HARMFUL MICROBES IN BALLAST WATER: PROTECTING THE GREAT LAKES ECOSYSTEM

NORTHEAST-MIDWEST INSTITUTE

Ships have been shown to carry harmful microbes, including viable pathogens, in their untreated ballast water (e.g., McCarthy & Khambaty, 1994; Ruiz *et al*., 2000; Drake *et al*., 2001; Drake *et al*., 2007). Consequently, there was justified concern around the role of ship ballast movements in further dispersal of a new form of *Viral hemorrhagic septicemia virus* (VHSV) which began causing major fish kills in the lower Great Lakes in 2005. Debate--including between Great Lakes states—raged over whether ship operations into the apparently yet unaffected Lake Superior should be restricted (Bain *et al*., 2010). Both sides sought to prevent unnecessary environmental and economic costs, but a fundamental lack of information on the real-time distribution of this harmful microbe fueled conflicting conclusions of how best to do so.

The Great Lakes region is headed toward a repeat of this fractious debate when the next harmful microbe emerges in the ecosystem—a virtual inevitability given the number of possible sources and infinite supply of possible agents—in the absence of better information. The Northeast-Midwest Institute (NEMWI), with support from the Great Lakes Protection Fund (GLPF), led a team of experts[1] from Cornell University, Old Dominion University, the University of Minnesota, the United States Geological Survey (USGS) and the Great Lakes Commission in a multi-year project to explore the need for—and best tools and methods to accomplish—a cost-effective early-detection monitoring system for ship-mediated harmful microbes in the Great Lakes. Project outcomes helped resolve the controversy around Lake Superior and VHSV, and helped prepare the region for efficient and effective response to the inevitable next introduction.

The project's soon to be released final report[2] contains more details on the conceptual analyses, methods development and empirical demonstrations carried out by project's interdisciplinary team. It concludes that early detection and monitoring of ship-mediated harmful microbes in the Great Lakes is warranted, useful (from the standpoint of the ship owner as well as the resource manager) and feasible. The report also lays out specific means by which early detection and monitoring could be best accomplished in the Great Lakes region. This *Note to the Coalitions* summarizes the project's findings.

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[2] To be published on the Northeast-Midwest Institute's website: www.nemw.org.

1: Introduction: Microbes, Ships and the Great Lakes

Ecosystems like the Great Lakes support rich and diverse microbial communities including bacteria, viruses and archaea, protozoa, fungi, algae, and the tiniest animals, such as rotifers and planarians. These invisible organisms fundamentally support the visible physical, chemical and biological processes of the Great Lakes. Harmful microbes are microorganisms that cause disease or adverse changes to the ecosystem. Non-native microbial introductions hold an often unknown level of risk for creating unwanted changes.

Pathogenic microbes (i.e., disease agents) present apparent and documented risk. VHSV has caused highly visible outbreaks of disease among a wide range of fish species in the Great Lakes since 2005 (Elsayed *et al*., 2006; Groocock *et al*., 2007; Lumsden *et al*., 2007). Spring viremia of carp virus (SVCV), another highly pathogenic rhabdovirus, may be emerging in the Great Lakes in the near future (Ahne *et al*., 2002). SVCV, discovered in freshwater carp in Hamilton, Ontario, Canada, in September of 2006, has caused five disease outbreaks throughout the U.S. since 2002 (Bain *et al*., 2010).

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Harmful microbes also can disrupt human structures (Oster, 2012). Hicks and Oster (2012) found that a combination of microbiological and chemical factors influence the corrosion rate of sheet steel structures in Duluth-Superior Harbor and possibly other areas in the western arm of Lake Superior. They estimate that corrosion in the U.S. costs $275.5 billion per year; in the Duluth-Superior Harbor alone, replacement of 20 km of already corroded steel structures will cost $200-250 million.

Untreated ballast water of commercial vessels is a known vector, and even a possible incubator, for several types of harmful microbes worldwide (e.g., McCarthy & Khambaty, 1994; Ruiz *et al*., 2000; Drake *et al*., 2001; Drake *et al*., 2007), and to U.S. waters specifically (e.g., McCarthy & Khambaty, 1994; Knight *et al*., 1999; Ruiz *et al*., 2000; Drake *et al*., 2001; Johengen *et al*., 2005; Drake *et al*., 2007). Most notably, *Vibrio cholerae* were detected in the ballast water of overseas ships visiting ports of the Great Lakes (Knight *et al*., 1999; Johengen *et al*., 2005), the Gulf of Mexico (McCarthy & Khambaty, 1994), and the Chesapeake Bay (Drake *et al*., 2001; Drake *et al*., 2007). Fecal indicators and human pathogens such as fecal coliforms, streptococci, *Clostridium perfringens*, *Salmonella* spp., *Escherichia coli*, *Cryptosporidium* spp., *Giardia* spp., *Encephalitozoon intestinalis*, *Pfiesteria piscicida*, *Aureococcus anophagefferens*, and enteroviruses were also evident in samples (Knight *et al*., 1999; Johengen *et al*., 2005). Research has yet to occur on harmful microbe occurrence in the ballast water of Canadian and U.S. domestic Great Lakes fleets.

Upcoming regulatory deadlines for ships to treat ballast water may diminish the role of this vector over time. However, the number of ship movements, particularly within the domestic fleets, with effective ballast treatment will be few for many years to come.

2: The Case for Early Detection Monitoring for Ship-Mediated Harmful Microbes in the Great Lakes

The conventional approach to monitoring for fish diseases is to record visible fish kills. Arguably, this *post mortem* approach serves the purposes of forensics at best; clinical signs of disease like fish kills occur long after infectious levels of pathogens are in play with vectors of spread. Detection of subclinical signs of known threats alone would allow resource managers and industry to proactively and efficiently attenuate spread and mitigate damage. For example, knowledge of pathogen dispersion (including clinically and pre-clinically infected sites) alone can prevent unintended trade of diseased organisms.

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Real time dispersal information would allow resource managers and industry to accurately assess costs and benefits of mitigation actions. Further, early warning systems yield insight into ecological risk levels and patterns of occurrence, aiding in effective prediction of risk.

But tough questions remain given today's tight budgets. In particular, one must ask: Is ship-mediated microbe monitoring relevant given: 1) other potential sources of harmful microbes in the Great Lakes, (i.e., are we targeting ships just because they are big and easy to blame?); 2) the long history of ship movements to date, (i.e., is the damage already done?); and 3) aren't we already monitoring everything under the sun in the Great Lakes region? The NEMWI project used qualitative and empirical methods to explore these questions.

- **QUESTION:** *How big a role do ships really play in introducing and dispersing harmful microbes in the Great Lakes compared to other possible vectors?*

With little data already available on this matter, the NEMWI project team mapped and ranked sources of pathogens into the Great Lakes and produced likelihood of occurrence estimates based on expert opinion. The exercise focused on harmful algae, human pathogens and fecal indicators, and pathogens of aquatic animals. The estimates, purely relative and subjective (i.e., qualitative), address potential rather than realized threats (although assignments are in some cases informed by documented occurrences), and generalized to a vector. Still, the estimates present a context for the system as a whole and a starting point for validation.

Figure 1 shows natural pathways (animals and wind) which historically accounted for microbe introductions to and spread within the Great Lakes and St. Lawrence Seaway System (GLSLSS). Figure 2 addresses the three principal human-mediated pathways (commerce, transportation, and dense human habitation).[3] In both figures, the estimated magnitude of vector importance is indicated with symbols.

[3] Figures 1 and 2 had their conceptual basis in a figure in a 29 October, 2003 Final Report by the Invasive Species Advisory Committee (ISAC) Invasive Species Pathway Team of the Prevention Working Group (Campbell & Kriesch, 2003). See Lodge *et al*. (2006) for a simplified version applicable to the U.S.

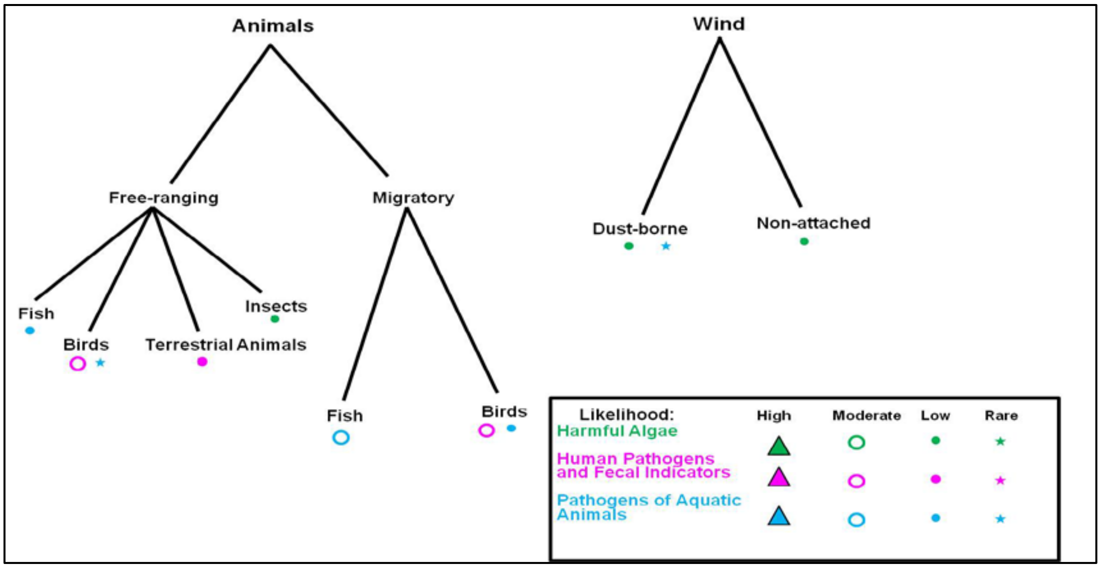

Figure 1. Natural Pathways for Harmful Microbe Introductions into the Great Lakes. Estimates of Likelihood Indicated Symbolically: Large closed triangle = high; medium open circle = moderate; small closed circle = low; small star = rare occurrence.

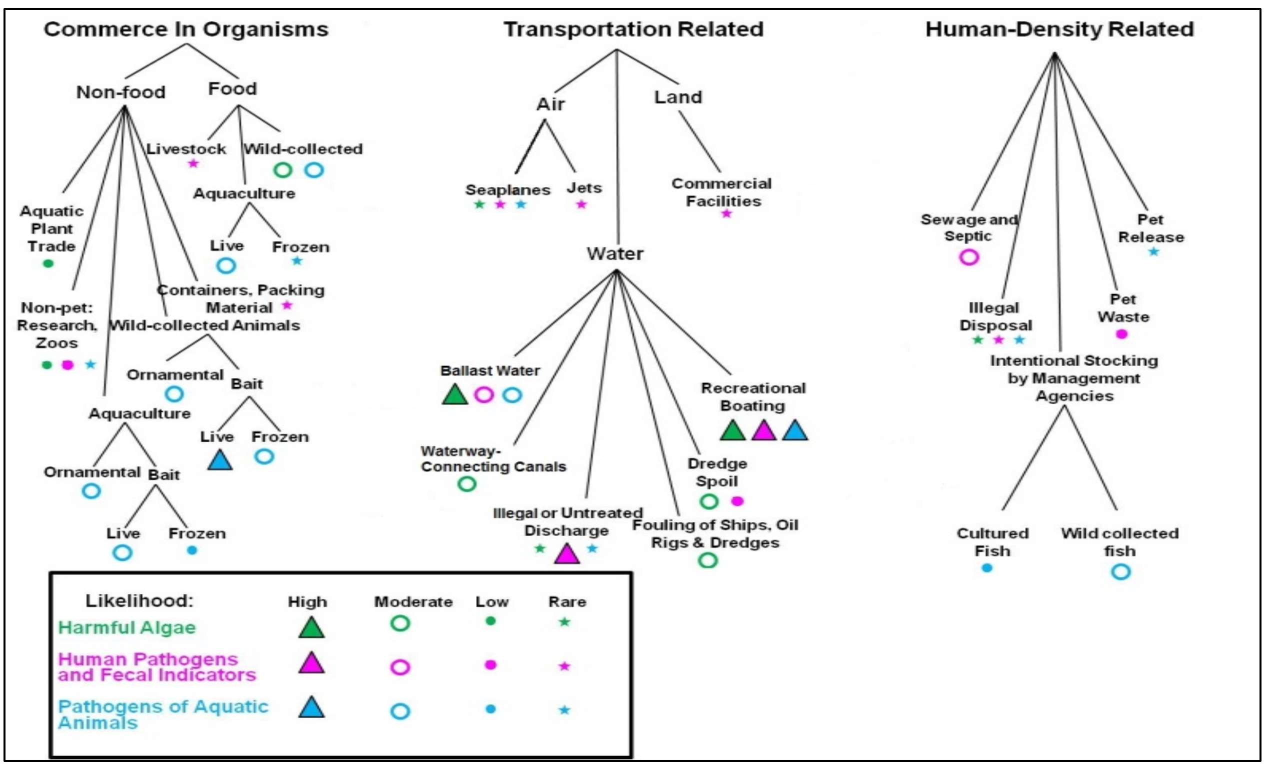

Figure 2. Human-Mediated Pathways of Harmful Microbe Introductions into the Great Lakes. Estimates of Likelihood Indicated Symbolically: Large closed triangle = high; medium open circle = moderate; small closed circle = low; small star = rare occurrence.

Conclusion*: Untreated ballast water constitutes an important—but not the sole—vector for the introduction and spread of harmful microbes in the Great Lakes. The vector warrants monitoring that acknowledges and tracks other vectors as well.*

- **QUESTION:** *Are there currently inherent differences in microbial community make-up between ships ballast water and receiving harbors?*

Monitoring for harmful microbes discharged by ships to Great Lakes harbors is only necessary if the microbial landscape is currently (whether or not it ever was) distinct from that of ships' ballast discharge. To date, there has been little empirical information on this threshold matter. The NEMWI project team applied advanced genetic detection and enumeration tools to assess differences between the composition and abundance of microbial communities in ballast water across types of vessels discharging into the region's busiest harbor, Duluth-Superior Harbor, and those already present in the receiving system. The study found, among other outputs, microbial abundances were higher in freshwater ballast compared to seawater and brackish water ballast samples ($p<0.05$), and bacterial community composition in ballast water was different from ship to ship, and between ballast discharge and the receiving harbor (Welch, 2012).

Conclusion: *There are existing differences in the microbial community in ballast discharges and the receiving harbor water of the busiest Great Lakes harbor suggesting that new microbial introductions could have an impact.*

- **QUESTION:** *The Great Lakes ecosystem is one of the most monitored systems globally. Aren't we already conducting early detection monitoring for ship-mediated harmful microbes?*

The NEMWI project reviewed existing monitoring programs relevant to the Great Lakes across key attributes (Table 1; adapted from Bain *et al*., 2011). Most existing monitoring programs target water quality, fisheries, and contaminants (Table 1).

Table 1: Existing Microbial Monitoring Programs Subject to Review.

Program	Purpose
OIE - Office International des Epizooties, World Organization for Animal Health	Standard methods for cultured organisms at production facilities
AFS - American Fisheries Society, Fish Health Section	Standard methods for health inspections on aquatic animals
MSU - Michigan water monitoring plan, Michigan State University	Plan for improving water monitoring to best standards with human threat focus
USFWS – U.S. Fish and Wildlife Service, National wild fish health survey	Monitoring and testing methods for determining the distribution of specific pathogens in wild fish
APHIS – U.S. Department of Agriculture (USDA), Animal and Plant Health Inspection Service	Identify VHSV distribution and need for control measures
USGS – U.S. Geological Survey, Microbiological Monitoring	National scale microbiological water quality monitoring as part of National Water-Quality Assessment Program (NAWQA)
USEPA – U.S. Environmental Protection Agency, Microbiological Monitoring	Monitoring and testing of recreational waters; mostly beaches for human health threats
AQUAVETPLAN - Australian Aquatic Veterinary Emergency Plan	Viral hemorrhagic septicemia virus (VHSV) detection for control action implementation and planning
Nordic countries fish disease surveillance	The four Nordic countries have national surveillance and disease control for aquatic animals

The existing programs with greatest relevance (APHIS and AQUAVETPLAN) focus exclusively on one target organism (i.e., VHSV); there is no existing broad spectrum monitoring system for harmful microbes. Moreover, the most relevant existing programs rely heavily on cell culture of tissues from diseased or suspected fish as a starting analysis, inhibiting their utility for early detection purposes (Bain *et al*., 2011).

Conclusion: *We are not already conducting early detection monitoring for ship-mediated harmful microbes in the Great Lakes, though some existing monitoring programs are related and could interact with or help support such as system.*

3: Feasibility of Great Lakes Harmful Microbe Monitoring

The Great Lakes are as vast as microbes are small; the size of ships is somewhere in between. Moreover, the number of potential microbial targets for a monitoring system is infinite. How could truly informative and cost-effective harmful microbe monitoring ever prove feasible as an early warning system?

- **QUESTION 1:** *Are analytical methods available to achieve the Great Lakes harmful microbe early warning monitoring objective?*

The conventional approach to fish pathogen monitoring—examination of tissues from diseased or dead fish to reveal causal agents—not only yields information too late for early detection purposes as noted earlier, but it is also too complex and costly for widespread monitoring use. This section describes some innovative tools and methods that the NEMWI project explored, developed and demonstrated to make early detection monitoring for harmful microbes in the Great Lakes newly feasible and cost-effective.

Molecular methods offer new and important potential to streamline time and costs for wide-range monitoring. They do, in turn, demand more expertise than conventional methods, but the NEMW region in general, and the Great Lakes region in particular, is rich with educational institutions training such experts. Molecular procedures, especially quantitative polymerase chain reaction (q-PCR) and quantitative reverse transcription PCR (qRT-PCR), readily detect trace pre-clinical microbial occurrence in water[4] as well as rapidly confirm suspected causal agents in tissue of moribund or dead fish. They can process much greater sample volume per unit time than conventional methods, and can target a wide range of problem microbes: economically and ecologically significant microbes as well as pathogenic microbes.

Conclusion: *Pre-clinical distribution of harmful microbes can be effectively monitored using genetic detection tools applied to water and fish samples.*

[4] Fish shed virus particles to surrounding water.

➢ **QUESTION 2:** ***Can genetic detection methods be effectively applied to more than one target organism at a time?***

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PCR requires specific methods and expertise for each microbial target, and there are likely to be multiple microbial targets for such a monitoring effort. The NEMWI project constructed and tested a protocol comprised of a series of qPCR assays for a suite of microorganisms. Target microbes (Table 2) directly or indirectly represented a range of threats that may be transported in ships' ballast water: human pathogens, fish pathogens and bacteria of potential economic significance (i.e., corrosion-causing bacteria).

Table 2. Microorganisms for which qPCR Assays were Developed or Refined.

Microorganism Type	Species
Human pathogens and fecal-indicators	*E. coli*
	Enterococcus faecalis
	Vibrio cholerae
	Giardia spp.
	Cryptosporidium spp.
Aquatic animal pathogens	*Aeromonas hydrophila*
	Piscirickettsia salmonis
Toxic cyanobacteria	*Microcystis aeruginosa*
	Anabaena spp.

Conclusion: *A single sample can be processed and screened using a suite of molecular assays to facilitate monitoring for multiple microbial targets.*

➢ ***QUESTION 3: How vast a network of harbor sampling sites is needed to support region-scale monitoring objectives?***

Random sampling of the entire Great Lakes harbor system is not an option. Far more feasible is sampling targeted sites for harmful microbial occurrence, such as commercial harbors, recreational boat centers, high human use sites, historic invasion hotspots, and biological entry and exit points. Program partner study sites are also important prospects for gathering more comprehensive information. Within each site, in addition to fish sampling, genetic detection tools offer the opportunity for water sampling; infected fish shed virus particles to surrounding water.

The NEMWI project described and demonstrated the potential feasibility of such a rapid, low cost, and meaningful microbe surveillance using site targeting and genetic detection tools (Bain *et al*., 2010). In 2005 VHSV caused a large fish die-off in Lake Ontario, and additional fish kills occurred afterward at several locations in Lakes Michigan, Erie, St. Clair, and connected waters. The NEMWI project sampled fish and water in shoreline waters of these lakes during a six week period in spring 2008. Samples were analyzed using a genetic detection methodology previously developed by Hope *et al*. (2010). The results confirmed broad distribution of VHSV despite the lack of evident fish kills (Figure 3; Bain *et al*., 2010). They also showed by the time of sampling no geographic linkage could be detected between areas of high shipping activity and VHSV occurrence (Bain *et al*., 2010).

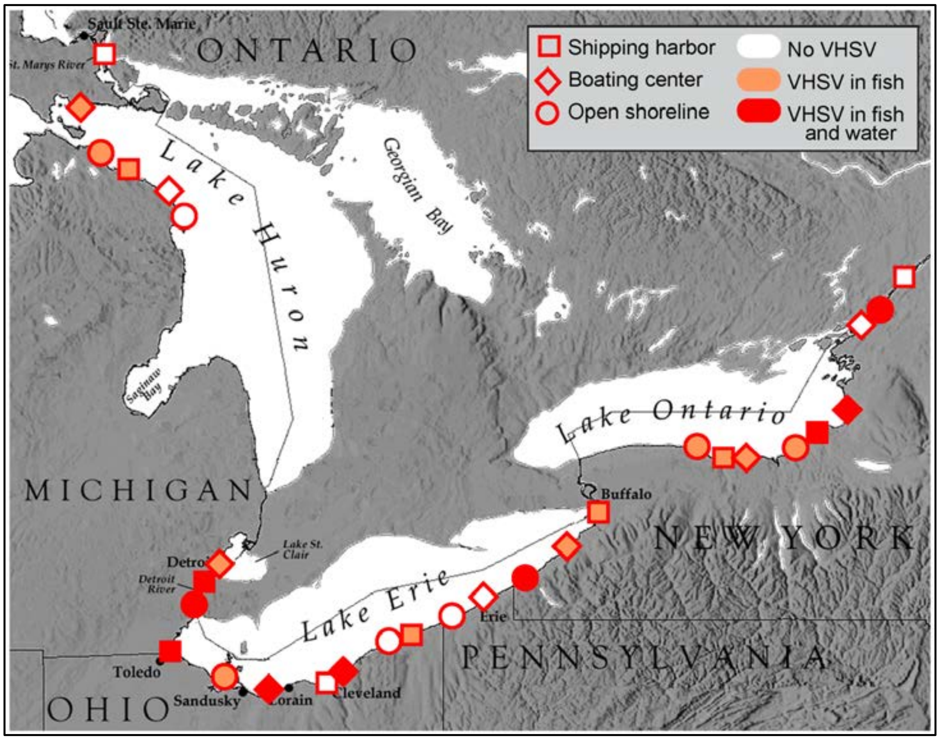

Figure 3. VHSV Monitoring Site Types, Locations and Outcomes

In non-project follow-on to the Lakes Ontario, Erie, and Huron study, project researchers, among others, conducted a similar rapid monitoring effort at sites along the Lake Superior coast for VHSV (Cornwell *et al.*, 2011). The objective of this survey was to determine occurrence and distribution of pre-clinical concentrations of VHSV in Lake Superior to validate a perceived need to protect the most upstream lake, considered free of the pathogen, from first infection by ships. In total, 874 fish (comprising species known to be susceptible to VHSV) were collected from seven sites along the shoreline of Lake Superior during June 2009 (Cornwell *et al*., 2011). The results unfortunately indicated that VHSV was already present in the lake though at subclinical levels at the time of the study (Figure 4; Cornwell *et al*., 2011).

Conclusion: *Sampling can yield rich and novel information on harmful microbe distribution if sampling sites are carefully selected to target possible occurrences, whether or not clinical signs of infection are present.*

- ***QUESTION 4: How about sampling ship ballast discharge? Is scientifically valid sampling possible?***

NEMWI project team members, as part of the Great Ships Initiative (GSI) developed and trialed a Ship Discharge Monitoring System (SDMS) to retrieve scientifically representative samples of a range of harmful aquatic organisms, including microbes, from operating ships' ballast uptake. This effort was conducted with substantial matching support from the U.S. Maritime Administration (MARAD) and the Legislative Citizens Commission on Minnesota Resources (LCCMR). Feasible and effective ship discharge monitoring methods were developed for planned[5] ship discharge monitoring exercises, and trialed on a number of different types of ships that ply the Great Lakes. The methods, their costs, and remaining challenges are detailed in "*A Ballast Discharge Monitoring System for Great Lakes Relevant Ships: A Guidebook for Researchers, Ship Owners, and Agency Officials*" (Cangelosi *et al*., 2011). GSI successfully installed ports for retrieving representative samples of ballast water on a wide range of types of ships that ply the Great Lakes (Figures 5 and 6; Table 3).

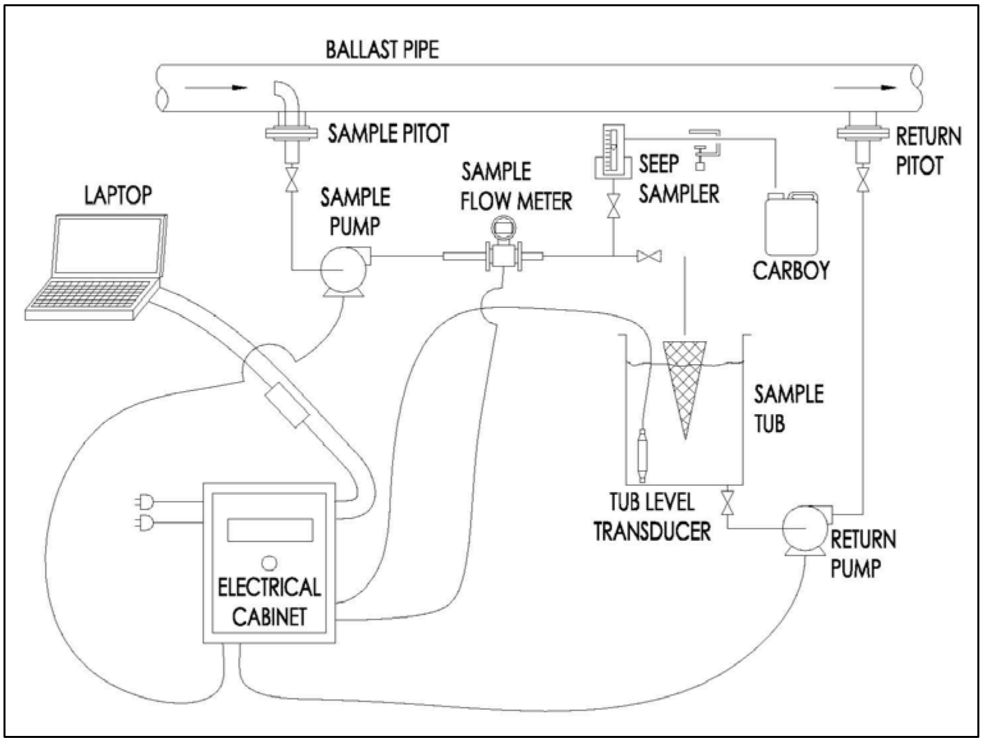

Figure 5. Schematic of the Great Ships Initiative (GSI) Ship Discharge Monitoring System (SDMS)

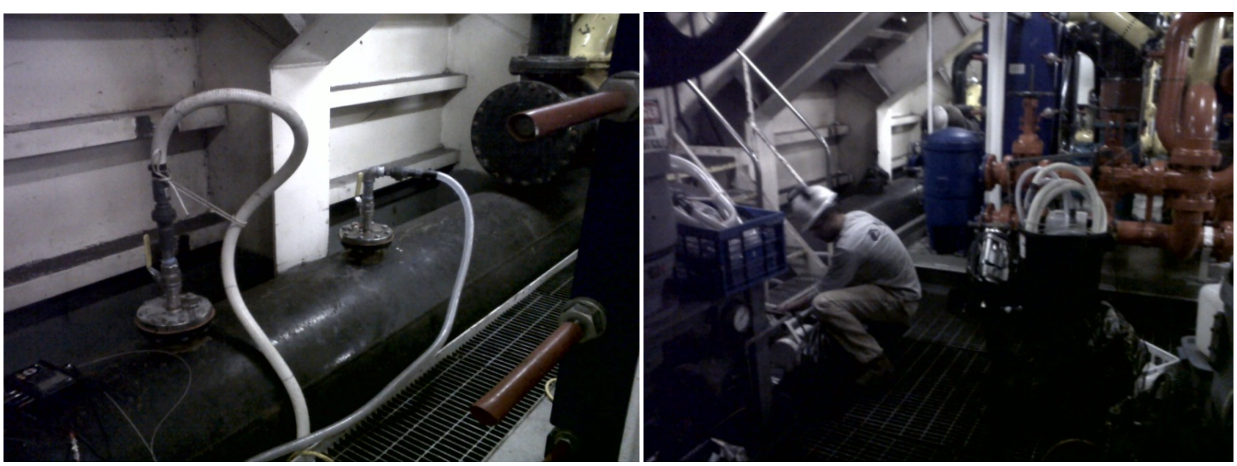

Figure 6. Photos of the Great Ships Initiative (GSI) Ship Discharge Monitoring System (SDMS) Trialed onboard a Commercially Operating Great Lakes Vessel.

[5] These methods would not be suitable to spot checks by regulatory organizations.

Table 3. Sampling Port installation on Vessels

Ship Name	Type (Salty, US Laker, Canadian Laker)
Niagara*	Canadian Laker
Richelieu	Canadian Laker
Tim S. Dool	Canadian Laker
Edwin H. Gott*	US Laker
Herbert R. Jackson	US Laker
James L. Oberstar	US Laker
Indiana Harbor*	US Laker
Federal Hunter	Salty

* Trialed

Based on project trials on a broad range of ship types, the method appears to be applicable to most ships which ply the Great Lakes. The costs of the exercise are dominated by a one-time investment in reusable operational equipment (approx. $45,000; Cangelosi *et al*., 2011). Installation of sample ports on ships is a relatively minor one-time expense ($2,000 to $5,000; Cangelosi *et al*., 2011)[6]. The U.S. Coast Guard and International Maritime Organization (IMO) require (e.g., USEPA, 2010; IMO, 2004) all ships to equip themselves with sample ports through which representative ballast samples can be retrieved will facilitate more comprehensive ballast discharge sample collection across ships over time.

Conclusion: *The GSI SDMS is a relatively low cost and scientifically valid means of collecting ballast uptake and discharge samples from ships that ply the Great Lakes.*

[6] Costs of sample collection and analysis are additional and largely dictated by the test plan under consideration, and the number of schedule changes associated with the ship visit.

- ***QUESTION 4: How many ships, which ones and how much water has to be sampled?***

The second challenge, which ships and how much water to sample, was outside the scope of this project. However, it is likely that a sampling plan involving site targeting similar to that applied to harbors above will be most efficient. NEMWI received subsequent funding from the GLPF to design an experimental approach to directly assess any relationship, for a given receiving water body, between rate of propagule discharge (release) and rate of establishment of invasive species (risk). The experimental approach includes a ship sampling design and methodology, and a harbor sampling design and methodology as well as the analytical methods for uniting the data from the two sampling exercises into a model which can identify any mathematical relationship between the two measured rates. This work will build on the project outcomes reported here and will further the effort to construct a feasible and effective monitoring program for ship-mediated harmful microbes in the Great Lakes. Validation studies are being conducted at two ports, Duluth-Superior Harbor and Two Harbors, Minnesota. The ship sampling plan is based on existing data on volumes of ballast water discharged to the harbors from various source regions (National Ballast Water Information Clearinghouse, NBIC, 2012). Figure 7 shows data for Duluth-Superior Harbor for 2012 (NBIC, 2012).

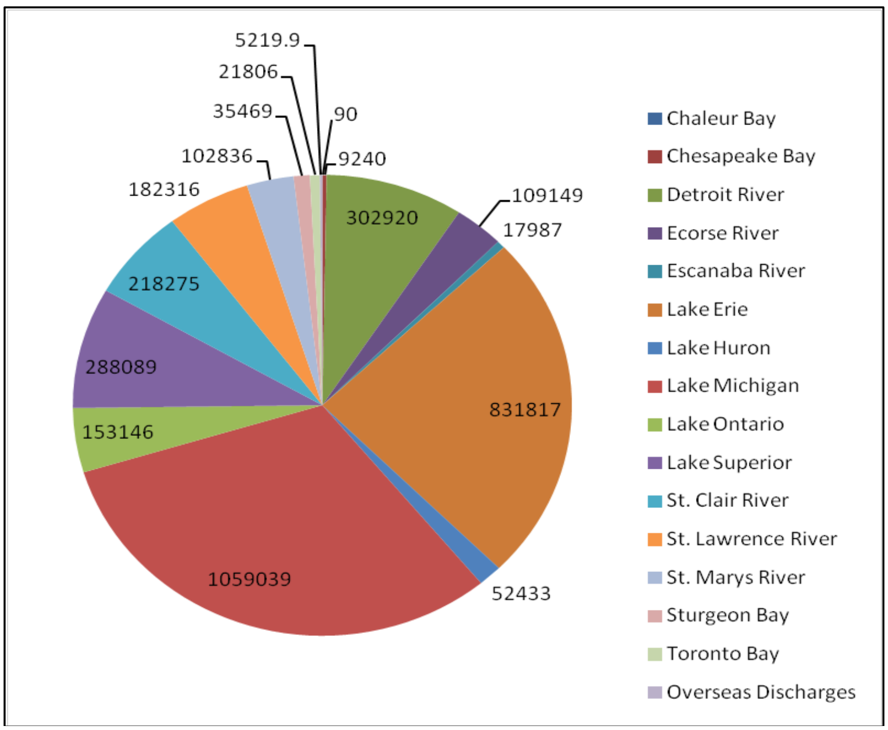

Figure 7. Metric Tons of Ballast Water Discharged into Duluth Superior Harbor in 2012.

Conclusion: *The number of ships, which ships and the volumes that must be sampled to effectively monitor harmful microbe discharges into a harbor has yet to be determined under the on-going NEMWI follow-on project, but an approach similar to the one described above for harbor sampling is likely best. NEMWI will provide a Note to the Coalitions sharing findings when they become available.*

4: What Would a Harmful Microbe Early Detection Monitoring Program in the Great Lakes Look Like?

Balancing competing interests of speed of valid reporting and reliability of interpretation for appropriate response in a Great Lakes harmful microbes monitoring regime will be challenging. A proposed approach to early detection and monitoring[7] based on input from expert participants in two Project Workshops is summarized in Table 4.

Table 4. Proposed Great Lakes Harbor Harmful Microbe Monitoring Approach: Attributes or Concepts

Program Element	Attribute or Concept
Purpose	Monitoring to build understanding, identify threats and risks, and allow proactive management planning.
Goal	Monitor existing and potentially introduced microbes with harmful consequences to the ecosystem, non-human organisms, and human uses of the Great Lakes.
Management structure	1. Governing Committee to set policy, direction, financing, and engage executive level representatives of relevant organizations. 2. Coordinating Organization that would manage activities and needs of the program. 3. Implementation Committee to handle technical matters, hold the science expertise, set quality standards for data and information, and interpret findings.
Sampling strategy	10 representative sites per lake emphasizing commercial harbors, recreational boat centers, current monitoring sites, high human use sites, invasion hotspots, and biological entry and exit points.
Sample collection	Fish, moribund taxa, and water are the targets for sampling. Fish: 60 specimens of three species and representative numbers of other species. Dead and moribund organisms should be opportunistically collected. Five 2 L water samples integrated to serve as a composite sample for a site.
Laboratory methods	Molecular procedures like qRT-PCR, cell culture, serology, and other techniques depending on target taxa for testing. There are no standardized methods for testing a variety of microbes.
Information management	Rapid posting of findings with the Implementation Committee providing first level interpretation and the Governing Committee approving information releases.

Three management groups are needed to oversee and operate the proposed approach: a governing committee; a coordinating organization; and an implementation committee.

A Governing Committee with representatives of states, provinces and federal agencies, ports, the shipping industry, and others, would build the annual program plan, arrange financing, identify response options, and make program policy decisions.

[7] The proposed focuses on fish and wildlife pathogens due to complex regulatory demands and costs associated with human pathogen research.

A Coordinating Organization (selected by Governing Committee) would synchronize tasks and manage activities like record keeping, report and data storage, communications, and rapid distribution of information.

An Implementation Committee, (selected by Governing Committee) comprising scientific expertise, would handle technical operations, set quality standards for data and information, and interpret findings for use by the Governing Committee. Functions include identification of threats for priority attention, organisms for targeting, sampling and analysis plans, assembling information for response action, and interpretation of results and findings. The committee should be independent of data collection and analysis entities to avoid conflicts of interest. Also, members should have fixed terms of service.

Critical program components will include:

Management-Accessible Outputs: High impact early detection monitoring must provide timely, reliable, and management-relevant interpretations of data in terms of policy- and management-relevant questions. An effective monitoring system must therefore include a specific plan for information release, notification contacts, and response recommendations. Further, the plan must include communications channels to identified responders in Canada and the U.S. responsible for management actions. The Implementation Committee could be charged with rapid posting of reliable data and first level interpretation. A new initiative coordinated by the International Joint Commission (IJC) Work Group on Aquatic Invasive Species Rapid Response could provide an existing framework for communication of outputs (Dupre, 2011).

Consistency and Continuity in Data Gathering and Interpretation: Collaborative approaches to gathering and interpreting data require consistent methods and clear decision criteria. The task of approving (and revising over time) these operative methods and criteria should fall to the Governing Committee, which should also approve all information releases. Consistent guidance for public outreach on microbial threats is equally important to support agency decisions and response management.

Searchable Archives: A long-term centralized database for use within the program and by others is critical for any eco-system relevant data. There will be rapid changes in analysis capabilities and target microbes. Both ship and harbor samples should be archived and clone libraries created to help assess new threats.

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Identification of standard operating procedures (SOPs), and a lead organization for this task, are critical. The database should include not only positive detections of microbe taxa but also sampling methodology and SOPs, sampling locations (GPS data), water depths, dates and times, sample handling and analysis methods, and other information. DNA samples should be routinely archived so that they are available for reanalysis as new methods and new pathogens emerge.

Program Development Support: Funding will be needed for experimentation, investigation, technology development, and modeling beyond the work of routine monitoring. Microbe monitoring in the Great Lakes is a new endeavor. Methods, tools, SOPs, and interpretation of results will evolve through time and especially at the start of program implementation. In particular, rapid development of molecular detection technology requires careful new method tracking and assimilation through time. Program support should afford flexibility to execute special investigations including development of predictive models and criteria signaling impending outbreaks or regional dispersal. This support will pay dividends in informing effective response capacity and alerting agencies and the public to emerging threats.

5: Findings and Conclusions

Ships can carry harmful microbes into and within the Great Lakes in untreated ballast water, but they are not the only vectors for such introductions and dispersals. This NEMWI project found early, reliable and basin-wide monitoring for the presence and dispersal of ship-mediated harmful microbes in the Great Lakes is feasible, particularly for known threats. Most valuable is early detection monitoring so that resource managers and industry know whether a harbor is affected by a harmful microbe before damage to fish, humans or infrastructure occurs, and before it is too late to undertake mitigation actions to attenuate spread. Early warning information will reduce unnecessary interruptions to shipping, and unnecessary impacts to the environment.

Genetic detection technology significantly speeds and simplifies the analysis burden once associated with a basin-wide microbe monitoring. Also, giving priority to target areas reduces effort while bringing important signals to bear. Similar approaches can be used in ship sampling.

Any data and information must reach decision-makers quickly to enable feasible management actions, yet it must be reliable. A three tier structure for collaborative information generation, management and communication will be required.

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