primary introductions (Tepolt et al. 2007) that have not resulted in establishment.

On 2 September 2004, a single female Chinese mitten crab was collected in the St. Lawrence River, opposite Quebec City (de Lafontaine, 2005). In 2007, Herborg et al. identified the lower Great Lakes and upper St. Lawrence River as suitable environments for adult Chinese mitten crabs to establish and thrive (Herborg et al., 2007). It is unlikely, however, that adult mitten crabs could become established throughout the Great Lakes, due to its catadromous lifestyle (de Lafontaine, 2005). Since the St. Lawrence River has been identified as hospitable for Chinese mitten crabs, it is worrisome that specimens have been recovered, especially as ballast water is likely the primary means of introduction. In 2007, Tepolt et al. concluded that "preventative measures, e.g., ballast-exchange regulations since the 1990s, do not appear to have limited the introduction of mitten crabs into the Great Lakes and St. Lawrence Seaway" (p. 665). Based on their continued introductions, it is likely that a population of adult crabs could become established in fresh waters of the St. Lawrence River, due to its proximity to saltwater for reproduction and overall salinity (de Lafontaine, 2005; Tepolt et al., 2007).

Recall that ships destined for the GLR have been requested to perform BWE since 1989, and that it has been mandatory since 1993. If ballast water is the vector responsible for the repeated primary introductions of Chinese mitten crabs, then it is evident that MOE is not effective for this particular species. Whether it is because the larvae of mitten crabs are euryhaline and have a wide salinity tolerance, or because MOE simply is not effective at flushing tanks cannot be determined here. It can be concluded, however, that this case study illustrates a gap in Canadian ballast water management that has yet to be addressed.

4.2.3 Copepods in the Pacific Northwest

Planktonic marine copepods, typically <1mm in total length, are the most abundant multicellular taxa on Earth (Turner, 2004). Copepods are small crustaceans, and are often referred to as ‘insects of the sea’ because of their abundance and importance to aquatic ecosystems (Cordell, 2012). Due to their overwhelming abundance, copepod species play a pivotal role in marine food webs (Turner, 2004). Additionally, due to their abundance and small size throughout the life-cycle, marine copepods are particularly at risk of being transported in ballast water. Indeed, a study by DiBacco et al. (2012) demonstrated that of the zooplankton species sampled in ballast tanks traveling to Canada, 73% to 89% of zooplankton sampled in ballast tanks were copepods.

A significant number of studies have illustrated the importance of intracoastal ballast water-mediated introductions of copepods to the Pacific Northwest (e.g. Wasson et al., 2001; Cordell et al., 2008; Cordell et al., 2009; Simkanin et al., 2009; Lawrence and Cordell, 2010; DiBacco et al., 2012). On the west coast of Canada, for example, vessels with unexchanged ballast water contained the highest density of non-indigenous zooplankton (DiBacco et al., 2012). Ballast water has been the mechanism of primary introduction for at least nine species of planktonic copepods in the Pacific Northwest (Orsi and Ohtsuka, 1999; Cordell et al., 2009). Although many studies focus on introductions in waters under American jurisdiction, Canadian waters are still at risk, due to the close proximity of introduction sites and secondary introductions due to the lack of required ballast water management for vessels travelling exclusively north of Cape Blanco (TC, 2011; DiBacco et al. 2012).

Some marine ecosystems are considered to be invasion hotspots, and contain a significant number of introduced species (i.e. eastern Mediterranean, Hawaiian Islands) (Ruiz et al., 2011). San Francisco Bay is considered to be such a hotspot, and contains at least 212 introduced taxa (Cohen and Carlton, 1995; 1998). Three copepod species from San Francisco Bay were recently found in the Columbia River Estuary, which is approximately 1000 km north of San Francisco Bay (Cordell et al., 2008). Research indicates that, although Columbia River Estuary receives transoceanic vessel traffic, the introductions most likely occurred via a secondary introduction by domestic shipping from San Francisco Bay (Cordell et al., 2008; 2009). Invasion hotspots, such as San Francisco Bay, could indirectly lead to the introduction of NIS to Canada (DiBacco et al., 2012). Although vessels travelling from San Francisco Bay to Canada's west coast are required to exchange ballast water *en route*, BWE is not required for vessels travelling from San Francisco Bay to areas such as the Columbia River, and the Columbia River has received unexchanged ballast water in the past (Simkanin et al., 2009). Since the Columbia River is north of Cape Blanco, Oregon, vessels travelling from the Columbia River Estuary to ports in Canada are not required to exchange ballast water. Therefore, introductions from invasion hotspots along the west coast could in fact provide a stepping stone, or leapfrog, into Canada.

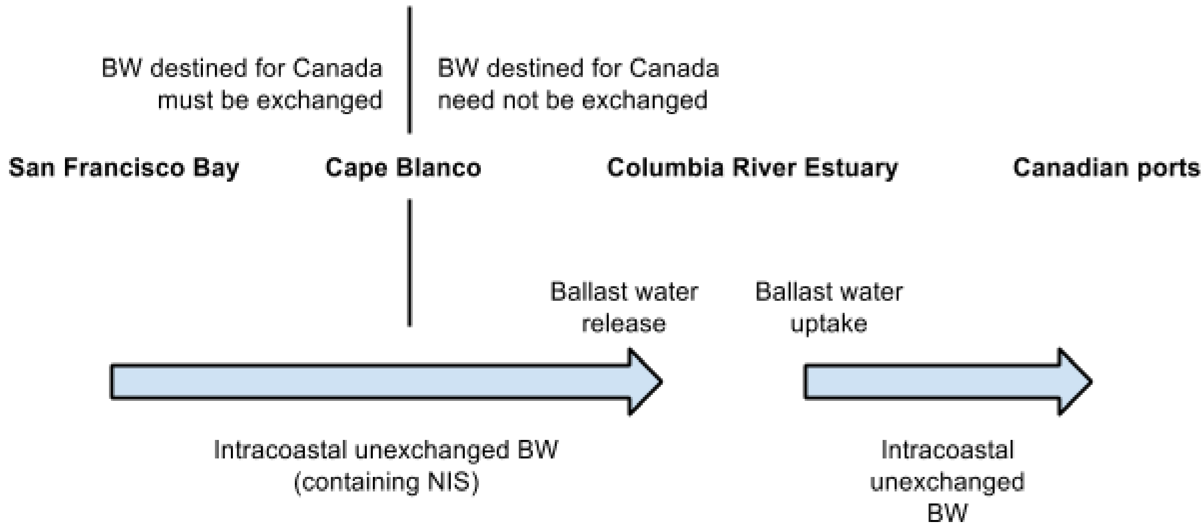

Figure 2 - Potential leapfrog or stepping stone effect of non-indigenous species from invasion hotspots, such as San Francisco Bay, into Canada.

Figure 2 demonstrates one of many ways that ballast water from intracoastal shipping may facilitate the secondary spread of NIS, such as copepods, into Canada. The lack of ballast water management for intracoastal shipping suggests that significant concessions (i.e. environmental protection) have been allowed for the sake of commerce (i.e. shipping). Although the importance of leapfrog and stepping stone effects have been pointed out in the past (Levings, 1999; Wasson et al., 2001), this management gap still exists today.

5.0 RECOMMENDATIONS

Based on the literature review and analysis of Canadian ballast water management regulations, several management gaps have been identified. Six recommendations, in no particular order, have been generated to help prevent the introduction of NIS via ballast water.

5.1 Resolve Intracoastal Shipping Issues

As one of the largest issues with the current ballast water management regime, intracoastal shipping not requiring ballast water management needs to cease in order to adequately protect Canada's marine ecosystems. At present, however, there are no viable alternatives to discontinue unexchanged intracoastal shipping, and cost effectiveness is at the forefront of this aspect of the NIS and ballast water management debate (IJC/GLFC, 1990). Thus, effort needs to be put into advancing onboard treatment systems (see section 5.4).

5.2 Prevent the Spread of NIS after Arrival in Canada

Based on the analysis, TC seems primarily concerned with preventing the initial introduction of NIS to Canada. Relatively few measures, however, are in place to control the spread of species that are introduced and that establish, reproduce, and dispersal locally via natural or anthropogenic vectors (e.g., small vessel traffic). Though prevention of primary introductions is critical, a federal mandate needs to be developed to stop or slow the spread of NIS once they have been introduced to Canada; we cannot simply focus on preventing NIS from arriving to the country. For instance, a rapid response framework for AIS was developed in 2010 by DFO, which focused on rapidly identifying and managing potential AIS (Locke et al., 2010). Despite recognition of the rapid response framework, which is in line with international frameworks, efforts and containment protocols, there are as yet no contingency funds available that are needed to implement a response based on steps outlined in the above framework (C. DiBacco, pers. comm.). Another such way to account for and prevent the further spread of NIS is to require ballast water management for intracoastal vessels traveling to Canada.

5.3 Strong Political Will

Canada relied on the US' 1993 mandatory regulations to protect the GLR for many years, resulting in a lack of forward-thinking progress for an extended period of time. This cannot be allowed to happen again, especially with international commercial shipping activity in the Arctic increasing. Political will needs to become strong, and the aforementioned gaps (e.g., intracoastal shipping, MOE as the dominant ballast water management strategy) in management need to be quickly and adequately addressed if the Arctic is to be protected from aquatic invaders.

5.4 Advance and Fund Treatment Technologies

Onboard treatment technologies are of the utmost importance to the future of ballast water management. Treatment options were identified as a priority by the IMO as early as 1991; however, 25 years have elapsed and still no onboard treatment technologies have been approved for use in Canada. Since Canada ratified IMO's BWMC and agreed to adhere by strict numerical concentration standards, emphasis needs to be placed on advancing and funding various treatment options. Indeed, onboard treatment systems could effectively resolve issues associated with intracoastal shipping.

5.5 Manage Fresh Water and Marine Ecosystems Separately

Although freshwater and marine ecosystems have been managed concurrently since ballast water management in Canada began, the ecosystems are inherently different. As such, management methods for one region may not be effective in another. For instance, there have been no new aquatic invasions via ballast water in the GLR since 2006, thus MOE appears effective in freshwater ecosystems (Bailey et al., 2011a). However, marine ecosystems continue to see newly introduced species (e.g., green crabs in Newfoundland; Moore et al., in press) on a regular basis, indicating that perhaps, moving forward, these contrasting ecosystems with different invasion risks and species assemblages should be managed separately.

5.6 Anticipate Future Issues - *i.e. Hull-Fouling*

Ballast water is not the only means by which NIS can become introduced by commercial shipping activities; it is, however, the most heavily scrutinized vector to date. Looking forward, Canada needs to focus on other major vectors that could result in the establishment of NIS. In the marine realm, this includes hull-fouling in particular. Hull-fouling can mediate primary introductions as well as significantly facilitate the secondary spread of NIS: for example, it has been implicated in the spread of several species of tunicates through regions of Atlantic Canada. AIS are always going to pose a risk to Canada's aquatic ecosystems: therefore, Canada needs to ensure that this is accounted for as much as possible.

6.0 CONCLUSIONS

This project sought to explore the development of ballast water management in Canada, as documented in the primary and grey literature, to determine if the current ways in which ballast water is managed is truly effective for protecting Canadian marine ecosystems. Initially, Canada's ballast water management policies were developed to prevent the further introduction of AIS to the Great Lakes. The application of the similar ballast water management procedures (i.e., ballast water exchange) nationwide should be reconsidered as an effective management strategy based on the current research presented here. Through the analysis of relevant international policies and Canada's own legislation, it has been determined that there were and are several gaps associated with both past and present Canadian ballast water management. Some gaps have been accounted for, while others have not. It is of the utmost importance that these gaps, and future issues such as hull-fouling, are addressed, in order to protect Canada's coasts for generations to come, especially our most pristine northern ecoregions which have experienced an increase in commercial and recreational traffic over the past decade, a trend expected to continue for the foreseeable future.

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APPENDIX

A history of Canada, United States (US), and International Maritime Organization's (IMO) ballast water management. Only US and IMO history relevant to Canadian policy is presented.

Date	Governing Bodies Involved	Event	Description
1948	IMO	Inter-Governmental Maritime Consultative Organization (IMCO) established	Convention establishing IMCO was adopted. Name changed to International Maritime Organization in 1982 (IMO, 2014a).
1958	IMO	IMO Convention entered into force	Mission of the IMO is to: "provide machinery for cooperation among Governments in the field of governmental regulation and practices relating to technical matters of all kinds affecting shipping engaged in international trade; to encourage and facilitate the general adoption of the highest practicable standards in matters concerning maritime safety, efficiency of navigation and prevention and control of marine pollution from ships" (IMO, 2014a, para. 3).
1972	US, Canada	*Great Lakes Water Quality Agreement* (GLWQA)	GLWQA ratified by Canada and the US to ensure that the chemical, physical, and biological integrity of the Great Lakes is maintained (Krantzberg, 2012). One of the most crucial requirements of the GLWQA is that governments must have compatible regulations regarding ballast water management in the Great Lakes (IJC/GLFC, 1990; Reeves, 2000; Wiley and Claudi, 2002; Vasarhelyi and Thomas, 2003).
1972	Environmental Protection Agency (EPA)	*Clean Water Act* (CWA)	The purpose of the CWA is to restore and maintain the chemical, physical, and biological integrity of the US' waters; prohibits pollution discharge without a CWA permit (CWA, 2002; Albert et al., 2013).
1973	EPA	Modifications to *CWA*	Ballast water and other related discharges are excluded from CWA permitting (Albert et al., 2013).

Date	Governing Bodies Involved	Event	Description
1982	Canadian Coast Guard (CCG)	Notice to Mariners #995	CCG issued Notice to Mariners #995 which prevented ships bound for the Mines Seleine's pier in the Grande Entrée Lagoon (Magdalen Islands) from discharging ballast water obtained in high risk areas (Gosselin et al., 1995; Gauthier and Steel, 1996; Claudi and Ravishankar, 2006). High risk areas included: Bay of Fundy, west of the eastern tip of Anticosti Island, and waters within five nautical miles of the Canadian shoreline (NOTMAR, 1982).
4 August 1988	Great Lakes Fishery Commission (GLFC)	Raised awareness of AIS	GLFC established after the invasion of the sea lamprey in the GLR in 1955. In 1988, the GLFC brought the federal government's attention to the problem of AIS (e.g., river ruffe, *Bythotrephes cederstroemi*, zebra mussel) in the GLR (IJC/GLFC, 1990).
5 September 1988	Canadian, American, and Australian delegates; IMO	Canadian meeting with IMO's Marine Environmental Protection Committee (MEPC)	Canadian delegates, with the full support of US and Australia, raised the issue of AIS, ballast water management, and MOE with the IMO, to protect the ecosystems of the GLR (IJC/GLFC, 1990).
1 May 1989	CCG (DFO, EC, USCG, GLFC, and commercial fishers involved)	*Voluntary Guidelines for the Control of Ballast Water Discharges from Ships Proceeding to the St. Lawrence River and Great Lakes*	Voluntary BWE program for ships destined for the Great Lakes, to protect the Great Lakes from "non-native fish and other aquatic organisms, that can be harmful to the balance of nature that now exists" (Locke et al., 1991, p. 47). The guidelines apply only to areas upriver of Montreal.
1990	US Fisheries and Wildlife Service (USFWS); enforced by USCG	*Non-Indigenous Aquatic Nuisance Prevention and Control Act* (NANPCA)	The US introduced NANPCA to prevent the spread of aquatic and terrestrial invasive species in the nation's waters (NANPCA, 1990; Albert et al., 2013). NANPCA has been described as "the cornerstone of [the US'] defense against the invasion of aquatic nuisance species in the Great Lakes" (Weathers and Reeves, 1996, p. 93).

Date	Governing Bodies Involved	Event	Description
1990	Enforced by USCG	Voluntary BWE guidelines for ships destined for the Great Lakes	US introduced voluntary BWE guidelines for ships entering the Great Lakes that travel from outside of the US' EEZ; parallel to Canadian guidelines (Dextrase, 2002).
1991	CCG	Boundary changes for *Voluntary Guidelines* in St. Lawrence River	All areas upriver of Quebec City now under protection of the 1989 *Voluntary Guidelines*; previously only areas upriver of Montreal were protected (Locke et al., 1993).
4 July 1991	IMO, MEPC	*International Guidelines for Preventing the Introduction of Unwanted Aquatic Organisms and Pathogens from Ships' Ballast Water and Sediment Discharges* (MEPC resolution 50(31))	MEPC resolution 50(31) was voluntary, and recognized the significance of ballast water in the primary introduction of NIS, requested member states to further research the role of ballast water in facilitating the spread of AIS, and urged states to minimize the probability that ballast water will contain unwanted species (IMO, 1991). Adoption of these guidelines was largely based on the 1989 Canadian *Voluntary Guidelines* implementation experience (IMO, 1991).
1993	USCG	Mandatory regulations requiring BWE for ships destined for GLR	Mandatory legislation requiring mid-ocean BWE for ships operating outside of the US EEZ and destined for the GLR was introduced; the regulations were modeled on the 1989 Canadian *Voluntary Guidelines*. Due to the GLWQA, mandatory BWE was now required for all ballasted ships travelling outside the US' EEZ that entered the GLR, regardless of whether the destination port was American or Canadian (Dextrase, 2002; Duggan et al., 2005).
November 1993	IMO	*Guidelines for Preventing the Introduction of Unwanted Organisms and Pathogens from Ships' Ballast Water and Sediment Discharge* (Resolution A. 774 (18))	IMO adopted resolution A.774 (18); this resolution was a formal adoption of the voluntary guidelines proposed in 1991 (IMO, 1993).

Date	Governing Bodies Involved	Event	Description
1996	US Congress	*National Invasive Species Act* (NISA)	The purpose of the NISA was to "provide for ballast water management to prevent the introduction and spread of nonindigenous species into the waters of the United States" (NISA, 1996, p. 1). NISA aims to prevent NIS from entering and spreading in the Great Lakes via ballast water; target species are zebra mussels and Eurasian ruffe (Albert et al., 2013).
1997	Port of Vancouver	Vancouver Port Authority (VPA) BWE Standing Orders	Mandatory BWE program for ballasted ships arriving at Port of Vancouver. The *Standing Orders* stated that ships intending to deballast within the Port of Vancouver must inform the VPA if they have performed MOE, and complete the associated ballast form. If MOE had not occurred, deballasting was not allowed within VPA waters. The protocols were soon adopted by the Fraser Port and Port of Nanaimo (Levings, 1999).
November 1997	IMO	*Guidelines for the Control and Management of Ships' Ballast Water to Minimize the Transfer of Harmful Aquatic Organisms and Pathogens* (Resolution A.868 (20)).	Resolution A.868 (20) was an updated version of the 1993 resolution A.774 (18), and included further recommendations and procedures for best ballast water management practices. Resolution A.868 (20) is the current resolution for global ballast water management (IMO, 1997).
11 June 1998	TC, DFO	Bill C-15 receives Royal Assent	Bill C-15 allows Canada to implement statutory, nationwide ballast water management regulations under *Canada Shipping Act* (Wiley and Claudi, 2002).
31 October 1998	TC, DFO	Bill C-15 receives Governor in Council authority	Canada now has statutory authority to institute national ballast water management regulations (Wiley and Claudi, 2002)

Date	Governing Bodies Involved	Event	Description
4 November 1998	Canada's Marine Advisory Council (CMAC)	Ballast water management working group created	Ultimately, the working group intended to "provide a scientifically based regulatory environment that will, to the greatest extent possible, prevent future introductions of aquatic alien species from the ballast water of ships" (Wiley and Claudi, 2002, p. 238). This facilitated the implementation of national voluntary ballast water management guidelines (Wiley, 2000).
July 1999	USCG	Establishes a national voluntary ballast water management program	USCG implements a nation-wide voluntary ballast water management program (Miller et al., 2007; Albert et al., 2013).
1 January 2000	TC	*A Guide to Canada's Ballast Water Control and Management Regulations*	The guide provides information for the application of the *Guidelines for the Control of Ballast Water Discharge from Ships in Waters Under Canadian Jurisdiction*, released in September of the same year (TC, 2007).
1 September 2000	TC, DFO (supported by CMAC, ship owners, environmental organizations, government departments, and USCG)	*Guidelines for the Control of Ballast Water Discharge from Ships in Waters Under Canadian Jurisdiction* (TP 13617)	Canada's ballast water management program expanded nationally: the *Ballast Water Guidelines* were a draft for those adopted in 2006, and were not mandatory (TC, 2000; Albert et al., 2013).The purpose of the *Ballast Water Guidelines* was to protect waters that fall under Canadian jurisdiction from pathogens and NIS that can be potentially harmful to aquatic ecosystems (TC, 2000). The guidelines were designed to minimize the probability of future introductions from ballast water, while protecting the safety of ships (TC, 2000).
28 September 2000	Shipping Federation of Canada	*Code of Best Practices for Ballast Water Management*	The non-statutory *Code* recognized that ballast water is the primary vector for the spread of AIS in the GLR, and encouraged all vessels entering the GLR to commit to the *Code* and its best practices for ballast water management. The *Code* encouraged vessels to conduct ballast water management whenever practical, and to undergo management even if it is not required for the port of arrival (SFC, 2000).

Date	Governing Bodies Involved	Event	Description
2003	DFO, Canadian Council of Fisheries and Aquaculture Ministers	*National Code on Introductions and Transfers of Aquatic Organisms*	The purpose of the Code was to create a framework for international introductions and transfers of aquatic organisms. The Code is designed to simultaneously protect aquatic ecosystems and encourage use of aquatic resources (DFO, 2003).
13 February 2004	IMO	*International Convention for the Control and Management of Ships' Ballast Water and Sediments* (BWMC)	The objective of the BWMC is to prevent the invasion of non-native species via ships' ballast water, and is the first attempt at international, legally binding legislation for ballast water management (IMO, 2004). The BWMC proposes a ballast water performance standard, whereby the quality of ballast water will be held to a predetermined, numerically-based concentration standard for allowable numbers of live organisms transported in ballast tanks (IMO, 2004). IMO's BWMC will enter into force 12 months after ratification by 30 States, representing at least 35% of the world shipping tonnage (Lawal, 2011; IMO, 2014b).
2004	Canadian Council of Fisheries and Aquaculture Ministers Aquatic Invasive Species Task Group (CCFAM)	*A Canadian Action Plan to Address the Threat of Aquatic Invasive Species*	CCFAM released an action plan that addresses the threat of AIS in Canada. Notably, the plan identifies primary and secondary vectors for the introduction a spread of AIS species (CCFAM, 2004).
2004	USCG	Mandatory ballast water reporting for vessels in all US waters	Ballast water reporting made mandatory for all ships in US waters. This step is a nationwide expansion of the ballast water reporting regulations in the 1993 USCG mandatory regulations for destined for the Great Lakes (Miller et al., 2007; TC, 2007; Albert et al., 2013).

Date	Governing Bodies Involved	Event	Description
2005	USCG	Mandatory ballast water management for all vessels in US waters	Ballast water management was now required for all ships in US waters (Miller et al., 2007; TC, 2007; Albert et al., 2013).
8 June 2006	TC, DFO	*Ballast Water Control and Management Regulations* (SOR 2006/129)	The intent of the Regulations is to: "require ships to manage ballast water in such a manner as to reduce the potential of [damaging] invasions" (TC, 2006, p. 712). The regulations are the first nationally relevant, legally-binding document produced for Canadian ballast water management. The regulations require all vessels traveling to Canadian ports from outside Canadian jurisdiction to conduct MOE or undergo a similarly effective treatment. The regulations are the first to define treatment standards for microorganisms (TC, 2006; Lo *et al.*, 2012).
2009	EPA	Ballast water and other vessel discharges become part of CWA	EPA began regulating ballast water after previous exemption of ballast water and related discharges from the 1973 CWA (Dobroski, Scianni, and Takata, 2011).
April 2010	TC, DFO	Canada ratifies IMO's 2004 BWMC	Canada ratified the BWMC in April 2010 (TC, 2012). TC is currently deciding how to proceed with the formal implementation of IMO's D-2 standards: recommendations to the Minister of Transport have been made. At the time of writing, ballast water management guidelines from the office of the Minister of Transport were not available; thus, Canada's next steps towards implementing numeric-based standards remain uncertain.
27 October 2011	TC, DFO	*Ballast Water Control and Management Regulations* (SOR/2011-237)	Repeals and replaces 2006 *Ballast Water Control and Management Regulations* (SOR/2006-129) (TC, 2011).

Date	Governing Bodies Involved	Event	Description
23 March 2012	USCG	Concentration-based ballast water discharge limits are established	The initial ballast water discharge standard requires vessels to meet IMO's BWMC D-2 Regulations (Phase 1 standard); Phase 2 standards, however, require that vessels meet a discharge standard 1000 times more stringent than Phase 1 for certain classes of organisms (Albert et al., 2013).
11 June 2014	All	Moving toward ratification of IMO's 2004 BWMC	Presently at 32.5% ratification: need to reach 35% for the BWMC to become ratified globally (IMO, 2014b).