NOBOB-B: Identifying, Verifying, and Establishing Options for Best Management Practices for NOBOB Vessels

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Project was completed in CY2007

Overview

Ballast water is widely recognized as the primary vector by which aquatic species are being transported and introduced to foreign coastal ecosystems on a global basis. Ballast water exchange (BWE) was established as an interim measure to reduce the risk of coastal species introductions. Despite the implementation of regulations requiring ballast water exchange in 1993, aquatic nonindigenous species were discovered at about the same rate in the Great Lakes during the 1990s compared to the preceding three decades (Ricciardi, 2006). Since that time many of the newly discovered nonindigenous species attributed to the ballast vector are invertebrates that produce resting stages. Resting stages are relatively resistant to adverse environmental conditions and thus represent an effective means of long-term survival for organisms that produce them, also making them primary candidates for ship-assisted dispersal.

A majority of foreign vessels enter the Great Lakes as NOBOBs – ships with no (pumpable) ballast on board and thus not subject to BWE. The Great Lakes NOBOB Assessment Project (NOBOB-A), funded by the Great Lakes Protection Fund and various federal agencies, concluded that ballast tank residuals in NOBOB vessels contain live biota and sometimes millions of resting eggs, and are a potential source for introduction of new phytoplankton, invertebrates, and pathogens to the Great Lakes. In addition, vessels that enter as “ballasted” may be partially loaded with cargo and may therefore have some ballast tanks that are empty, but that will be used for ballasting while in the Great Lakes, creating the same situation as found in NOBOB vessels. Thus, empty ballast tanks, primarily associated with NOBOB vessels, are an important potential ship-related vector for new invading species to the Great Lakes, due to their predominance within the foreign trade, the live biota they contain, and the abundance of viable resting stages contained in residual sediments (Bailey et al. 2003; Johengen et al. 2005)

Until 2006, NOBOBs were simply not addressed by ballast management or treatment regulations. The quantity of total residuals (water + sediment) found in empty ballast tanks during the NOBOB-A study ranged from negligible to 200 metric tones (MT) per ship with an average of 54 MT, and sediments comprised, on average, ~30% of the total residual. All residual samples contained varying numbers and species of live larval and adult invertebrate organisms, viable resting eggs and phytoplankton cysts, and microbial communities containing one or more pathogens, although the latter were not found in substantial concentrations. Based on these data, a ship carrying 10 MT of residual sediment could contain a half-million to nearly a billion invertebrate resting eggs spread throughout its ballast tanks. Viable phytoplankton cells were found in all residual samples and active growth occurred when residuals were inoculated into various types of freshwater culture media including Lake Michigan and Grand River water. Microbiological analyses found that approximately 50% of the tanks sampled tested positive for one or more forms of pathogenic microorganisms or their indicator species. The NOBOB-A outcomes also established the importance and potential benefits for the Great Lakes of an effective management strategy for minimizing the accumulation of sediment and viable freshwater organisms in empty ballast tanks.

A set of practices and guidelines was developed and endorsed by the International Maritime Organization (IMO) with the expectation that by following the specified practices, ships will minimize sediment accumulations in ballast tanks, expose coastal and freshwater organisms to saltwater, and minimize the risk of new species introductions to coastal ecosystems. The Shipping Federation of Canada and the (U.S.) Lake Carrier's Association adopted a "Code of Best Practices for Ballast Water Management" ("the Code") in 2000 that was substantially based on the IMO guidelines and input from various other entities. In September 2002, the St. Lawrence Development Corporation and the St. Lawrence Seaway Management Corporation of Canada issued Seaway Notice No. 6-2002, which required mandatory compliance with the "Code of Best Practices for Ballast Water Management" by foreign ships to obtain clearance to transit the Seaway. The Code promotes the maintenance of relatively clean ballast tanks through a program of regular inspection and cleaning, combined with a precautionary approach to ballasting with the objective of limiting or avoiding the uptake of ballast under specified conditions.

Data from NOBOB-A suggested that minimizing sediment accumulation and maximizing exposure of residual material to seawater may be two of the most important steps that can be taken to reduce the risk of species introductions via NOBOB operations in the absence of effective technology-based treatment systems. Therefore, developing a ballast tank management approach, such as presented by the Code, which can decrease residuals and/or incapacitate the biological components is of great importance. However, there has been no assessment of how regularly the practices identified in the Code can be implemented under actual operating conditions or the effectiveness of any of the practices to reduce the risk of species introductions from residual ballast material carried in NOBOB tanks.

This project (NOBOB-B) proposed to repeatedly use one or two selected operating vessels to examine the effectiveness of the following ballast management practices: (1) avoidance, when possible, of loading ballast from shallow, turbid, or algal bloom locations, (2) flushing muddy water out of tanks as soon as possible, and (3) regular use of saltwater rinses during transits.

Summary

The “Code of Best Practices for Ballast Water Management” was established with the expectation that by following the specified practices, ships will minimize sediment accumulations in ballast tanks, subject coastal and freshwater organisms to saltwater exposure, and minimize the risk of new species introductions to coastal ecosystems such as the Great Lakes. However, there have been no assessments of how regularly the actions identified in the Code of Best Management Practices can be implemented under actual operating conditions and no verification of their effectiveness at reducing the risk of additional invasions.

NOBOB-B was a demonstration project designed to examine the effectiveness of selected ballast tank management practices aimed at reducing the abundance of residual sediment and propagules of nonindigenous organisms. The research was focused on (1) avoidance, when possible, of loading ballast water with high turbidity or algal blooms or flushing muddy water out of tanks as soon as possible, and (2) regular use of saltwater flushing during oceanic transits.

To complete this project we conducted detailed biological assessments of microbial, phytoplankton, and invertebrate communities present within both sediment and water ballast residuals for two participating ships during each entry into the lakes and compared results against ballasting history and any BMPs applied. Lastly, we examined the extent to which salinity toxicity, whether through open-ocean ballast water exchange (BWE) or saltwater flushing, can prevent the transfer of low-salinity species to the Great Lakes.

Constraints on Experimental Design

Despite substantial effort by the project team, both ships we engaged for this study unexpectedly altered their trading patterns and voyages after our experimental plans were set, and we had to substantially change our experimental design. Instead of sampling paired “control” and “treatment” tanks, we collected a chronological series of samples and added the use of emergence traps for a direct test of the enhanced saltwater flushing BMP. This modification also provided the opportunity to conduct experiments on the effectiveness of BWE when the ballast originated from a freshwater port.

Task 1: Assess the effectiveness of specific ballast management practices on sediment accumulation and characteristics within ballast tanks.

We moored water quality instruments in ballast tanks (Figure 1) to help define the timing and quantity of ballasting as well as the overall quality of source water. Instrument data provided direct records of ballast operations and confirmation of when saltwater flushes or BWE were applied to the tanks (Figure 2). In addition, instrument data provided insight to patterns of sediment accumulation observed during direct tank sampling. The structural complexity within tanks and the nature of the ballast intake and stripping systems created a general pattern of thicker sediment accumulation in the forward and outer bilge areas of the tanks. Qualitative estimates based on visual observations in a limited number of NOBOB tanks suggest that significant resuspension and removal of sediment occurs during discharge, affecting between

30% and 80% of the bottom area, depending on the previous ballasting and sediment management history of the tank.

Due to the changes in experimental design and relatively infrequent application by the ships of specific BMPs, we could not quantitatively assess the potential effectiveness of BMPs to reduce sediment accumulation. Instrument data confirmed that saltwater flushing, or ‘swish and spit’, can resuspend a portion of the ballast tank sediment and increase the likelihood of eliminating this sediment on subsequent discharge. We also observed ballasting events at highly turbid (river) ports that resulted in significant addition of sediment and that the sediment very quickly settled and became more difficult to eliminate.

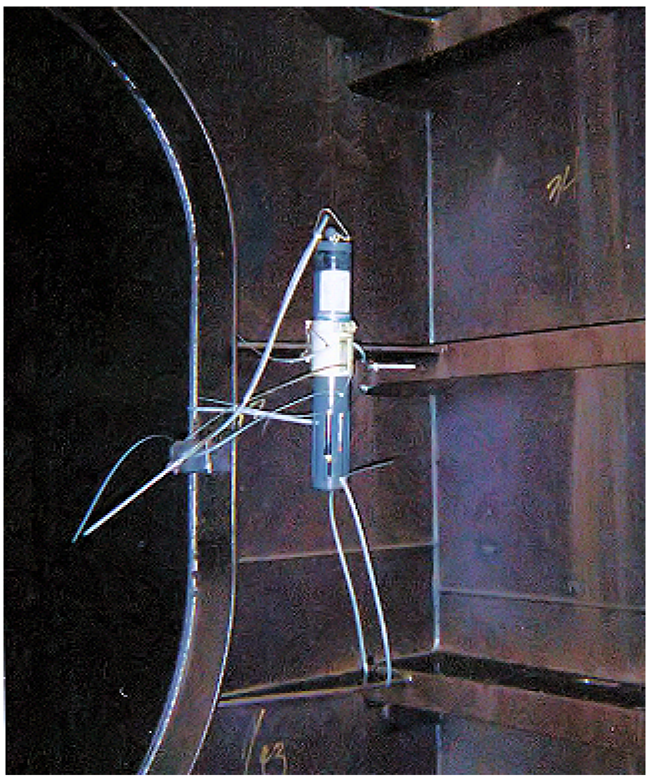

Figure 1: *A multiparameter instrument sonde moored about 1.5 m above the bottom of a ballast tank, to measure temperature, salinity, depth, turbidity, and chlorophyll during ballasted periods.*

We evaluated the Code for practicability and showed that consistent implementation of the Code is problematic, especially for the environmental precautionary actions (Item 6), because application is very much dependent on local conditions at the dock. Acceptance and implementation of the Code by the shipping industry must be understood as a commitment to make a “good faith” effort, which if regularly and consistently conducted, may somewhat lower overall risk of introductions, but will not eliminate it. The practical realities and limitations associated with vessel operations makes the existing BMPs inadequate as the lone strategy for reducing the risk of nonindigenous species introductions from NOBOB vessels.

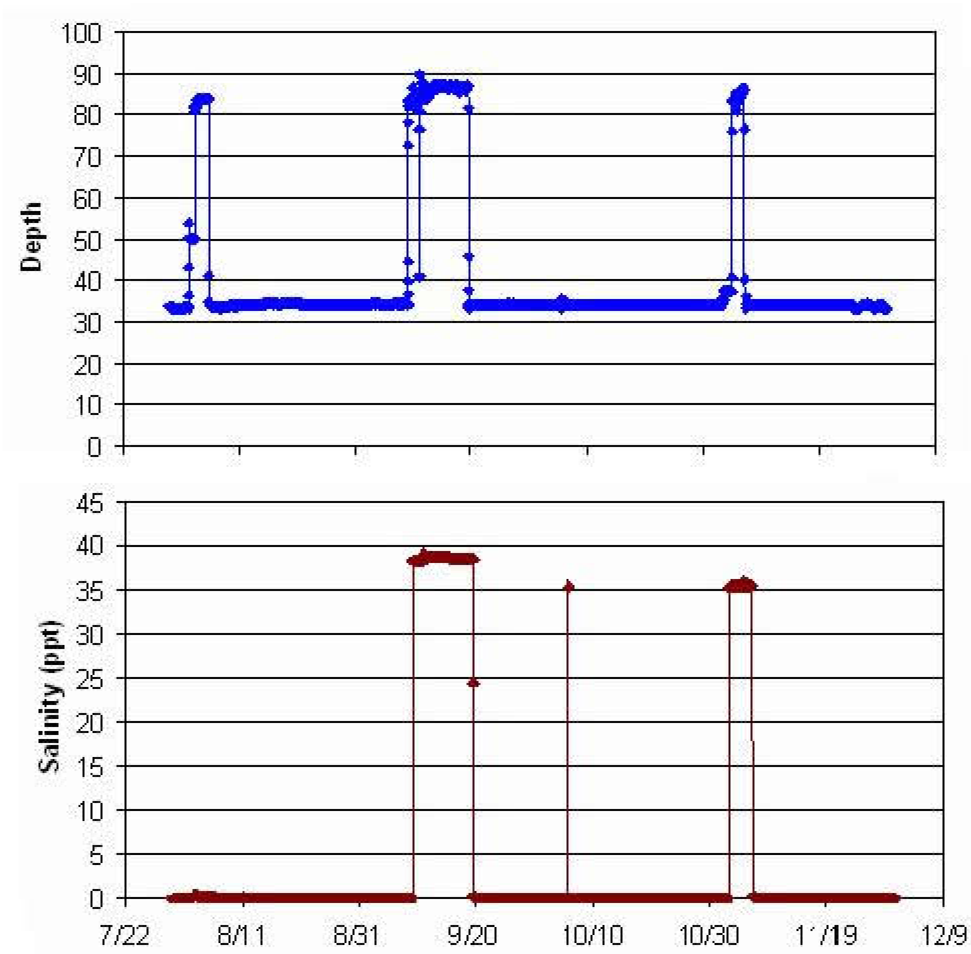

***Figure 2**: Depth and salinity time series from a multiparameter instrument sonde moored in a ballast tank from late July to early December. Depth shows the addition of freshwater ballast in early August that is not apparent at this scale on the salinity record. Alternately, salinity shows a ballast tank flushing event in early October that was barely apparent in the depth record because of the small amount of water used. The combination of time-dated depth and salinity measurements provides a comprehensive record for comparison with ship ballast logs.*

Task 2: Assess the effectiveness of specific ballast management practices to reduce the density and viability of organisms and resting stages.

Microbiology

In every tank sampled over the course of this study (total of 20 tanks), at least one of the potential pathogens or indicator species for which we assayed was present, but we did not assay for actual concentration and thus cannot quantify potential risk to human health. We reiterate, therefore, a point expressed in the NOBOB-A study that "it seems prudent to regard all NOBOB ships entering the Great Lakes as potential carriers of pathogens".

Phytoplankton

Our data showed that switching from freshwater to saltwater conditions, as produced by BWE or saltwater flushing, reduced phytoplankton community diversity and restricted phytoplankton growth in lake water media. The effects of the saltwater exposure/exchange were greater on the water samples than sediment samples; flushing muddy sediment out of tanks may be important steps to minimize the risk of phytoplankton via NOBOB operation. Variations in phytoplankton composition and growth occurred in response to BWE and saltwater flushing, however it was not possible to directly relate differences in populations or viability to any given management activity given the experimental limitations resulting from the altered ship schedules.

Invertebrates

Ballasting events changed (increased or decreased) the number of organisms found in association with both water and sediment residuals, whether ballast was with fresh, brackish, or saltwater. However, there was no consistency to the changes, either in the types of organisms present, or the densities at which they were present. Due to the multiple ballast events between each sampling opportunity, we are unable to associate particular changes with specific ballast events or practices.

High densities of animals were detected in residuals from both fresh- and salt-water sources. Therefore, it is recommended that all ships complete a BWE or saltwater flush in mid-ocean during all voyages to the Great Lakes to reduce or eliminate the viability of fresh- or low-salinity organisms, as the potential risk for introducing saltwater animals to the Great Lakes is much lower than those from freshwater sources.

Ballast Water Exchange Experiments

Freshwater animals were completely absent or in only low concentrations in exchanged ballast tanks on ships originally ballasted with Great Lakes water. Overall, sequential (empty-refill) exchange resulted in a decrease in total freshwater zooplankton abundance by › 99% for the ships on which we conducted BWE experiments. The effectiveness of BWE for freshwater organisms in this study was less variable than for previously reported results for marine organisms and may result from the pronounced osmotic shock and prolonged exposure to saltwater experienced by freshwater animals in ballast tanks after BWE.

Vessels transiting between marine ports must rely on purging and dilution of ballast water to eliminate coastal organisms. Vessels transiting between freshwater ports can expect decreases in zooplankton density due both to purging of organisms and to salinity effects. However, it should be noted that this subset of experiments was performed in upper wing tanks and the efficiency of water exchange in these tanks may be greater owing to their structural design and location.

Benthic Invertebrates

To evaluate the effect of BWE on benthic invertebrates, 30 *Echinogammarus ischnus* amphipods and 30 *Brachiura sowerbyi* oligochaetes collected from the Great Lakes were placed with sediments inside an incubation chamber placed within control and treatment ballast tanks (Figure 3). Most oligochaetes in the control tanks survived their intercontinental voyages, with mortalities of 16.6%, 0%, and 20%, on three voyages respectively. However, nearly all individuals perished i n the exchanged ballast tanks, with mortalities of 100%, 100%, and 96.6% (one live individual out of 30).

The survival of one of the oligochaetes in the incubation chambers after exchange highlights one of the potential problems with BWE. The lone live individual was found at the very bottom of the sediment layer, suggesting that saline water may not have been able to penetrate through the sediment. In thicker accumulations of sediment, individuals that burrow well below the sediment:water interface may survive saltwater exposure and thus represent an invasion risk, especially if these animals are later disturbed during subsequent ballasting activities.

Echinogammarus ischnus mortality in the control tanks was higher than that for the oligochaetes at 40%, 60%, and 53.3% on three voyages respectively. In the treatment tanks that had undergone exchange, 100% of E. ischnus individuals were deceased at the end of each experiment. These results suggest that saltwater exposure during BWE is likely to be lethal for many species found above the sediment:water interface.

***Figure 3**: Live animals being added to one of three incubation chambers moored together in a ballast tank prior to an exchange experiment.*

Invertebrate Resting Eggs

The effect of saltwater exposure on diapausing invertebrate eggs was evaluated using incubation chambers placed into both control and treatment (exchanged) tanks. The number of animals recovered from incubation chambers in control tanks (mean = 0.5 – 3.25 ind/trap) was significantly higher than that from chambers in the exchanged tanks (mean = 0 - 0.25 ind/trap). Three possible explanations for the lower abundance in exchanged tanks are: 1) saltwater exposure may have killed animals that hatched during the pre-exchange period; 2) the presence of saltwater in the chambers could have prevented further recruitment from diapausing eggs in the sediment since environmental conditions would not cue hatching; or 3) environmental conditions inside the incubation chambers deteriorated to conditions unsuitable for hatching. We conducted experiments in which instrument sondes were embedded inside separate incubation chambers of the same design used here. Results showed that exchange between ambient water and water trapped in the chamber can be limited, depending on ship motion, and hence biochemical oxygen demand from sediment can lead to hypoxic or anoxic conditions inside the chambers. Such conditions would prevent most diapausing eggs from hatching.

In follow-up post-BWE laboratory viability experiments, neither the total abundance of hatched individuals nor the species richness of hatched individuals differed significantly between sediments from incubation chambers in the exchanged versus control ballast tanks (Figure 4). These results suggest that diapausing invertebrate eggs may be largely resistant to saltwater exposure, and that BWE may not mitigate the threat of species introductions posed by this life stage.

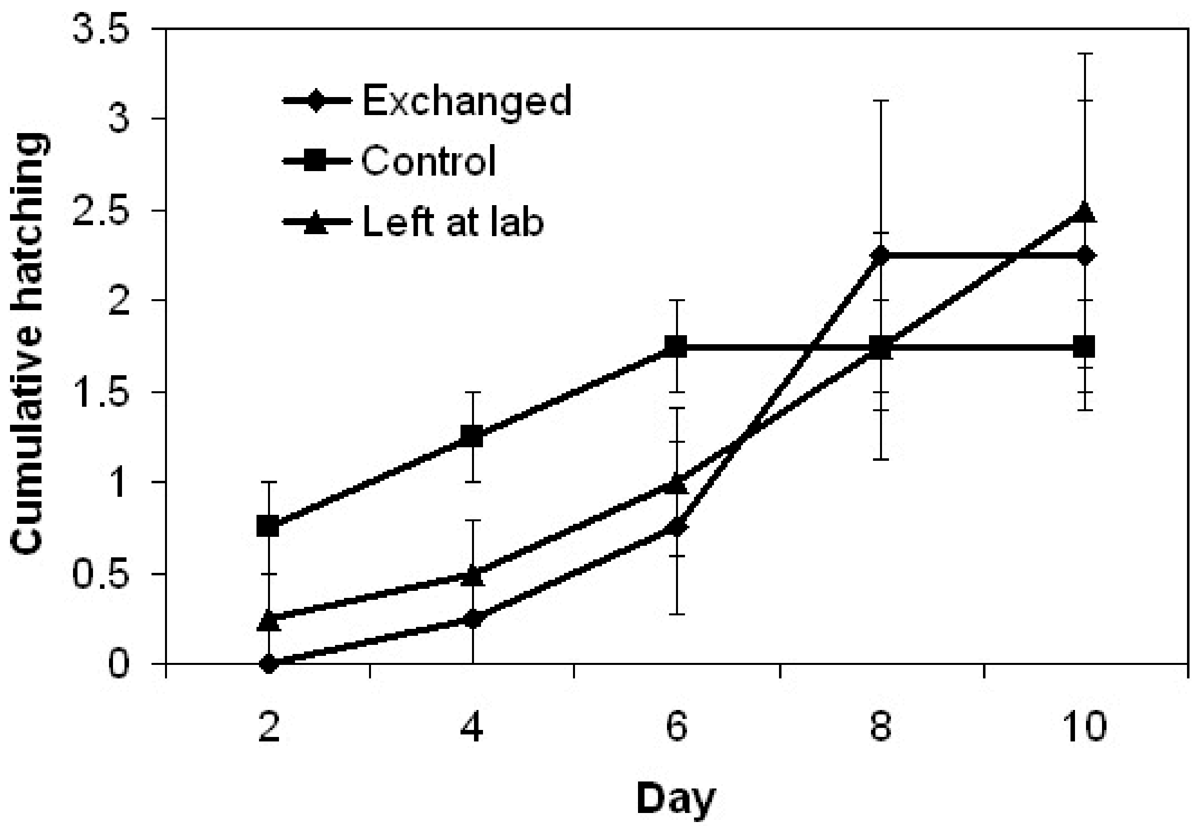

Figure 4*: Comparison of laboratory hatching results for invertebrate resting eggs placed in freshwater after 1) exposure to saltwater (diamonds) in a ballast tank during ballast water exchange, 2) continuous exposure to freshwater (squares) in a ballast tank, and 3) retained in*

the lab and never placed in a ballast tank. There was no significant difference in the hatching rates of the eggs retained under controlled conditions in a laboratory, those placed in a ballast tank, and exposed to saltwater via ballast water exchange.

Task 3: Characterize source invertebrate populations and assess salinity toxicity as a barrier to prevent transfers of "high risk" species to the Great Lakes in ballast tanks.

Characterizing Source Populations

The Great Lakes and low salinity ports of the east coast of the U.S. and Canada share an invasion threat from the North Sea and Baltic Sea. Of the 269 species reviewed, the Great Lakes and port systems of the North Sea and Baltic Sea have at least 100 species (37%) in common, with 18 of these considered exotic to the Great Lakes region.

In particular, commercial ships from ports of the Netherlands, Belgium, Germany, Finland, and Russia may represent the greatest threat of invasive species to the Great Lakes and estuarine ecosystems of the eastern United States. Based on trends of temperature, salinity, and ship traffic, the ports of Rotterdam, Antwerp, Ghent, Brake, Bremen, Klaipeda, Kotka, and St. Petersburg have been classified as high invasion risk donor ports.

Based on species diversity and environmental tolerances, the most likely taxonomic groups to invade the Great Lakes are the amphipods, isopods, harpacticoid copepods, cladocerans, mysids, and mollusks. During the last 50 years, several long-term shifts in zooplankton composition and abundance have occurred within the North Sea and may potentially increase the invasion rate of Ponto-Caspian species into adjacent freshwater port systems and hence possibly to the Great Lakes.

Salinity Tolerance Experiments

Salinity tolerance experiments, designed to mimic both flow-through and empty-refill methods were carried out in several different regions known for high invasion rates and commercial ship traffic. Experiments were conducted in the Chesapeake Bay (Maryland), San Francisco Bay (California), and in the European ports of Curonian Lagoon, Klaipeda, Lithuania, Vistula River (Poland), and Rotterdam (The Netherlands) located within the Baltic Sea and North Sea. Over 70 experiments were conducted using 43 invertebrates identified to the species level, 4 invertebrates identified to the genus level, and 10 experiments that included unidentified species of bivalve veligers, barnacle nauplii, cladocerans, polychaetes, flatworms, and copepods.

All of the cladocerans were eliminated by either 14 or 24 ppt seawater. There are marine cladocerans that can survive in salinities greater than 24 ppt such as species of *Podon*, *Pseudoevadne*, *Evadne,* on three voyages respectively. and Pleopsis. However, these species are rarely found within freshwater habitats or cannot survive in constant freshwater systems.

The majority of copepods in our experiments were not tolerant of full-strength seawater, but some species are capable of recovering from short-term exposures to dramatic salinity shifts. Therefore, exposure duration should be at least a day to assure mortality of all copepod species.

The larvae of crabs, shrimps, barnacles, and bivalves as well as adult amphipods, isopods, cumaceans, and mysids were generally tolerant of full-strength seawater (or higher salinities). For these taxa, it is a better discriminator of ‘invasion risk’ for the Great Lakes region to determine species that are capable of establishing populations within a constant freshwater habitat. However, all pose a significant invasion threat to estuarine systems.

In addition, salinity tolerance experiments were conducted in the Great Lakes by both SERC (western Lake Erie; Grand Traverse Bay, MI) and the University of Windsor. The common native cladoceran species; *Bosmina longirostris*, *Leptodora kindtii*, and *Daphnia retrocurva* were all eliminated in the initial exposure to 14 ppt seawater. This was also true for the highly abundant rotifer, *Asplachna priodonta*. Two of the most problematic invasive species in the Great Lakes, the predatory cladocerans Cercopagis and Bythotrephes, were slightly more tolerant of higher salinities and survived until the 24 ppt treatment. This was also true for the widely distributed cladoceran species of *Polphemus*, *Alona,* and *Eurycercus*. Late stage juveniles brooded within adults of Bosmina longirostris and *Eurycercus lamellatus* survived in some of these short-term salinity treatments when returned to ambient water. The only species exhibiting tolerance to full-strength seawater were Quagga and Zebra mussel veligers. However, as a final check of viability we transferred these animals to freshwater at the end of the experiment and left them overnight, and no individuals survived the double shock of freshwater-to-seawater treatment plus return to freshwater.

With regard for ballast water exchange methods, the greater risk for the Great Lakes lies with species or particular life stages that can tolerate full-strength seawater for at least two days and also establish viable populations within a constant freshwater system. Clearly, this is not the case for the adult forms of the invasive cladocerans *Cercopagis pengoi* and *Bythotrephes longimanus*. There may be several reasons for their establishment in the Great Lakes, including that these species were introduced prior to ballast water exchange practices, that ballast water exchange practices had not been followed rigorously, or that their resting stages have more physiological resistance than the adults. Previous experiments designed to test the efficacy of ballast water exchange on the hatching success of resting stages of other species of cladocerans from the Great Lakes suggested that saltwater exposure is unlikely to significantly reduce the risk from this potential source of propagules (Bailey et al. 2004).

Though not a complete barrier against all exotic species, these experiments clearly show that many taxa that originate from low-salinity ports can be eradicated from ballast tanks relatively quickly through exposure to full-strength seawater. This is especially true for several species of rotifers, cladocerans, and copepods that are more likely to occur in freshwater or oligohaline habitats (0-2 ppt). It is not surprising that our experiments with animals from habitats with higher average salinities (2-5 and 5-10 ppt) exhibited greater resistance to treatments of full-strength seawater.

These findings support similar conclusions drawn from ballast water exchange simulation experiments conducted on species from the Chesapeake Bay and San Francisco Bay. Invertebrates identified from our experiments as salinity-tolerant (34 ppt) include mysid shrimps, amphipods, isopods, harpacticoid copepods, bivalve veligers, and decapod zoea. These taxonomic groups often experience dramatic fluctuations in salinity and temperature as part of their normal life histories and these factors have contributed to their ability to invade estuarine habitats. Of these estuarine animals, only a subset are both salinity-tolerant species and capable of surviving and reproducing in a constant freshwater habitat such as the Great Lakes. Identifying species and populations with both these characteristics from the port systems of the east coast of the U.S. and Canada, North Sea, and Baltic Sea is paramount for identifying problematic species that pose a high risk of invading the Great Lakes region via the operations of commercial ships.

Conclusions

Our research results strongly support the implementation of the new Canadian ballast management regulations adopted in 2006 that require, and the policy statement issued by the United States Coast Guard in 2005 that encourages, mid-ocean tank flushing by NOBOBs. We recommend that vessels operating outside of the Great Lakes conduct saltwater flushing of their empty (NOBOB) tanks prior to each entry.

We conclude that many of the recommendations put forth in Item 6 of the Code of Best Practices for Ballast Water Management (Shipping Federation of Canada, 2000) require information on local water quality conditions that is not generally available to the shipping industry, or are not practicable on a consistent and regular basis due to cargo loading and unloading requirements. While BMPs, if consistently and repeatedly applied, can reduce the risk of introductions from NOBOB vessels by minimizing the amount of sediment and associated organisms that are transported within ballast tanks, the practical realities and limitations associated with vessel operations makes the existing BMPs inadequate as the lone strategy for reducing the risk of nonindigenous species introductions from NOBOB vessels. The designation and routine use of saltwater flushing as an official BMP would greatly improve the protection framework for the Great Lakes, if aggressively implemented by the shipping industry.

Products

Publications

Information Sheet: *Transoceanic NOBOB Vessels as Vectors for Nonindigenous Species Introductions to the Great Lakes*

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