NOBOB-A: Assessment of Transoceanic NOBOB Vessels and Low-Salinity Ballast Water as Vectors for Nonindigenous Species Introductions to the Great Lakes

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Background

Over the last 15 years much attention has been focused on ballast water as a vector for nonindigenous species introductions to our Great Lakes and marine coastal ecosystems, and on open-ocean ballast water exchange as a defense against new introductions. Ballast water is taken on by cargo vessels to adjust trim, balance structural stress, and maintain stability. However, ballast water carries with it whatever local organisms and sediment get entrained during ballasting. When ballast water is discharged, organisms and their eggs or larvae in the ballast tank that originated in a foreign ecosystem can be discharged into the local ecosystem. Ballast water has been identified as one of the primary vectors by which nonindigenous species are being transported and introduced to coastal ecosystems on a global scale. In 1993 the United States implemented “ballast water exchange (BWE)” regulations for ships entering the Great Lakes from overseas that require them to exchange coastal ballast water, when it can be done safely, for open-ocean water to achieve a salinity in their ballast tanks of at least 30 ppt.

NOBOB (no-ballast-on-board) vessels are loaded with cargo and thus do not need ballast water for safe operations. However, ballast tanks are structurally complex and often contain small amounts residual water and accumulated mud that cannot be pumped out. Once cargo is offloaded, ballast water is needed to replace the cargo weight until new cargo is loaded. Such fresh ballast water provides a potentially suitable environment for larval and adult organisms trapped in the residual ballast material present in the tanks, as well as establishing conditions potentially suitable for the hatching of resting stages in the accumulated residual sediments. Resting stages are embryonic forms that are relatively resistant to adverse environmental conditions and thus represent an effective means of assuring the long-term survival for some organisms, but also making them primary candidates to survive the rigorous conditions found in ballast tanks. NOBOB vessels enter the Great Lakes without any mandatory regulatory requirements aimed at reducing the risk of nonindigenous species introductions via ballast water discharge. As they offload cargo they add Great Lakes water to their ballast tanks which is later discharged at a port where cargo is loaded. When cargo loading occurs at a Great Lakes port, the discharge of the previously loaded Great Lakes ballast water can include nonindigenous organisms that were in the original residual ballast water and sediment, thus providing an avenue for the introduction of nonindigenous species within the Great Lakes.

Project Rational and Purpose

In the late 1990s the issue of NOBOB (no-ballast-on-board) vessel operations in the Great Lakes rose from a position of relative obscurity to become a major concern for the Great Lakes basin. Since the mid-1980s, on average less than 10% of ocean vessels entering the Great Lakes from overseas contained declarable ballast water on board. However, while operating in the Great Lakes, NOBOB vessels often take on water as ballast to maintain their trim and stability as they unload cargo and move from port to port. This new (Great Lakes) ballast water mixes with the residual ballast water, mud, and associated organisms in these tanks and is later discharged as the vessels take on new cargo. NOBOB vessels escaped scrutiny under existing U.S. and Canadian federal, state, and provincial laws, yet their ballast tanks retain residual volumes of unpumpable ballast water and sediment (residuals) which contain live aquatic organisms and resting stages - eggs, spores, and cysts - accumulated over numerous previous ballasting operations. This project, started in late 2000 and completed in April 2005, was the first significant biological characterization and risk assessment of NOBOB residuals.

Another management concern is the effectiveness of ballast water (BWE) exchange as a preventive measure against nonindigenous species introductions. In 1993 the United States implemented mandatory BWE requirements for ships entering the Great Lakes from overseas. Studies of BWE during the 1990s produced varied results concerning the effectiveness of BWE and none looked specifically at the combination of BWE and salinity (osmotic) shock relative to brackish and freshwater organisms. Of particular relevance to the Great Lakes is the efficacy of open-ocean ballast exchange when the original ballast is fresh or low salinity water, which differs in density and biota from saline water. The coastal regions of Europe and especially the coastal regions of the Baltic and Black Seas have been implicated as source regions for many of the Great Lakes invaders found since 1985. Therefore, the effectiveness of exchanging low-salinity coastal water for open-ocean saltwater is an important consideration when evaluating how well BWE reduces the threat of new invasions to the Great Lakes. As part of this project, the effectiveness of BWE in replacing coastal water was experimentally examined and the efficacy of “salinity shock” on various fresh water and estuarine organisms was studied.

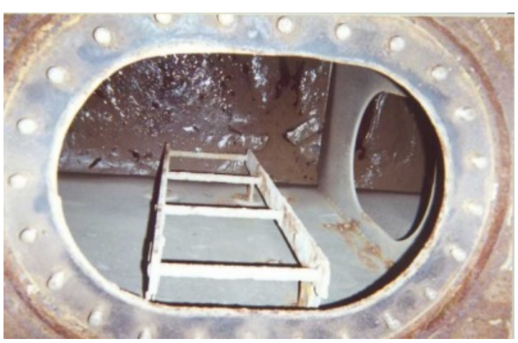

Figure 1*: Looking into the entry hatch to a double-bottom ballast tank on a transoceanic bulk carrier that entered the Great Lakes during 2001. Note layer (about 2-3 cm) of residual ballast mud and puddles of residual ballast water covering bottom of tank (image: Great Lakes NOBOB team).*

Final Report and Summary Outcomes

The NOBOB-A Final Report (April 2005) provides a complete project summary and new information for regulatory and/or management agencies, including a detailed analysis of ballast management practices used by cargo ships (Chapter 2), a detailed biological characterization of NOBOB residuals and an assessment of the risks associated with those residuals (Chapters 3 and 4), and an assessment of the efficacy of BWE for removing coastal water and of “salinity shock” as a protective mechanism against coastal species (Chapter 5).

Until this report was published there were few data with which to assess the risk posed by NOBOB residuals or evaluate the potential effectiveness of ballast water exchange for reducing or preventing continued nonindigenous species introductions to the Great Lakes. There was no strong scientific basis for establishing protocols or guidelines to reduce the threat of aquatic species introductions due to ballasting operations of NOBOB vessels once they entered the Great Lakes. Our results showed that the water and sediment ballast residuals in NOBOB vessels house large numbers of live or viable (eggs, cysts) organisms, a portion of which are nonindigenous and not yet present in the Great Lakes. Our findings also suggested that the risk of NOBOB-related nonindigenous species introductions may be lowered with conscientious and consistent application of good management practices, especially flushing NOBOB tanks with saltwater on the open ocean whenever possible unless ballast water exchange has occurred since the last uptake of low-salinity coastal ballast water. Coincident with the publication of the NOBOB-A Final Report, the U.S. Coast Guard conducted a public hearing and a technical workshop in May 2005 to address management of NOBOB vessels entering the Great Lakes. In August 2005 the U.S. Coast Guard issued voluntary NOBOB management guidelines calling for ships to take steps to assure that the salinity of their residual ballast water is over 30 ppt, either through ballast water exchange or tank flushing, as appropriate and safe (Federal Register / Vol. 70, No. 168 / Wednesday, August 31, 2005, pp 51831-51836).

Results from three on-board experiments and additional laboratory tests suggest that use of ballast water exchange, while clearly imperfect, can be a beneficial management practice in the absence of more effective and consistent alternative ballast treatment or management tools. We also found that the effectiveness of salinity shock in killing freshwater-tolerant organisms varied widely depending on taxa and the form in which the organisms are represented. So while salinity shock may be a useful treatment, it is also imperfect. To assure maximum protection, new and highly effective methods to reliably treat ballast water and/or ballast residuals to significant and scientifically defensible biological endpoints are required.

***Figure 2**: View inside the ballast tank of a transoceanic vessel, showing residual ballast mud. Note how mud accumulation reflects drainage flow patterns through structural openings. (image: Great Lakes NOBOB team, P.T. Jenkins)*

Proposed Work 2006

Close-out project - prepare and submit additional journal papers for:

- Instrumented IETrap results
- NOBOB Synopsis
- Phytoplankton results
- Microbiological results

Program Description and Significant Findings by Task

The goals of this study were to

- greatly expand the biological and physical characterization of residual ballast water and sediment in NOBOB tanks,
- assess the invasion risk associated with “clean” (i.e., little sediment accumulation) vs. “dirty” (i.e., significant sediment accumulation) ballast tanks,
- measure the relationship between ship management practices and invasion risk to determine if certain management practices appear to reduce the risk posed by NOBOB vessels, and
- quantify the effectiveness of open-ocean exchange in decreasing the diversity and concentration of nonindigenous species that enter the Great Lakes in “exchanged” ballast water.

Project activities were organized around three interrelated Tasks that were designed to help accomplish these goals and serve as the organizational structure for presenting our project results:

Task 1 (NOBOB)

sampled over 80 individual NOBOB ballast tanks and developed detailed biological and physical characterizations of the residual water and sediment in those tanks; investigated the relationship between ship management practices and sediment accumulation; and developed a biological risk assessment of NOBOB ballast operations in the Great Lakes based on invertebrates in the residuals.

Significant Task 1 Results:

- We sampled over 80 individual NOBOB ballast tanks and developed detailed biological and physical characterizations of the ballast residuals in those tanks.
- Microbial, phytoplankton, and invertebrate analyses confirm that NOBOB vessels are vectors for non-indigenous species introductions to the Great Lakes Basin.
- NOBOB ships were clearly shown to be a significant vector for possible introductions of nonindigenous invertebrates and phytoplankton to the Great Lakes. Although 99% of the nonindigenous invertebrates are associated with residual mud, a risk assessment calculation indicates that the risk for new introductions may be equal or greater in the 1% of organisms that are associated with residual water, because pelagic species should have more opportunity and are more likely to be entrained in ballast water discharge than benthic organisms.
- Concentrations of microbial and virus-like particles were generally in the range found in the natural environment, with a few unusually high and unusually low outliers. There was no evidence that ballast tanks are acting as incubators for microbe growth and the overwhelming majority of these bacteria are natural, nonpathogenic forms, and their constancy of number is a balance between nutrient supply and grazing by their predators.
- There was no evidence of a significant human health risk due to pathogens present in ballast tanks, although pathogens (Vibrio cholerae, Cryptosporidium parvum, Giardia lamblia, Encephalitozoon intenstinalis, Pfiesteria piscicida, P. shumwayae, and Aureococcus anophagefferens) were detected (but not enumerated) in 26 of 42 (62%) ships and 40 of 82 (49%) ballast tanks sampled during the two field years. E. coli or enterococci were not detected, indicating the absence of sewage-contaminated ballast. However, it would be simplistic and possibly very wrong to assume that aquatic microbial invasions do not occur or could not be mediated by ballast water.
- A significant percentage (31 out of 103) of the NOBOB vessels surveyed over a three year period period entered the Great Lakes system with fresh or low-salinity ballast water residuals. The greatest risk of new introductions is associated with these ships due to the live freshwater-tolerant organisms found therein.
- An evaluation of shipboard ballast management practices revealed a significant improvement over the last 20-25 years by the shipping industry.

- The potential benefits of flushing of NOBOB tanks with ocean water if such practice is used regularly and often were identified from management practices surveys and in-tank observations. Regular and consistent flushing was associated with less residual sediment accumulation, along with the added benefit that it raises the salinity of the residual water.

Figure 3: *Scientist collecting mud from a NOBOB ballast tank. (image: Great Lakes NOBOB team)*

Task 2 (NOBOB)

experimentally evaluated the effects of adding Great Lakes water as ballast to NOBOB tanks on germination and growth of nonindigenous species present in ballast residuals and on their potential release from ballast tanks. Ballast remained in the tanks for 6 to 11 days, depending on ship schedule and biological samples were taken from the ballast tank water column at various times during each voyage. Resting egg hatching experiments using Emergence Traps (IETraps) were conducted on four voyages between October 2002 and September 2003.

Significant Task 2 Results:

Microbial abundance declined by about a factor of 2 during ballast transit within the Great Lakes. Pathogens were detected intermittently during most ballast transits through the GL, but there was large variability between experiments.

Phytoplankton species diversity declined during vessel transit and there tended to be a shift in species dominance, with the potentially harmful blue-green alga, Microcystis, being the favored competitor in ballast tanks.

Resting eggs were not as likely to hatch in situ as compared to laboratory experiments. Both total abundance and species richness of organisms hatched were significantly lower in situ than in laboratory experiments. In addition, burial appeared to have a significant impact on the number of eggs that hatched.

On one occasion we conducted an in situ experiment that included an IETrap modified to contain an imbedded water quality sonde and a duplicate sonde mounted adjacent to and outside the instrumented IETrap. The same amount and sediment material used in a parallel in-tank hatching experiment was placed into the instrumented IETrap. The environment inside the IETrap went hypoxic over the first two days, but a number of re-oxygenation events were recorded during the voyage that coincided with periods when the ship was in transit, presumably causing water flow within the tanks. In spite of strong evidence that the traps likely go hypoxic or anoxic due to sediment biological and/or chemical oxygen demand, hatching of diapausing eggs did occur inside the other, non-instrumented traps during shipboard experiments, but at a very low rate compared to in-lab hatching. However, associated live animal controls using the same sediment had a high rate of survivorship, which suggests that if oxygen deprivation occurred in all IETraps, it may not have been consistent or as severe as measured in the instrumented trap. Still, the potential for hypoxia or anoxia developing in IETraps means that hatching rate results must be approached with caution, as they likely would have been affected by such conditions.

Zooplankton densities for all of the taxa across all voyages tended to decrease as voyage length increased. However, during some voyages rotifera species increased in abundance as the voyage progressed to the upper Lakes.

Several NIS were detected in the Great Lakes water loaded in the lower lakes as ballast at the beginning of the in-tank experiments, including: the calanoid copepod Eurytemora affinis, the fishhook waterflea, Cercopagis pengoi; and the amphipod, Echinogammarus ischnus. These organisms are already known to be established in the lower Great Lakes, and thus their presence in the filled NOBOB tanks was not a surprise. However, these observations do show that ballasting in the lower lakes by NOBOBs presents a risk of spreading NIS to the upper lakes.

Two NIS rotifers that are currently not found in the Great Lakes were detected in ballast water samples; Brachionus diversicornis and Brachionus leydigi. The former was also detected in harbor samples collected during the same voyage and may constitute a new invasion by this species. B. leydigi was detected in a tank 10 days after ballasting and may have hatched in tank.

Figure 4: *Recovery of water and hatched organisms from Incubator Emergence Traps at end of one of the FY2003 field experiments. (image: Great Lakes NOBOB team)*

Task 3 (BWE)

conducted three on-board ballast water exchange experiments to determine the effectiveness of open-ocean exchange in decreasing the diversity and concentration of coastal species in "exchanged" ballast water and also carried out both on-board and in-lab experiments to examine the salinity tolerance (effectiveness of salinity shock) of various fresh and low-salinity coastal organisms.

Significant Task 3 Results:

- Ballast water exchange was found to be highly effective at removing coastal water and removing or killing many biological tracer organisms examined during the study. Although it is clearly imperfect, BWE can be a beneficial management practice in the absence of more effective and consistent alternative management tools.
- The assumption that "salinity shock" is an additional advantage for protecting the Great Lakes ecosystem from invasive species must be viewed with some caution and requires further examination - the effectiveness of salinity shock in eliminating freshwater-tolerant organisms varied widely depending on taxa and the form in which the organisms are represented. So while salinity shock may be a useful tool, like ballast water exchange, it is also imperfect.

***Figure 5**: Ballast tank overflow during one of the flow-through exchange experiments*

Products

Publications and Presentations

A complete list of publications and presentations through mid-2005 is presented as Appendix 6 in the Final Report. Additional publications are expected during CY2006. Therefore this program will be held as "on-going" until all appropriate publications have been submitted.

Publications: FY2005

Bailey, S.A., K. Nandakumar, I.C. Duggan, C.D.A. van Overdijk, T.H. Johengen, D.F. Reid and H.J. MacIsaac. 2005. In situ hatching of invertebrate diapausing eggs from ships' ballast sediment. *Diversity and Distributions*, 11:453-460.

Bailey, S.A., I.C. Duggan, P.T. Jenkins, and H.J. MacIsaac. 2005. Invertebrate resting stages in residual ballast sediment of transoceanic ships. *Canadian Journal of Fisheries and Aquatic Sciences*, 62: 1090-1103.

Duggan, I.C., C.D.A. van Overdijk, S.A. Bailey, P.T. Jenkins, H. Limén, and H. J. MacIsaac. 2005. Invertebrates associated with residual ballast water and sediments of cargo carrying ships entering the Great Lakes. *Canadian Journal of Fisheries and Aquatic Sciences*, 62: 2463-2474.

Johengen, T. D.F. Reid, G.L. Fahnenstiel, H.J. MacIsaac, F.C. Dobbs, M. Doblin, G. Ruiz, and P. T Jenkins. 2005. *A Final Report for the Project Assessment of Transoceanic NOBOB Vessels and Low-Salinity Ballast Water as Vectors for Non-indigenous Species Introductions to the Great Lakes*. NOAA, Great Lakes Environmental Research Laboratory and University of Michigan, Cooperative Institute for Limnology and Ecosystems Research, Ann Arbor, 287 pp.

Presentations FY2005

Reid, D. F., Johengen, T.H., and Jenkins, P.T., *Great Lakes NOBOB assessment final briefing* (Invited). Great Lakes Shipping Association Annual Meeting, Cleveland, OH. January 25, 2005. Reid, D. F.

U.S. Coast Guard Marine Community Day, Cleveland, OH, January 26, 2005. Johengen, T.H., D.F. Reid, and P.T. Jenkins, *Great Lakes NOBOB assessment: final briefing*.

Great Lakes Protection Fund, Chicago, IL, March 4, 2005. Reid, D. F., T.H. Johengen, and P.T. Jenkins, Great Lakes NOBOB assessment final briefing Fednav International, Montreal, Canada, May 4, 2005. Reid, D. F., T.H. Johengen, and P.T. Jenkins, *The Great Lakes NOBOB assessment - findings and conclusions* (Invited).

Public Meeting on Ballast Water Management for Vessels Declaring No Ballast Onboard (NOBOB), U.S. Coast Guard, Cleveland, OH, May 8, 2005. Reid, D. F., T.H. Johengen, and P.T. Jenkins, *Great Lakes NOBOB Assessment: Summary and Overview of Results* (Invited). Technical Workshop on Ballast Water Management for Vessels Declaring No Ballast Onboard (NOBOB), U.S. Coast Guard, Cleveland, OH, May 9, 2005.

Reid, D. F., Johengen, T.H., and Jenkins, P.T, *Great Lakes NOBOB assessment - summary of findings* (Invited). National Interagency Aquatic Nuisance Species Task Force, Monterey, CA, May 24-25, 2005.