

(1989). Voluntary guidelines for the control of ballast water discharges from ships proceeding to the St. Lawrence seaway and the Great Lakes. Notice to Shipowners, Masters and Officers of Merchant Ships. London, Department of Transport, Marine Directorate. **Merchant Shipping Notice No. M.1394**: 4 p.

Anderson, E., W. Austin, et al. (2000). Literature review on nonindigenous invertebrates of the Strait of Georgia, Edward Anderson Marine Sciences.

Anonymous (1981). The presence and implication of foreign organisms in ship ballast waters discharged into the Great Lakes. Georgetown, Ontario, Bio-Environmental Services Limited: 2 volumes.

This study provides a preliminary assessment of the potential for impact of ballast water organism discharge to the Great Lakes and the direction that future investigations should take. The overall assessment is that organisms are alive in ship ballast water when it is discharged. The potential, therefore, exists for foreign organisms to enter the Great Lakes system in a viable state. The potential for any particular foreign organism to survive and create a detrimental impact on the Great Lakes ecosystem will depend on the ability of the organisms to adapt to the new environment. Successful establishment of an organism will depend on the density (numbers) originally discharged from a ballast tank and their ability to sustain a reproducing population. Several viable, marine and freshwater organisms, nonendemic to the Great Lakes or the St. Lawrence estuary were found in the samples and appear to meet the above criteria. This report is divided into 2 volumes. The text is contained in volume 1 and the report data and appendix are presented in volume 2.

Anonymous (1981). The presence and implication of foreign organisms in ship ballast waters discharged into the Great Lakes, Bio-Environmental Services Limited, Canada.

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Anonymous (1990). Exotic Species and the Shipping Industry: The Great Lakes-St. Lawrence Ecosystem at Risk. I. J. C. a. t. G. L. F. Commission: 1-74.

Anonymous (1992). A review and evaluation of ballast water management and treatment options to reduce the potential for the introduction of non-native species to the Great Lakes. Technical Appendix B Ballast Water Treatment. Sarnia, Ontario, Pollutech Environmental Limited: ix + 218.

Anonymous (1992). A review and evaluation of ballast water management and treatment options to reduce the potential for the introduction of non-native species to the Great Lakes. Appendix A ballast water characterization. Sarnia, Ontario, Pollutech Environmental Limited: vii + 48.

Anonymous (1994). 1994 Joint Report of the Canadian and United States Coast Guards on Progress Towards Achievement of the Objectives of the Great Lakes Water Quality Agreement of 1978 (as Amended by its protocol of 1987). S. S. Branch, Great Lakes Water Quality Coast Guard, Ship Safety Branch: 1-M3.

The health and integrity of the Great Lakes Basin Ecosystem, including the 40 million humans who live in the basin, are jeopardized by an immediate and growing problem: the rampant colonization by shipborne exotic organisms. It is a problem that can and must be curtailed.

This special report, entitled *Exotic Species and the Shipping Industry: The Great Lakes-St. Lawrence Ecosystem at Risk*, is a unique endeavor by the International Joint Commission and the Great Lakes Fishery Commission. It reflects our mutual concerns and conveys our joint recommendations for short-term and long-term actions -- actions we believe would significantly reduce the immediate and continuing risks to the health and integrity of the Great Lakes Basin Ecosystem and its connected waters.

Anonymous (1995). Canadian Coast Guard assessment of the potential for introduction of exotic species through exchange of industrial shipping ballast water. Final Report ASI Project E9254. St. Catherines, Ontario, Aquatic Sciences Inc. : 1-39.

Anonymous (1996). Examination of aquatic nuisance species introductions to the Great Lakes through commercial shipping ballast water and assessment of control options phase I and phase II. ASI Project E9225/E9285. St. Catherines, Ontario, Aquatic Sciences Inc.: vii + 52.

Anonymous (1996). Examination of aquatic nuisance species introductions to the Great Lakes through commercial shipping ballast water and assessment of control options phase II. Final Project ASI Project E9225/E9285. St. Catherines, Ontario, Aquatic Sciences Inc. : ii + 57.

Anonymous (2000). Vessel traffic / Vessel shipping patterns on the east Coast of Canada, CEF, CEF Consultants Ltd: 8 p.

Evaluation of vessel traffic/shipping patterns for 1998

Anonymous (2001). Alien invasive species and biological pollution of the Great Lakes Basin Ecosystem, Great Lakes Water Quality Board of the International Joint Commission: v + 21.

Anonymous (2002). Quantification of risks of alien species introductions associated with alternative area for ballast water exchange in the Laurentian Channel of the Gulf of St. Lawrence, RNT Consulting Inc.: 37 + ii.

Bailey, S. A. (2005). "In situ hatching of invertebrate diapausing eggs from ships' ballast sediment." *Diversity and Distributions* **11**(5): 453-460.

Ships that enter the Great Lakes laden with cargo carry only residual ballast water and sediment in ballast tanks. These ships are designated 'no ballast on board' (NOBOB) and constitute > 90% of inbound traffic. We conducted in situ experiments using emergence traps to assess the viability and the introduction potential of invertebrate diapausing stages present in ships' ballast sediment. All trials commenced while vessels operated on the lower lakes (Erie, Ontario) and were completed 6–11 days later at ports on the upper lakes (Michigan, Lake Superior). Eight trials were conducted on four ships using five different ballast sediments. Hatching was observed on every ship, although not from all sediments on all ships. Overall hatch rates were very low (0.5 individuals per 500 g sediment), typically involving activation of < 0.05% of total eggs present. Five species of rotifers and copepod nauplii were hatched from ballast sediments, although only one or two species typically hatched from any one sediment. Results of this study indicate that hatching of diapausing eggs contained in ballast sediment of NOBOB ships poses a relatively low risk of invasion to the Great Lakes. However, as reproduction may occur in tanks, and non-indigenous species may be involved in numerous introduction events, the risk posed by this vector is small but potentially important. While dormancy is a characteristic enabling enhanced survival during transportation in ballast tanks, it becomes a hindrance for introduction.

Bailey, S. A., I. C. Duggan, et al. (2005). "Invertebrate resting stages in residual ballast sediment of transoceanic ships." *Canadian Journal of Fisheries and Aquatic Sciences* **62**(5): 1090.

Ballast water has been the primary vector of nonindigenous species (NIS) to the Laurentian Great Lakes over the past 45 years. Although ballast water exchange regulations were implemented in 1993 to reduce propagule loads, new NIS continue to be discovered. A possible explanation for this trend is the importance of alternative vectors, such as residual ballast of ships claiming "no ballast on board". We investigate resting stages of invertebrates in residual ballast sediments of transoceanic ships as a possible vector of NIS to the Great Lakes. To model the introduction effort potentially associated with this vector, we collected sediment samples from 39 ships entering the Great Lakes and measured the density, viability, and species richness of resting stages contained therein. Viable resting stages of NIS were found in 32% of ships, at a mean density of $3.0 \times 10^5 \text{ ship}^{-1}$. Temperature, salinity, and removal of eggs from sediment during

incubation had a significant impact on total abundance and species richness of hatched taxa. A total of 21 NIS were identified, consisting exclusively of rotifers and cladocerans. Salinity of residual ballast water and geographic region of ballast uptake were predictive variables for profiling invasion risk due to ships, although explained variability was low.

L'eau de ballastage a été le vecteur principal d'introduction des espèces non indigènes (NIS) dans les Grands Lacs laurentiens au cours des 45 dernières années. Bien que des règlements concernant l'échange des eaux de ballastage en vigueur depuis 1993 visent à réduire les charges de propagules, de nouvelles NIS continuent d'être découvertes. Une explication possible de cette tendance est l'importance des vecteurs secondaires, tels que l'eau résiduelle de ballastage dans les navires qu'on déclare avoir les ballasts vides. Nous avons étudié les stades de repos d'invertébrés dans les sédiments des eaux résiduelles des ballasts de navires transocéaniques comme vecteurs possibles des NIS vers les Grands Lacs. Afin de faire un modèle du potentiel d'introduction associé à ce vecteur, nous avons récolté des sédiments dans 39 navires à leur arrivée dans les Grands Lacs et nous avons mesuré la densité, la viabilité et la richesse spécifique des stades de repos présents. Nous avons trouvé des stades de repos viables de NIS dans 32 % des navires, à une densité moyenne de $3,0 \times 10^5 \cdot \text{navire}^{-1}$. La température, la salinité et la récolte des oeufs dans les sédiments durant l'incubation ont un impact significatif sur l'abondance totale et la richesse spécifique des taxons éclos. Nous avons identifié 21 NIS en tout, toutes des rotifères et des cladocères. La salinité de l'eau résiduelle de ballastage et la provenance géographique de l'eau sont des variables prédictives pour évaluer le risque d'invasion présenté par le navire, bien que la variabilité qu'elles expliquent soit faible.

Bailey, S. A., I. C. Duggan, et al. (2003). "Viability of invertebrate diapausing eggs collected from residual ballast sediment." *Limnology and Oceanography* **48**(4): 1701-1710.

Natural or anthropogenic movement of sediments may be an important vector for the dispersal of invertebrate resting stages between water bodies. Here we record the presence of invertebrate diapausing eggs in residual sediments from transoceanic vessels and explore whether these may pose an invasion risk. Viability of diapausing eggs was explored under light and dark conditions using sediment collected from eleven tanks on nine vessels operating on the Great Lakes. Seventeen cladoceran, copepod, and rotifer taxa were identified. Four of the species

hatched have not yet been reported as established in the Great Lakes. Egg viability for individual species varied from 0% to 92%. Exposure to saline water may impact egg viability of some freshwater species. Generally, the proportion of eggs hatched in light and dark treatments did not differ significantly, indicating that light was not required to terminate diapause. As a result, eggs could potentially hatch in dark ballast tanks when immersed in freshwater loaded as ballast during operation on the Great Lakes. Viability of diapausing eggs differed among ballast tanks on a single vessel, indicating that tanks with independent ballast histories have different invasion risks. While additional work is needed to quantify risk, results from this study indicate that vessels entering the Great Lakes with only residual ballast are a potential vector for the introduction of new nonindigenous species during multiport operations.

Bailey, S. A., I. C. Duggan, et al. (2004). "Salinity tolerance of diapausing eggs of freshwater zooplankton." *Freshwater Biology* **49**(3): 286-295.

1. Many freshwater zooplankton produce diapausing eggs capable of withstanding periods of adverse environmental conditions, such as anoxia, drought and extreme temperature. These eggs may also allow oligostenohaline species to survive increased salinity during periods of tidal flux or evaporation, and here we test the ability of diapause eggs to withstand such conditions.
2. Salinity tolerance may also enable organisms to invade new environments. The increased rate of introduction of non-indigenous species to the Laurentian Great Lakes since 1989, when ballast water exchange regulations (to replace fresh brackish water at sea with full seawater) were first implemented for transoceanic vessels, has stimulated studies that explore mechanisms of introduction, other than of active animals, in ballast water. One hypothesis proposes that freshwater organisms transported in ballast tanks as diapausing eggs may be partially responsible for the increased rate of species introduction, as these eggs may tolerate a wide array of adverse environmental conditions, including exposure to saline water.
3. We collected ballast sediments from transoceanic vessels entering the Great Lakes, isolated diapausing eggs of three species (*Bosmina liederi*, *Daphnia longiremis* and *Brachionus calyciflorus*), and measured the effect of salinity on hatching rate. In general, exposure to salinity significantly reduced the hatching rate of diapausing eggs. However, as non-indigenous species can establish from a small founding population, it is unclear whether salinity exposure will be effective as a management tool.

Bailey, S. A., I. C. Duggan, et al. (2003). Do Resting Eggs in Ballast Tanks Pose an Invasion Risk? 12th International Conference on Aquatic Invasive Species, Windsor, Ontario, Canada.

Ship-mediated biological invasions continue to be recorded within the Great Lakes, despite the implementation of ballast water exchange regulations in 1993. We explore whether vessels declaring no ballast on board (NOBOB) status, being currently exempt from regulations, may be a vector for introduction of nonindigenous species (NIS) to the Great Lakes. These vessels potentially pose an invasion risk owing to the presence of viable invertebrate resting eggs contained in residual sediment. NOBOB ships that ballast and deballast Great Lakes water while in transit may deposit invertebrates or their resting eggs. To determine the possibility that NOBOB sediments act as a vector for NIS we investigated the density, diversity and viability of invertebrate resting eggs within residual sediments of 69 tanks on 39 vessels over two years. The density and viability of resting eggs varied widely, from 0.3 to 91.3 eggs/g sediment and 0 to 92%, respectively. Viability of resting eggs was explored under various day length and salinity conditions. Here, we report preliminary findings from hatching experiments, providing the first evidence that residual sediments can carry viable invertebrate resting eggs. Thirty-three species have been identified to date, seven of which are not currently established in the Great Lakes. In addition, we will present preliminary findings on the effect of saltwater exposure on viability of freshwater species' resting eggs.

Balaban, M. (2001). Vessel traffic/vessel shipping patterns on the east coast of Canada 2000 shipping season. M. S. Transport Canada, Transport Canada Marine Safety Technical Report: 1-13.

Aquatic non-native species invasions through ballast water discharges are now recognized as a serious problem threatening global biological diversity and human health worldwide. On November 27, 1997, the IMO Marine Environmental Protection Committee (MEPC) 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" The IMO recommends that all maritime nations of the world adopt and use these voluntary guidelines. A precursor to the international initiative can be considered as stemming from concerns for Great Lakes and St. Lawrence Seaway following the introduction of non-native fish, aquatic organisms and pathogens. This resulted in the introduction, in May 1989, of voluntary Guidelines for the control of ballast water discharges from ships which on September 1, 2000, were extended as national Guidelines for all waters in Canada and were published as TP 13617E. Ecosystems vary within Canada, and may be similar or different when compared with ecosystems for ports of origin of ballast water. Thus, regional implementation of these

Guidelines is appropriate to account for differences in trade, ship type, geography, specific exotic species introduction risk, etc. For this purpose, ANNEX V of the new national Guidelines will incorporate the results of scientific evaluation and application of an acceptable regime which may include Alternative Ballast Water Exchange Zones (ABWEZ). The establishment of such zones is intended to balance the reduced risk to the marine environment versus the safety and economics of commercial shipping. During the periodical meetings of the Atlantic Region Ballast Water Sub-Committee, it was generally accepted that at present, reliable scientific data has not been applied to support the establishment of ABWEZ, as part of the ANNEX V of the new national Guidelines. The Sub-Committee agreed that substantial scientific research is needed to enable provident future decision and recommended that ballast water sampling and biological analysis be conducted in conjunction with a comprehensive physical oceanography evaluation of waters adjacent to the edge of Scotian Shelf. The present vessel traffic/shipping patterns study is intended to up-date and complement a similar study conducted by CEF Consultants in February - March 2000 and will set the principles for the next phase (September 2001 - March 2002) of the on-going ballast water sampling project.

Barry, K. L. and C. D. Levings (2002). Assessing the risk of exotic species establishment from ballast water of ships in Vancouver Harbour: A possible application of the RAMAS model to the copepod *Pseudodiaptomus marinus*. . C. T. R. o. F. a. A. S. 2401, Fisheries and Oceans Canada: 25.

Barry, K. L. and C. D. Levings (2002). Feasibility of using the RAMAS-metapopulation model to assess the risk of a non-indigenous copepod (*Pseudodiaptomus marinus*) establishing in Vancouver Harbour from ballast water. C. T. R. o. F. a. A. S. 2401, Fisheries and Oceans Canada: iv + 25.

We assessed the feasibility of using a readily available model to predict the risk of establishment of a non-indigenous species (NIS) in Vancouver Harbour. Using life-history data from the literature and the RAMAS Metapop program, we conducted simulations using a single population and a metapopulation to assess the risk of population explosion of the copepod *Pseudodiaptomus marinus* released into the harbour from ballast water. Parameters which affected the explosion included initial density, population structure, and transport or dispersal rate. In general, this model provided a useful tool for assessing the risk of invasion and establishment by NIS. However, this approach is not comprehensive since it only considers survival after release from a ballast tank and it assumes a niche is available in the recipient habitat. The model may be useful to compare risk of establishment between NIS with varying life history parameters, and to identify which parameters most affect NIS establishment.

Nous avons évalué la faisabilité d'appliquer un modèle facilement disponible pour estimer le risque qu'une espèce non indigène (ENI) s'établisse dans le port de Vancouver. Nous nous sommes servis du programme RAMAS Metapop et de dynamique publiées sur le cycle vital du copepode *Pseudodiaptomus marinus* pour simuler la dynamique d'une seule population et celle d'une metapopulation afin d'évaluer le risque d'une flambée de population de cet organisme introduit dans le port par la

vidange d'eau de ballast. La densité initiale, la structure de la population et le taux de transport ou de dispersion étaient des paramètres qui influencent sur la flambée de population. En général, ce modèle constitue un outil utile qui permet d'évaluer le risque d'invasion et d'établissement d'une ENI. Toutefois, cette démarche n'est pas exhaustive puisqu'elle n'aborde que la survie d'un organisme après son introduction à partir d'une citerne de ballast et qu'elle suppose qu'une niche libre convenable est présente dans le milieu récepteur. Le modèle pourrait s'avérer utile pour comparer les risques d'établissement d'ENI dont les paramètres du cycle vital diffèrent et pour déterminer les paramètres qui influencent le plus sur l'établissement d'une ENI.

Bourgeois, M., M. Gilbert, et al. (2001). Maritime traffic coming from foreign ports to the St. Lawrence from 1978 to 1996 and the implications and risks of the introduction of nonindigenous species. Can. C. T. R. o. F. a. A. S. 2338, Fisheries and Oceans Canada: 1-42.

Brickman, D., B. D. Petrie, et al. (2004). Assessing ballast water exchange zones on the Scotian Shelf and Gulf of Maine. C. S. A. S. R. D. 2004/119, Fisheries and Oceans Canada: iv + 44.

Carver, C. E. and A. L. Mallet (2001). A preliminary assessment of the risks of ballast water-mediated introduction of non-indigenous phytoplankton and zooplankton species in Nova Scotian waters. Dartmouth, Nova Scotia, Mallet Research Services Ltd. : iv + 46.

To assess the risk of ballast water-mediated introduction of non-indigenous phytoplankton and zooplankton species, samples of ballast water were obtained from 34 ships docking at three ports in Nova Scotia - Halifax, Point Tupper and Hantsport. The ships were selected on the basis of their port of origin to comprise a representative cross-section of the foreign vessel traffic. This traffic included a total of 26 Container carriers, General Cargo carriers and Bulk Gypsum carriers in Halifax, five Bulk Gypsum carriers and Oil tankers in Point Tupper and three Bulk Gypsum carriers in Hantsport. An analysis of ballast water records indicated that the Container carriers and General Cargo carriers rarely discharged any ballast water or only a small proportion of their load (150-2700 m³). In contrast, the Bulk Gypsum carriers and Oil tankers consistently discharged >90% of their ballast water (1600-40,000 m³). Whereas the Container carriers and General Cargo carriers originated from ports in Europe, the US and the Caribbean, the Bulk carriers and Oil tankers all originated from ports on the east coast of the US.

Examination of ballast water samples from the various ships revealed 226 phytoplankton taxa of which 14 (6%) were classified as non-indigenous; none of these was considered toxic or harmful although two were listed as a potential risk. Of the remaining 212 taxa, 112 (49%) were classified as indigenous of which ten (4%) were toxic or harmful species commonly observed in Atlantic Canadian waters and another six (3%) were classified as a potential risk. The remaining 100 taxa (45%) were of unknown geographic affiliation; this included 51 marine taxa which could not be identified beyond the genus level, 32 brackish-water taxa which are not normally observed in marine waters and 17 unidentified taxa. Of these 100 taxa 24 (11%) were listed as a potential risk, including the 17 unidentified taxa. A total of 44 zooplankton taxa were observed in samples from 20 of the 34 ships. Only one taxa was considered non-indigenous, although many larval and juvenile stages which could not be fully identified.

Overall, the ballast water of Bulk Gypsum carriers and Oil tankers originating from ports on the US east coast (FAO regions A and G) had the highest number of taxa as well as the highest cell concentrations, probably because the water was <5 d old. Ballast water sampled from Container carriers and General Cargo carriers originated from various FAO regions in the Atlantic, the Pacific and the Mediterranean; these samples typically had fewer taxa and lower cell concentrations due in part to their greater age. Overall, ballast water originating from coastal ports had more taxa and higher cell concentrations than those originating from open ocean sites. Non-indigenous taxa, toxic/harmful indigenous taxa, and potentially toxic/harmful taxa of unknown geographic affiliation were observed in the ballast water arriving from seven of the eight FAO regions.

Strategies for mitigating the risk of introduction include the implementation of strict ballast water discharge guidelines for the Container and General Cargo carriers docking in Halifax. For the Bulk Gypsum carriers and Oil tankers which discharge relatively large volumes of water originating in the US, one option is to explore the possibility of establishing a Ballast Water Exchange Zone. In the meantime, however, there is an urgent need for a joint US-Canada east coast management plan to identify the specific risks associated with various ports of origin and to target future research programs accordingly.

Carver, C. E. and A. L. Mallet (2003). Implications of ballast water discharge for the introduction/dispersion of harmful algal species in Atlantic Canada *In Proceedings of the Eighth Canadian Workshop on Harmful Marine Algae*. C. T. R. o. F. a. A. S. 2498, Fisheries and Oceans Canada: xi + 141.

One hundred and five participants from Canada and nine other countries attended the workshop as representatives of research and management departments within federal and provincial governments, universities, and the private sector. The thirty five oral and twenty six poster presentations encompassed current knowledge and awareness of Harmful Algal Blooms (HABs). Topics included : HABs impacting fisheries and management strategies; ecological factors influencing emerging assays for marine biotoxins; public health issues and phycotoxins management; analysis, effects, and mechanisms for production of biotoxins; interactions of HAB species with other organisms; and spatial distribution of phycotoxins and kinetics of animal toxicity. Contained in this report are abstracts, extended abstracts and papers of the oral and poster presentations, together with reports from two Working Group discussions.

Carver, C. E. and A. L. Mallet (2004). Investigating potential ballast water management strategies for ships travelling from Chesapeake Bay to ports in Nova Scotia. Dartmouth, Mallet Research Services Ltd.: v + 62.

Chapman, J. W. (1988). "Invasions of the Northeast Pacific by Asian and Atlantic Gammaridean Amphipod crustaceans, including a new species of *Corophium*." Journal of Crustacean Biology **8**(3): 364-382.

Northeast Pacific estuaries may be severely altered by a broad diversity of accidentally introduced exotic invertebrates, but few detailed analyses of individual species have been made. The gammaridean amphipods *Ampelisca abdita*, *Melita nitida*, *Corophium alienense*, new species, and *Parapleustes derzhavini* have previously appeared to be introduced. However, the specific identities of the last two species and the origins of the last three species have remained unknown. Analyses based on criteria for introduced species, that include evidence from systematics, geography, and ecology, indicate the four species are introduced in 26 of 27 possible instances. They are thus exotic as predicted, and partially corroborate Carlton's thesis that extensive and persistent faunal invasions have occurred in northeast Pacific estuaries.

Colautti, R. and H. J. MacIsaac (2006). "Propagule pressure: A null model for biological invasions." Biological Invasions (**in press**).

Colautti, R., A. J. Niimi, et al. (2003). Spatial and temporal analysis of transoceanic shipping vectors to the Great Lakes. Invasive Species: Vectors and Management Strategies

G. M. Ruiz, J. T. Carlton and R. N. Mack. Washington, D.C, Island Press: 227-246.

The world's lakes are among ecosystems most impacted by the introduction of nonindigenous species (NIS). The Great Lakes of North America are among the

best-studied aquatic ecosystems on the planet. A range of human uses has resulted in considerable disturbance of this system, including the introduction of at least 163 NIS that have successfully invaded and profoundly affected the basin. Species are introduced to lakes by a variety of intentional and unintentional vectors, including stocking programs, fouling on pleasure boats or trailers, advective movement from connecting waterways, and by discharge of contaminated ballast water by commercial ships. Examples of each of these invasion vectors exist for NIS in the Great Lakes. The Great Lakes are a model system for the study of invasion patterns and processes in freshwater ecosystems, owing largely to their high level of investigation, susceptibility to invasion, and diverse array of introduction mechanisms. Release of ballast water by transoceanic commercial ships has been the dominant vector of NIS to the Great Lakes during the 20th century. Here we review spatial and temporal patterns of ballast release by foreign, transoceanic ships entering the Great Lakes system with saline ballast water (BOB ships) and those that enter the system without ballast water (i.e. they are loaded with cargo) but which load and subsequently discharge ballast water within the lake system (NOBOB ships). A large percentage (79.5%) of in-bound ships visit first ports-of-call on Lakes Erie and Ontario, which lie just upstream of the St. Lawrence entryway. However, a disproportionate percentage of BOB (55.4%) and NOBOB (74.5%) ships discharge ballast water into Lake Superior, the farthest upstream lake in the system.^{22 23}

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ports function as 'stepping stones' between Ponto-Caspian and other Eurasian donor sources and recipient ecosystems in the Great Lakes. Ballast water discharge patterns of BOB and NOBOB vessels indicate that Lake Superior should be particularly vulnerable to new invasions of NIS.

Colautti, R. I., S. A. Bailey, et al. (2006). "Characterised and projected costs of nonindigenous species in Canada." Biological Invasions **8**: 45-59.

Cosgrove, S. and L. Gateman (2002). Aquatic Invasive Species Background Papers, Biodiversity Science Branch
Department of Fisheries and Oceans.

Crossman, E. J. (2000). Overview of the spread of fishes introduced by various vectors. 10th International Aquatic Nuisance Species and Zebra Mussel Conference, Toronto, Canada.

de Lafontaine, Y. and G. Costan (2002). Introduction and transfer of alien aquatic species in the Great Lakes - St. Lawrence river drainage basin. Alien invaders: in Canada's waters, wetlands, and forests. R. Claudi, P. Nantel and E. Muckle-Jeffs. Ottawa, Natural Resources Canada, Canadian Forest Service, Science Branch: 73-91.

An extensive review was conducted to update the list of alien freshwater species introduced into the Great Lakes–St. Lawrence River drainage basin. Information was gathered on the presence, date and location of the first report, vector of introduction, and spatial distribution of alien species. A total of 163 species have been introduced into the Great Lakes–St. Lawrence River drainage basin during the past two centuries, and 85 of these have been reported from the St. Lawrence River. Of the species for which date of introduction is known, most (83%) were first reported in the Great Lakes, but 17% were first reported in the St. Lawrence River. These data suggest that, once introduced, species can be transferred within the drainage basin by both passive, unassisted means (downstream transfer) and active, human-assisted vectors (upstream transfer). The rate of introduction in the Great Lakes seems to have leveled off during the past 80 years (at about one species per year), but in the St. Lawrence River it is still increasing, as a result of downstream transfer of organisms introduced elsewhere. The estimated transfer times between the Great Lakes and the St. Lawrence River are highly variable among species and are independent of taxonomic group. The presence of an alien species in the river depends on the time elapsed since its first report in the Great Lakes and on the distance from the site of first observation. More stringent management strategies should be applied across the entire drainage basin, rather than locally, to control or prevent future introductions and to reduce species transfer within and between aquatic basins. These management strategies should be supported by adequate monitoring programs.

de Lafontaine, Y. and M. DeBlois (2004). Rapid Deoxygenation of Ballast Water: Effectiveness and Applicability of a Bio-reactive Process. 13th International Conference on Aquatic Invasive Species, Ennis County Clare, Ireland.

Laboratory experiments in 200-liter tanks were conducted to determine the effectiveness of a bio-reactive process to induce rapid oxygen depletion in ballast tanks in order to reduce the risk of transferring invasive aquatic organisms. Results showed that dissolved oxygen levels dropped below 0.2 mg/L in 1 to 5 days after the beginning of the treatment. The rate of oxygen depletion in water was inversely related to temperature ranging between 4 and 25°C. The performance of the process is similar in both fresh and salt water and was unaltered by the level of mixing of the medium. Hypoxic conditions (<0.2 mg/L) were maintained up to 12 days after inoculation. During treatment, levels of nitrates dropped to zero, while levels of ammonia increased. Levels of dissolved organic carbon declined and particulate carbon and particulate nitrogen both increased over time. Production of hydrogen sulfide was noted but levels were low and tended to increase with experimental temperature. Toxicity testing using Microtox bioassay showed no evidence of environmental toxicity of the treated waters once discarded. The above results suggest that this technology seems environmentally-safe and that its application as a ballast water treatment method on board ships should be considered. A cost-benefit analysis of this method relative to other treatment methods is presented.

de Lafontaine, Y. and N. Simard (2003). Alternative areas or alternative methods? Lessons from the Gulf of St. Lawrence Ballast Water Workshop, Halifax, Nova Scotia.

DeBlois, M. and Y. De Lafontaine (2003). Deoxygenating Ballast Water Using a Dry Biomass Process: A New Technique to Treat Ballast Water to Reduce Aquatic Invasive Species Transfer. 12th International Conference on Aquatic Invasive Species Windsor, Ontario, Canada

Following the suggestion by Tamburri et al. (2002) that deoxygenating ballast water may be an effective treatment method to minimize the risk of transferring invasive aquatic organisms, we developed and conducted preliminary testing of a new technology capable of generating rapid oxygen depletion and inducing significant mortality of organisms in ballast water tanks. The method is based on a biological process using dry multi-species biomass which

rapidly depletes dissolved oxygen once in water solution. Preliminary tests done on large volumes of St. Lawrence River water showed that oxygen levels dropped from 12 mg/L to 0 mg/L in less than 24 hours.

The effectiveness of this method is temperature-dependent and can yield significant positive results between 5 °C and 35°C. This technology is environmentally safe and could be easily implemented on board ships. Further testing conducted at pilot-scale is planned for assessing the application of this technology for ballast water treatment.

Dermott, R. (1997). Changing Amphipod Community in the Lower Great Lakes Following the Introduction of Ponto-Caspian Species. 7th International Zebra Mussel and Other Aquatic Nuisance Species Conference, New Orleans, Louisiana.

Dermott, R. (1999). Changing Dreissena Density and Species Composition in Lake Erie and Niche Interactions with Other Exotic Species. 9th International Zebra Mussel and Aquatic Nuisance Species Conference, Duluth, Minnesota.

Doblin, M. A., L. C. Popels, et al. (2004). "Transport of the Harmful Bloom Alga *Aureococcus anophagefferens* by Oceangoing Ships and Coastal Boats." Appl. Environ. Microbiol. **70**(11): 6495-6500.

It is well established that cyst-forming phytoplankton species are transported in ships' ballast tanks. However, there is increasing evidence that other phytoplankton species which do not encyst are also capable of surviving ballast transit. These species have alternative modes of nutrition (hetero- or mixotrophy) and/or are able to survive long-term darkness. In our studies of no-ballast-on-board vessels arriving in the Great Lakes, we tested for the presence of the harmful algal bloom species *Aureococcus anophagefferens* (brown tide) in residual (i.e., unpumpable) ballast water using methods based on the PCR. During 2001, the brown tide organism was detected in 7 of 18 ballast water tanks in commercial ships following transit from foreign ports. Furthermore, it was detected after 10 days of ballast tank confinement during a vessel transit in the Great Lakes, a significant result given the large disparity between the salinity tolerance for active growth of *Aureococcus* (>22 ppt) and the low salinity of the residual ballast water ([~]2 ppt). We also investigated the potential for smaller, recreational vessels to transport and distribute *Aureococcus*. During the summer of 2002, 11 trailered boats from the inland bays of Delaware and coastal bays of Maryland were sampled. Brown tide was detected in the bilge water in the bottoms of eight boats, as well as in one live-well sample. Commercial ships and small recreational boats are therefore implicated as potential vectors for long-distance transport and local-scale dispersal of *Aureococcus*.

Dochoda, M. R. (1991). "Meeting the challenge of exotics in the Great Lakes: The role of an international commission." Canadian Journal of Fisheries and Aquatic Sciences **48**(suppl.1): 171-176.

The Great Lakes Fishery Commission has traditionally supported the conservation of genetic diversity native to the Great Lakes, and counseled caution in adding new species to the Great Lakes aquatic community. Since extinction of sub-specific taxa and establishment of new species in the Great Lakes have proven irreversible, caution and conservatism are warranted. The Commission's mandate has served the Great Lakes well in preventing, controlling, and managing exotics.

Dochoda, M. R., A. L. Hamilton, et al. (1990). Workshop on exotic species and the shipping industry: Summary and recommendations. Toronto, Ontario, International Joint Commission
Great Lakes Fishery Commission: 46 p.

Drake, J. M. (2005). "Risk analysis for species introductions: forecasting population growth of Eurasian ruffe (*Gymnocephalus cernuus*)."
Canadian Journal of Fisheries and Aquatic Sciences **62**(5): 1053.

The North American distribution of the Eurasian ruffe (*Gymnocephalus cernuus*), an ecologically important and costly invasive fish, is presently limited to the Laurentian Great Lakes. Risk analyses for accidental introductions of ruffe to inland lakes should focus on the chance of establishment for small introductions such as those that would result from transporting ruffe as bait. Here I use Akaike's Information Criterion to select a population growth model for ruffe based on observed population dynamics during the invasion of Loch Lomond, Scotland. This population is regulated by a high carrying capacity and Allée effects were undetected. Parameter estimates obtained from this population forecast that the chance of establishment for possible introductions of ruffe to inland lakes in North America is high. A model for ruffe winter survival suggests that survivorship between introductions and spawning may be an important determinant of establishment success, but that the chance of establishment is high for introductions of only a few individuals. To prevent invasions of ruffe in inland waters, release of ruffe, whether intentional or accidental, should not be tolerated.

La répartition nord-américaine du poisson eurasiatique, la grémille (*Gymnocephalus cernuus*), une espèce d'importance écologique et un envahisseur coûteux, se limite actuellement aux Grands Lacs laurentiens. Les analyses de risque d'introductions accidentelles dans les lacs de l'intérieur du continent devraient se concentrer sur la probabilité d'établissement de petites introductions, comme, par exemple, celles qui résulteraient du transport de grémilles pour servir d'appât. Le critère d'information d'Akaike permet de choisir un modèle de croissance pour la grémille d'après la dynamique de la population observée lors de l'invasion du Loch Lomond, Écosse. La population est contrôlée par un stock limite élevé et aucun effet Allee n'a été détecté. L'utilisation des estimations de paramètres obtenues dans cette

étude pour prédire la probabilité d'un établissement lors d'introductions possibles de grémilles dans les lacs continentaux d'Amérique du Nord indique que la probabilité d'établissement est forte. Un modèle de la survie de la grémille à l'hiver indique que la survie entre l'introduction et la fraie peut être un important facteur déterminant du succès de l'établissement; cependant, la probabilité d'un établissement est forte même lors de l'introduction d'un petit nombre d'individus. Afin de prévenir l'invasion des eaux continentales par la grémille, on ne peut tolérer ni la libération volontaire, ni la libération accidentelle de grémilles.

Drake, L., A. Meyer, et al. (2005). "Potential Invasion of Microorganisms and Pathogens via 'Interior Hull Fouling': Biofilms Inside Ballast Water Tanks." Biological Invasions 7(6): 969-982.

Surfaces submerged in an aquatic milieu are covered to some degree with biofilms – organic matrices that can contain bacteria, microalgae, and protozoans, sometimes including disease-causing forms. One unquantified risk of aquatic biological invasions is the potential for biofilms within ships' ballast water tanks to harbor pathogens, and, in turn, seed other waters. To begin to evaluate this vector, we collected biofilm samples from tanks' surfaces and deployed controlled-surface sampling units within tanks. We then measured a variety of microbial metrics within the biofilms to test the hypotheses that pathogens are present in biofilms and that biofilms have higher microbial densities compared to ballast water. Field experiments and sampling of coastwise and oceangoing ships arriving at ports in Chesapeake Bay and the North American Great Lakes showed the presence of abundant microorganisms, including pathogens, in biofilms. These results suggest that ballast-tank biofilms represent an additional risk of microbial invasion, provided they release cells into the water or they are sloughed off during normal ballasting operations.

Duggan, I. C., S. A. Bailey, et al. (2003). Biological Invasions in Lake Ontario: past, present and future. State of Lake Ontario: past, present and future M. Munawar. Netherlands, Backhuys Publishing: 541-558.

Lake Ontario has an extensive history of biological invasions, extending more than 170 years. The rate of invasion began to increase during the 1870s, and accelerated after the opening of the St. Lawrence Seaway in the 1950s. Currently, there exist approximately 60 nonindigenous species (NIS) of vertebrate and invertebrate animals, protozoans, algae and aquatic macrophytes established in the lake. Fish

are the most widely represented taxon (15 species), followed by algae (14 species), molluscs (11 species) and crustaceans (8 species), respectively. Vectors responsible for NIS introductions vary temporally and by taxon. Before 1920, deliberate release and solid shipping ballast were the dominant vectors for NIS introduction. Ships' ballast water was the dominant vector between 1961 and 2002. All algal species, and most of the crustaceans and protozoans, were introduced via ballast water discharge, whereas fish vectors consisted of deliberate introductions, canals, accidental introductions, ballast water discharge, and bait release. Identified mollusc vectors include solid or liquid ballast discharge, movement through canals and aquarium release. Since all transoceanic vessels entering the Great Lakes system must pass through Lake Ontario, these ships could potentially introduce new species, either by ballast water discharges or hull fouling. Approximately 17% of all the ships entering the Great Lakes with saline ballast water discharge into Lake Ontario, potentially exposing the lake to euryhaline NIS such as the crustacean *Cercopagis pengoi* and the diatom *Thalassiosira baltica*. Lake Ontario is the first port-of-call for 43% of non-ballasted vessels, which may expose port areas to NIS introduction via hull fouling. Additionally, about 5% of non-ballasted vessels will load and then discharge ballast water while operating on Lake Ontario, potentially allowing NIS contained in ballast residuals to establish in the lake. Alternative vectors, including the baitfish and aquarium trades, and particularly the commercial sale of live freshwater fishes for human consumption, may add to the complement of established NIS in the lake. NIS is now abundant components of the lake's phytoplankton, invertebrate and fish communities, and jeopardize effective management of the lake. Despite recent implementation of ballast water exchange legislation, Lake Ontario remains highly vulnerable to future invasions. Management efforts must focus on identifying and eliminating vectors that may bring additional NIS to Lake Ontario and the other Great Lakes.

Duggan, I. C., C. D. A. Van Overdijk, et al. (2005). "Invertebrates associated with residual ballast water and sediments of cargo carrying ships entering the Great Lakes." Canadian Journal of Fisheries & Aquatic Sciences **62**: 2463-2474.

Most ships entering the Great Lakes carry cargo and declare "no-ballast-on board" (NOBOB) status. Approximately 250 of these vessels annually load Great Lakes' ballast water when they offload inbound cargo and then discharge this water (which has now mixed with residual water previously present in the tanks) when they load outbound cargo. This procedure potentially allows nonindigenous species present in ballast residuals to invade the Great Lakes. We collected residual sediment, water, and associated organisms from 38 NOBOB ships entering the Great Lakes. We recorded seven established Great Lakes' nonindigenous species, including some discovered since ballast water exchange was implemented. Occurrences of species not yet invaded indicate that this vector provides further opportunity

for invasion. Collectively, NOBOB vessels appear to constitute a greater risk than ballasted vessels, as they make up a greater proportion of the traffic entering the lakes (~90%), and they do not undergo ballast exchange. Invertebrates in residual water appear to have a greater opportunity for discharge than those in sediments, although most in the water fraction have already invaded this system. Invertebrate numbers in residual freshwater ballast could be dramatically lowered if these vessels flushed with open-ocean water prior to entering the Great Lakes.

La plupart des navires qui pénètrent dans les Grands Lacs sont chargés de marchandises et déclarent n'avoir pas d'eau de ballastage à bord (statut NOBOB). Environ 250 de ces navires chaque année se chargent d'eau de ballastage en provenance des Grands Lacs lors du débarquement des marchandises à destination locale et déchargent cette eau (maintenant mêlée à l'eau résiduelle déjà présente dans les ballasts) lors du chargement des marchandises destinées à l'exportation. Cette procédure permet potentiellement aux espèces non indigènes présentes dans les eaux de ballastage résiduelles d'envahir les Grands Lacs. Nous avons prélevé des sédiments et de l'eau résiduels ainsi que les organismes associés dans 38 navires NOBOB arrivant dans les Grands Lacs. Nous y avons retrouvé sept espèces non indigènes déjà établies dans les Grands Lacs, dont certaines découvertes depuis que la politique d'échange des eaux de ballastage est en vigueur. La présence d'espèces qui n'ont pas encore envahi les Grands Lacs indique que ce véhicule de transmission procure des occasions pour des envahissements futurs. Dans leur ensemble, les navires NOBOB semble constituer un risque plus élevé que les navires qui portent de l'eau de ballastage, parce qu'ils représentent un proportion plus importante (~90 %) du trafic maritime qui pénètre dans les Grands Lacs et qu'ils ne font pas d'échange de leurs eaux de ballastage. Les invertébrés dans les eaux résiduelles semblent être plus susceptibles d'être déversés que ceux dans les sédiments, bien que la plupart de ceux qui sont dans la fraction aqueuse ont déjà envahi le système. Le nombre d'invertébrés dans les eaux de ballastage résiduelles pourrait être considérablement réduit si les ballasts de ces navires étaient rincés à l'eau salée en haute-mer avant leur entrée dans les Grands Lacs.

Edlund, M. B., C. M. Taylor, et al. (2000). "Thalassiosira baltica (Grunow) Ostenfeld (Bacillariophyta), a new exotic species in the Great Lakes." Canadian Journal of Fisheries and Aquatic Sciences **57**(3): 610-615.

Microfossil analysis of sediment cores collected in 1994 and phytoplankton collected in 1998 from Lake Ontario indicated that the diatom *Thalassiosira baltica* (Grunow) Ostenfeld was introduced and became established ca. 1988 according to ^{210}Pb date estimates and has remained a predominant component of the phytoplankton since its establishment. *Thalassiosira baltica* is an exotic species in the Laurentian Great Lakes and is more commonly found in coastal brackish waters in western and northern Europe and only rarely reported from North American coastal waters. The probable vector for introduction of *T. baltica* was ballast water exchange and the successful establishment attributed to this taxon's euryhalinity tolerance.

D'après l'analyse des microfossiles contenus dans des carottes de sédiments prélevées en 1994 et du phytoplancton recueilli en 1998 dans le lac Ontario, la diatomée *Thalassiosira baltica* est une espèce introduite; son établissement remonterait à 1988 environ selon les estimations au ^{210}Pb , et elle est depuis un élément prédominant du phytoplancton. Il s'agit d'une espèce exotique dans les Grands Lacs laurentiens, et sa présence est plus fréquente dans les eaux saumâtres côtières de l'ouest et du nord de l'Europe; elle n'a été signalée qu'à de rares occasions dans les eaux côtières d'Amérique du Nord. La vidange des eaux de lest est probablement le vecteur d'introduction de *Thalassiosira baltica*, et l'euryhalinité de ce taxon explique son établissement.

Elston, R. (1997). Pathways and Management of Marine Nonindigenous Species in the Shared Waters of British Columbia and Washington. Environmental Report Series: Number 5. Olympia, Washington, Puget Sound/Georgia Basin International Task Force: 1-94.

The introduction of nonnative or nonindigenous species (NIS) to new environments can cause environmental and economic problems. Such problems have occurred worldwide, including in the shared marine waters of British Columbia and Washington (defined for the purposes of this report as the Straits of Georgia and Juan de Fuca, Puget Sound including Hood Canal, and the smaller straits and waters surrounding the San Juan and Gulf Islands).

This report was commissioned by the Puget Sound Water Quality Authority through an agreement between the U.S. Environmental Protection Agency (EPA) and the Canadian Department of Fisheries and Oceans (DFO). Its purpose is to assist the Washington and British Columbia Working Groups on Minimizing the Introduction of Exotic Species in developing their recommendations to the British Columbia/Washington Environmental Cooperation Council. It assesses the status and management of NIS introductions into the shared marine waters of British

Columbia and Washington. Pathways of NIS introduction are evaluated, and the management programs in place to reduce risks from these pathways are described. It is intended that from this report and from the work groups that will consider it, recommendations will emerge that address risk and management of NIS introductions, and needs for further information.

Pathways of NIS introduction to the shared marine waters include aquaculture activities; the aquarium trade; public aquaria; releases of NIS by individuals; commercial, military, and recreational marine vessels; research institutions; and seafood commodity distribution. Risk of NIS introduction from aquaculture is well defined, the industry is highly regulated, and active processes are underway for continuous review of aquaculture activities as they involve NIS. Risk of NIS introduction from aquarium activities and release of NIS by individuals is poorly defined, and only limited information is available to define the risks from research, seafood distribution, and marine recreational vessel activities. The relative risk associated with the large inoculation of marine NIS from ballast water discharges is assessed from shipping industry data and relevant scientific literature. Management of NIS in other selected states and countries is briefly reviewed.

More complete and detailed baseline information regarding the presence and distribution of native and NIS in shared waters is needed, because in some cases, there is disagreement on whether particular species are native or introduced, or whether or not particular NIS are established. Risk standards for genetic effects and ecological interactions are needed if NIS management is going to address these areas.

There is presently an opportunity to reduce the frequency and negative effects of future NIS introductions by expanding and improving a voluntary ballast water exchange program, by developing educational materials addressing several of the NIS introduction pathways, and by enhancing intergovernmental communication. Protocols and operational codes for aquarium activities and research could also reduce the risks of NIS introductions. In order to determine the risk of NIS introduction from aquarium-related activities, research, live seafood distribution, and marine recreational vessel movements, more detailed information is required.

Shipping, food production and processing, and other marine activities with the potential to affect NIS introductions will continue. A zero-risk condition is unattainable; a more realistic objective of NIS management should be to reduce the frequency of unintended introductions, and to understand and minimize negative consequences of introduced species.

Fofonoff, P. W., G. M. Ruiz, et al. (2003). In ships or on ships? Mechanism of transfer and invasion for nonnative species to the coasts of North America. Invasive Species: Vectors and Management Strategies. G. M. Ruiz and J. T. Carlton. Washington, DC, Island Press: 152-182.

Gauthier, D. and D. A. Steel (1996). A synopsis of the situation regarding the introduction of nonindigenous species by ship-transported ballast water in Canada and selected countries. C. M. R. o. F. a. A. S. 2380. Mont-Joli, PQ, Fisheries and Oceans Canada: vi + 57.

Each year, vessels transport hundreds of million of tonnes of ballast water around the world. Those water and associated sediments contain hundreds of species of organisms, of which many have established in new habitats and caused negative effects on human health, economy and environment. This report describes the Canadian situation, in its international context, regarding the introduction of nonindigenous species by ship-transported ballast water, reviewing specifically vessel traffic, regulations, management and scientific research activities, and possible controls and treatments. Essentially, the international recognition of the problem has not led to concrete action in countries other than Australia, the United States, and more recently, Israel and Chile. Canada is particularly vulnerable to the introduction of nonindigenous species by ships, considering the large quantities of ballast water discharged in its ports and the near absence of control measures in regions other than the Great Lakes. As for many countries, Canada needs to assess the risks posed to its aquatic habitats and resources.

Chaque année, les navires transportent de centaines de millions de tonnes d'eau de lest autour du monde. Ces eaux et les sédiments qui y sont associés, contiennent de centaines d'espèces d'organismes, parmi lesquels plusieurs se sont établis dans de nouveaux habitats et ont causé des effets négatifs sur la santé humaine, l'économie et l'environnement. Ce rapport décrit la situation canadienne, dans son contexte international, concernant l'introduction d'espèces non indigènes par les eaux de lest transportées par les navires, examinant particulièrement le trafic maritime, la réglementation, les activités de gestion et de recherche scientifique, ainsi que les contrôles et les traitements possibles. Essentiellement, la reconnaissance internationale du problème n'a pas donné lieu à des actions concrètes dans d'autres pays que l'Australie, les Etats-Unis et, plus récemment, Israël et Chili. Le Canada est particulièrement vulnérable à l'introduction d'espèces non indigènes es par les navires, compte tenu des grandes quantités d'eau de lest déversées dans ses ports et de la quasi absence de mesures de contrôle dans les régions autres que les Grands Lacs. À l'instar de plusieurs pays, le Canada a besoin d'évaluer les risques qui se posent à ses habitats et ressources aquatiques.

Gilbert, M. and F. J. Saucier (2000). Suitability of the Gulf of St.Lawrence as a backup zone for ballast water exchanges by foreign ships proceeding up the St. Lawrence seaway. 10th International Aquatic Nuisance Species and Zebra Mussel Conference, Toronto, Ontario.

Gilbert, M., D. A. Steel, et al. (1995). Risks of introduction of nonindigenous species through ballast water exchanges in the Estuary and Gulf of St. Lawrence: problematics and consequences. Nouvelles des Sciences: 1-7.

Gosselin, S., M. Levasseur, et al. (1995). Transport and deballasting of toxic dinoflagellates via ships in the Grande Entree Lagoon of the Iles-de-la-Madeleine (Gulf of Saint-Lawrence, Canada). Harmful marine algal blooms. P. Lassus, G. Arzul, E. Erard-Le Denn, P. Gentien and C. Marcaillou-Le Baut. PARIS (FRANCE), LAVOISIER: 591-596.

Dispersal of exotic species via ballast water may cause unpredictable repercussions to the ecology of their new environment. The Iles-de-la-Madeleine are a major site for mussel farming in the Gulf of St Lawrence. Historically free of phycotoxins, this site has been threatened for the last decade by ship ballast water arriving from the St Lawrence estuary, where *Alexandrium* spp. abundance and toxicity are an acute problem. The objective of this study was to determine the importance of deballasting toxic algae by ocean-going ships in the Grande Entree Lagoon at the Iles-de-la-Madeleine. From May to September 1992, 60% of the ballast tanks sampled carried small concentrations of four potentially toxic dinoflagellates. Ballast concentrations of *Alexandrium* spp. reached a maximum of 41 cells L⁻¹ in June. Three potentially toxic *Dinophysis* species were also present in the ballast tanks. The highest surface concentration measured was of *D. norvegica*, with a maximum of 218 cells L⁻¹ in July. The total concentrations of *Dinophyceae* measured in the ballast tanks were within the same range as the concentrations found in the lagoon during the same period.

Gramling, J. (2000). BallastWater and Shipping Patterns in Puget Sound; Considerations for Siting of Alternative Ballast Water Exchange Zones. M. Pearlman. Olympia, Washington, Puget Sound Water Quality Action Team: 1-68.

The Puget Sound Water Quality Action Team has a legislative mandate to coordinate

local, state and federal action to protect and restore the health of Puget Sound. Aquatic nuisance species have been identified by the Action Team for priority attention during the 1999-2001 state biennium (Puget Sound Water Quality Work Plan). Ballast water is a significant pathway for the introduction of nonindigenous species to ports around the world and, potentially, to Puget Sound.

During the year 2000, the Action Team will prepare a new program on aquatic nuisance species for the Puget Sound Water Quality Management Plan. One use of this report will be to help the Action Team consider how to address ballast water in the aquatic nuisance species program. There are already a number of federal and regional programs in place to address ballast water. The Action Team will coordinate with those programs, and with stakeholders, to determine an appropriate approach to ballast water in the management plan and any immediate steps the Action Team should take regarding ballast water.

This report summarizes current shipping trends and ballast water practices in the Puget Sound/Georgia Basin area as well as ballast water exchange programs on the Pacific coast. In addition, the report outlines a series of institutional, operational, oceanographic and biological considerations for locating alternative zones for ballast water exchange for vessels entering the Strait of Juan de Fuca. Existing information and management gaps are identified and possible directions are proposed. These findings

will be made available to the Puget Sound/Georgia Basin Task Force, the Pacific

Ballast Water Group and other interested parties for further consideration.

Gray, D. K., S. A. Bailey, et al. (2005). "Viability of invertebrate diapausing eggs exposed to saltwater: implications for Great Lakes' ship ballast water management." Biological Invasions 7(3): 531-539.

International shipping has been the dominant vector of nonindigenous species introductions to the Laurentian Great Lakes over the past century. Apparent ballast-mediated invasions have been recorded in recent years, despite the implementation of voluntary ballast water exchange regulations in 1989. Since unregulated ballast-on-board vessels currently dominate inbound traffic to the Great Lakes, it has been proposed that live or dormant organisms contained in residual ballast of these vessels may be partially responsible for recent invasions. Alternatively, euryhaline species may pose a significant invasion threat because they can potentially survive ballast exchange. In this study, we explored whether exposure to open-ocean water (32permil) reduced the viability of invertebrate diapausing eggs in ballast sediments. Sediments collected from three transoceanic ships and from three freshwater habitats were exposed to open-ocean seawater. Egg viability, assessed as the abundance of taxa hatched between exposed and unexposed sediments, was not affected by saltwater exposure in any experiment. Species richness of hatched diapausing eggs was reduced by saltwater exposure in only one of seven trials. Our results indicate that oligostenohaline zooplankton may pose an invasion risk because their diapausing eggs are largely resistant to exposure to open-ocean saltwater.

Griffiths, R. W. (1990). Spatial distribution and dispersal mechanisms of zebra mussels in the Great Lakes Basin International Zebra Mussel Research Conference, Columbus, Ohio, The Ohio State University.

Grigorovich, I. (2000). Biology of the Spiny Cladoceran Cercopagis pengoi, a Recent Invader of Lake Ontario. 10th International Aquatic Nuisance Species and Zebra Mussel Conference, Toronto, Canada.

Grigorovich, I., T. W. Therriault, et al. (2003). "History of aquatic invertebrate invasions in the Caspian Sea." Biological Invasions 5: 103-115.

Incorporation of the fossil record and molecular markers into studies of biological invasions provides new historical perspectives on the incidence of natural and human-mediated invasions of nonindigenous species (NIS).

Palaeontological, phylogeographic, and molecular evidence suggests that the natural, multiple colonizations of the Caspian basin via transient connections with the Black Sea and other basins played an important role in shaping the diversity of Caspian fauna. Geographically isolated, conspecific Ponto-Caspian lineages that currently inhabit fragmented habitats in the Ponto-Caspian region show limited genetic divergence, implying geologically recent episodes

of gene flow between populations during the Pliocene to Pleistocene. Several molluscan lineages in the Caspian Sea may have descended from Lake Pannon stock before the Late Miocene isolation of the Caspian depression, about 5.8 million years ago. Anthropogenic activities during the 20th century were responsible for a 1800-fold increase in the rate of establishment of new aquatic species in the Caspian Sea compared to the preceding two million years of natural colonization. The observed success of NIS invasions during the 20th century was due primarily to human-mediated transport mechanisms, which were dominated by shipping activities (44%).

Human-mediated species transfer has been strongly asymmetrical, toward the Volga Delta and Caspian Sea from or through Black and Azov Seas. Global and regional trade, particularly that mediated by commercial ships, provides dispersal opportunities for nonindigenous invertebrates, indicating that future invasions in the Caspian Sea are anticipated.

Grigorovich, I. A., R. I. Colautti, et al. (2003). "Ballast-mediated animal introductions in the Laurentian Great Lakes: retrospective and prospective analyses." Canadian Journal of Fisheries and Aquatic Sciences **60**(6): 740-756.

Since completion of the St. Lawrence Seaway in 1959, at least 43 nonindigenous species (NIS) of animals and protists have established in the Laurentian Great Lakes, of which ~67% were attributed to discharge of ballast water from commercial ships. Twenty-three NIS were first discovered in four "hotspot" areas with a high representation of NIS, most notably the Lake Huron - Lake Erie corridor. Despite implementation of the voluntary (1989, Canada) and mandatory (1993, U.S.A.) ballast water exchange (BWE) regulations, NIS were discovered at a higher rate during the 1990s than in the preceding three decades. Here we integrate knowledge of species' invasion histories, shipping traffic patterns, and physicochemical factors that constrain species' survivorship during ballast-mediated transfer to assess the risk of future introductions to the Great Lakes. Our risk-assessment model identified 26 high-risk species that are likely to survive intercontinental transfer in ballast tanks. Of these, 10 species have already invaded the Great Lakes. An additional 37 lower-risk species, of which six have already invaded, show some but not all attributes needed for successful introduction under current BWE management. Our model indicates that the Great Lakes remain vulnerable to ship-mediated NIS invasions.

Depuis l'ouverture de la Voie maritime du Saint-Laurent en 1959, au moins 43 espèces non indigènes (NIS) d'animaux et de protistes se sont établies dans les Grands Lacs laurentiens et la présence de ~67 % d'entre elles s'explique, croit-on, par la vidange de l'eau des ballasts des navires commerciaux. Vingt-trois des NIS ont été découvertes la première fois dans quatre « points chauds » qui abritent un grand nombre de NIS, en particulier dans le corridor du lac Huron au lac Érié. Malgré la mise en application des règlements volontaire (Canada, 1989) et obligatoire (É.-U., 1993) sur l'échange des eaux de ballasts (« ballast water exchange » (BWE)), les NIS ont été retrouvées à un taux plus élevé pendant les années 1990 que durant les trois décennies précédentes. On trouvera ici une synthèse des connaissances sur l'histoire des invasions des espèces, sur les patterns de transport maritime et sur les facteurs physico-chimiques qui restreignent la survie des espèces durant leur transport dans les ballasts, ainsi qu'une évaluation des risques d'introductions futures dans les Grands Lacs. Notre modèle d'évaluation des risques identifie 26 espèces qui présentent des risques élevés et qui sont susceptibles de survivre à des transferts intercontinentaux dans les ballasts; dix de celles-ci se retrouvent déjà dans les Grands Lacs. Trente-sept espèces additionnelles, qui représentent des risques plus faibles et dont six sont déjà présentes dans les Grands Lacs, possèdent une partie seulement des caractéristiques nécessaires pour une invasion réussie dans les conditions actuelles de la gestion de BWE. Notre modèle démontre que les Grands Lacs restent vulnérables aux invasions de NIS via le transport maritime.

Grigorovich, I. A., A. V. Korniushev, et al. (2003). "Lake Superior: an invasion coldspot?" *Hydrobiologia* **499**(1 - 3): 191-210.

Lake Superior receives a disproportionate number of ballast water discharges from transoceanic ships operating on the Laurentian Great Lakes. Although this provides dispersal opportunities for nonindigenous species (NIS), relatively few NIS were initially discovered in this lake prior to being recorded elsewhere in the basin. A lack of NIS records from this lake may be an artefact of sampling bias. We tested this hypothesis by sampling benthos and plankton from littoral and deepwater habitats around the perimeter of Lake Superior during June and August 2001. Using morphological analysis techniques, we identified a total of 230 invertebrate taxa representing planktonic, benthic and nektonic lifestyles. Five species with invasion histories in the lower Great Lakes, the bivalves *Sphaerium corneum*, *Pisidium amnicum* and *P. moitessierianum*, gastropod *Potamopyrgus antipodarum* and amphipod *Echinogammarus ischnus*, were identified for the first time in Lake Superior. In addition, records of expanded distributions within this lake are presented for the amphipod *Gammarus fasciatus* and oligochaetes *Ripistes*

parasita and *Vejdovskyella intermedia*. Recently introduced NIS in Lake Superior were found near international ports, implicating shipping as the vector of their introduction. Intrinsic physical-chemical aspects of Lake Superior may account for the scarcity of NIS in this lake as compared to the lower Great Lakes.

Hall-Armstrong, J. (1994). Ballast water: state of the science, guidelines and regulations. North Shore of Lake Superior Remedial Action Plans Technical Report #21, Canada-Ontario Great Lakes Remedial Action Plan Program: 1-42.

Harvey, M., M. Gilbert, et al. (1999). A preliminary assessment of risks for the ballast water-mediated introduction of nonindigenous marine organisms in the Estuary and Gulf of St. Lawrence. C. T. R. o. F. a. A. S. 2268, Fisheries and Oceans Canada: x + 56.

Risks for the introduction of nonindigenous marine species into the Estuary and Gulf of St. Lawrence (EGSL) by foreign commercial shipping activities were evaluated by conducting three different surveys to characterize 1) the vessel traffic of foreign origin in the EGSL, 2) ballasting operations of foreign vessels entering ports of the EGSL, and 3) the biodiversity and species richness of protistan and metazoan taxa found in ballast water and sediment of incoming foreign vessels. A total of 709 vessels originating from 49 countries and 11 Food and Agriculture Organization (FAO) ocean regions visited 23 different ports of the EGSL in 1995, resulting in the discharge of about 11.5×10^6 tonnes (t) of ballast water from a foreign origin. Respectively 66% and more than 97% of foreign arrivals and associated ballast water discharges in the EGSL occurred in ports of the Estuary and northwestern Gulf, mainly those of Baie-Comeau, Port-Cartier, and Sept-Îles, because of their use by bulk carriers for the exportation of minerals and cereals. However, it is estimated that 86.5% of the foreign ballast water discharged in the EGSL originates from the Northwest Atlantic as a result of an apparent high level of compliance to the *Voluntary Guidelines for the Control of Ballast Water Discharges from Ships Proceeding to the St. Lawrence River and Great Lakes (GLBWCG)*, while only 13.5% originates from previous ports of call. These ports are mainly located in the northwest, northeast, and western central Atlantic and the Mediterranean Sea, particularly around the North Sea and Baltic Sea area and along the eastern and southern coasts of the United States. Except for the Baltic Sea, all these areas exhibit warmer environmental conditions than those prevailing in the EGSL, particularly in the northern Gulf. A total of 292 phytoplanktonic and 89 zooplanktonic species were identified in ballast water of 94 ships from a foreign origin that were sampled and a total of 65 protistan taxa in ballast sediments collected in 8 of these ships. Respectively 60% and 57% of the phytoplanktonic and zooplanktonic species observed in the ships' ballast waters were nonindigenous species that are not yet found or reported in the EGSL, and some of them were found at densities as high as 100,000 cells or ind./m³. Although mid-ocean ballast water exchanges as prescribed by the GLBWCG appear to be efficient in reducing the number and density of zooplankton taxa in ballast tanks, unusually high zooplankton densities in ballast water of a number of incoming sampled ships having reported complete exchanges indicate that these exchanges were in fact not complete or conducted in unsuitable areas.

Nevertheless, observations suggest that risks for the ballast water-mediated introduction of nonindigenous marine species into the EGSL do not appear to be as high as in other areas of the world with documented introductions related to ballast water transport. However, some areas in the Gulf of St. Lawrence do present significant risks for such introductions, particularly in the southern Gulf area - mainly Chaleur Bay and Northumberland Strait - where incoming foreign ships are not subjected to the GLBWCG and where warmer conditions prevail in summer and fall. While additional studies are needed to complete this risk assessment, results point out that necessity to reevaluate and better implement the existing guidelines for offshore ballast water exchange in order to provide better protection for the marine environment of the Estuary and Gulf of St. Lawrence. Some modifications to the current GLBWCG are proposed in this regard as well as the potential use of some community characteristics in ballast waters to monitor compliance to the guidelines.

Holeck, K. T., E. L. Mills, et al. (2004). "Bridging Troubled Waters: Biological Invasions, Transoceanic Shipping, and the Laurentian Great Lakes." *BioScience* **54**(10): 919-929. Release of contaminated ballast water by transoceanic ships has been implicated in more than 70{percnt} of faunal nonindigenous species (NIS) introductions to the Great Lakes since the opening of the St. Lawrence Seaway in 1959. Contrary to expectation, the apparent invasion rate increased after the initiation of voluntary guidelines in 1989 and mandatory regulations in 1993 for open-ocean ballast water exchange by ships declaring ballast on board (BOB). However, more than 90{percnt} of vessels that entered during the 1990s declared no ballast on board (NOBOB) and were not required to exchange ballast, although their tanks contained residual sediments and water that would be discharged in the Great Lakes. Lake Superior receives a disproportionate number of discharges by both BOB and NOBOB ships, yet it has sustained surprisingly few initial invasions. Conversely, the waters connecting lakes Huron and Erie are an invasion hotspot despite receiving disproportionately few ballast discharges. Other vectors, including canals and accidental release, have contributed NIS to the Great Lakes and may increase in relative importance in the future. Based on our knowledge of NIS previously established in the basin, we have developed a vector assignment protocol to systematically ascertain vectors by which invaders enter the Great Lakes.

Horns, W. H. (2002). "Let's put someone in charge of this - a proposal to create a Great Lakes Ballast Water Commission." *Journal of Great Lakes Research* **28**(2): 117-118.

Horvath, T. G., R. L. Whitman, et al. (2001). "Establishment of two invasive crustaceans (Copepoda: Harpacticoida) in the nearshore sands of Lake Michigan." *Canadian Journal of Fisheries and Aquatic Sciences* **58**(7): 1261.

Benthic copepods (Copepoda: Harpacticoida) in the nearshore sediments of southern Lake Michigan appear to be dominated by two new invasive species. We report the first occurrence in North America of *Schizopera borutzkyi* Montschenko,

a native to the Danube River delta, and *Heteropsyllus* nr. *nunni*, likely a new species that is morphologically similar to the marine species *Heteropsyllus nunni* and represents the first occurrence of this genus in freshwater.

Jamieson, G. S. (2000). European Green Crab, *Carcinus maenas*, Introductions in North America: differences between the Atlantic and Pacific Experiences. 10th International Aquatic Nuisance Species and Zebra Mussel Conference Toronto, Canada.

Jenkins, P. T. (2003). Ballast Management and the Control of Sediment Accumulation in Water Ballast Tanks. 12th International Conference on Aquatic Invasive Species Windsor, Ontario, Canada.

Ballast water management, including the management of residuals, has been identified internationally as the only existing defense against the proliferation of aquatic nuisance species through the vector of international shipping, and is likely to remain so in the near term. In the context of protection of the Great Lakes, ballast management was initially viewed solely as open ocean exchange for ships proceeding on the transoceanic voyage in ballast. However the vast majority of ships entering the Great Lakes from overseas do so with cargo on board and with only unpumpable ballast residual in their tanks, which will eventually commingle with water ballast taken in and subsequently discharged within the Great Lakes basin. For these ships, the other elements of ballast management become critical, as they can be ballasting at both ends of the transoceanic voyage in fresh or brackish water without the prophylactic effect of saline shock that open ocean exchange provides. Unpumpable ballast, the residual that cannot be stripped from the tanks, is as much a factor of commercial shipping as ballast water itself, as there are few ships, particularly in the dry bulk trades that can completely evacuate their ballast during the course of the deballasting/cargo loading cycle. Sediment intake during ballasting, particularly at berths in rivers and estuaries, may be unavoidable, and once precipitated can form a major component of that residual if not addressed promptly and regularly. Significant efforts are being made by the industry for both commercial and environmental reasons to manage residuals. This presentation, based on field observations of the deep sea Great Lakes trade over a six year period in studies sponsored by Fisheries and Oceans, Canada, Sea Grant and the Great Lakes Protection Fund as part of their overall assessment of NOBOB ships, examines the management options available to the ship operator for limiting or

eliminating these residuals, the technical and operational limitations that they currently deal with, and the overall application and effectiveness of sound management practice in the trade.

Johengen, T. H., H. Ying, et al. (2003). The Great Lakes NOBOB Project: 38 Ships and 82 Tanks Later. 12th International Conference on Aquatic Invasive Species Windsor, Ontario, Canada.

The majority of vessels arriving from overseas to the Great Lakes enter as NOBOBs (no-ballast-on-board). A major goal of the Great Lakes NOBOB Project is to assess whether these vessels are a potential vector for nonindigenous aquatic species introductions to the Great Lakes. Task 1 of the project is to characterize the amount, and biological and chemical content of sediment and water residuals within NOBOB ballast tanks. Over a two-year period, 82 ballast tanks were entered and sampled on 38 different vessels. Salinities of residual water ranged from 0 to 36 ppt, with approximately 50% in the fresh to brackish water range. In residual water samples we found: bacterial levels typical of environmental samples, occasional presence of pathogenic protozoa, *Pfiesteria*, and *vibrio cholerae*; live phytoplankton cells in all samples, including nonindigenous species, that exhibited various growth response during experimental grow-outs; and over 45 species of live zooplankton including nonindigenous species. In residual sediments we found: viable phytoplankton cysts in all samples, including nonindigenous species of diatoms and marine dinoflagellates (some HAB species); and zooplankton resting eggs in all samples, including nonindigenous species, at densities ranging from 100–10 000 eggs/m² with an average viability of 36% under experimental hatching studies.

Kelly, B. (2003). GIS Mapping of marine vessel ballast water exchange endpoint data in Atlantic Canada, for the 2002 shipping season. Falmouth, NS, Geocentric Mapping Consulting: 81 p.

Kelly, D. W., I. C. Duggan, et al. (Accepted). "Can sodium hypochlorite reduce the risk of species introductions from diapausing invertebrate eggs in non-ballasted ships? ." Marine Pollution Bulletin.

Kerr, S. J., C. S. Brousseau, et al. (2005). Invasive aquatic species in Ontario: A review and analysis of potential pathways for introduction. Fisheries Magazine. **30**: 21-30.

We review eight different pathways for invasion by aquatic species into Ontario. These include fish stocking programs, private aquaculture, bait industry, aquarium and ornamental pond industry, live food fish industry, recreational boating, canals and diversions, and commercial shipping. These pathways have been responsible

for the introduction of more than 160 invasive aquatic organisms into Ontario. Due to several gaps in policy and legislation, we conclude that the greatest potential pathways for the future introduction and spread of invasive aquatic species are associated with ballast water from the shipping industry, the live food fish industry, and the ornamental pond/aquarium trade. We offer recommendations to reduce the potential for establishment of additional invasive aquatic species. New legislation is required and public awareness programs need to be expanded. Response protocols need to be developed which clearly define roles and responsibilities of different agencies. Finally, a more coordinated effort between stakeholders and various levels of government with regard to invasive aquatic species is needed.

Kerr, S. R. (1990). The risk to Atlantic Canadian waters of unwanted species introductions carried in ships' ballast. C. A. F. S. A. Committee. **035**: 11.

The risk of harmful species introductions, carried by ships' ballast water, to receiving waters in the Laurentian Great Lakes, Australian coastal waters, and other vulnerable parts of the world is well documented. The risks to Atlantic Canada appear comparable. This report reviews existing information and its implications for the aquaculture and capture fisheries of Atlantic Canada. There are cogent reasons to suggest that the productive potential of Canadian Atlantic fisheries, and those of the Pacific Coast of Canada, are at risk. The potential for enduring harm needs to be assessed; first for the Gulf of St. Lawrence backup exchange zone designated for Seaway traffic, and second, for Canadian east coast waters generally. Appropriate and affordable approaches to evaluating the risks are identified as guides to further action. It appears that the most economical, effective course may be to extend current voluntary guidelines for high-seas ballast exchange, now applicable to shipping destined for the Great Lakes, to include all shipping entering Canadian waters.

Le risque d'introduction d'espèces dangereuses, provenant de l'eau de ballast, dans les réceptrices des Grands Lac, dans les eaux de la côte australienne et dans d'autres zones vulnérables est un fait attesté. Ce risque semble comparable dans la région canadienne de l'Atlantique. Dans le présent rapport, on examine l'information dont on dispose sur cette situation et ses conséquences sur l'aquiculture et la pêche dans le Canada atlantique. On a de bonnes raisons de croire que le potentiel de productivité des pêches canadiennes dans la région de l'Atlantique, tout comme celui de la région canadienne du Pacifique, est menacé. Il convient d'évaluer les dangers; d'abord dans la zone de transfert du golfe du Saint-Laurent conçue pour le trafic de la voie navigable et, en second lieu, dans l'ensemble des eaux de la côte est du Canada. On présente ici des moyens raisonnables et adéquats d'évaluer les risques pour décider de mesures à prendre. Il semble que la solution la plus économique et la plus raisonnable réside dans l'élargissement de la ligne de conduite volontaire actuelle sur le transfert des eaux de ballast en haute mer. Il s'agirait d'étendre cette ligne de conduite, s'appliquant maintenant au trafic de Grands Lacs, à tous les navires qui pénètrent dans les eaux canadiennes.

Kerr, S. R., B. MacKay, et al. (2004). Invasive Aquatic Species in Ontario: A Review and Analysis of Potential

Pathways for Introductions. 13th International Conference on Aquatic Invasive Species, Ennis County Clare, Ireland.

We review eight different pathways for invasion by aquatic nuisance species into Ontario. These include fish stocking programs, private aquaculture, the bait industry, the aquarium and ornamental pond trade, the live food fish industry, recreational boating, canals and diversions, and commercial shipping. These pathways have been responsible for the introduction of more than 160 exotic aquatic organisms into Ontario. Several gaps in policy and legislation are identified. We conclude that the greatest potential for the future introduction and spread of invasive species are with the commercial shipping industry, the live food fish industry, and the ornamental pond aquarium trade.

Recommendations are offered to reduce the potential for additional aquatic invasive species to become established in the future. New legislation is required and public awareness programs need to be expanded. Response protocols need to be developed which clearly define roles and responsibilities of different agencies.

Finally, there needs to be a more coordinated effort between stakeholders and various levels of government with regard to invasive species.

Langevin, A. (2003). Ballast Water Management Practices of Foreign Flag Vessels. 12th International Conference on Aquatic Invasive Species, Windsor, Ontario, Canada.

The Shipping Federation of Canada is an association of ship owners, commercial operators and agents who represent 95% of Canadian-owned oceanic traffic moving to and from ports on the east coast, the St. Lawrence and the Great Lakes. The Federation has been an active player in the implementation of ballast water management regulations for the Great Lakes, and is keenly interested in the development of a regionally coordinated approach to ballast water management that is based on internationally accepted standards and practices. In 2000, the Federation developed a "Code of Best Practices for Ballast Water Management," which is a voluntary program used by oceans ships as a means of minimizing the risk of introducing non-indigenous aquatic organisms and pathogens into the Great Lakes. The code enumerates a variety of measures that ships agree to undertake in this respect, including the cleaning of tanks, commitments with regard to areas and periods for ballast water intake, and agreement to conduct ballast water management at every practical opportunity.

Oceanic shipping is an international activity by its very nature, with ships sailing many different routes throughout the world. The masters and crews of those vessels are subject to an increasing number of standards, procedures and regulations. As a result, it is important to ensure that such rules and regulations are as simple and user friendly as possible.

Foreign-going vessels rarely have to conduct full ballast exchange along the east coast (which would take 24 to 30 hours, or some 350 nautical miles, to complete). They more frequently exchange ballast from two or three tanks (which takes 8 to 9 hours). However, coastal vessels coming from ports along the east coast or the Atlantic provinces usually find it impossible to conduct a full exchange outside the Economic Exclusive Zone (more than 200 nm from shore) due to their trading limits. Thus, such vessels have, until now, been exempted from requirements to comply with Canadian and US ballast water guidelines.

We believe that the most viable means of addressing cases in which vessels are unable to exchange ballast water at sea (due to safety considerations or coastal trade limitations) is to define a clear alternative ballast water management option. Effective development and use of such a zone or procedure would, however, require bi-national coordination.

It is extremely important that any effort to develop new measures governing ballast water management be consistent with the guidelines and regulations that are either already in place or under development at the international and national level. Legislators should also bear in mind that frequently changing limits and reporting procedures over a short period of time would lead to confusion and a reduction in compliance. A common approach from the Atlantic provinces and the States on the East Coast is absolutely essential.

Ballast water treatment systems are probably the more promising tool for effective ballast water management. The

Shipping Federation supports the development of efficient treatment options and some of its members have installed

trial systems on their vessels. However, at this stage, none of the systems that are available on the market have proven to be sufficiently effective to be installed on a large scale. In addition, treatment systems represent major financial investments that ship owners are not likely to undertake until an international or national standard has been developed.

It is also important to remember that the installation of treatment systems on board fleets could take several years given

the extensive dry-docking that might be required. Thus, given the highly competitive environment in which shipping takes place, any effort to impose a treatment requirement on vessels calling at a particular state or region would result in a diversion of cargo to other ports and threaten the economy of the region as a whole.

Lantz, I. (2000). An Industry Perspective on the Ballast Water Problem. 10th International Aquatic Nuisance Species and Zebra Mussel Conference, Toronto, Canada

Larson, M. R., M. G. Foreman, et al. (2003). "Dispersion of discharged ship ballast water in Vancouver Harbour, Juan De Fuca Strait, and offshore of the Washington Coast." Journal of Environmental Engineering and Science 2(3): 163-176.

The dispersion of harmful nonindigenous biological organisms that may be present in discharged ship ballast water is an issue of international interest. The present paper examines this issue as it applies to Vancouver Harbour and Juan de Fuca Strait, British Columbia, and the adjacent U.S. waters. The objective is to determine whether potential mechanisms exist to transport viable organisms that might be present in discharged ballast water to favourable reproductive habitats within British Columbian coastal waters. The study applied three-dimensional harmonic finite element models to generate representative tidal, atmospheric, and density-driven flow fields.

Particle-tracking techniques were used to simulate representative trajectories of passive and active ballast water organisms discharged at existing deballasting sites. It was determined that the safest deballasting sites are off the west coast. Under normal conditions, organisms move southward (summer) or northward (winter) in the Shelf Break Current and only under strong eastward or northward winds are they transported to the Washington or Vancouver Island shorelines.

La dispersion d'organismes biologiques nuisibles et non indigènes qui peuvent être présents dans l'eau de ballast éliminée des navires est une question d'intérêt international. Cet article examine la question par rapport au Port de Vancouver et au détroit Juan de Fuca, en Colombie-Britannique, et aux eaux américaines voisines. L'objectif est de déterminer s'il existe des mécanismes potentiels de transporter des organismes viables qui pourraient être présents dans l'eau de ballast déchargée dans des habitats favorables à la reproduction dans les eaux côtières de la Colombie-Britannique. L'étude applique des modèles d'éléments finis harmoniques à trois dimensions pour générer des champs

tidaux, atmosphériques et de courant géré par la densité. Des techniques de suivi des particules ont été utilisées pour simuler les trajectoires représentatives des organismes passifs et actifs dans l'eau de ballast déchargée à des sites de vidange existants. Il a été déterminé que les sites de vidange les plus sécuritaires sont au large de la côte Ouest. En condition normale, les organismes se déplacent vers le sud (été) ou le nord (hiver) dans le courant en bordure de la plate-forme continentale et ils sont transportés vers les rives de Washington ou de l'Île de Vancouver uniquement sous de forts vents vers l'est ou vers le nord.

Leppäkoski, E., S. Gollasch, et al. (2002). "The Baltic—a sea of invaders." Canadian Journal of Fisheries and Aquatic Sciences **59**(7): 1175-1188.

There are about 100 nonindigenous species recorded in the Baltic Sea. Invasive species have resulted in major changes in nearshore ecosystems, especially in coastal lagoons and inlets that can be identified as "centres of xenodiversity". Fewer than 70 of these species have established reproducing populations. Dominant invasion vectors include unintentional introductions via ballast water, tank sediments, and hull fouling, aquaculture, and the construction of canals that have facilitated active or passive natural dispersal. Of the approximately 60 unintentionally introduced species with a known invasion history, 38 are transoceanic (including 19 Atlantic species of American origin) and 18 of Ponto-Caspian origin. Species that have caused economic damage to fisheries, shipping, and industry include the hydrozoan *Cordylophora caspia*, the barnacle *Balanus improvisus*, the cladoceran *Cercopagis pengoi*, and the bivalve *Dreissena polymorpha*. The Baltic Sea has served as a secondary source of nonindigenous species to the North American Great Lakes. Further study is warranted to quantify large-scale ecosystem changes in the Baltic associated with establishment and population growth of nonindigenous species and to prevent future invasions.

On a recensé une centaine d'espèces non indigènes dans la Baltique. Les espèces envahissantes ont causé des changements majeurs dans les écosystèmes côtiers, particulièrement dans les lagunes et les anses qui peuvent être qualifiées de centres de « xénodiversité ». Moins de 70 de ces espèces ont réussi à établir des populations qui se reproduisent. Les principaux vecteurs d'introduction sont les apports involontaires par les eaux de ballastage, les sédiments

des réservoirs et l'encroûtement des coques, ainsi que la construction de canaux qui ont facilité la dispersion naturelle active ou passive. De la soixantaine d'espèces introduites involontairement dont l'histoire est connue, 38 sont d'origine transocéanique (dont 19 espèces atlantiques d'origine américaine) et 18 proviennent de la région pontocaspienne. Parmi les espèces qui ont nui aux pêches commerciales, au transport maritime et à l'industrie, on trouve l'hydrozoaire *Cordylophora caspia*, la balane *Balanus improvisus*, le cladocère *Cercopagis pengoi* et le bivalve *Dreissena polymorpha*. La Baltique sert de source secondaire d'espèces non indigènes qui envahissent les Grands-Lacs d'Amérique du nord. Des études supplémentaires sont nécessaires pour arriver à quantifier dans l'écosystème de la Baltique les changements à grande échelle qui sont dus à l'établissement et à la croissance démographique des espèces non indigènes et ainsi prévenir les invasions futures.

Levings, C. D. (1999). Review of current practices to reduce the risk of introducing non-indigenous species into the Pacific Region via ballast water. C. S. A. S. R. D. 99/211, Fisheries and Oceans Canada: 1-13.

Levings, C. D., E. Anderson, et al. (2000). Nonindigenous species in the Strait of Georgia, British Columbia, with comments on possible modes of introduction. 10th International Aquatic Nuisance Species and Zebra Mussel Conference, Toronto, Canada.

Levings, C. D., J. R. Cordell, et al. (2004). "The origin and identity of invertebrate organisms being transported to Canada's Pacific coast by ballast water." Canadian Journal of Fisheries and Aquatic Sciences **61**(1): 1-11.

We assessed the colonization risk of invertebrate nonindigenous species (NIS) in ballast water being brought into Canada's Pacific coast by indirect and direct methods. Initially we mapped the locations in the northern Pacific Ocean where ships coming into Vancouver Harbour had performed mid-ocean exchange (MOE). Exchange transects (the distance between the start and end positions for the onset and end of MOE) were on average about 400 km long. Samples were also taken from ballast tanks after filling at a northwestern Pacific port and then again after MOE in the mid-Pacific. Invertebrate communities were different pre- and post-MOE, but some coastal organisms were still present after flushing. In addition, samples were obtained from ballast tanks aboard ships in Vancouver Harbour. In "low" salinity

samples (<25‰), 13 different taxa were found, and 52 taxa were found in “high” salinity samples (>25‰). Risks could be reduced if MOE was performed in the southerly subtropical domain, south of the subarctic domain and transition zone in the mid-Pacific, or well offshore for north–south shipping routes. For voyages on the west coast of North America, colonization risk of invertebrate NIS is likely higher for ballast water from harbours already colonized by NIS.

Nous avons évalué le risque de colonisation par des espèces non indigènes (NIS) d'invertébrés dans les eaux de ballastage apportées sur la côte canadienne du Pacifique par des méthodes directes et indirectes. Au départ, nous avons cartographié les sites dans le Pacifique nord où des navires destinés au port de Vancouver ont opéré un remplacement d'eau de ballastage en mer (MOE). Les transects où ont eu lieu ces remplacements, soit les positions extrêmes des points du début et de la fin de l'opération de remplacement, ont en moyenne 400 km de longueur. Nous avons aussi prélevé des échantillons dans les ballasts après un remplissage dans un port de la côte pacifique du nord-ouest des États-Unis et de nouveau après un remplacement de l'eau (MOE) dans le centre du Pacifique. Les communautés d'invertébrés sont différentes avant et après le remplacement de l'eau, mais il reste encore des organismes des côtes après l'évacuation. De plus, nous avons prélevé des échantillons dans les ballasts de navires dans le port de Vancouver. Nous avons trouvé 13 taxons différents dans les échantillons de « faible » salinité (<25 ‰) et 52 taxons dans les échantillons de « forte » salinité (>25 ‰). Les risques pourraient être minimisés si le remplacement de l'eau de ballastage se faisait dans le domaine subtropical austral, au sud du domaine subarctique et de la zone de transition dans la région centrale du Pacifique, ou encore bien au large des routes de navigation nord–sud. Dans le cas des déplacements le long de la côte occidentale de l'Amérique du Nord, le risque de colonisation par des invertébrés non indigènes (NIS) est vraisemblablement plus élevé lorsqu'on utilise de l'eau de ballastage provenant de ports déjà colonisés par les NIS.

Levings, C. D. and M. G. G. Foreman (2004). Ecological and oceanographic criteria for alternate ballast water exchange zones in the Pacific Region. Canadian Journal of Fisheries and Aquatic Sciences. C. S. A. S. R. D. 2004/118, Fisheries and Oceans Canada: iv + 37.

We present an overview of the ecological risk associated with draft zoning regulations for disposal of ballast water that has not been exchanged in mid-ocean before vessels arrive at ports in British Columbia. Using data on average seasonal currents off the BC coast, we analysed the possible transport of ballast water organisms into deep ocean habitats and away from key ecosystems and habitats (pilot MPAs, productive fishing grounds, spawning grounds, areas of high primary and secondary productivity, aquaculture operations, areas where ballast water is already being discharged or exchanged, and submarine and estuarine features promoting landward transport). To decrease the risk of possible harm to coastal ecosystems, an amendment of the draft Transport Canada "Annex II" alternate ballast water exchange zone (ABWEZ) is suggested, as given below. Our analysis of currents, bathymetry, and eddies provide rationale for these amendments. Consideration is required to special ABWEZs inshore of the 50 n mi/500 m depth boundary, should weather conditions or other factors require them. Previous assessments showed that an ABWEZ in Juan de Fuca Strait and entrance was associated with risk for non-indigenous species introduction. Further risk assessment is required to investigate the suitability of other special ABWEZs in Pacific region. We also discuss the problematic issue of coastal transport of ballast water organisms and suggest some possible steps to reduce dispersal from this vector into BC waters.

Levings, C. D., D. Kieser, et al. (2002). Marine and estuarine alien species in the Strait of Georgia, British Columbia. Alien invaders: in Canada's waters, wetlands, and forests. R. Claudi, P. Nantel and E. Muckle-Jeffs. Ottawa, Natural Resources Canada, Canadian Forest Service, Science Branch: 111-131.

The Strait of Georgia on the west coast of Canada is an important inland sea used for seafood production, recreational activity, and maritime industry. In this chapter, the presence and role of alien species in the ecosystem of the strait are reviewed. On the basis of the literature and authoritative personal communications, the number of alien species that have reported in the strait or along its shoreline are estimated as follows: 23 algae, 21 vascular plants, 66 invertebrates, 5 fish, 2 birds, and 1 mammal. Some of the records of these species may represent only range extensions, and other species may be cryptogenic (that is, their status as native or introduced cannot be determined). Because of the lack of ecological surveys and monitoring in the strait, there is uncertainty about when most of the alien species arrived there, their modes of introduction, and their ecological impact. However, it is clear that numerous species arrived as hitchhikers with Pacific, or Japanese, oysters (*Crassostrea gigas*), which were intentionally introduced. Other species may have arrived via ballast water, ship fouling, releases of live food organisms, the plant nursery and aquarium trade, and research and teaching activities. Because of the variety of pathways by which alien species can enter the strait, it is difficult to implement effective control mechanisms to minimize or prevent introductions. However, programs already in place, such as quarantine procedures, ballast-water control and management, and public education, could be expanded to help reduce the risk.

Levings, C. D., G. E. Piercey, et al. (1998). Analyses of Invertebrate Fauna in Ballast Water Collected in Ships Arriving at British Columbia Ports, Especially Those from the Western North Pacific. 8th International Zebra Mussel and Other Aquatic Nuisance Species Conference, Sacramento, California.

Lim, P. (2004). Pathways and regulation of aquatic nuisance species into British Columbia's waterways. Georgia Basin/Puget Sound Research Conference Proceedings, Vancouver, British Columbia.

Aquatic nuisance species are of concern in British Columbia not only because of the extent of the province's marine coastline, but also because of the large network of freshwater lakes and rivers which support commercially important species. There are numerous pathways of introduction of nuisance species into British Columbia's aquatic systems. These include ballast water, the pet and aquarium trade, live seafood and transportation of pleasure boats from the Great Lakes area. There is limited documentation of the status of aquatic nuisance populations in the province. European Green Crab (*Carcinus maenas*), Zebra Mussels (*Dreissena polymorpha*), Eurasian Water Milfoil (*Myriophyllum spicatum*), Purple Loosestrife (*Lythrum salicaria*), Common Carp (*Cyprinus carpio*) and *Spartina* (*Spartina alterniflora*) are among the nuisance species that have been observed in British Columbia. Review of federal and provincial legislation that are applicable to limiting the intentional introduction of aquatic nuisance species shows that many regulatory gaps exist. For example, Schedule VIII, Section 5 of the Pacific Fisheries Regulations of the Canada Fisheries Act provides a list of prohibited live fish for importation. The adequacy of this list for the purpose of preventing the importation of species that might threaten local indigenous species needs to be examined. Present knowledge of aquatic nuisance species and their pathways of introduction provide a basis for updating some of these regulations.

Locke, A. (1992). Mid-Ocean Ballast Water Exchange by Ships Entering the St. Lawrence Seaway: Is it Effective? Second International Zebra Mussel Conference, Toronto, Ontario.

Locke, A. (2000). Marine bioinvasions via ballast water - What can be learn from the Great Lakes experience ? 10th International Aquatic Nuisance Species and Zebra Mussel Conference, Toronto, Ontario.

Locke, A. (2000). Marine Bioinvasions: What Can We Learn from the Great Lakes Experience? 10th International Aquatic Nuisance Species and Zebra Mussel Conference, Toronto, Canada.

Locke, A., D. M. Reid, et al. (1991). "Ballast water compliance and effectiveness study." 1-108.

Locke, A., D. M. Reid, et al. (1991). Effectiveness of mid-ocean exchange in controlling freshwater and coastal zooplankton in ballast water. C. T. R. o. F. a. A. S. 1822, Fisheries and Oceans Canada: vii + 93.

We studied ballast water carried by foreign ocean going vessels into the Laurentian Great Lakes and upper St. Lawrence River from May to December 1990 in order to monitor compliance with the Great Lakes Ballast Water Control Guidelines and effectiveness of these guidelines in limiting occurrence of foreign freshwater and coastal organisms in ballast water. Compliance of vessels with the guidelines is 95 percent (all vessels) or 89 percent (excluding vessels not carrying ballast water). Effectiveness of mid-ocean ballast water exchange in eliminating live freshwater zooplankton from ships originating in freshwater ports is 67 percent. Some risk of invasions may still exist since some ships do not comply with the guideline, live freshwater organisms may still exist after mid-ocean exchange, and foreign organisms are released in fresh and brackish parts of the St. Lawrence River which supply much of the ballast water released in the Great Lakes.

Nous avons étudié l'eau de ballast transportée par des navires de haute-mer étrangers qui ont navigué dans les Grands Lacs laurentiens et la partie supérieure du fleuve Saint-Laurent, entre mai et décembre 1990, afin de vérifier s'ils respectaient les Lignes directrices sur le contrôle des ballasts d'eau dans les Grands Lacs, et si ces lignes directrices permettaient vraiment de limiter la présence d'organismes dulcicoles et cotiers étrangers dans l'eau de ballast. Les lignes directrices sont respectées dans une proportion de 95 pour cent (tous les navires) ou de 89 pour cent (en excluant les navires qui n'ont pas d'eau de ballast). L'efficacité de l'échange de l'eau de ballast au milieu de l'océan en vue d'éliminer le zooplancton dulcicole vivant des navires en provenance de ports d'eau douce est de 67 pour cent. La possibilité d'invasions demeure toujours étant donné que certains navires ne respectent pas les lignes directrices, que des organismes dulcicoles vivants peuvent encore exister même après l'échange au milieu de l'océan, et que des organismes étrangers sont libérés dans les secteurs d'eaux douces et saumâtres du fleuve Saint-Laurent qui fournissent une grande partie de l'eau de ballast rejetée dans les Grands Lacs.

Locke, A., D. M. Reid, et al. (1993). "Ballast water exchange as a means of controlling dispersal of freshwater organisms by ships." Canadian Journal of Fisheries & Aquatic Sciences **50**(10): 2086-2093.

During May-December 1990 and March-May 1991, 546 foreign ocean-going vessels entered the Laurentian Great Lakes and upper St. Lawrence River, areas protected by the Great Lakes Ballast Water Control Guidelines. Between 88 and 94% of the vessels exchanged their ballast water with seawater as required by the guidelines. Living representatives of 11 invertebrate phyla were sampled from ballast tanks. Between 14 and 33% of ships that exchanged freshwater ballast in midocean carried living freshwater-tolerant zooplankton at the time of entry to the Seaway, although these included many taxa already found in the Great Lakes. Four freshwater-tolerant zooplankton species that were identified as living specimens in ballast water have apparently not been recorded from the Great Lakes. Voluntary ballast water controls reduced but did not eliminate the risk of species invasion, since some ships did not comply with the guidelines, and even ships that did exchange ballast water could introduce viable freshwater-tolerant organisms into

the Great Lakes. About half of the ballast water carried into the Seaway by ocean-going vessels and lakers each year originates from the St. Lawrence River, portions of which are not yet protected by any ballast controls.

Maclsaac, H., I. Grigorovich, et al. (2001). "Reassessment of Species Invasions Concepts: The Great Lakes Basin as a Model." *Biological Invasions* 3(4): 405-416.

The Laurentian Great Lakes have an extensive history of species introductions, many of which occurred as a result of ballast water discharge by trans-oceanic ships. Most nonindigenous species (NIS) of animals and protozoans that established in the Great Lakes since 1985 are native to the Black, Azov and Caspian Seas or other regions of Eurasia. Analysis of vector strength from global port regions indicates that these NIS, which include amphipods, crustacean zooplankton, mussels and fishes, have been transported principally along dominant shipping routes from native or introduced habitats in northern and western Europe to the Great Lakes. A large group of additional taxa, many of which have extensive invasion histories, is available for transfer to the Great Lakes from key European ports. Thus, joint consideration of invasion corridors and the NIS species established in key donor ports provides an indication of taxa that may colonize the Great Lakes in future. Recent studies indicate that risk assessment may be extended even further for inland lakes subject to NIS invasion from the Great Lakes in cases where invasion vectors can be identified and quantified. Identification of invasion corridors and quantification of vector pathways, using lakes as model systems, provide a promising opportunity for the evolution of invasion biology from a largely descriptive science into a more predictive and quantitative discipline.

Maclsaac, H. J. (2000). Risk-based Standards. 10th International Aquatic Nuisance Species and Zebra Mussel Conference Toronto, Canada.

Maclsaac, H. J., J. V. M. Borbely, et al. (2004). "Backcasting and forecasting biological invasions of inland lakes." *Ecological Applications* 14(3): 773-783.

Human introduction of nonindigenous species constitutes a serious threat to many ecosystems, particularly lakes. Recent attempts to predict invasions have focused on the supply of propagules of nonindigenous species to recipient ecosystems from source populations. Here we develop a spatially explicit "gravity" model to test this concept for *Bythotrephes longimanus*, a crustacean waterflea from Eurasia that is rapidly invading lakes in Ontario, Canada. The gravity model predicted spread of *Bythotrephes* based upon seven

identified risk factors (e.g., use of contaminated fishing or boat anchor line) that may allow dispersal of either live individuals or their resting eggs from invaded to noninvaded lakes, as well as based on the spatial arrangement of invaded and noninvaded lakes in Ontario. Discriminant analysis of lake gravity scores successfully identified invasion status for 74% of 170 inland lakes. A retrospective analysis of 31 invaded lakes revealed that the order in which lakes were invaded was directly related to the magnitude of vector inflows from invaded sources. Analysis of the dominant vector inflow to each invaded lake revealed a "stepping stone" pattern in which at least five lakes were sequentially invaded from the source population in Lake Huron. One invaded lake (Muskoka) apparently served as an invasion "hub," resulting in up to 18 additional direct and 17 indirect invasions. Species spread occurred via a combination of dominant, local diffusion (median distance 12.5 km) and rare, long-distance (.100 km) dispersal. Eleven of 131 lakes that were not invaded in 2000 were reported invaded in 2001. Gravity scores of these lakes were significantly higher

than those of other noninvaded systems, indicating that susceptibility to invasion can be related to the magnitude of vector inflows. A GIS model based on gravity scores indicated that distribution of *Bythotrephes* is expected to expand to eastern and northwestern Ontario,

although most new invasions are expected to occur in the central region of the province. Our results indicate that quantitative analysis of human dispersal vectors provides a robust starting point with which to assess vulnerability of discrete ecosystems to invasion.

Management

efforts focused on reducing the number and magnitude of human-mediated dispersal vectors may reduce the rate of invasion of new ecosystems.

Maclsaac, H. J., I. A. Grigorovich, et al. (1999). "Invasion of Lake Ontario by the Ponto-Caspian predatory cladoceran *Cercopagis pengoi*." Canadian Journal of Fisheries and Aquatic Sciences **56**(1): 1-5.

Cercopagis pengoi, a waterflea native to the Ponto–Caspian region, was discovered during 1998 in Lake Ontario. Individuals were found throughout the lake during summer snagged on sportfishing lines. The population included parthenogenetic (92%) and sexual (2%) females and males (6%). *Cercopagis* has a very long caudal appendage that is more than five times the body length and terminates in a distinctive loop. Females and males from Lake Ontario were significantly smaller than individuals from the Neva Estuary, Baltic Sea. In Eurasia, *C. pengoi* occurs in relatively warm fresh and brackish waters (0–14‰) at population densities usually <3000 individuals·m⁻³; mean and maximum population densities in Lake Ontario were 170 and 322 individuals·m⁻³, respectively. The presence of females with resting eggs indicates that *Cercopagis* will likely establish in Lake Ontario. As with other recently introduced invertebrates, *Cercopagis* likely was transported to the Great Lakes in ballast water from eastern Europe.

The rapid influx of Ponto–Caspian species into the Great Lakes warrants further study including identification of source populations, mechanisms of dispersal, impacts on recipient ecosystems, and efficacy of ballast water exchange programs.

On a détecté en 1998 dans le lac Ontario la présence de *Cercopagis pengoi*, une puce d'eau indigène de la région ponto–caspienne. On a trouvé des individus partout dans le lac durant l'été, fixés à des lignes à pêche. La population comprenait des femelles qui se reproduisaient par parthénogenèse (92%) et par reproduction sexuée (2%) ainsi que des mâles (6%). *Cercopagis* a un très long appendice caudal (longueur plus de cinq fois supérieure à celle du corps) qui se termine en une boucle distinctive. Les femelles et les mâles du lac Ontario étaient significativement plus petits que les sujets de l'estuaire de la Neva, dans la mer Baltique. En Eurasie, on trouve *C. pengoi* en eau douce ou saumâtre (salinité de 0 à 14‰) relativement chaude et à des densités habituellement inférieures à 3 000 individus·m⁻³; les densités de population moyenne et maximale dans le lac Ontario étaient de 170 et 322 individus·m⁻³, respectivement. La présence de femelles avec des oeufs durables indique que *Cercopagis* s'établira probablement dans le lac Ontario. Comme dans le cas d'autres invertébrés récemment introduits, *Cercopagis* a probablement été transporté dans les Grands Lacs dans des eaux de lest provenant d'Europe de l'Est. Vu l'influx rapide d'espèces ponto–caspiennes dans les Grands Lacs, on devra entreprendre de nouvelles études, ayant trait notamment à l'identification des populations sources, aux mécanismes de dispersion, aux impacts sur les écosystèmes récepteurs et à l'efficacité des

Maclsaac, H. J., T. C. Robbins, et al. (2002). "Modeling ships' ballast water as invasion threats to the Great Lakes." Canadian Journal of Fisheries and Aquatic Sciences **59**(7): 1245-1256.

The spread of nonindigenous species (NIS) in aquatic ecosystems provides an opportunity to develop new perspectives on the invasion process. In this paper we review existing invasion models, most of which were developed to describe invasions of terrestrial habitats, and propose an alternative that explores long-distance invasions mediated by discharge of contaminated ballast water by ships inbound to the Great Lakes. Based on current knowledge of shipping traffic to the Great Lakes, our model predicts that mid-ocean exchange of ballast water lowers propagule delivery by

approximately three to four orders of magnitude relative to unexchanged ballast water.

Propagule pressure of individual ships that enter the Great Lakes loaded with cargo and that declare "no ballast on board" (NOBOB) is typically one to two orders of magnitude higher than that of vessels that exchange ballast. Because NOBOB vessels dominate (~90%) inbound traffic into the Great Lakes, these vessels collectively appear to pose the greatest risk of new introductions, even though their individual risks are low.

La dispersion accrue des espèces non indigènes dans les écosystèmes aquatiques est une occasion d'obtenir de nouvelles perspectives sur le processus d'invasion. On trouvera ici une revue des modèles existants d'invasion, dont la plupart ont été créés pour étudier l'invasion des habitats terrestres. Nous proposons un modèle de rechange qui décrit les invasions sur de longues distances occasionnées par le déchargement d'eau de ballast contaminée par les navires à destination des Grands-Lacs à l'intérieur du continent. D'après les données actuelles de navigation vers les Grands-Lacs, notre modèle prédit que l'échange d'eau de ballast en mi-océan diminue l'apport de propagules par un facteur de 1 000 à 10 000 par comparaison à de l'eau de ballast non échangée. La pression exprimée en nombres de propagules par les navires qui entrent dans les Grands-Lacs chargés de cargo et qui déclarent ne pas avoir de ballast (NOBOB) est généralement 10 à 100 plus grande que celle des navires qui ont changé leur ballast. Parce que les navires NOBOB prédominent (~90 %) dans le trafic qui pénètre dans les Grands-Lacs, ils semblent présenter collectivement un très grand risque d'introduction d'espèces dans leur eau de ballast.

MacIassac, H. J. and I. Grigorovich (1999). "Ponto-Caspian invaders in the Great Lakes." Journal of Great Lakes Research **25**(1): 1-2.

Mills, E. L., K. T. Holeck, et al. (2004). Bioinvasions in North America's Great Lakes and the Shipping Vector. 13th International Conference on Aquatic Invasive Species, Ennis, County Clare, Ireland.

The Laurentian Great Lakes have 176 established nonindigenous species (NIS) of which over 40% have been attributed to the ship vector. The invasion rate in these waters has increased to nearly six times the previous rate since the opening of the St. Lawrence Seaway in 1959. Interestingly, the invasion rate of ship-vectored faunal species has increased despite implementation of voluntary guidelines (1989) and mandatory legislation (1993) requiring openocean

ballast water exchange. Such an increase in the face of current ballast water exchange policies may be related to the fact that 90% of transoceanic vessels entering the Great Lakes-St. Lawrence Seaway during the 1990s reported no ballast on board (NOBOB) and were therefore exempt from the legislation. NOBOB ships unload cargo at their first port of call, take on Great Lakes water (mainly from Lakes Ontario and Erie), which mixes with residual water and sediments present in the tanks of these vessels, and release this mixed ballast water prior to leaving the Great Lakes. Of all the Great Lakes, Lake Superior receives the most ballast water discharges from both ballasted and NOBOB ships but has sustained surprisingly few invasions since 1959, possibly owing to its relatively inhospitable physical environment. Recent studies have revealed that NOBOB vessels may carry viable resting eggs, and these vessels may pose an invasion risk to Great Lakes waters.

Mills, E. L., J. H. Leach, et al. (1993). "Exotic species in the Great Lakes: a history of biotic crises and anthropogenic introductions." Journal of Great Lakes Research **19**(1): 1-54.

Through literature review, we documented introductions of non-indigenous aquatic flora and fauna into the Great Lakes basin since the early 1800s. We focused on the origin, probable mechanism(s) of introduction and the date and locality of first discovery of Great Lakes exotic species. The Laurentian Great Lakes have been subject to invasion by exotic species since settlement of the region by Europeans. Since the 1800s, 139 non-indigenous aquatic organisms have become established in the Great Lakes. The bulk of these organisms has been represented by plants (59), fishes (25), algae (24), and mollusks (14). Most species are native to Eurasia (55%) and the Atlantic Coast (13%). As human activity has increased in the Great Lakes watershed, the rate of introduction of exotic species has increased. Almost one-third of the organisms have been introduced in the past 30 years, a surge coinciding with the opening of the St. Lawrence Seaway in 1959. Five categories of entry mechanisms were identified: unintentional releases, ship-related introductions, deliberate releases, entry through or along canals, and movement along railroads and highways. Entry mechanisms were dominated by unintentional releases (29%) and ships (29%). Unintentional releases included escapees from cultivation and aquaculture, bait, aquarium,

and other accidental releases. Ship-related introductions included ballast water (63%), solid ballast (31%), and fouling. Introductions via canals represent a small percentage of entries into the Great Lakes.

We have identified 13 non-indigenous species (9%) that have substantially influenced the Great Lakes ecosystem, both economically and ecologically. The apparent lack of effects of 91% of the exotic species in the Great Lakes does not mean that they have had little or no ecological impact. Alterations in community structure may predate modern investigations by decades or centuries, and the effects of many species have simply not been studied. As long as human activities provide the means through which future species can be transported into the Great Lakes basin, the largest freshwater resource in the world will continue to be at risk from the invasion of exotic organisms.

Mills, E. L., J. H. Leach, et al. (2004). "Exotic Species and the Integrity of the Great Lakes: Lessons from the past." *Biosciences* **44**(10): 666-669.

One of the most pervasive and damaging impacts on the world's ecosystems is the introduction of nonindigenous species (Elton 1958, Mooney and Drake 1989). In the United States, at least 4500 nonindigenous species including several thousand plant and insect species and several hundred non-native vertebrate, mollusk, fish, and plant pathogen species have established free-living populations (OTA 1993). Approximately 15% of these nonindigenous species have caused severe harm affecting agriculture, industry, human health, and the natural environment (OTA 1993).

Since the early 1800s, some of the greatest ecological disasters in North America's Great Lakes, the world's largest freshwater resource, have resulted from biological invasions. The cumulative effects of many nonindigenous species on the natural structure of the Great Lakes ecosystem have compromised its biological integrity. In addition to this loss, some individual invaders such as sea lamprey (*Petromyzon marinus*) and the zebra mussel (*Dreissena polymorpha*) have caused substantial economic hardships and ecological instability. Human activities such as construction on the Erie Canal and the St. Lawrence Seaway have played a major role in the introduction of nonindigenous species to the Great Lakes Ecosystem. At present, species introductions continue to pose a threat to the integrity of the lakes.

In this article, we review new documentation of the extent, timing, origins, dispersal mechanisms, and impacts of biological invasions in the Great Lakes basin. Eight states and one province claim Great Lakes shoreline, and major port cities such as Chicago and Toronto use the Great Lakes as part of a national and international trade route--the St. Lawrence Seaway. The Great Lakes play a major role in the economies of these regions, and the string of ecological disasters associated with

biological invasions must be stopped. We hope that lessons from the past help to prevent future invasions.

Mills, E. L., J. Leach-Task, et al. (1991). What's Next?: The Prediction and Management of Exotic Species in the Great Lakes, Campus Inn, Ann Arbor, Michigan.

A workshop entitled What's Next? The Prediction and Management of Exotic Species in the Great Lakes was held in October 1991 to examine issues pertaining to exotic species and to recommend prevention and control strategies for future unplanned introductions into the Great Lakes. As long as the Great Lakes are inoculated with exotic species, new species will become established regardless of the state or condition of the ecosystem. As legislative and regulatory policies are designed to prevent new unplanned introductions, they must consider vector management and broaden in scope to include the North American continent. The workshop recommends that: 1) ballast water controls extend from the Great Lakes to the North American continent and include provisions to monitor both compliance to and effectiveness of the regulations; 2) a public education program be developed in the Great Lakes basin to alert the public of the dangers associated with releasing exotic species into non-native waters; 3) studies begin immediately to determine the extent of actual or potential release of exotic species associated with the aquaculture, bait fish, and pet industries and advisories should be issued against the use of organisms not present in the Great Lakes by these industries; 4) a Nonindigenous Aquatic Species Information Network (NASIN) be established to act as a clearing-house for information and coordinator of research and management within North America and a liaison with the regions that serve as the sources for North American introduced species.

Momot, W. T. (1999). Status of Several Recently Introduced Exotic Species in Thunder Bay, Lake Superior, Ontario. 9th International Zebra Mussel and Aquatic Nuisance Species Conference, Duluth, Minnesota.

Morris, T. (2000). Canada's Regulatory Response - International and Binational. 10th International Aquatic Nuisance Species and Zebra Mussel Conference, Toronto, Canada.

Morris, T. (2003). The Development of the International Convention for the Control and Management of Ships'

Ballast Water and Sediments. 12th International Conference on Aquatic Invasive Species, Windsor, Ontario, Canada.

The threat of introductions of harmful aquatic organisms and pathogens from the discharge of ship's ballast is an international issue that is appropriately being addressed by the International Maritime Organization (IMO), the United Nations specialized agency that deals exclusively with marine matters. The IMO's Marine Environment Protection Committee (MEPC) has identified addressing the ballast water issue as its number one environmental priority.

The IMO first developed guidelines on the management and control of ballast water in 1991 and, since 1994, has been working on the drafting of mandatory regulations. The process was interrupted in the late 1990s when it was recognized that an update to the guidelines was necessary.

In attempting to reach consensus on the contents of the regulations, many issues have been debated, such as a global vs. regional approach, the continued acceptance of ballast water exchange and requirements for new ships vs. existing ships, but the greatest challenge has been to develop treatment and discharge standards. When the Working Group developing the regulations met in March 2002, they considered 14 possible ballast water treatment standards, which they have since reduced to just one performance standard, but the parameters for the standard remain undecided.

As currently drafted the regulations would require ships to carry an approved Ballast Water Management Plan, to keep a Ballast Water Management Book, and to manage sediment and ballast. New ships would be required to discharge no detectable quantities of viable organisms above a certain size (proposed as 50 microns) and to discharge no other organisms above a certain concentration (to be determined). Existing ships conducting ballast exchange would have to do so with an efficiency of 95% volumetric exchange, but only those ships constructed before the entry into force of the Convention would be considered as conducting an equivalent exchange by using three times flow through. Issues such as the parameters for the performance standard, the definition of a new ship, the decision of whether or not ballast water exchange will be phased out for existing ships, whether special requirements are required in certain areas and whether special areas should be established are still significant items being debated.

The MEPC will further discuss the proposed ballast water convention when it meets again in July 2003. If issues

can be resolved, it is expected that the Convention would be adopted at a Conference of Parties in early 2004. The Convention would then come into force when a sufficient number of countries ratify it after implementing its provisions in their national legislation.

Moyle, P. B. (1991). "Ballast water introductions." Fisheries **16**: 4-6.

Muirhead, J. R. and H. J. Macisaac (2005). "Development of inland lakes as hubs in an invasion network." Journal of Applied Ecology **42**(1): 80-90.

1.

The ability to predict spatially explicit dispersal by non-indigenous species is a difficult but increasingly important undertaking as it allows management efforts to be focused around areas identified as susceptible to invasion. Lakes may serve as useful models for these studies because the habitats are well defined, and vectors of spread may be readily identified and quantified. In this study, we examined patterns of spread of the non-indigenous spiny waterflea *Bythotrephes longimanus* to inland lakes in Ontario, Canada, to identify lakes for which management efforts to reduce traffic would be most effective.

2.

We surveyed people using lakes for recreational purposes to quantify movements of trailered boats and other risky activities, to model relative vector traffic from invaded lakes to non-invaded and other invaded lakes. Non-linear functions were developed to describe the cumulative number of invaded and non-invaded destination lakes visited by people leaving five important lakes already invaded by the spiny waterflea (Huron, Simcoe, Muskoka, Panache and Kashagawigamog). The relative difference in these functions was used to identify which lakes will develop into future invasion hubs and will therefore be most important to future dispersal of the species.

3.

In the recent past, Lake Muskoka has been an important hub from which the spiny waterflea has invaded other lakes. It is unlikely to continue to be a source for waterflea invasion as most outbound traffic is to previously invaded lakes. Conversely, most outbound traffic from Lakes Kashagawigamog and Simcoe is to non-invaded lakes and, therefore, these lakes are likely to develop into hubs in the future.

4.

Synthesis and applications. These data on zooplankton in lake systems and associated mechanisms of transport indicate patterns not only of intrinsic value to lake management, but also of potential importance in understanding invasions more generally. Frequency distributions of the number of outbound connections to both invaded and non-invaded destinations from invaded sources follow a power function, consistent with scale-free networks. These networks indicate that small proportions of sources function as hubs. Management efforts targeted to remove developing hubs from the invasion network, rather than equal effort applied to outbound vector traffic from all sources, may reduce the predicted rate of new invasions.

Niimi, A. J. (2000). "Influence of vessel transit patterns on developing a ballast water treatment strategy for exotic species." MARINE POLLUTION BULLETIN **40**(3): 253-256.

Niimi, A. J. (2004). "Environmental and Economic Factors Can Increase the Risk of Exotic Species Introductions to the Arctic Region Through Increased Ballast Water Discharge." Environmental Management **33**(5): 712-718.

The effects of global warming can increase the risk of exotic species introductions in eastern Canadian Arctic waters by reducing surface ice cover and allow increased access to commercial vessels. Ballast water discharged by incoming overseas vessels is an important means for introducing species on a global scale. Analyses of air temperatures at Churchill, Manitoba between 1943 and 2002 indicated an increase in mean temperature within the past decade. Churchill is the only major northern port in this region where grain has been exported on a limited basis due to the short navigation season. Economic analyses of grain exported from Canadian and U.S. ports indicated some cost advantages for using northern ports. The Hudson Bay region is vulnerable to increased exotic species introductions because of its southerly location. Current ballast water exchange measures to reduce the risk of introductions may not be effective because most vessels enter the region with ballast, and the ballast exchange zone is located relatively close to coastal areas where the habitat could be favorable for an introduced species to become established. The probability of a large crab species introduced to this region from northern European waters is discussed. The risk of ballast water-related exotic species introduction to this region may be reduced by expanding the types of cargo handled and developing a strong import market. This approach would accommodate an increase in the number of vessels with cargo, and substantially reduce the volume of ballast carried to this region.

Niimi, A. J. (2004). "Role of container vessels in the introduction of exotic species." Marine Pollution Bulletin **49**(9-10): 778-782.

Ballast water exchange practices were monitored on 28 incoming container vessels at the Port of Montreal. Measurements on 15 vessels indicated 13 of 32 tanks had salinities of <30permill.. The 16 transits with a North Atlantic route visited 31 of 37 ports located on freshwater or near freshwater outflows. Ballast carried by this vessel type represents an important means for the introduction of species on a global scale because of its transit routes, dockside discharge and moving ballast between tanks. Container vessels represent about 15% of the world fleet, but account for 32% of all visits to global ports, and 46% of visits to the 25 largest ports. The 10 ports that handled the largest volumes of international cargo also included 8 that handled the most cargo containers. Large ports can receive over 100,000 visits by all vessel types annually, and serve as hubs for over 500 ports in 100 countries. Secondary transport of exotic species is also a concern because of frequent visits by regional vessels. Copyright 2004 Elsevier Ltd. All rights reserved.

Niimi, A. J. and D. M. Reid (2003). "Low salinity residual ballast discharge and exotic species introductions to the North American Great Lakes." Marine Pollution Bulletin **46**(10): 1334-1340.

Exotic species introductions to the North American Great Lakes have continued even though ballast water management strategies were implemented in the early 1990s. Overseas vessels that arrive with little or no exchangeable ballast on board have been suspected to be an important source for discharging low salinity ballast containing low salinity tolerant organisms in this region.

Residual ballast averaged 18.1 ± 13.4 salinity among 62 samples taken primarily from bottom tanks on 26 vessels that entered the Great Lakes in 1999 and 2000. Sampling of 2–4 tanks each on nine vessels indicated all carried at least one tank of residual ballast of 65 salinity. Many of these transits originated from the northeast Atlantic, Mediterranean and Black Sea regions which have been the probable source for many of the more recent introductions to this region.

Panov, V. E., P. I. Krylov, et al. (2004). "Role of diapause in dispersal and invasion success by aquatic invertebrates." Journal of Limnology **63**(Suppl. 1): 56-69.

Review of existing literature shows an important role of diapause in dispersal of aquatic invertebrates. There is evidence that among aquatic invertebrates, the role of diapause in dispersal can be important in crustaceans, specifically for species that produce resting eggs. Analysis of dispersal vectors of diapausing species revealed the increasing role of human-mediated vectors of species dispersal during last century (intentional and unintentional introductions, specifically associated with shipping) in comparison with natural vectors (currents, wind, birds). Generally, the role of human-mediated vectors is most important for species dispersal across geographical barriers and into large aquatic ecosystems affected by shipping. Current human-mediated transport vectors increase rates of aquatic species introductions in many orders of magnitude in comparison with historical nature-driven species dispersal rates. Ability to develop diapausing resting stages facilitates species survival during movement across geographical barriers under extreme conditions, such as in ballast tanks of ships. Case studies for invasive species of Cladocera show that some invaders may possess adaptive life cycles, switching to the early prolonged gamogenetic reproduction, which facilitates their invasion success into novel ecosystems and further dispersal by both natural and human-mediated vectors.

Paradis, S. (2005). Alternative ballast water exchange zones. C. S. A. S. P. S. 2004/042, Fisheries and Oceans Canada: vi - 21.

Over the last few years, DFO scientists have provided scientific advice for the management and regulation of ballast water

exchange to Transport Canada via a number of mechanisms (e.g., Halifax Workshop (2003), personal communications, advice to DFO Habitat Management, regional committees, etc.). These informal processes, however, are not consistent with DFO's objective of providing peer-reviewed science advice for use in regulatory development or decision-making. As a result, DFO undertook this peer review of alternative ballast water exchange zones.

DFO scientists developed three working papers:

- alternative ballast water exchange zones on the east coast;
- alternative ballast water exchange zones on the west coast and;
- the Laurentian Channel as an alternative ballast water exchange zone.

A DFO-hosted National Peer Review was held on 30 November – 1 December 2004 in Montreal to review the working papers. The purpose of the peer review was to assess whether the conclusions presented in the working papers were credible and supported by scientific data. This proceedings report outlines the general recommendations regarding ballast water and specific recommendations for regional alternative ballast water exchange zones on the east and west coasts and the Laurentian Channel. Research needs related to ballast water are also provided.

Ces dernières années, les scientifiques du MPO ont fourni des avis scientifiques à Transports Canada concernant la gestion et la réglementation de l'échange des eaux de lest à travers divers mécanismes (atelier de Halifax en 2003, communications personnelles, avis à la Gestion de l'habitat du MPO, comités régionaux, etc.). Or, ces mécanismes informels ne respectent pas l'objectif du MPO, qui est de fournir des avis scientifiques soumis à une revue par les pairs pour l'élaboration de mesures réglementaires ou la prise de décisions. Pour corriger la situation, le MPO a entrepris le présent examen par les pairs des zones alternatives pour l'échange des eaux de lest.

Les scientifiques du MPO ont élaboré trois documents de travail :

- zones alternatives pour l'échange des eaux de lest sur la côte est;
- zones alternatives pour l'échange des eaux de lest sur la côte ouest; et
- le chenal Laurentien comme zone alternative pour l'échange des eaux de lest.

Un examen par les pairs national a été organisé par le MPO le 30 novembre et le 1er décembre 2004, à Montréal, pour examiner ces documents de travail. Le but de l'examen par les pairs était d'évaluer si

les conclusions présentées dans les documents de travail étaient crédibles et soutenues par des données scientifiques. Le

présent compte rendu résume les recommandations générales concernant les eaux de lest et des recommandations spécifiques concernant des zones alternatives régionales pour l'échange des eaux de lest sur les côtes est et ouest ainsi que dans le chenal Laurentien. Le présent rapport traite aussi des besoins de recherche sur les eaux de lest.

Pederson, J. (2003). Ballast water exchange: Exploring the feasibility of alternate ballast water exchange zones in the North Atlantic, Halifax, Nova Scotia, Massachusetts Institute of Technology.

Pederson, J. (2004). Integrating Science in Ballast Water Management. 13 International Conference on Aquatic Invasive Species, Ennis County Clare, Ireland.

Ballast water exchange at sea is used to reduce and minimize introductions into coastal areas. In many regions, coastal traffic is exempt from ballast exchange and may be responsible for dispersing non-native organisms from local regions of invasion throughout the coast. In northeastern North America, coastal vessels travel between Cape Hatteras and northern reaches of Atlantic Canada creating complicated compliance issues that may or may not provide optimal protection.

A regional effort is underway to work with industry, regulators, policy makers, and scientists to promote ballast water exchange by coastwise vessels. A workshop was held to provide information on physical and biological oceanographic data, vessel traffic, industry practices for ballast exchange, and current policies and regulations. Using criteria developed by the workshop participants, data from oceanographic studies have identified areas where ballast water exchange is less likely to result in onshore currents thus, minimizing the potential for introductions. Three regions, the Gulf of Maine, the Laurentian Channel, and the productive Georges Bank areas have unique political, industry limitations, and oceanographic issues that will require further exploration of how best to proceed. Recommendations for proposed exchange areas and practices have been reviewed by industry, regulators and policy makers based on the available scientific data. A proposal that includes proposed best management practices for industry and a regional policy has been drafted, however, a new deep water invasion has modified the recommendations.

Within a few months of the initial draft of the recommendations, a highly invasive ascidian, *Didemnum cf. lahillei*, has been found in the productive fishing area of Georges Bank. This is one of the first documented invasions in an area near the continental shelf and has implications for the proposed ballast water exchange policies and management practices. This presentation will review the findings of the workshop participants and the recommendations of the proposed ballast water exchange areas for coastal traffic.

Piercey, G. E., C. D. Levings, et al. (2000). Invertebrate fauna in ballast water collected in vessels arriving in British Columbia ports, especially those from the Western North Pacific. C. D. R. o. F. a. A. S. 1060, Fisheries and Oceans Canada: iii + 50.

Data are presented on the invertebrate fauna identified from the ballast water of 63 vessels arriving at five British Columbia ports between December, 1995 and January, 1997. Those arriving from the western North Pacific were of particular interest. In total, 352 vessels were boarded and appropriate ship personnel were interviewed. Those vessels with ballast water from various locations in the western North Pacific were sampled if permission from the vessel's representative was obtained. Information on ballast capacity, ballast on board, and other pertinent information has been summarized for all vessels, where available. Temperature and salinity data were obtained at the same time as the biological samples were collected.

Prior, A. D. (1995). *Ballast Water Exchange Study: Phase I*. Ottawa, Ontario, Mellville Shipping.

Reeves, M. E. (1997). Techniques for the protection of the Great lakes from infection by exotic organisms in ballast water. Zebra Mussels and aquatic nuisance species. F. M. D'Itri. Chelsea, Michigan, Ann Arbor Press, Inc. : 1-638.

Reeves, M. E. and C. J. Wiley (1996). The Nature of the Aquatic Nuisance Species Problem: A Global Perspective. 6th International Zebra Mussel and Other Aquatic Nuisance Species Conference, Dearborn, Michigan.

Reid, D. and T. Johengen (2001). Assessment of transoceanic NOBOB vessel and low-salinity ballast water as vectors for nonindigenous species introductions to the Great Lakes. Ann Arbor, MI: 2 p.

Reid, D. F. and M. I. Orlova (2002). "Geological and evolutionary underpinnings for the success of Ponto-Caspian species invasions in the Baltic Sea and North American Great Lakes." Canadian Journal of Fisheries and Aquatic Sciences **59**(7): 1144.

Between 1985 and 2000, ~70% of new species that invaded the North American Great Lakes were endemic to the Ponto-Caspian (Caspian, Azov, and Black seas) basins of eastern Europe. Sixteen Ponto-Caspian species were also established in the Baltic Sea as of 2000. Many Ponto-Caspian endemic species are characterized by wide environmental tolerances and high phenotypic variability. Ponto-Caspian fauna evolved over millions of years in a series of large lakes and seas with widely varying salinities and water levels and alternating periods of isolation and open connections between the Caspian Sea and Black Sea depressions and between these basins and the Mediterranean Basin and the World Ocean. These conditions probably resulted in selection of Ponto-Caspian endemic species for the broad environmental tolerances and euryhalinity many exhibit. Both the Baltic Sea and the Great Lakes are geologically young and present much lower levels of endemism. The high tolerance of Ponto-Caspian fauna to varying environmental conditions, their ability to survive exposure to a range of salinities, and the similarity in environmental conditions available in the Baltic Sea and Great Lakes probably contribute to the invasion success of these

species. Human activities have dramatically increased the opportunities for transport and introduction and have played a catalytic role.

Reid, D. M. (1994). Determination of the spatio-temporal distribution of given species that could be introduced into the Gulf of St. Lawrence by the ballast waters of ocean-going vessels: xlili.

Forty species of concern as potential ballast water mediated invaders of the Estuary and Gulf of St. Lawrence were identified in Reid 1994. The purpose of this study was to collect additional spatio-temporal information on those species of concern, in order to describe more completely those aspects of their life history and ecology that enable or facilitate their transport via ballast water

Reid, D. M. (1994). Potential ballast water mediated invaders of the Gulf of St. Lawrence and estuary: iv + 51.

Reid, D. M. (1995). Preliminary analysis of vessel traffic data collected in the estuary and gulf of St. Lawrence between January 23 and March 31, 1995.

As part of continuing studies related to the transport and introduction of nonindigenous aquatic and marine organisms in the ballast water of international commercial cargo vessels, a survey was organized in various ports in the estuary and Gulf of St. Lawrence (EGSL). The purpose of this survey was to collect ballast water related information on vessels operating in the EGSL, in order to characterize vessel traffic according to certain parameters, including vessel type, last-port-of-call, quantity and source of ballast water carried.

While a number of agencies currently collect information on vessel traffic in EGSL ports, none of those agencies is specifically concerned with the ballast water carried by these vessels, so any information specifically related to ballast water is generally unavailable. The intent of this survey was to collect a complete year's worth of data, although it was recognized that vessel traffic could be operating at very low levels of activity in the EGSL during the winter.

Reid, D. M. (1996). Ecological risk assessment methods: their review and application to the transport of unwanted species by ships' ballast in the Gulf of St. Lawrence and estuary. Sainte-Foy, Quebec, BIOREX Inc. : vi + 47.

Reid, D. M. and J. T. Carlton (1997). Shipping study I-A : A study of the introduction of aquatic nuisance species by vessels entering the Great Lakes and Canadian waters adjacent to the United States, Maritime Studies Program
Williams College - Mystic Seaport: 14 p.

This study investigated the extent to which shipping contributes to the introduction of nonindigenous species into U.S. waters; potential options for controlling such introductions; and the issue of whether this problem is of regional or national concern. Data on shipping traffic patterns and ballast water management practices were collected, and estimates were made of the amount and sources of ballast water released in or near U.S. waters. The feasibilities of various options for

controlling ballast water-mediated invasions were examined via consultations with experts in various fields and investigation into capabilities of products on the market. Recommendations include potential strategies for managing/reducing the risk of nonindigenous species invasions

Reid, D. M., H. J. MacIsaac, et al. (2002). Research and management priorities for aquatic invasive species in the Great Lakes, International Association for Great Lakes Research 1-22.

Ricciardi, A. (2001). "Facilitative interactions among aquatic invaders: Is an "invasional meltdown" occurring in the Great Lakes?" Canadian Journal of Fisheries and Aquatic Sciences **58**(12): 2513.

A widely cited hypothesis in ecology is that species-rich communities are less vulnerable to invasion than species-poor ones, owing to competition for limiting resources (the "biotic resistance" model). However, evidence for biotic resistance in aquatic ecosystems is equivocal.

Ricciardi, A. and H. J. MacIsaac (2000). "Recent mass invasion of the North American Great Lakes by Ponto–Caspian species." Trends in Ecology and Evolution **15**(2): 62-65.

The North American Great Lakes have been invaded and dramatically altered by more than 145 alien species. Many invasions have occurred during the past few decades because of the release of Eurasian ballast water from transoceanic ships. Current regulations require ships to exchange foreign ballast with highly saline water before entering the Great Lakes; this procedure should prevent colonization by strictly freshwater species, but species with broad salinity tolerance might survive transport in exchanged water. A recent series of invasions by euryhaline organisms from the Black and Caspian Seas region signals a new phase in the transformation of the Great Lakes – one that supports the concept of an 'invasional meltdown'.

Ricciardi, A. and J. B. Rasmussen (1998). "Predicting the identity and impact of future biological invaders: A priority for aquatic resource management." Canadian Journal of Fisheries and Aquatic Sciences **55**(7): 1759.

The identification and risk assessment of potential biological invaders would provide valuable criteria for the allocation of resources toward the detection and control of invasion threats. Yet, freshwater biologists have made few attempts at predicting potential invaders, apparently because such efforts are perceived to be costly and futile.

Salt, J. (1992). Current Status of the Canadian Ballast Water Exchange Guidelines. Second International Zebra Mussel Conference Toronto, Ontario.

Sano, L. L., S. M. Bartell, et al. (2005). "Decay model for biocide treatment of unballasted vessels: Application for the Laurentian Great Lakes." Marine Pollution Bulletin **50**(10): 1050-1060.

A biocide decay model was developed to assess the potential efficacy and environmental impacts associated with using glutaraldehyde to treat unballasted overseas vessels trading on the Laurentian Great Lakes. The results of Monte Carlo simulations indicate that effective glutaraldehyde concentrations can be maintained for the duration of a vessel's oceanic transit (approximately 9–12 days): During this transit, glutaraldehyde concentrations were predicted to decrease by approximately 10% from initial treatment levels (e.g., 500 mg/L). In terms of environmental impacts, mean glutaraldehyde concentrations released at Duluth-Superior Harbor, MN were predicted to be 100-fold lower than initial treatment concentrations, and ranged from 3.2 mg /L (2 SD: 2.74) in April to 0.7 mg/L (2 SD: 1.28) in August. Sensitivity analyses indicated that the reballasting dilution factor was the major variable governing final glutaraldehyde concentrations; however, lake surface temperatures became increasingly important during the warmer summer months.

Sano, L. L., M. A. Mapili, et al. (2004). "Comparative efficacy of potential chemical disinfectants for treating unballasted vessels." Journal of Great Lakes Research **30**(1): 201-216.

The release of ballast water from transoceanic vessels is a major vector for the introduction of nonindigenous species into the Laurentian Great Lakes. This study assessed the effectiveness of treating unballasted transoceanic vessels using three different biocides: glutaraldehyde plus a surfactant adjuvant (Disinfekt 1000®), sodium hypochlorite (NaOCl), and SeaKleen™ (menadione and menadione metabisulfite 2:8). Efficacy against several classes of aquatic organisms was evaluated using 24 h acute toxicity experiments and 11 day ballast tank simulation experiments. The results indicate substantial, compound-specific variations in organism sensitivity. For water-only exposures, NaOCl and SeaKleen™ were most effective: NaOCl had the lowest LC90 (90% lethal concentration value) for the oligochaete *Lumbriculus variegatus* (1.0 mg L⁻¹), while SeaKleen™ had the lowest LC90 for the amphipod *Hyaella azteca* (2.5 mg L⁻¹). Sediments profoundly affected efficacy, particularly for NaOCl: At a 1:4 sedimentwater ratio, the estimated LC90 for *L. variegatus* was > 2,000 mg L⁻¹. Sediment quality also impacted efficacy: Sediments with higher organic carbon content typically required greater biocide concentrations to achieve comparable

toxicity. Efficacy was further evaluated with 11 day bioassays using sediments from unballasted vessels. Results indicated that NaOCl and Disinfekt 1000® were more effective than predicted based on small scale sediment-water exposures. Overall, the data suggest that although NaOCl may be effective under water-only conditions, the higher concentrations required in the presence of sediments may cause corrosion problems for ballast tanks. Because of this, less reactive, non-oxidizing biocides such as SeaKleen™ and Disinfekt 1000® may be better candidates for treating sedimented tanks.

Scarrett, D. J. and R. E. Drinnan (1990). Canadian strategies for risk reductions in introductions and transfers of marine and anadromous species. Dispersal of living organisms into aquatic ecosystems. A. Rosenfield and R. Mann. Maryland, Maryland Sea Grant Publication: 377-385.

Simard, N. (2001). A survival and viability study of phytoplankton in ballast tanks of an ore carrier during a transoceanic voyage from Northern Europe to Eastern Canada. Proceedings of the Second International Conference on Marine Bioinvasions, New Orleans, Louisiana.

A real-time study of phytoplankton survival was conducted in September 1999 on-board the M/S Berge Nord (BergesenDY ASA) during an 8-day transoceanic voyage from the port of Rotterdam (The Netherlands) to Sept-Îles (Gulf of St. Lawrence, Canada). Results on temporal changes in phytoplankton communities (diversity, biomass, survival and viability) in transported ballast waters during the voyage are presented. The effects of offshore ballast water exchanges on phytoplankton communities in ballast tanks were also tested by comparing changes in diversity and abundance in exchanged and unexchanged tanks. Two different exchange methods were tested: the continuous 300 % flow through method, as recommended by the International Maritime Organization, and a combination of the sequential and flow through methods (ship's standard procedure). Results of laboratory experiments conducted on ballast water samples collected upon arrival and tested for the viability of nonindigenous phytoplankton species will also be discussed.

Simard, N. and M. Hardy (2004). The Laurentian Channel as an alternative ballast water exchange zone: risks, analysis and recommendations. C. S. A. S. R. D. 2004/120, Fisheries and Oceans Canada: iii + 74.

The present report aims to provide an assessment of the risks that the use of the Laurentian Channel as an Alternative Ballast Water Exchange Zone (ABWEZ) may pose to fisheries and to the marine ecosystem of the St. Lawrence and Atlantic waters. These risks were evaluated by analysing: 1) the importance of foreign origin vessel traffic that used or can potentially use the Laurentian Channel for exchange; 2) the biodiversity and species richness of organisms found in ballast water and sediments of incoming foreign vessels; 3) environmental conditions of the Gulf of St. Lawrence (GSL); and 4) the dispersion patterns of organisms inoculated in this area with ballast water discharges.

Although the shipping industry does not appear to use the Laurentian Channel extensively as an ABWEZ, analyzed data indicated that a high number of vessels (1948), transporting 12.2 Mt of ballast waters, could have transited in this area in 2000 and potentially use it to perform ballast water exchanges. The majority of ballast waters from all vessels originated from FAO Region B where environmental conditions can be similar to those found in the GSL, particularly during the summer for the North and Baltic Seas. However, the vessels which have declared to have used the Laurentian Channel as ABWEZ originated principally from FAO Region A; the duration of trips from this region is generally shorter than for other FAO regions. Several studies showed that a diverse assemblage of live organisms (including non-indigenous taxa, toxic/harmful taxa and potential risk taxa) from all around the world are present in the ballast tanks of foreign vessels entering the Gulf of St. Lawrence. Simulations of the discharge of organisms in the Laurentian Channel showed that inoculated plankton is retained within the Gulf (higher retention of phytoplankton occurred in spring and late summer) and transported towards coastal areas. The model identified a few areas that are particularly at risk, depending on the season: the Magdalen Islands, southwestern Newfoundland, Northern Cape Breton Island and southern Anticosti Island.

The present risk assessment identified the ABWEZ southeast of Anticosti Island as a potentially vulnerable area for ballast water-mediated introduction of non-indigenous species into the Estuary and Gulf of St. Lawrence and Atlantic provinces. This risk is considered to be generally lower in winter because of cold conditions that prevail throughout the Gulf during that time of the year. However, although the survival rate would be low, there are always a few highly opportunistic forms which can manage to adapt to cold conditions. On the other hand, many taxa may survive during the summer months but their long-term prognosis may be limited.

Given the high potential risk of aquatic invasive species (AIS) introduced through ballast water to the Gulf of St. Lawrence, River and Estuary, where local ecological conditions have proven conducive to the establishment of many types of AIS, the use of the Laurentian Channel as an ABWEZ should be minimized as much as possible. Under extraordinary circumstances, it is recommended that ballast water exchange be allowed if the ship is transiting the Laurentian Channel between December 1 and May 1 or if the ship is carrying freshwater ballast. A decision-support system would be needed to control ballast water exchange between the months of May and December.

Smith, T. E. and S. R. Kerr (1992). Introductions of species transported in ships' ballast waters : the risk to Canada's marine resources. C. T. R. o. F. a. A. S. 1867, Fisheries and Oceans Canada: v + 16.

On April 24, 1991, a workshop entitled "The Risk to Canada's Marine Resources of Species Carried in Ships' Ballast Waters" was held at the Bedford Institute of Oceanography (BIO) in Dartmouth, N.S. The workshop focused on the problem of harmful marine organisms transported in ships' ballast waters and subsequently

introduced into new ecosystems. The danger posed by such introductions has already been witnessed in the Laurentian Great Lakes, in Australia, and in other parts of the world. With the dramatic changes in global shipping technology and traffic patterns in recent decades, the risk of introductions from this vector has increased proportionately.

The problem also threatens the coastal waters of Atlantic Canada, because this is where major commercial fisheries and many aquaculture sites are located. The danger is both ecological and economic in nature, because shipping and aquaculture are fundamentally incompatible industries. The solution does not lie in simple extension of the measures initially introduced to protect the Laurentian Great Lakes, because the types of ships entering Canada's coastal regions, and the conditions mediating the ballast waters they carry, are significantly different from those in freshwater regimes.

The consensus reached by the expert group attending the workshop was that the transport of harmful marine organisms in ships' ballast waters is a problem of global dimensions that poses a significant threat to the marine ecosystems of Canada. The threat was perceived as immediate and pressing. The appropriate response embodies two phases. First, there is a need to define that scale and nature of the current imports of organisms to Canadian marine waters. Secondly, control measures must be identified and implemented, and they must be international in scope, given the nature of the shipping industry. The problem is complex, and the cost of action may initially seem appreciable; but there is potentially a far greater cost to do nothing at all. A unique feature of the problem is that control measures must be proactive, rather than simply reactive, because the situation is almost always irreversible once a species or disease agent has been introduced; and the incurred costs then become inescapable. A complete list of the recommendations forthcoming from this workshop is contained in Part II of this report.

Le 24 avril 1991, l'Institut océanographique de Bedford a été l'hôte d'un atelier portant sur la menace que posent les organismes transportés dans les eaux de ballast des navires pour nos ressources marines. On y a débattu du problème de l'introduction d'organismes nuisibles provenant des eaux de ballast dans de nouveaux écosystèmes, phénomène dont on a déjà pu observer les effets dans les Grandes Lacs, en Australie, et dans d'autres régions du monde. Les changements radicaux qu'ont connus la navigation et le transport maritimes à l'échelle mondiale au cours de dernières décennies ont encore accru cette menace.

Le problème touche aussi les eaux côtières du Canada atlantique, qui sont le site des principales pêches commerciales et exploitations aquicoles. Le danger est à la fois écologique et économique, le transport maritime et l'aquaculture étant des industries fondamentalement incompatibles. Or, la solution ne réside pas dans un simple élargissement de mesures initialement adoptées pour protéger les Grandes Lacs, car les navires qui pénètrent dans les eaux côtières du Canada et les conditions propres à leurs eaux de ballast sont de genres bien différents des ceux que l'on rencontre en eaux douces.

Les experts présents à l'atelier se sont entendus sur le fait que le transport d'organismes nuisibles dans les eaux de ballast des navires est un problème de dimensions

globales, qui menace gravement les écosystèmes marins du Canada. Ils ont perçu cette menace comme imminente et pressante. La solution à envisager comporte deux étapes. En premier lieu, il convient de définir l'ampleur et la nature des importations actuelles d'organismes dans les eaux maritimes canadiennes. En second lieu, il faut concevoir et mettre en œuvre des mesures restrictives, cela à l'échelle internationale étant donné la nature de l'industrie du transport maritime. Le problème est complexe et sa solution paraîtra peut-être coûteuse initialement, mais l'inaction pourrait s'avérer encore plus onéreuse. On devra s'y attaquer d'une façon proactive, et non se contenter de réagir. En effet, une fois qu'un organisme ou un agent pathogène s'est introduit dans le milieu, la situation est presque toujours irréversible et les coûts qui y sont associés sont alors inévitables. Une liste complète de recommandations formulées à l'atelier est présentée dans la deuxième partie du rapport.

Subba Rao, D. V., W. G. Sprules, et al. (1994). Exotic phytoplankton from ships' ballast waters : risk of potential spread to mariculture sites on Canada's east coast. C. D. R. o. F. a. A. S. 937, Fisheries and Oceans Canada: iv + 51.

Ballast water was analyzed from 86 foreign vessels that visited the Laurentian Great Lakes and upper St. Lawrence River during the period May to December 1990 and March to May 1991. A total of 102 taxa belonging to seven groups were recognized. These preserved samples contained 69 diatoms and 30 dinoflagellates, several new to Canadian Atlantic waters. Most of the algae were in good condition and contained chloroplasts. From live samples, cultures were also established. There were 21 potentially bloom-forming, red tide, and/or toxicogenic algal species in these ballast waters; and the potential risk of their spread to mariculture sites on Canada's east coast is discussed.

Les eaux de ballaste de 86 navires étrangers qui ont visité les Grands Lacs Laurentides et la Rivière supérieure du Saint-Laurent pendant les mois de mai à décembre 1990 et mars à mai 1991 ont été analysées. Au total, 102 taxa qui appartiennent à sept groupes ont été reconnus. Ces échantillons préservés contenaient 69 diatomées et 30 dinoflagelles, dont quelques uns qui sont nouveaux aux eaux Atlantique du Canada. La plupart des algues étaient en bon état et contenaient des chloroplastes. Les cultures ont été établies à partir des échantillons vivants. Il y avait 21 espèces dans ces eaux de ballaste, capables d'initier des blooms, de provoquer des marées rouges et/ou d'être toxigénique; et le risque potentiel de leur relargage aux emplacements de mariculture sur la côte Est du Canada est discuté.

Sutherland, T. F., C. D. Levings, et al. (2001). "Effect of a ballast water treatment system on survivorship of natural populations of marine plankton." Marine Ecology Progress Series **210**: 139-148.

A field experiment was carried out to determine the influence of a 2-stage ballast water treatment system on the survivorship of natural populations of plankton. This Integrated Cyclone-UV

Treatment System (ITS) was designed and constructed by Velox Technology Inc. and consisted of 2 treatment phases: (1) the cyclonic pre-treatment phase, (2) the ultraviolet-radiation phase (UV-C). The ITS was deployed on the Vancouver Port Authority dock, British Columbia on April 11, 1999. Seawater samples were collected from ports located along the treatment stages of the ITS and analyzed for plankton survivorship. The sampling stages were defined as Pre-Intake, Pre-Cyclone, Post-Cyclone, Post-Solids, and Post-UV-on and Post-UV-off. The survivorship of planktonic invertebrates was assessed immediately through direct observations, while phytoplankton survivorship was assessed through incubation grow-out experiments. With respect to zooplankton, live copepods were observed in the Pre-Intake and Pre-Cyclone samples, while dead or moribund copepods were observed in samples collected from both early and late stages of the ITS. Statistical comparisons were carried out on phytoplankton growth parameters such as starting concentration, lag phase, growth rate, and relative abundance generated during the incubation experiment. *Chaetoceros gracile* appeared to be the most sensitive organism to the ITS as it exhibited a 4 d lag phase prior to growth. The starting concentration, growth rate, and relative abundance of this species observed in the Post UV-on samples were significantly lower than those observed in the Pre-Intake samples (control). In addition, the auxospores formed by *Skeletonema costatum* during the incubation experiment were observed in all treatment samples with the exception of those exposed to the Post-UV-on stage of the ITS. A second phytoplankton incubation experiment was carried out using the original samples following a 3 mo storage period in dark, cold conditions (4°C). The results of this experiment revealed that the phytoplankton population in the UV-treated samples was not capable of growth, while those in the remaining treatments exhibited growth. Thus, future studies assessing the effect of the ITS on phytoplankton survivorship should incorporate increases in the intensity and exposure period of ultraviolet radiation followed by a dark, cold-storage period, thereby reducing the chance of photorepair.

Sutherland, T. F., C. D. Levings, et al. (2000). The effect of velox ballast water treatment system on the survivorship of natural populations of marine plankton. 10th International Aquatic Nuisance Species and Zebra Mussel Conference, Toronto, Canada.

Therriault, T. W., I. A. Grigorovich, et al. (2002). "Range Expansion of the Exotic Zooplankter *Cercopagis pengoi* (Ostroumov) into Western Lake Erie and Muskegon Lake." Journal of Great Lakes Research **28**(4): 698-701.

Previously reported from Lakes Ontario and Michigan, the nonindigenous zooplankter *Cercopagis pengoi* was found for the first time in western Lake Erie, the Detroit River, and Muskegon Lake, Michigan, during summer 2001. A native of the Ponto-Caspian region, *C. pengoi* is currently expanding its range in North America. Analysis of mitochondrial gene ND5 sequences confirmed that the Lake Erie haplotype is identical to that reported previously from Lakes Ontario and Michigan and the Finger Lakes, New York. These findings support the hypothesis that *C. pengoi*'s range expansion in the Great Lakes likely resulted from inter-lake transfer of ballast water, rather than from additional introductions from European locations. Pleasure-craft traffic operating between Lake Michigan and Muskegon Lake is likely responsible for this inland transfer of *Cercopagis*, a trend that likely will increase due to human activities.

Van Overdijk, C. D. A., S. A. Bailey, et al. (2004). Transfer of Nonindigenous Species to the Laurentian Great Lakes in Residual Ballast Water from No-Ballast-On-Board (NOBOB) Vessels. 13 International Conference on Aquatic Invasive Species, Ennis, County Clare, Ireland.

The majority (>90%) of vessels entering the Laurentian Great Lakes are laden with cargo and declare no-ballast-on-board (NOBOB) status. Current ballast exchange regulations do not apply to NOBOBs despite the presence of tonnes of residual salt-, brackish- or fresh-water, sediments, and the species contained in these ballast tanks. Residuals may eventually be released into the Great Lakes after ballast unloading events are conducted within the system, thus potentially transferring nonindigenous species (NIS). During 2001 and 2002, we sampled residual ballast water from 66 tanks on 30 ships at their first port-of-call in the Great Lakes, and recorded 7 rotifer and 37 microcrustacean species, predominantly cyclopoid and harpacticoid copepods, as well as 8 species of cladocerans. We detected three nonindigenous cyclopoid species (*Acanthocyclops venustus*, *Eucyclops serrulatus*, *Cyclops abyssorum*), and three nonindigenous cladoceran species (*Daphnia magna*, *D. cristata*, *D. atkinsoni*) currently not found in the Great Lakes. Total invertebrate abundance was not related to ballast water salinity, although total invertebrate species diversity was significantly higher in high salinity water.

Vanderploeg, H. A., T. F. Nalepa, et al. (2002). "Dispersal and emerging ecological impacts of Ponto-Caspian species in the Laurentian Great Lakes." Canadian Journal of Fisheries and Aquatic Sciences **59**(7): 1209.

We describe, explain, and "predict" dispersal and ecosystem impacts of six Ponto-Caspian endemic species that recently invaded the Great Lakes via ballast water. The zebra mussel, *Dreissena polymorpha*, and quagga mussel, *Dreissena bugensis*, continue to colonize hard and soft substrates of the Great Lakes and are changing ecosystem function through mechanisms of ecosystem engineering (increased water clarity and reef building), fouling native mussels, high particle filtration rate with selective rejection of colonial cyanobacteria in pseudofeces, alteration of nutrient ratios, and facilitation of the rapid spread of their Ponto-Caspian associates, the benthic amphipod *Echinogammarus ischnus* and the round goby, *Neogobius melanostomus*, which feeds on zebra mussels. The tubenose goby, *Proterorhinus marmoratus*, which does not feed on zebra mussels, has not spread rapidly. Impacts of these benthic invaders vary with site: in some shallow areas, habitat changes and the *Dreissena* to round goby to piscivore food chain have improved conditions for certain native game fishes and waterfowl; in offshore waters, *Dreissena* is competing for settling algae with the native amphipod *Diporeia* spp., which are disappearing to the detriment of the native deep-water fish community. The predatory cladoceran *Cercopagis pengoi* may compete with small fishes for zooplankton and increase food-chain length.

Vasarhelyi, C. and V. G. Thomas (2003). "Analysis of Canadian and American legislation for controlling exotic species in the Great Lakes." AQUATIC CONSERVATION: MARINE AND FRESHWATER ECOSYSTEMS 13(5): 417-427.

1. The legislation of the Great Lakes jurisdictions dealing with control of exotic species introduced through ballast water, canals, and recreational boating was analysed to determine whether the USA and Canada have the capacity to manage nuisance exotic species effectively. Despite the deleterious ecological effects attributed to exotic aquatic species, there is a lack of complementary legislation between Canada and the USA to remedy this problem. Current legislation is fragmented at the bilateral, national, and the state/provincial level.
2. American legislative initiatives are far ahead of Canada's, especially for regulating ballast water in oceanic shipping. Canada lacks strong federal and provincial legislation to regulate ballast water in shipping and to prevent the secondary spread of exotic aquatic species through watersheds.
3. Legislation to regulate ballast water is developing quickly among the US federal government and the Great Lakes states. However, legislation affecting the spread of exotic nuisance species via canals and recreational boaters is needed to complement ballast water laws and to give agencies a broader mandate for management.

4. Amendment of the Boundary Waters Treaty Act, the Fisheries Act, and the Canada Water Act could give the Canadian federal government authority to regulate ballast water in vessels entering the St Lawrence and to begin the rehabilitation of aquatic habitats impaired by nuisance exotic species.
5. Preventing further species introduction and spread through the Great Lakes basin requires restricting certain shipping and boating practices. This can be achieved only by the enactment of complementary laws among all the American and Canadian jurisdictions.

Vasarhelyi, C., V. G. Thomas, et al. (2004). Analysis of legislation pertaining to the control and management of exotic aquatic species in Canadian and Adjacent United States waters. C. T. R. o. F. a. A. S. 2561, Fisheries and Oceans Canada: vii + 39.

Canadian and American legislation was examined at all levels to determine if there were provisions for the control of exotic species (EAS) introduced into their common waters of the Atlantic, Pacific and Great Lakes region. No Canadian laws exist to allow rapid control management of EAS, but several federal laws could be amended to authorize such action. By contrast, U.S. federal and state laws allow control EAS in ballast waters, but no provisions yet exist to permit control of EAS introduced from other sources. Greater international shipping trade with all regions of North America, growth of aquaculture and live fish sales, and global warming of freshwaters mean that further introductions of EAS are to be expected. Thus a bilateral and harmonized approach to EAS control is required.

Les legislation canadiennes et americaines ont ete examinees a tous les niveaux pour determiner s'il y avait des prestations pour le controle des especes non indigenes (NIS) introduites dans leurs eaux communes de l'Atlantique, du Pacifique, et de la region des Grands Lacs. Il n'existe aucune loi canadienne qui permet une gestion a controle rapide des NIS, mais plusieurs lois americaines federales et les lois des Etats permettent le controle des NIS dans l'eau des ballasts, mais il n'existe encore aucune prestation pour permettre le controles des NIS introduits par d'autres sources. Plus de commerce de transport international avec toutes les regions de l'Amerique du Nord, plus d'augmentation des ventes de poissons vivants et d'aquaculture, et plus d'effets de serre dans les eaux douces indiquent que d'autres introductions des NIS sont precisibles. Donc, une approche reglementee bilaterale et harmonisee pour le controle des NIS est necessaire.

Wappel, T. (2003). Aquatic Invasive Species: Unwanted Guests. S. C. o. F. a. Oceans, Communication Canada: ix + 38.

In September 2002, various ministerial councils adopted the blueprint for a national plan to address the threat of invasive alien species. The federal plan will guide the development of a national policy and management framework for action. The plan emerges eight years after the release of the Canadian Biodiversity Strategy. Ballast water

regulations, expected early next year, have been 14 years in the making (since the first guidelines were issued in 1989). They should be in place 10 years after the American regulations, 6 years after amendments to the Canadian Shipping Act authorizing their making, and 4 years after the new 2000 guidelines on ballast water management. They are likely to appear at the same time as an international convention on ballast water management is to be approved by member states of the International Maritime Organization (IMO).

The Committee is dismayed by the extremely slow progress that Canada has made since 1992 when world leaders recognized invasive species as one of the most serious threats to health and to ecological, social and economic well-being of the planet. It is now well accepted that (1) invasive species can have a devastating effect on species diversity, that (2) following habitat destruction, invasive species are the second-leading threat to endangered species, that (3) aquatic invasive species cause significant, negative regional, national, and international effects, that (4) the impact of several invaders is greater than the sum of their effects if they had acted alone, that (5) aquatic invasive species damage infrastructure, disrupt commerce, outcompete native species, reduce biodiversity, and threaten human health, and that (6) aquatic invasive species continue to be introduced into Canadian waters, the apparent inaction at all levels of the Canadian government is unacceptable. This is highlighted by the fact that frustration over the slow pace of action prompted both the Commissioner of the Environment and Sustainable Development and the co-chairs of the International Joint Commission to request the opportunity to appear before the Committee.

Waters, R., N. Haigh, et al. (2001). Synoptic investigation for algae in ballast water and sediments of ships using selected British Columbia ports. C. D. R. o. F. a. A. S. 1083, Fisheries and Oceans Canada: iii + 19.

Data are presented on the algae identified from ballast water and sediment of eight of fifty-four ships arriving at five British Columbia ports from western North Pacific ports between November 25, 1999 and March 29, 2000. Information on the duration of time the water/sediment was in the ballast tanks, ballast water capacity, quantity on board, and associated characteristics were collected along with temperature and salinity data. Ten of the thirteen incubated ballast water samples grew phytoplankton, most of which were diatoms; the sediment samples were predominated by benthic phytoplankton species. There were very few dinoflagellates noted.

Il s'agit de données concernant les algues et les sédiments trouvés dans l'eau de ballast de huit des cinquante-quatre navires en provenance de divers ports du Pacifique Nord-Ouest ayant séjourné dans cinq ports de la Colombie-Britannique au cours de la période comprise entre le 25 novembre 1999 et le 29 mars 2000. Données recueillies: information sur la durée de temps passée par cette eau et les sédiments dans les citernes de ballast, capacité de citernes, quantité à bord et autres caractéristiques assimilées, ainsi que données sur la température et la salinité. Dix des treize échantillons d'eau de ballast prélevés contenaient du phytoplancton, principalement des diatomées, alors que les échantillons de

sédiments contenaient principalement du phytoplankton benthique. On a observé très peu de dinoflagellés.

Whittaker, R. (2003). The Natural Ballast Water Exchange Method. 12th International Conference on Aquatic Invasive Species Windsor, Ontario, Canada.

The United States, Canada, Australia, and New Zealand have led the way by adopting strict guidelines for ballast water exchange, and the rest of the international shipping community is rallying to combat the threat of biological pollution. In fact, the International Maritime Organization (IMO) passed a resolution in November 1997 that identifies two methods for ballast water exchange: the sequential and flow-through methods. Both methods protect the aquatic environment but require a considerable amount of fuel and staff time. When the sequential method is used, water is pumped out of the ballast tank until suction is lost and clean ballast water is pumped in. The flow-through method involves pumping ballast water into the tank until the dirty water overflows through the openings on top of the ballast water tank. Both methods rely on the use of an electric or steamdriven ballast pump and a diesel generator or a boiler. Careful monitoring of deballasting and ballasting operations is essential, and both methods create extra work for the duty engineer. The Natural Ballast Water Exchange method takes into consideration the well-being of seafarers and the environment. The method relies on natural forces of pressure and gravity to achieve ballast water exchange. Unlike the sequential and flow-through methods, the new method does not require extra personnel to operate and monitor auxiliary machinery. Instead, clean water enters the ballast tank main line through a water inlet at the ship's bow. The pressure from the water flowing into the tank forces the biologically tainted water out through an opening located at the forward bottom end of the ballast water tank. To complete the operation, a limited amount of power is required to pump in enough clean ballast water to meet the initial water level. When the ship is in forward motion, the pressure of the water acting on the hull is greater than the pressure of the water in the ballast tank. Simply put, this process uses the pressure differential to force the ballast water from the ballast tank, thereby replacing the water automatically. Overall, the new method saves on fuel costs and offers certain safety advantages.

Wiley, C. J. (1995). Ballast water control - the Canadian approach. Proceedings of the Fifth International Zebra Mussel and Other Aquatic Nuisance Organisms Conference, Toronto, Ontario.

Ballast water discharges from ships have been identified as a major vector in the transfer of nuisance aquatic species from one area of the world to another. Ballast water is carried on ships to maintain stability and comfort when the ship has little or no cargo on board. Water was not always used - most ships in the days of sail carried solid ballast in the form of rock or sand, To discharge this was a laborious, often dangerous job and there are many records of ships taking days or weeks to discharge ballast in preparation of loading a cargo. With the advent of steam, and the technology to pump water into tanks in minutes or hours, the economic benefits of using water ballast were quickly grasped by shipowners and shipbuilders. The fact that ballast tanks could be used for the carriage of fresh water or fuel oil was an additional bonus. Water ballast was the accepted form of ballast by the late 1800's.

Until fairly recently discharge of ballast water was considered environmentally benign. Canadian and International regulations have permitted the discharge of water ballast from ships as long as the water did not contain either oil or certain chemicals.

In Canada, the primary study that identified the perhaps not so benign side of ballast water was undertaken by Bio-Environmental Services Ltd on behalf of Environment Canada and was published in 1981. This study found viable aquatic organisms in ballast water of ships sampled and warned of the possibility of the introduction of unwanted species into the Great Lakes.

However it was concern over the fragile ecology of Grand-Entree Lagoon in the Magdelan islands that first brought restrictions on the discharge of ballast water to Canada. The Federal Department of Fisheries was concerned that ships discharging ballast prior to loading salt would introduce exotic species into the area. As a result, in 1982 a Notice to Mariners was published prohibiting the discharge of ballast water into Grande-Entree Lagoon or within 10 miles of the Magdelan Islands unless the ballast was taken on in a well defined area off Canada's east coast at a distance of 5 miles or greater from the shoreline.

It was not until 1988 that the Canadian and U.S. Coast Guards were put on notice by the Great Lakes Fishery Commission that action was needed to reduce the threat to the Great Lakes from non native fish and other nuisance species.

On May 1, 1989, the Canadian Coast Guard, after consultation with the U.S. Coast Guard, the Great Lakes Fishery Commission, Fisheries and Oceans Canada, and Environment Canada as well as representatives from the shipping industry, promulgated the Voluntary Guidelines for the Control of Ballast Water Discharges from Ships Proceeding to the St. Lawrence River and Great Lakes.

Under these guidelines all vessels bound for St. Lawrence river and Great Lakes ports west of 64 degrees west longitude were to exchange their ballast far from any coastline. By doing so it is theorized that any non indigenous freshwater organisms picked up in the ballast would be flushed out and that any remaining freshwater organisms will be placed in a stressed condition by the influx of saltwater. Provision was made in the guidelines for ships that were unable to exchange ballast far out at sea to exchange ballast within the Laurentian Channel in an area southeast of 64 degrees west longitude in water depths greater than 300 metres.

Wiley, C. J. (1997). Pathogens and Ballast Water. 7th International Zebra Mussel and Other Aquatic Nuisance Species Conference, New Orleans, Louisiana.

Wiley, C. J. (1998). Treatment Options for Vessels Not in Ballast. 8th International Zebra Mussel and Other Aquatic Nuisance Species Conference, Sacramento, California.

Wiley, C. J. (1999). Canadian Ballast Water Initiatives. 9th International Zebra Mussel and Aquatic Nuisance Species Conference, Duluth, Minnesota.

Wiley, C. J. (2000). Effects of Aquatic Nuisance Species on Great Lakes Ships. 10th International Aquatic Nuisance Species and Zebra Mussel Conference, Toronto, Canada.

Wiley, C. J. (2000). Ships and Barges as a Vector for the Introduction of Aquatic Nuisance Species. 10 International Aquatic Nuisance Species and Zebra Mussel Conference, Toronto, Ontario.

Wiley, C. J. and R. Claudi (2002). Alien species transported in ships' ballast water: from known impact to regulations. Alien invaders: in Canada's waters, wetlands, and forests. R. Claudi, P. Nantel and E. Muckle-Jeffs. Ottawa, Natural Resources Canada, Canadian Forest Service, Science Branch 233-241.

As the primary means of world commerce, ships have long provided a link between continents. Ballast water from ships is probably the major and most visible vector of introduction of alien species, in terms of the number and diversity of organisms transported and the number of resulting invasions. However, there is justified concern that fouling of ships' hulls and the cargoes they carry are also contributing to successful invasions. The International Maritime Organisation essentially adopted the Canadian model in its 1997 resolution containing guidelines for the control and management of ships' ballast water to minimize the transfer of harmful aquatic organisms and pathogens. Ballast exchange, the present standard for protection, is based on the concept that exchanging the water in ballast tanks while in deep ocean waters will flush organisms into areas where they cannot survive. The process is not perfect, and considerable research on both shipboard and shore-side treatment options is in progress to meet the higher standards that will be required to protect Canada's and the world's environments.

Wiley, C. J. and W. Hall (1996). Aquatic Nuisance Species in Relation to Ships and Shipping. 6th International Zebra Mussel and Other Aquatic Nuisance Species Conference, Dearborn, Michigan.

Wonham, M. J., S. A. Bailey, et al. (2005). "Modelling the invasion risk of diapausing organisms transported in ballast sediments." Canadian Journal of Fisheries and Aquatic Sciences **62**(10): 2386-2398.

Biological invasions via ship ballast are a major driver of biodiversity change in aquatic systems. In the Laurentian Great Lakes basin, unique shipping operations pose a particular invasion risk. The majority (>90%) of incoming vessels are not fully loaded with ballast water but carry ballast sediments and residual water. Ballast sediments contain viable diapause organisms that could hatch and be released during routine ballast operations. To assess invasion risk and control of this pathway, we constructed and parameterized a dynamic hatching model for three representative groups of freshwater organisms that undergo diapause: rotifers, cladocerans, and copepods. Numerical model simulations show that ballast sediment is a plausible invasion pathway for all three groups. The model also illustrates that postuptake ballast treatment to remove or kill potential invaders should be applied as late as possible prior to deballasting to minimize the number of live organisms released. Simulations show that the ability of taxa to reproduce parthenogenetically inside a ballast tank greatly influences quantitative predictions of both risk and control.

Les invasions biologiques par l'intermédiaire des eaux de ballastage des navires sont des causes majeures de changements de biodiversité dans les systèmes aquatiques. Dans le bassin hydrographique des Grands Lacs laurentiens, des opérations de transport maritime particulières posent un risque spécial d'invasion. La majorité (>90 %) des navires qui y pénètrent ne portent pas une pleine charge d'eau de ballastage, mais contiennent des sédiments et de l'eau résiduelle dans leurs ballasts. Les sédiments dans les ballasts contiennent des organismes viables en diapause qui peuvent éclore et être libérés durant les opérations de ballastage de routine. Afin d'évaluer le risque d'invasion et le contrôle de cette voie d'introduction, nous avons construit un modèle dynamique de l'éclosion pour trois groupes d'organismes d'eau douce qui subissent la diapause, les rotifères, les cladocères et les copépodes, et nous en avons précisé les paramètres. Des simulations du modèle numérique montrent que les sédiments des ballasts sont une voie plausible d'invasion pour l'ensemble des trois groupes. Le modèle démontre aussi que le traitement des eaux de ballastage après le remplissage afin d'éliminer ou de tuer les organismes envahisseurs possibles devrait se faire le plus tard possible avant la vidange des ballasts, afin de réduire au minimum le nombre d'organismes vivants libérés. Les simulations montrent que la capacité des taxons de se reproduire par parthénogenèse dans les ballasts influence fortement les prédictions numériques à la fois du risque et du contrôle.

Wonham, M. J. and J. T. Carlton (2005). "Trends in marine biological invasions at local and regional scales: the Northeast Pacific Ocean as a model system." Biological Invasions 7(3): 369-392.

Introduced species are an increasing agent of global change. Biogeographic comparisons of introduced biotas at regional and global scales can clarify trends in source regions, invasion pathways, sink regions, and survey effort. We identify the Northeast Pacific Ocean (NEP; northern California to British Columbia) as a model system for analyzing patterns of marine invasion success in cool temperate waters. We review literature and field surveys, documenting 123 introduced invertebrate, algal, fish, and vascular plant species in the NEP. Major invasion pathways were shipping (hull fouling, solid and water ballast; 1500s-present) and shellfish (particularly oysters) and fish imports (commonest from the 1870s to mid-1900s). The cumulative number of successful invasions over time increased at linear, quadratic, and exponential rates for different taxa, pathways, and regions within the NEP. Regional analysis of four major NEP estuaries showed that Puget Sound and the contiguous Straits had the most introduced species, followed by Humboldt Bay, Coos Bay and Willapa Bay. Data on cumulative shipping volumes predicted smaller-scale, but not larger-scale spatial patterns in the number of shipping-mediated invasions. We identify the major challenges in scaling up from regional to global invasion analysis in cool temperate regions. Retrospective analyses for distinct biogeographic regions such as the NEP provide insight into vector dynamics and regional invasibility, and are a necessary foundation for monitoring and managing global change caused by biotic invasions.

Wonham, M. J., M. A. Lewis, et al. (Submitted). "Minimizing invasion risk by reducing propagule pressure: application to ballast-water exchange." Ecological Applications.

Yan, N. D., A. Blukacz, et al. (2000). Transitions in Invader Demographics and Prey Community Composition Following the Invasion of Harp Lake, Ontario. 10 International Aquatic Nuisance Species and Zebra Mussel Conference, Toronto, Ontario.

Zaranko, D. T., D. G. Farara, et al. (1997). "Another exotic mollusc in the Laurentian Great Lakes: the New Zealand native *Potamopyrgus antipodarum* (Gray 1843) (Gastropoda, Hydrobiidae)." Canadian Journal of Fisheries and Aquatic Sciences 54(4): 809-814.

In 1991, the hydrobiid snail *Potamopyrgus antipodarum* (Gray 1843), native to New Zealand, was found 1 km offshore Wilson, New York, in Lake Ontario. This is the first known occurrence of the snail in eastern North America. Densities of *P. antipodarum* have increased since its discovery, and the snail is expected to spread quickly throughout the Great Lakes area. The biofouling potential of *P. antipodarum* is probably low; however, its most serious threat may be resource competition with native molluscs. This species was probably introduced in ballast water from transoceanic vessels, thus increasing the list of nonindigenous aquatic organisms introduced into the Great Lakes since the 1800s to 140 different organisms. The risk of other species invasions into the Great Lakes is still possible, despite the now mandatory ballast water regulations.

En 1991, l'escargot *Potamopyrgus antipodarum* (Gray 1843) appartenant aux hydrobiidés et qui est originaire de la Nouvelle-Zélande a été retrouvé dans le lac Ontario, à 1 km au large de Wilson, New York. Il s'agissait de la première observation de cet escargot dans l'est de l'Amérique du Nord. La densité de *P. antipodarum* a augmenté depuis cette première observation et on s'attend que cet organisme se répande rapidement dans toute la région des Grands Lacs. Le potentiel de *P. antipodarum* comme agent d'encrassement biologique est probablement faible; cependant, la menace la plus sérieuse qu'il laisse planer est la compétition avec les mollusques indigènes pour s'approprier des ressources disponibles. Cette espèce a probablement été introduite dans les eaux de ballast de navires transocéaniques et elle devient le 140e organisme à être inscrit sur la liste des organismes aquatiques non indigènes introduits dans les Grands Lacs depuis les années 1800. Le risque d'invasion des Grands Lacs par d'autres espèces continue d'exister en dépit des règlements maintenant obligatoires régissant les eaux de ballast.