SCIENCE ADVICE FROM THE NATIONAL RISK ASSESSMENT FOR BALLAST WATER INTRODUCTIONS OF AQUATIC NONINDIGENOUS SPECIES TO CANADA

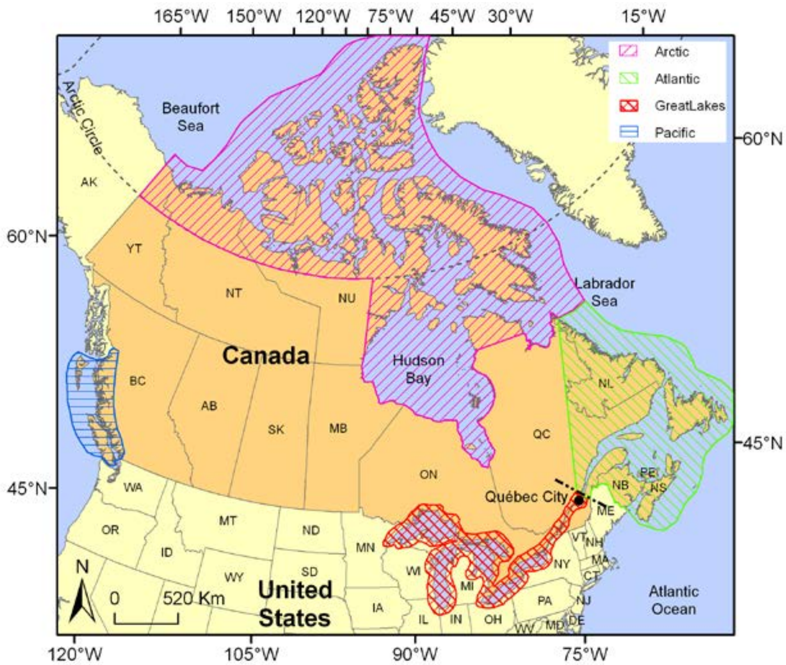

Figure 1. Geographic regions examined for the national ballast water risk assessment.

Context:

Transport Canada is tasked with managing a regulatory program that sets shipping procedures in order to reduce the risk of ship-mediated transfer of invasive species. Current Ballast Water Control and Management Regulations are being revised and Transport Canada has submitted a formal request to Fisheries and Oceans Canada (DFO) for science advice on the level of risk posed by the commercial shipping ballast vector to Canadian waters. DFO's Centre of Expertise for Aquatic Risk Assessment (CEARA) has established guidelines for assessing biological risk of aquatic invasive species in Canada.

The objective of the current advisory process is to assess the level of risk of introduction of aquatic invasive species (AIS) to Canadian waters in the ballast water of ships transiting between international and Canadian ports and by domestic shipping.

Specifically, Transport Canada requested science advice from DFO on the following:

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

This Science Advisory Report is from the Fisheries and Oceans Canada, Canadian Science Advisory Secretariat national meeting held March 25-27, and June 19-21, 2013 in Burlington, Ontario to assess the risk of ballast water introductions of nonindigenous species to Canada. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- Ballast water is a vector that poses a significant risk for primary and secondary introductions of aquatic nonindigenous species (NIS) to all regions. A proportion of these NIS is or may become invasive. Invasive species can cause economic, social, or ecological impacts.
- The following Science Advisory Report (SAR) is based on a comparative analysis of the relative risk among 11 ballast water pathways in Canada across Atlantic, Pacific, Arctic and Great Lakes regions (Figure 1).
- The comparative analysis considers the potential for arrival and survival of zooplankton and phytoplankton NIS (microbes are not considered) in determining introduction potential as well as the magnitude of consequences of these aquatic NIS. The relative risk posed by the discharge of ballast water from commercial ships in Canadian waters was assessed under current ballast water regulatory requirements, as well as future requirements for International Maritime Organization (IMO) D-2 performance standards.
- The invasion risk currently posed by International Transoceanic vessels arriving to the Great Lakes and St. Lawrence River (GLSLR) was used as the lowest risk benchmark in this study, since ballast water exchange (BWE) is thought to be particularly effective for this pathway and no ballast-mediated NIS have been reported from the Great Lakes since 2006. However, as this is a relative risk assessment, it should be noted that even the lowest ranked pathways pose a risk of invasion.
- Although few ballast water discharges occur in the Arctic, resulting in a relatively low annual risk, the risk posed by individual discharges of International Transoceanic vessels in the Arctic is comparatively high. This risk will increase in the future with expected growth of commercial shipping activities due to longer ice free seasons and northern development. Arctic ports are unlikely to serve as a source of NIS for other Canadian waters.
- Ships operating within the Ballast Water Exemption Zones in the Pacific and Atlantic regions currently pose a relatively high invasion risk. International Exempt vessels are an important pathway for the introduction of zooplankton and phytoplankton NIS into Canadian waters through the transport of un-exchanged ballast water.
- The risk of domestic vessels for introduction of aquatic NIS is variable across regions, taxa and timescales. Lakers pose a relatively high risk for zooplankton NIS at both timescales, while Eastern Coastal Domestic vessels pose a relatively high risk for both zooplankton and phytoplankton NIS on an individual discharge basis. The risk posed by domestic ships in the Arctic is relatively low, while Pacific Coastal Domestic vessels were not assessed due to lack of data.

- While current regulatory requirements for BWE by transoceanic vessels reduce the risk of invasions to freshwater ecosystems (e.g., Great Lakes), these regulations are less effective in reducing the risk to marine ecosystems (i.e., Atlantic and Pacific International Transoceanic pathways are relatively high risk in this assessment).
- The abundance (i.e., number of individuals) of zooplankton NIS would be reduced for all pathways if managed in accordance with the IMO D-2 standard. However, the abundance of phytoplankton NIS would be reduced only for half of the pathways.
- Effective management of all ship-mediated NIS introductions will require consideration of other shipping vectors such as hull biofouling and ballast sediments, by both commercial and non-commercial vessels.

INTRODUCTION

Species that have established populations outside of their native range are known as nonindigenous species (NIS). While only a small proportion of NIS introductions have measurable impacts, NIS can severely impact recipient ecosystems and cause long-term economic and ecological consequences. NIS invasions have become increasingly prevalent, as globalization has increased both intentional and unintentional species transfers worldwide.

The biological invasion process begins with founding individuals, known as propagules, which must be taken up by, and survive conditions within a transport vector, to be moved from the source region to a new environment. Once released, the propagules must survive in the new environment in order to form a reproductive population (i.e., establish). Any established NIS population can act as a source of propagules for further introduction of the species (i.e., “secondary” invasion). The process and impacts of secondary invasions are the same as for primary invasions – the term “secondary” implies the transport of propagules from an intermediate location rather than the native range.

Although biological invasions do occur naturally, the rapid rate, global spatial scale and immense diversity of human-assisted invasions are a unique driver of global change. Vectors for aquatic NIS in Canada’s freshwater and marine ecosystems include intentional (e.g., authorized stocking programs) and unintentional releases of aquatic species. Unintentional releases can be associated with commercial shipping activities (e.g., ballast water discharge or hull fouling), escape from aquaculture facilities, and unauthorized releases of aquarium, baitfish, and ornamental pond species.

Ballast water has historically been a dominant vector for aquatic NIS introductions to Canada. Ballast water is defined as water with its suspended matter taken on board a ship to control trim, list, draught, stability or stresses of the ship. Since water taken on as ballast is comprised of ambient waters surrounding the ship at the source port, diverse assemblages of plankton present in the water column are pumped into ballast tanks in conjunction with water uptake, along with re-suspended port sediments and associated benthic communities. These communities are then transported and released at subsequent commercial ports in a relatively short period of time, which can be located thousands of kilometres from the source port – a distance far greater than typically achieved by natural dispersal.

Current Canadian *Ballast Water Control and Management Regulations* are being revised to align with international commitments at the International Maritime Organization (IMO), an agency of the United Nations that works to improve maritime safety and prevent pollution from ships. In this context, Transport Canada requested science advice on the level of risk posed by the commercial shipping vector to Canadian waters from Fisheries and Oceans Canada (DFO) to inform revisions to the current *Ballast Water Control and Management Regulations*. Specifically, Transport Canada requested advice on the following questions:

1) "What is the level of risk posed by ships transiting to, or from, Arctic ports for the introduction of AIS (aquatic invasive species) to Canadian waters?

2) What is the level of risk posed by ships operating within the ballast water exchange exemption zones on the East and West coasts?

3) What is the level of risk posed by domestic shipping activities?

4) Do current ballast water management regulations provide sufficient protection against ship-mediated AIS introductions?"

The following document provides science advice to Transport Canada about the level of risk posed by the shipping vector to Canadian waters through ballast water. This Science Advisory Report (SAR) is the final step of an iterative process to address the above questions – initially, invasion risk was examined for the most active ports in the Great Lakes, Arctic, Atlantic and Pacific regions. This national SAR builds on the regional documents (e.g., Chan et al., 2012, Bailey et al. 2012, DFO 2012a,b) by evaluating invasion risk on the scale of shipping pathways as opposed to ports, and also incorporates new data from recent biological surveys of ballast water.

The following science advice is based on recent shipping patterns and environmental conditions; any changes to one or both factors in the future will lead to changes in invasion risk. In particular, increases in shipping traffic to Canada would result in higher arrival potential and shifting trade patterns could establish new connections with global source ports sharing high environmental similarity to Canadian recipient ports. Further, climate change scenarios predict both thermal and physical changes across Canada, which could impact analyses of environmental similarity between port pairs. A reanalysis of environmental similarity between donor and recipient port pairs, using environmental variables projected under climate change scenarios, would be useful to further refine predictions of future invasion risk across Canada.

Ballast Water Control and Management Regulations

Current

Voluntary ballast water management was initiated in the Great Lakes and St. Lawrence Region (GLSLR) in 1989 and was extended to all waters under Canadian jurisdiction in 2000. National, mandatory ballast water regulations (the *Ballast Water Control and Management Regulations*) were established in 2006, and revised in 2007 and 2011. The present regulations require all vessels operating in Canadian waters to manage their ballast water, with some exceptions as specified in the Regulations.

Ballast water exchange (BWE) is the main option utilized by vessels for ballast water management. BWE is a process by which a ship exchanges ballast water loaded near shore with open-ocean saltwater. BWE is based on two main principles: (1) coastal species contained in ballast water are replaced by oceanic species that are unlikely to survive when discharged into a coastal environment; and, (2) exposure to oceanic levels of salinity would be fatal for many near-shore organisms, reducing the probability of their survival. Similar to BWE, tank flushing involves rinsing ‘empty’ tanks with open-ocean water, and is required for all vessels entering the Great Lakes from overseas.

To maximize BWE efficacy, vessels must replace a minimum of 95% of their ballast water.

BWE must be conducted ≥ 200 nautical miles from land where water depth is ≥2000 meters; vessels not voyaging in waters meeting these conditions may undertake BWE ≥ 50 nautical miles from land where water depth is ≥ 500 m. In both cases, the vessel’s ballast water must achieve a final salinity of ≥ 30 parts per thousand (*Ballast Water Control and Management Regulations*). Under certain weather conditions or other reasonable circumstances, Canada will accept BWE in designated alternate exchange zones closer to shore.

Proposed Changes

The IMO adopted the *International Convention for the Control and Management of Ships Ballast Water and Sediments* in 2004 (hereinafter referred to as the “Convention”). The Convention sets maximum allowable discharge limits, known as the IMO D-2 performance standard, for organisms and indicator microbes in ballast water (Table 1). The Convention has not yet entered into force. Canada ratified the Convention in 2010, thereby agreeing to adopt this standard for waters under Canadian jurisdiction once the Convention enters into force. In order to comply with the performance standard in the Convention, most vessels are expected to fit a ballast water treatment system to remove or eradicate the vast majority of organisms in their ballast water (Transport Canada 2012). Although the Convention envisions replacement of BWE with the IMO D-2 performance standard, Transport Canada proposed retaining requirements for BWE in combination with the IMO D-2 standard to provide enhanced protection to recipient freshwater ports (Transport Canada 2012).

Table 1. Ballast water performance standards in the International Convention for the Control and Management of Ships’ Ballast Water and Sediments (IMO 2004, Regulation D-2).

Category	Size range	Discharge standard
Zooplankton	≥50 µm	<10 organisms•m^{-3}
Phytoplankton	≥10-<50µm	<10 cells•mL^{-1}
Indicator Microbes	*Vibrio cholera*	1 CFU per 100mL or 1 CFU per 1g (wet weight) zooplankton samples
	Escherichia coli	250 CFU per 100mL
	Intestinal Enterococci	100 CFU per 100mL

ASSESSMENT

For the national risk assessment, Canada was divided into four regions (Atlantic, Pacific, Arctic and Great Lakes-St. Lawrence River; Figure 1). A three-step risk assessment was conducted separately for zooplankton and phytoplankton NIS; microbes were not assessed due to a lack of data/information. First, introduction potential was estimated by combining the individual potentials for arrival and survival of NIS, based on ballast water discharge volume, abundances sampled from ballast water, and environmental similarity between source and recipient regions.

Establishment was assumed to occur if arriving NIS were deemed capable of surviving in recipient environmental conditions. Since vessels transiting different geographic regions will carry different species assemblages with different characteristics and requirements affecting invasion risk, introduction potential was assessed according to each vessel's operational profile during the entire period of study (this profile is hereafter referred to as a pathway; see Table 2 for definitions).

Second, the potential magnitude of consequences of introduction was estimated based on the number of high impact ballast-mediated NIS occurring in each source ecoregion. Finally, introduction potential and potential magnitude of consequences were combined using a risk matrix (Table 3) to determine the final relative invasion risk rating among shipping pathways. Invasions are a stochastic process (subject to non-deterministic factors such as chance) and it is currently not possible to assign absolute probabilities of invasion success; therefore, the invasion risk currently posed by GLSLR International Transoceanic vessels was used as the "lowest risk" benchmark in this study, since BWE is thought to be particularly effective for this pathway and no new ballast-mediated NIS have been reported from the Great Lakes since 2006 (Bailey et al. 2011).

Table 2. Definitions of vessel pathways utilized in the risk assessment.

Pathway	Definition
Arctic Coastal Domestic	Operate exclusively between ports within GLSLR, Atlantic and Arctic regions
Arctic International Transoceanic	Operations must include at least one port in Arctic region and at least one port outside Canada and the U.S.; may also operate within GLSLR and Atlantic regions, and the U.S.
Eastern Coastal Domestic	Operate exclusively between ports within GLSLR and Atlantic regions
GLSLR International Transoceanic	Operations must include at least one port in GLSLR region and at least one port outside Canada and the U.S.; may also operate within Atlantic regions, and the U.S.
Lakers	Operate exclusively between ports within the GLSLR region and the St. Lawrence Estuary (i.e., from Duluth to Sept-Iles)
Atlantic International Coastal U.S.	Operate exclusively between ports within Atlantic region and coastal U.S. (south of Cape Cod)
Atlantic International Exempt	Operate exclusively between ports within Atlantic region and coastal U.S. north of Cape Cod
Atlantic International Transoceanic	Operations must include at least one port in Atlantic region and at least one port outside Canada and the U.S.; may also operate within the U.S.
Pacific International Coastal U.S.	Operate exclusively between ports within Pacific region and coastal U.S. (south of Cape Blanco)
Pacific International Exempt	Operations include at least one port within Pacific region, with last port-of-call in the coastal U.S. north of Cape Blanco; typically also operate at ports outside of Canada and the U.S. prior to arrival within the exemption zone
Pacific International Transoceanic	Operations must include at least one port in Pacific region and at least one port outside Canada and the U.S.; may also operate within the U.S.

Table 3. Matrix used to combine introduction potential and magnitude of consequences of introduction into final relative risk rankings; green = lowest risk, yellow = intermediate risk and red = highest risk. Note the placement of GLSLR International Transoceanic vessels in the upper left corner, which was used as a benchmark for the relative rankings in the risk assessment.

		P (Introduction)				
		Lowest	Lower	Intermediate	Higher	Highest
Consequence	Highest	Lowest (GLSLR I.T.)	Intermediate	Highest	Highest	Highest
	Higher	Lowest	Intermediate	Intermediate	Highest	Highest
	Intermediate	Lowest	Intermediate	Intermediate	Intermediate	Highest
	Lower	Lowest	Lowest	Intermediate	Intermediate	Intermediate
	Lowest	Lowest	Lowest	Lowest	Lowest	Lowest

Relative invasion risk was calculated based on annual and per event ballast water discharge volumes, allowing examination of risk at different temporal scales. Since Canada will transition soon to a new ballast water management regime that is expected to enhance protection against NIS, the assessment process was repeated to assess relative risk under the IMO D-2 performance standard. Abundances of zooplankton and phytoplankton NIS expected after ballast water treatment to the IMO D-2 performance standard were estimated and used in the calculation of arrival potential to estimate the future risk of ballast-mediated introductions after entry into force of the Convention in order to compare present and future risk of ballast-water mediated introductions.

Data Sources

Ship Data

For each region, a comprehensive database of merchant vessel discharge events and volume of ballast water discharged at Canadian ports was compiled. Analyses were limited to vessels at least 50 m in length with ballast capacity of at least 8 m^3 since these vessels facilitate the vast majority of ballast water movements in Canada and are subject to Canadian ballast water management and reporting regulations (i.e., bulk carriers, tankers, general cargo, and roll on/roll off vessels). To maximize data coverage and quality, shipping activity information was extracted and cross-referenced from at least two government sources (see Table 4).

Table 4. Data sources for shipping activity by region with year(s) of data available: Transport Canada Ballast Water Database (TCBWD); Canadian Coast Guard Information System on Marine Navigation (INNAV); U.S. National Ballast Information Clearinghouse (NBIC); Canadian Coast Guard Vessel Traffic Operations Support System (VTOSS).

Region	**Data Source**				**Year**	**Reference**
	TCBWD	*INNAV*	*NBIC*	*VTOSS*		
Arctic	*X*	*X*			*2005-2008*	Chan et al. 2012
GLSLR	*X*	*X*	*X*		*2007*	Bailey et al. 2012
Atlantic	*X*	*X*			*2006*	Adams et al. 2013
Pacific	*X*		*X*	*X*	*2008*	Linley et al. pers.comm.[a]

[a]Linley, R.D., Doolittle, A.G., Chan, F.T., O'Neill, J., Sutherland, T. and Bailey, S.A. 2013. Relative Risk Assessment for ship-mediated introductions of aquatic nonindigenous species to the Pacific Region of Canada. Working Paper.

Biological Data

Biological data (i.e., number of organisms per unit area and number of species) of zooplankton and phytoplankton NIS in ballast water were obtained from recent sampling surveys conducted by the Canadian Aquatic Invasive Species Network (CAISN) and Fisheries and Oceans Canada (Humphrey 2008; Klein et al. 2009; Bailey et al. 2011; Briski et al. 2012 a,b; Casas-Monroy 2012; DiBacco et al. 2012; Roy et al. 2012; Adebayo et al. 2013; S. Bailey and M. Munawar, Fisheries and Oceans Canada, unpublished data). Biological data were not available for Arctic pathways, thus, zooplankton data for the Atlantic International Transoceanic pathway were re-evaluated to calculate abundances of species that are NIS to the Arctic. Phytoplankton NIS density calculated for the Atlantic International Transoceanic pathway was applied to the Arctic International Transoceanic pathway. A subset of data from the Eastern Coastal Domestic pathway (Quebec-sourced ballast water) was used to estimate zooplankton NIS transported by Arctic Coastal Domestic vessels; no data was available for phytoplankton NIS for Arctic Coastal Domestic vessels.

Environmental Data

Annual mean salinity was determined for each coastal source and recipient port, using the online World Ocean Atlas database (Antonov et al. 2006; Locarnini et al. 2006). Data for the "sea surface" layer representing the first 10 m of the water column were selected as most representative of coastal ports due to lack of data at a finer spatial (horizontal and vertical) resolution (Glasby et al 2007). Mean salinity values for inland ports (e.g., Great Lakes ports) were obtained from Keller et al. (2011). Ports were categorized as either freshwater (0.0 - 5.0 ‰), brackish (5.1 – 18 ‰) or marine (18.1 ‰ and higher). All ports were further classified by latitude into four climate zones: Tropical (0°-20°), Warm-Temperate (20°-40°), Cold-Temperate (40°-60°) and Polar (>60°) following Spalding et al. (2007), Keller et al. (2011) and Rubel and Kotter (2010).

Consequences Data

A list of high impact (i.e., invasive) ballast-mediated NIS present in 232 coastal ecoregions was extracted from the Nature Conservancy's Marine Invasive Database (species ranked at harm levels 3 or 4; Molnar et al. 2008). In addition, since the GLSLR ecoregion is not included in the Nature Conservancy dataset, 11 freshwater high impact ballast-mediated NIS were added for a total of 167 species in 233 ecoregions. The list was reviewed for accuracy in the context of Canadian recipient ecoregions by experts during the peer review of this risk assessment; species native to a Canadian recipient ecoregion and marine species connected to a freshwater recipient port were removed, and taxonomic nomenclature was updated. Adding species was considered beyond the scope of what could be accomplished and reviewed at the meeting, so the species list represents an index of relative risk rather than a comprehensive list of potential invaders.

Results

The relative risks for ballast-mediated NIS under current *Ballast Water Control and Management Regulations* are presented in Table 5. Relative risks under future requirements for IMO D-2 performance standards are presented in Table 6. The detailed results for all risk assessment components are listed in Appendices 1 and 2.

Table 5. Relative invasion risk for ballast-mediated NIS by vessel pathways under current regulations in Canada. Note that risk differed for some pathways depending on taxonomic group being considered.

	Current Risk			
	Annual		Per Discharge Event	
Pathway	**Zooplankton**	**Phytoplankton**	**Zooplankton**	**Phytoplankton**
Arctic Coastal Domestic	Lowest	Lowest	Lowest	Lowest
Arctic International Transoceanic	Lowest	Intermediate	Highest	Highest
Eastern Coastal Domestic	Lowest	Intermediate	Highest	Highest
GLSLR International Transoceanic	Lowest	Lowest	Lowest	Lowest
Lakers	Highest	Lowest	Highest	Lowest
Atlantic International Coastal U.S.	Intermediate	Highest	Highest	Highest
Atlantic International Exempt	Intermediate	Highest	Highest	Highest
Atlantic International Transoceanic	Highest	Highest	Highest	Highest
Pacific International Coastal U.S.	Highest	Highest	Highest	Highest
Pacific International Exempt	Highest	Highest	Highest	Highest
Pacific International Transoceanic	Highest	Highest	Highest	Highest

Table 6. Relative invasion risk for ballast-mediated NIS by vessel pathways under future requirements for IMO D-2 standards in Canada. Note that risk differed for some pathways depending on taxonomic group being considered.

	Future Risk			
	Annual		Per Discharge Event	
Pathway	**Zooplankton**	**Phytoplankton**	**Zooplankton**	**Phytoplankton**
Arctic Coastal Domestic	Lowest	Lowest	Lowest	Lowest
Arctic International Transoceanic	Lowest	Intermediate	Lowest	Highest
Eastern Coastal Domestic	Lowest	Lowest	Lowest	Lowest
GLSLR International Transoceanic	Lowest	Lowest	Lowest	Lowest
Lakers	Lowest	Lowest	Lowest	Lowest
Atlantic International Coastal U.S.	Lowest	Highest	Lowest	Highest
Atlantic International Exempt	Lowest	Highest	Lowest	Highest
Atlantic International Transoceanic	Lowest	Highest	Lowest	Highest
Pacific International Coastal U.S.	Lowest	Highest	Lowest	Highest
Pacific International Exempt	Lowest	Highest	Lowest	Highest
Pacific International Transoceanic	Lowest	Highest	Lowest	Highest

Sources of Uncertainty

- Shipping arrival frequency and discharge quantities can vary significantly from year to year (DiBacco et al. 2012).
- There is uncertainty surrounding the number of NIS in ballast for pathways where biological sample sizes were small or unavailable (e.g., Arctic pathways).
- Environmental conditions (temperature and salinity) vary temporally and spatially, and are not usually available at the resolution of ports (near-shore, shallow coastal waters). This variation may influence the survival component of the risk assessment.
- The list of high impact NIS by ecoregion used to determine magnitude of consequence in this assessment is a static, conservative list based on available information, which may not represent current species' distributions. The list does not account for species

that may cause high impacts in new recipient regions despite low or negligible impact in source regions, or high impact species that are native to the source region but NIS to the recipient region.

- The assessment of future risk assumes the IMO D-2 performance standard will be required for all shipping pathways and that BWE will be required in combination with the IMO D-2 standard for freshwater recipient ports; should this not occur, introduction potential will be higher for certain transits, which may affect the final risk.

- As there are limited long term phytoplankton datasets and baseline data for many regions in Canada available with respect to species diversity and distribution, it is difficult to accurately assess the risks of phytoplankton introductions.

Knowledge Gaps

- Domestic shipping in the Pacific region is conducted exclusively by tug and barge; while tugs do report their movements to traffic databases, barges, which carry the ballast water, do not. As a result, data were not available to assess the risk associated with Pacific Coastal Domestic vessels.

- More data are needed on vessel history and ballasting activities for shipping transits between Canadian ports to improve the accuracy of future risk assessments.

CONCLUSIONS AND ADVICE

This advice is based on a comparative risk assessment, allowing prioritization of different ballast pathways. Rankings are relative to the invasion risk currently posed by International Transoceanic vessels in the GLSLR; even the lowest ranked pathways pose a risk of invasion. The following provides specific advice for each of the questions posed by Transport Canada.

1) What is the level of risk posed by ships transiting to, or from, Arctic ports for the introduction of AIS (aquatic invasive species) to Canadian waters?

In comparison to the other shipping pathways, Arctic Coastal Domestic vessels pose lowest relative invasion risk (both temporal scales). Survival appears to be the limiting factor for Arctic Coastal Domestic vessels, however, Arctic Coastal Domestic vessels that conduct voluntary BWE in the Strait of Belle Isle, despite good intentions, may not be reducing introduction potential effectively since this area is more environmentally similar to Arctic ports (high salinity, colder temperatures) than are ballast source ports in the St. Lawrence River. Further, it should be noted that this pathway had the second highest mean abundance of zooplankton NIS; if environmental similarity between donor and recipient ports increases due to climate change, introduction potential for this pathway will increase. As there are no NIS reported from Canadian Arctic waters, there is limited opportunity for Arctic ports to serve as a source of NIS for other Canadian waters.

Arctic International Transoceanic vessels pose lowest/intermediate invasion risk for zooplankton/phytoplankton at the annual scale, but highest invasion risk for both taxa on the per-event basis, indicating that individual discharges by transoceanic vessels are high risk and cumulative risk will increase if international shipping traffic increases in the region. Our shipping traffic analysis indicates that Canadian Arctic ports are connected with a variety of international ports, providing a mechanism for the introduction of a variety of NIS into the Canadian Arctic.

It should be noted that future risk for Arctic ports will increase if global climate change results in greater shipping traffic (and more ballast water discharges). Increasingly warm surface water temperatures may extend the length of the shipping season and open new waterways in the Arctic and may increase the potential for survival in Arctic ports. If proposed large-scale resource extraction developments progress as planned, they will rank amongst Canada's largest ballast discharge sites.

2) What is the level of risk posed by ships operating within the ballast water exchange exemption zones on the East and West coasts?

International Exempt vessels are an important pathway for the introduction of zooplankton and phytoplankton NIS into Canadian waters through the transport of un-exchanged ballast water.

Atlantic International Exempt Vessels currently pose intermediate invasion risk for zooplankton NIS and highest invasion risk for phytoplankton NIS on an annual basis, and highest relative risk for both taxonomic groups on a per-event scale. Although this pathway operates within a limited geographic range, the source ports have a moderate number of high impact AIS which could be transported to Canadian ports.

Pacific International Exempt Vessels currently pose highest invasion risk for both taxonomic groups, on both temporal scales. Despite the low volume of ballast water discharged per year and the relatively small amount of vessel activity associated with this pathway, the average abundance of NIS is relatively high per vessel, and survival potential is highest with highest magnitude of consequences.

It should be noted that Transport Canada Inspectors in the Pacific region apply the exemption more liberally than in the Atlantic region, by granting the exemption based on a vessels' last port of call rather than limiting the exemption to vessels which operate 'exclusively' in the exemption zone as is written in Canadian regulations. This liberal application of the ballast water management exemption in the Pacific parallels the 'no ballast on board' (NOBOB) situation in the Great Lakes prior to requirements for saltwater flushing, where discharge of ballast water sourced from local ports posed a risk of new introductions by mixing with untreated residual ballast water from foreign ports.

3) What is the level of risk posed by domestic shipping activities?

The risk of domestic vessels is variable across regions, taxa and timescales. Lakers pose highest risk for zooplankton NIS but lowest for phytoplankton NIS, for both annual and per-event temporal scales. Eastern Coastal Domestic vessels pose highest risk for both zooplankton and phytoplankton on a per event basis. The risk posed by domestic ships in the Arctic is lowest for both temporal scales, while Pacific Coastal Domestic vessels were not assessed due to lack of data.

In general, domestic vessels transport high abundances of zooplankton NIS, and since environmental similarity between ports within regions is very high, survival potential of NIS is high at recipient ports. Despite high environmental similarity (e.g., temperature, salinity), biological communities at different ports within regions can be very different. As a result, domestic ballast water can facilitate primary invasions of species that are native to a subset of

Canadian ports but are NIS to other Canadian ports. Similarly, domestic shipping can facilitate secondary invasions of NIS initially introduced to one Canadian port (by any vector) to other Canadian ports. For these reasons, domestic ships are important to consider when developing management plans to reduce risk.

4) Do current ballast water management regulations provide sufficient protection against ship-mediated AIS introductions?

Evaluating the appropriateness of the current *Ballast Water Control and Management Regulations* is a management exercise that involves determining a level of risk tolerance. While such an evaluation is beyond the scope of this advice, DFO Science can provide relevant information for consideration in the decision-making process.

Nine shipping pathways in Canada currently pose intermediate to highest invasion risk for either zooplankton or phytoplankton NIS; five of these pathways are already required to conduct BWE, indicating that the level of protection provided by current ballast water management regulations is not equivalent for all pathways. This is because the efficacy of BWE is highly variable, particularly for coastal voyages. In fact, in some studies BWE has increased the introduction potential of NIS, particularly for phytoplankton on the Atlantic coast (e.g., Carver and Mallet 2002). Similarly, on the Pacific coast, Cordell et al. (2009) reported that BWE had no significant influence on coastal zooplankton species.

In addition to variable efficacy, a potentially confounding factor is that vessels on the three Canadian coasts have a shorter history and experience in undertaking BWE than do vessels in the GLSLR. In addition, ships entering the Great Lakes are required to manage ballast residuals through tank flushing and a comprehensive bi-national ballast water inspection program was established in 2006 for the GLSLR region, which, in turn, has decreased arrival potential of aquatic NIS (Bailey et al. 2011).

Future risk projections indicate that ballast water management at the level of the IMO D-2 standards will dramatically reduce arrival potential for zooplankton for all pathways in all regions. In contrast, the IMO D-2 standards will have a lesser effect on arrival potential for phytoplankton (reducing expected abundances of NIS for only five pathways). The proposed requirements for BWE in combination with the IMO D-2 standards for vessels arriving to Canadian freshwater ports are expected to maintain very low survival potential of introduced NIS while also systematically reducing arrival potential.

Recommendations

- Future biological sampling of ballast water should be prioritized for shipping pathways and taxa having no data available or small sample size to more accurately quantify the arrival potential of NIS.
- Research should be conducted at dominant ballast water source ports, both within and outside Canada, to more accurately estimate the diversity of all NIS taxa, including zooplankton, phytoplankton and microbes that could be introduced by shipping pathways.
- Advice on potential benefits and risks associated with different locations of BWE should be developed for Arctic Coastal Domestic transits.

- A reanalysis of environmental similarity between donor and recipient port-pairs, using environmental variables projected under down-scaled (regional) climate change scenarios, would be useful to further refine predictions of future invasion risk across Canada.
- Additional assessments should be conducted to evaluate the risk of domestic vessels in the Pacific region.
- Additional assessments should be conducted to evaluate the risk of hull biofouling and ballast water sediments, by both commercial and non-commercial ships.

OTHER CONSIDERATIONS

Any established NIS population can act as a source of propagules for further introductions of the species, a process known as secondary invasions. The risk of secondary invasions within the same biogeographic region can be very high because the NIS has already demonstrated a tolerance for physical, chemical and biological conditions of the region and, as such, secondary invasions should be considered as important as primary invasions when developing management plans to reduce risk.

Some non-merchant and recreational vessels, such as large fishing vessels and cruise ships, do carry and exchange >8 m^3 ballast water, but because of a lack of data and inconsistent reporting, these vessels were not included in this risk assessment.

Protection against all ship-mediated NIS introductions will require consideration of other non-commercial and commercial shipping vectors such as hull fouling and ballast sediments, in addition to the ballast water vector.

SOURCES OF INFORMATION

This Science Advisory Report is from the Fisheries and Oceans Canada, Canadian Science Advisory Secretariat, national advisory meeting of March 25-27, and June 19-21 2013 on the National Risk Assessment for ship-mediated introductions of aquatic nonindigenous species to Canada. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

Adams, J.K., Ellis, S.M., Chan, F.T., Bronnenhuber, J.E., Simard, N., McKenzie, C.H, Martin, J.L., and Bailey, S.A. 2013. Relative risk assessment for ship-mediated introductions of aquatic nonindigenous species to the Atlantic Region of Canada. DFO Canadian Science Advisory Secretariat Research Document. 2012/116. vi + 404 p.

Adebayo AA, A Zhan, SA Bailey and HJ MacIsaac. 2013. Domestic ships as a potential pathway of nonindigenous species from the St. Lawrence River to the Great Lakes. Biological Invasions *DOI 10.1007/s10530-013-0537-5*.

Antonov, J.I., Locarnini, R.A., Boyer, T.P., Mishonov, A.V., and Garcia, H.E. 2006. World Ocean Atlas 2005, Volume 2: Salinity. Edited by S. Levitus. NOAA Atlas NESDIS 62, U.S. Government Printing Office, Washington, D.C. 182 p.

Bailey, SA, Deneau, M.G., Jean, L., Wiley, C.J., Leung, B., and MacIsaac, H.J. 2011. Evaluating efficacy of an environmental policy to prevent biological invasions. Environmental Science and Technology 45: 2554-2561.

Bailey, S.A., Chan, F., Ellis, S.M., Bronnenhuber, J.E., Bradie, J.N., and Simard, N. 2012. Risk Assessment for ship-mediated introductions of aquatic nonindigenous species to the Great Lakes and freshwater St. Lawrence River. Fisheries and Oceans Canada. Canadian Science Advisory Secretariat. Research Document. 2011/104 vi+224p.

Briski, E., Bailey, S.A., Casas-Monroy, O., DiBacco, C., Kaczmarska, I., Levings, C., MacGillivary, M.L., McKindsey, C.W., Nasmith, L.E., Parenteau, M., Piercey, G., Rochon, A., Roy, S., Simard, N., Villac, M.C., Weise, A., and MacIsaac, H.J. 2012a. Browne, R.A., and Wanigasekera, G. 2000. Combined effects of salinity and temperature on survival and reproduction of five species of Artemia. Journal of Experimental Marine Biology and Ecology 244: 29-44.

Briski, E., Ghabooli, S., Bailey, S.A., and MacIsaac, H.J. 2012b. Invasion risk posed by macroinvertebrates transported in ships' ballast tanks. Biological Invasions 1: 1843-1850.

Casas-Monroy, O. 2012. Introduction des dinoflagellés non-indigènes dans les écosystèmes aquatiques canadiens via les réservoirs de ballast de navires. Ph.D. thesis. Univ. of Quebec at Rimouski.

Carver, C. E., and Mallet, A. L. 2002. An assessment of the risk of ballast water-mediated introduction of non-indigenous phytoplankton and zooplankton into Atlantic Canadian waters. Mallet Research Services, Dartmouth, Nova Scotia. (accessed 25 February 2011).

Chan, F.T., Bronnenhuber, J.E., Bradie, J.N., Howland, K.L., Simard, N., and Bailey, S.A. 2012. Risk assessment for ship-mediated introductions of aquatic nonindigenous species to the Canadian Arctic. DFO Canadian Science Advisory Secretariat Research Document. 2011/105. vi + 93 p.

Cordell, J. R., Lawrence, D. J., Ferm, N. C., Tear, L. M., Smith, S. S., and Herwig, R. P. 2009.Factors influencing densities of non-indigenous species in the ballast water of ships arriving at ports in Puget Sound, Washington, United States. Aquatic Conservation: Marine and Freshwater Ecosystems. 19: 322-343.

[DFO] Fisheries and Oceans Canada. 2012a. Science advice from the risk assessment for ship-mediated introductions of aquatic non-indigenous species to the Great Lakes and freshwater St. Lawrence River. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2011/066.

[DFO] Fisheries and Oceans Canada. 2012b. Science advice from the risk assessment for ship-mediated introductions of aquatic non-indigenous species to the Canadian Arctic. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2011/067.

DiBacco, C., Humphrey, D. B., Nasmith, L. E., and Levings, C. D. 2012. Ballast water transport of non-indigenous zooplankton to Canadian ports. ICES Journal of Marine Science. 69: 483-491.

Glasby, T., Connell, S., Holloway, M., and Hewitt, C. 2007. Nonindigenous biota on artificial structures: could habitat creation facilitate biological invasions? Marine Biology 151: 887-895.

Humphrey, D.B. 2008. Characterizing ballast water as a vector for nonindigenous zooplankton transport. M.Sc. thesis, Faculty of Graduate Studies (Oceanography), The University of British Columbia, Vancouver, B.C.

[IMO] International Maritime Organization. 2004. International convention for the control and management of ships' ballast water and sediments. Adopted 13 February 2004.

Keller, R.P., Drake, J.M., Drew, M.B., and Lodge, D.M. 2011. Linking environmental conditions and ship movements to estimate invasive species transport across the global shipping network. Diversity and Distribution. DOI: 10.1111/j.1472-4642.2010.00696.x.

Klein, G., Kaczmarska, I., and Ehrman, J.M. 2009. The Diatom chatoceros in ships' ballast waters-survivorship of stowaways. Acta Botanica Croatia 68: 325-338.

Locarnini, R.A., Mishonov, A.V., Antonov, J.I., Boyer, T.P., and Garcia, H.E. 2006. World Ocean Atlas 2005, Volume 1: Temperature. Edited by S. Levitus. NOAA Atlas NESDIS 61, U.S. Government Printing Office, Washington, D.C. 182 p.

Molnar, J.L., Gamboa, R.L., Revenga, C., and Spalding, M.D. 2008. Assessing the global threat of invasive species to marine biodiversity. Frontiers in Ecology and the Environment 6: 485-492.

Roy, S., Parenteau, M., Casas-Monroy, O., and Rochon, A. 2012. Coastal ship traffic: a significant introduction vector for potentially harmful dinoflagellates in eastern Canada. Canadian Journal for Fisheries and Aquatic Sciences 69: 627-644.

Rubel, F., Kottek, M. 2010. Observed and projected climate shifts 1901-2100 depicted by word maps of the Köppen-Geiger climate classification. Meteorologische Zeitschrift 19: 135-141.

Spalding, M.D., Fox, H.E., Allen G.R., Davidson, N., Ferdeña Z.A., Finlayson M., Halpern, B.S., Jorge M.A., Lombana A., Lourie S.A., Marin, K.D. McManus, E., Molnar, J., Recchia, C.A., and Robertson J. 2007. Marine Ecoregions of the World: a Bioregionalization of Coastal and Shelf Area. BioScience 57: 573-583.

Transport Canada. 2012. Discussion Paper: Canadian implementation of the Ballast Water Convention. Transport Canada, Ottawa.

APPENDIX 1

Results of the relative invasion risk assessment for a) annual and b) per-event timescales, for ballast-mediated NIS by vessel pathways under current regulations in Canada. The level of uncertainty for each component is indicated in brackets below each column heading. Note that introduction potential, and resulting final risk, differed for some pathways depending on taxonomic group being considered. Introduction is the lowest value reported for arrival and survival, while final risk is determined by consulting Table 3. The asterisk (*) denotes pathways with greater (moderate) uncertainty for zooplankton NIS arrival potential as additional assumptions were applied.

a) Annual Zooplankton and Phytoplankton invasion risk

Pathway (Uncertainty)	Annual arrival zooplankton (Low)	Annual arrival phytoplankton (Moderate)	Survival (Moderate)	Introduction potential for zooplankton (Moderate)	Introduction potential for phytoplankton (Moderate)	Magnitude of Consequence (Moderate)	FINAL RISK for zooplankton (Moderate)	FINAL RISK for phytoplankton (Moderate)
Arctic Coastal Domestic	Intermediate*	Not assessed	Lowest	Lowest	Lowest	Higher	Lowest	Lowest
Arctic International Transoceanic	Lowest*	Lower	Highest	Lowest	Lower	Highest	Lowest	Intermediate
Eastern Coastal Domestic	Lowest	Lower	Highest	Lowest	Lower	Highest	Lowest	Intermediate
GLSLR International Transoceanic	Higher	Higher	Lowest	Lowest	Lowest	Highest	Lowest	Lowest
Lakers	Highest	Lowest	Highest	Highest	Lowest	Intermediate	Highest	Lowest
Atlantic International Coastal U.S.	Lower	Higher	Highest	Lower	Higher	Highest	Intermediate	Highest
Atlantic International Exempt	Lower	Intermediate	Intermediate	Lower	Intermediate	Highest	Intermediate	Highest
Atlantic International Transoceanic	Highest	Highest	Highest	Highest	Highest	Highest	Highest	Highest
Pacific International Coastal U.S.	Higher	Intermediate	Highest	Higher	Intermediate	Highest	Highest	Highest
Pacific International Exempt	Higher	Highest	Highest	Higher	Highest	Highest	Highest	Highest
Pacific International Transoceanic	Intermediate	Higher	Highest	Intermediate	Higher	Highest	Highest	Highest

b) Zooplankton and Phytoplankton invasion risk per ballast discharge event

Pathway (Uncertainty)	Per-event arrival zooplankton (Low)	Per-event phytoplankton (Moderate)	Survival (Moderate)	Introduction potential for zooplankton (Moderate)	Introduction potential for phytoplankton (Moderate)	Magnitude of consequence (Moderate)	FINAL RISK for zooplankton (Moderate)	FINAL RISK for phytoplankton (Moderate)
Arctic Coastal Domestic	Highest*	Not assessed	Lowest	Lowest	Lowest	Higher	Lowest	Lowest
Arctic International Transoceanic	Higher*	Highest	Highest	Higher	Highest	Highest	Highest	Highest
Eastern Coastal Domestic	Intermediate	Higher	Highest	Intermediate	Higher	Highest	Highest	Highest
GLSLR International Transoceanic	Higher	Highest	Lowest	Lowest	Lowest	Highest	Lowest	Lowest
Lakers	Highest	Lowest	Highest	Highest	Lowest	Intermediate	Highest	Lowest
Atlantic International Coastal U.S.	Intermediate	Highest	Highest	Intermediate	Highest	Highest	Highest	Highest
Atlantic International Exempt	Intermediate	Higher	Intermediate	Intermediate	Intermediate	Highest	Highest	Highest
Atlantic International Transoceanic	Higher	Highest	Highest	Higher	Highest	Highest	Highest	Highest
Pacific International Coastal U.S.	Higher	Highest	Highest	Higher	Highest	Highest	Highest	Highest
Pacific International Exempt	Higher	Highest	Highest	Higher	Highest	Highest	Highest	Highest
Pacific International Transoceanic	Intermediate	Highest	Highest	Intermediate	Highest	Highest	Highest	Highest

APPENDIX 2

Results of the relative invasion risk assessment for a) annual and b) per-event timescales, for ballast-mediated NIS by vessel pathways under future requirements for IMO D-2 standards in Canada. The level of uncertainty for each component is indicated in brackets below each column heading. Note that introduction potential, and resulting final risk, differed for some pathways depending on taxonomic group being considered. Introduction is the lowest value reported for arrival and survival, while final risk is determined by consulting Table 3. The asterisk (*) denotes pathways with greater (moderate) uncertainty for zooplankton NIS arrival potential as additional assumptions applied.

a) Annual Zooplankton and Phytoplankton invasion risk

Pathway (Uncertainty)	Annual arrival zooplankton (Low)	Annual arrival phytoplankton (Moderate)	Survival) (Moderate)	Introduction potential for zooplankton (Moderate)	Introduction potential for phytoplankton (Moderate)	Magnitude of Consequence (Moderate)	FINAL RISK for zooplankton (Moderate)	FINAL RISK for phytoplankton (Moderate)
Arctic Coastal Domestic	Lowest*	Not assessed	Lowest	Lowest	Lowest	Higher	Lowest	Lowest
Arctic International Transoceanic	Lowest*	Lower	Highest	Lowest	Lower	Highest	Lowest	Intermediate
Eastern Coastal Domestic	Lowest	Lower	Lowest	Lowest	Lowest	Highest	Lowest	Lowest
GLSLR International Transoceanic	Lowest	Higher	Lowest	Lowest	Lowest	Highest	Lowest	Lowest
Lakers	Lowest	Lowest	Highest	Lowest	Lowest	Intermediate	Lowest	Lowest
Atlantic International Coastal U.S.	Lowest	Intermediate	Intermediate	Lowest	Intermediate	Highest	Lowest	Highest
Atlantic International Exempt	Lowest	Intermediate	Intermediate	Lowest	Intermediate	Highest	Lowest	Highest
Atlantic International Transoceanic	Lowest	Highest	Highest	Lowest	Highest	Highest	Lowest	Highest
Pacific International Coastal U.S.	Lowest	Intermediate	Highest	Lowest	Intermediate	Highest	Lowest	Highest
Pacific International Exempt	Lowest	Highest	Highest	Lowest	Highest	Highest	Lowest	Highest
Pacific International Transoceanic	Lowest	Higher	Highest	Lowest	Highest	Highest	Lowest	Highest

b) Zooplankton and Phytoplankton invasions risk per ballast discharge event

Pathway (Uncertainty)	Per-event arrival zooplankton (Low)	Per-event arrival phytoplankton (Moderate)	Survival (Moderate)	Introduction potential for zooplankton (Moderate)	Introduction potential for phytoplankton (Moderate)	Magnitude of consequence (Moderate)	FINAL RISK for zooplankton (Moderate)	FINAL RISK for phytoplankton (Moderate)
Arctic Coastal Domestic	Lowest*	Not assessed	Lowest	Lowest	Lowest	Higher	Lowest	Lowest
Arctic International Transoceanic	Lowest*	Highest	Highest	Lowest	Highest	Highest	Lowest	Highest
Eastern Coastal Domestic	Lowest	Higher	Lowest	Lowest	Lowest	Highest	Lowest	Lowest
GLSLR International Transoceanic	Lowest	Highest	Lowest	Lowest	Lowest	Highest	Lowest	Lowest
Lakers	Lowest	Lowest	Highest	Lowest	Lowest	Intermediate	Lowest	Lowest
Atlantic International Coastal U.S.	Lowest	Highest	Intermediate	Lowest	Intermediate	Highest	Lowest	Highest
Atlantic International Exempt	Lowest	Higher	Intermediate	Lowest	Intermediate	Highest	Lowest	Highest
Atlantic International Transoceanic	Lowest	Highest	Highest	Lowest	Highest	Highest	Lowest	Highest
Pacific International Coastal U.S.	Lowest	Highest	Highest	Lowest	Highest	Highest	Lowest	Highest
Pacific International Exempt	Lowest	Highest	Highest	Lowest	Highest	Highest	Lowest	Highest
Pacific International Transoceanic	Lowest	Highest	Highest	Lowest	Highest	Highest	Lowest	Highest

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