Great Lakes and Lake Champlain Invasive Species Program

Great Lakes Ballast Water Research and Development Plan

Prepared by
Prihoda, K.R.¹; TenEyck, M.C.¹; Thomson, T.²; and Junemann, C.E.²

Prepared for
United States Environmental Protection Agency
Office of Water
Washington, D.C.

U.S. Department of Transportation
Maritime Administration

¹ Lake Superior Research Institute’s Great Waters Research Collaborative; University of Wisconsin-Superior; Superior, WI
² United States Department of Transportation Maritime Administration; Washington, D.C.
# TABLE OF CONTENTS

List of Figures ................................................................................................................................. 4
Purpose ............................................................................................................................................... 5
Great Lakes Ballast Water R&D Plan Summary ............................................................................. 8
Ballast Water R&D Plan Timeline .................................................................................................. 12
Great Lakes and Lake Champlain Invasive Species Program Research Coordination and Review .... 13
Stakeholder Group Involvement ....................................................................................................... 14

A. Approach and Objectives ........................................................................................................... 14
   Objective 1: Formation of Ballast Water R&D Plan Stakeholder Group and Kick-Off Meeting ...... 14
   Objective 2: Formation of Data Working Group and Mining, Sharing, and Compiling Existing Data... 15
   Objective 3: Engaging Stakeholders during R&D Plan Implementation ....................................... 15
B. Timeline ....................................................................................................................................... 15

I. Research Area 1: Identification of Methods/Alternatives and Assessment of Cost for Great Lakes Ballast Water Management .............................................................................................................. 16
A. Research Approach and Objectives .......................................................................................... 17
   Objective 1: Determination of Operational Characteristics of Commercial Vessels Trading within the Great Lakes System ........................................................................................................ 17
   Objective 2: Land-Based Evaluation of the Effectiveness of IMO Compliant and U.S. Coast Guard Type Approved BWMS in Great Lakes Water .......................................................... 19
   Objective 3: Shipboard Evaluation of the Effectiveness of IMO Compliant and U.S. Coast Guard Type Approved BWMS in Great Lakes Water .............................................................. 21
   Objective 4: Evaluating the Effectiveness of Ballast Water Best Management Practices Including Hybrid Solutions ........................................................................................................ 22
   Objective 5: Evaluating the Feasibility and Significant Impacts of Ballast Water Reception Facilities within the Great Lakes .................................................................................................. 26
   Objective 6: Assessing the Cost of Ballast Water Management Strategies on Commercial Vessels Operating Exclusively within the Great Lakes System ........................................... 27
B. Timeline ....................................................................................................................................... 28

II. Research Area 2: Toward Development of a Great Lakes Relevant BWMS Testing Protocol ....... 29
A. Research Approach and Objectives .......................................................................................... 34
   Objective 1: Characterizing BWMS Challenge Conditions in the Great Lakes System ............... 34
   Objective 2: Evaluating Alternative/Emerging Sample Analysis Methods for Ballast Water Treatment Technology Testing ...................................................................................................... 36
   Objective 3: Development of a Great Lakes-Adapted Protocol for Verification of BWMS .......... 37
III. Research Area 3: Accelerating Development of Emerging Ballast Water Treatment Technologies

A. Research Approach and Objectives

Objective 1: Acceleration of Ballast Water Treatment Technology Development

Objective 2: Research and Development Testing for Emerging Ballast Water Treatment Technologies

B. Timeline

III. Research Area 3: Accelerating Development of Emerging Ballast Water Treatment Technologies

A. Research Approach and Objectives

Objective 1: Acceleration of Ballast Water Treatment Technology Development

Objective 2: Research and Development Testing for Emerging Ballast Water Treatment Technologies

B. Timeline

IV. Research Area 4: Development of Ballast Water Indicative Monitoring Methods

A. Research Approach and Objectives

Objective 1: Development of a Method to Collect Representative Ballast Water Discharge Samples Onboard Great Lakes Commercial Vessels

Objective 2: Great Lakes Verification of Ballast Water Indicative Monitoring Tools

B. Timeline

IV. Research Area 4: Development of Ballast Water Indicative Monitoring Methods

A. Research Approach and Objectives

Objective 1: Development of a Method to Collect Representative Ballast Water Discharge Samples Onboard Great Lakes Commercial Vessels

Objective 2: Great Lakes Verification of Ballast Water Indicative Monitoring Tools

B. Timeline

V. Research Area 5: Assessing the Risk of Aquatic Nuisance Species Transfer from Ballast Water Discharge

A. Research Approach and Objectives

Objective 1: Establishment of Great Lakes Focal Ports to Determine Interlake Transfer

Objective 2: Using Semi-Field Methodologies to Determine the Impact of ANS Reduction in Managed Ballast Water

B. Timeline

V. Research Area 5: Assessing the Risk of Aquatic Nuisance Species Transfer from Ballast Water Discharge

A. Research Approach and Objectives

Objective 1: Establishment of Great Lakes Focal Ports to Determine Interlake Transfer

Objective 2: Using Semi-Field Methodologies to Determine the Impact of ANS Reduction in Managed Ballast Water

B. Timeline

VI. Programmatic Capability and Past Performance

VII. References

VIII. Great Lakes Ballast Water R&D Plan Deliverables
LIST OF FIGURES

Figure 1. Great Lakes Ballast Water Research and Development Plan Five-Year Timeline by Federal Fiscal Year with Start Date, Duration (in working days), and End Date for each Proposed Project. The black bars represent the timing associated with the adjacent Research Area (duration on the right includes all projects within that Research Area), and the green bars represent the timing associated with each proposed project within that Research Area. The light-colored arrows represent links between projects within the R&D Plan. ................................................................. 12

Figure 2. Timing of Tasks Associated with Stakeholder Group Involvement in the Great Lakes Ballast Water R&D Plan. ........................................................................................................................................ 15


Figure 4. Timing, by Federal Fiscal Year, of Projects Implemented under Research Area 1 of the Great Lakes Ballast Water R&D Plan with Project Start Date, Duration (in working days), and End Date........... 28

Figure 5. Protist Densities (cells/mL) in Samples Collected from Montreal Pier Facility in Summer 2013 (Author Credit: Euan Reavie, 2013). Grey-Shaded Areas Representing Density of Protist Propagules ≥5 µm in any Visible Dimension and Black-Shaded Areas Representing Density of Protist Propagules ≥10 µm in Minimum Dimension................................................................. 30

Figure 6. Figure from Reavie & Cangelosi (2020) Showing the Protist Cell Size Distribution, by Density, in Samples Collected over 14 Years throughout the Great Lakes. Boxes represent the lower and upper quartiles, whiskers represent the 1.5 interquartile distance from the lower and upper quartiles, and small circles are outliers.................................................................................. 31

Figure 7. Photomicrographs (Paerl, 2018) of Coccoid and Filamentous Cyanobacteria Genera (a) Microcystis spp.; (b) Synechococcus sp.; (c) Oscillatoria sp.; (d) Lyngbya sp.; (e) Dolichospermum sp.; (f) Nodularia sp. From Paerl et al., 2018. Note that (a), (c), and (e) are freshwater species, while (b), (d), and (f) are marine species........................................................................................................... 32

Figure 8. Timing, by Federal Fiscal Year, of Projects Implemented under Research Area 2 of the Great Lakes Ballast Water R&D Plan with Project Start Date, Duration (in working days), and End Date........... 38

Figure 9. Timing, by Federal Fiscal Year, of Projects Implemented under Research Area 3 of the Great Lakes Ballast Water R&D Plan with Project Start Date, Duration (in working days), and End Date........... 40

Figure 10. Timing, by Federal Fiscal Year, of Projects Implemented under Research Area 4 of the Great Lakes Ballast Water R&D Plan with Project Start Date, Duration (in working days), and End Date........... 43

Figure 11. Risk-Release Relationship Curves as Modified from Ruiz and Carlton (2003). Output from Research Area 5 - Project 2 will result in similar data for a variety of freshwater taxa, and these curves will be overlaid by the propagule data collected during Research Area 1 – Project 1 .................. 47

Figure 12. Timing, by Federal Fiscal Year, of Projects Implemented under Research Area 5 of the Great Lakes Ballast Water R&D Plan with Project Start Date, Duration (in working days), and End Date........... 47
PURPOSE

The Vessel Incidental Discharge Act of 2018 (VIDA) was passed into law as part of the Frank LoBiondo Coast Guard Authorization Act of 2018 and established the Great Lakes and Lake Champlain Invasive Species Program (GLLCISP). The LLCISP has several stated purposes related to ballast water management including:

- Early detection monitoring of aquatic nuisance species (ANS) within the Great Lakes and Lake Champlain Systems;
- Rapid response to ANS introduction and transport within the Great Lakes and Lake Champlain Systems;
- Monitor ballast water operations likely to be contributing to the introduction or spread of ANS; and
- Develop, achieve type approval for, and pilot shipboard or land-based ballast water management systems (BWMS) applicable to commercial vessels operating solely within the Great Lakes and Lake Champlain Systems.

Although several vectors for introduction of ANS exist within the Great Lakes (e.g., organisms in trade and water recreation), it is believed that commercial shipping accounts for approximately 60% of known invasions since the opening of the St. Lawrence Seaway in 1959 (Pagnucco et al., 2015). Commercial vessels that operate exclusively within the Great Lakes System (i.e., Laker vessels) are not major contributors of novel invaders into the Great Lakes. Less than 1% of ballast water discharged in the Great Lakes by Laker vessels originates from ports in the St. Lawrence River (Rup et al., 2010). However, Laker vessels do pose a risk of accelerating the secondary spread of introduced ANS within the Great Lakes (Rup et al., 2010), especially given the high frequency of ballast water discharge events, the large volume of ballast water discharged per event, and short voyage times that ensure discharge of relatively healthy propagules (Rup et al., 2010). A ballast water monitoring study conducted in 2017 onboard United States and Canadian Laker vessels documented five ANS species not previously reported in Lake Superior in samples collected from ballast water being discharged to commercial ports within western Lake Superior. The documented ANS species included *Hemimysis anomala*, *Nitrokra hibernica*, *Heteropsyllus nunni*, *Schizopera borutzkyi*, and *Thermocyclops crassus* (Cangelosi et al., 2018).

Questions remain regarding the acceptable level of environmental risk associated with discharge of ballast water from Laker vessels and the methods available for these vessels to manage their ballast water to reduce environmental risk. Risk associated with ANS establishment is a function of many variables, including number of propagules and frequency/magnitude of ballast discharge events (i.e., propagule pressure), and the relative differences between source and receiving environments (Aliff et al., 2018). Congress established the LLCISP in order to assess the risk of ANS introduction and spread via ballast water as a vector within the Great Lakes System and identify and develop ballast water management practices for use by commercial vessels as necessary to prevent the spread of ANS within this System.

In many cases, environmental risk (i.e., reduction of propagules) associated with the ballast water vector can be substantially reduced through installation and operation of a BWMS, with the perceived protective effect established globally through a numeric discharge standard (2013 VGP, 33 CFR Part 151, IMO D-2 Standard). However, Great Lakes water quality (e.g., low salinity, low temperature, high...
turbidity) and the unique operations of Laker vessels (e.g., high ballast flow rates, large ballast volumes, short voyage times) have proven difficult obstacles to overcome in the development of effective and practicable ballast water management technologies for use on Laker vessels. In addition, the Great Lakes market is not as attractive to BWMS developers because it represents a very small fraction of the total global market. According to Burroughs (2019), the worldwide fleet with a deadweight tonnage (DWT) of >2,000 DWT is approximately 53,600 vessels, whereas the number of vessels operating exclusively in the Great Lakes System with >2,000 DWT is approximately 50 (0.09% of the worldwide fleet; T. Rayburn, personnel communication, 26 June 2019). Further, a substantial portion of these approximately 50 vessels are uniquely constructed, unlike seagoing ships of similar size, making installation and operation of a BWMS more complicated. Historically, targeted development of Great Lakes-applicable BWMS has been done by academic researchers and small start-up companies that do not have the capital needed to fully develop their technology for large-scale operation and testing. All these challenges and issues have led to Great Lakes-relevant technology development that is very slow in comparison with technologies developed for seagoing vessels.

Given these realities and in the context of this plan, an important first question is whether existing type approved BWMS can treat Great Lakes ballast water effectively to meet the current discharge standard, either using existing test methods or a method adjusted to reflect the different environmental conditions of the Great Lakes and the operational realities of Laker vessels. Depending on the outcome of that research, development of a discharge standard that is different than the national standard may be more appropriate for vessels operating exclusively in the Great Lakes System because this different standard would be based on performance of the best available technology economically achievable in the Great Lakes System. Longer term, emerging technologies may be identified that can meet the current (national) discharge standard. In the interim, there may be best management practices, other methods, and technologies available that are capable of effectively reducing ANS risk associated with ballast water discharges in the Great Lakes System.

Per VIDA, the primary goal of this R&D Plan is to identify approaches, methods, and best available technologies that are effective at reducing propagules in Great Lakes ballast water, thereby decreasing the environmental risk associated with the ballast water vector from vessels operating exclusively within the Great Lakes System. Coincidently, the projects outlined in this R&D Plan will also consider the implications of these ballast water management approaches for vessels that operate in the Great Lakes System, but not solely within these waters. For example, a seagoing vessel that may visit the Great Lakes once a year may still be faced with having to treat Great Lakes water using a BWMS that has never been tested in Great Lakes water quality and biological conditions. In addressing these goals, ballast water treatment will be considered in addition to alternative approaches, such as ballast water best management practices. Importantly, the research projects outlined in this plan will provide essential scientific and technical information that will support science-based decisions during the VIDA rulemaking and implementation processes.

The research questions addressed within this R&D Plan assume the following:

1. The focus of the research is on the ballast water vector exclusively.
2. The primary research area is the waters of the Great Lakes System, defined in the U.S. Clean Water Act §118(a)(3) to mean all the streams, rivers, lakes, and other bodies of water within the drainage basin of the Great Lakes. “Great Lakes” means Lake Ontario, Lake Erie, Lake Huron
(including Lake St. Clair), Lake Michigan, and Lake Superior, and the connecting channels (Saint Mary’s River, Saint Clair River, Detroit River, Niagara River, and Saint Lawrence River to the Canadian Border; Clean Water Act, 2002). Lake Champlain is not included in the study area. However, by addressing the ballast water vector of ANS introduction and secondary spread in the Great Lakes System, this plan addresses the primary source of ANS introductions into Lake Champlain (Lake Champlain Steering Committee, 2018).

3. Research objectives will address ballast water associated with United States and Canadian commercial vessels having a cargo-carrying capacity of greater than 1,600 gross registered tons and trading within the Great Lakes System (Vessel General Permit for Discharges Incidental to the Normal Operation of Vessels (VGP), 2013). The primary focus will be on such vessels operating exclusively within the Great Lakes System, but will also address other vessels that do not operate exclusively within these waters but that do uptake or discharge ballast water in the Great Lakes System.

4. The projects described in this plan will be implemented over a five-year timeframe; any reduction in resources (i.e., time and/or funding) would require prioritization of the proposed work and a commensurate rescoping of each research area.

5. The data generated during the implementation of this R&D Plan is intended to be considered during the five-year (or sooner, if appropriate) review of the ballast water discharge standards established under VIDA by the U.S. EPA and will inform any post-review revision of established discharge standards.

6. This R&D Plan is a living document, and the proposed projects may be revised to reflect the outcomes of project planning meetings (see Stakeholder Group Involvement).

7. The University of Wisconsin-Superior’s Lake Superior Research Institute (UWS-LSRI) will lead and manage the implementation of the projects described in this R&D Plan as part of the Great Waters Research Collaborative (GWRC), in cooperation with and with oversight from, the U.S. Department of Transportation Maritime Administration (MARAD). All project planning and implementation activities will be closely coordinated with, and communicated to, the U.S. EPA Office of Water, U.S. EPA Great Lakes National Program Office, the United States Coast Guard (U.S. Coast Guard), and their subcontractors (as needed).

8. The projects described in this plan will build on ballast water research conducted by the U.S. EPA Office of Research and Development, U.S. Coast Guard Research and Development Center, Naval Research Laboratory, Canada’s Department of Fisheries and Oceans, and other institutions.
# Great Lakes Ballast Water R&D Plan Summary

<table>
<thead>
<tr>
<th>Research Area</th>
<th>Objective</th>
<th>Key Research Question(s) Addressed by Project</th>
<th>Project(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>STAKEHOLDER GROUP INVOLVEMENT</td>
<td><strong>Objective 1:</strong> Formation of the Ballast Water R&amp;D Stakeholder Group and Kick-Off Meeting</td>
<td>1. Which organizations are key for input on the goals and direction of the R&amp;D plan?</td>
<td>1: Form Stakeholder Group/Kick-Off</td>
</tr>
</tbody>
</table>
| | **Objective 2:** Formation of Data Working Group and Mining, Sharing, and Compiling Existing Data | 1. Which stakeholder group member organizations should form the data working group?  
2. What is the process for mining, compiling, and sharing critical historical data that will inform project design?  
3. Based upon published literature and data from the working group, what are the data gaps that must be addressed through R&D Plan projects? | 2: Form Data Working Group/Data Mining & Sharing |
| | **Objective 3:** Engaging Stakeholders during R&D Plan Implementation | 1. Is the Ballast Water R&D Plan on track and are there any necessary updates based on the current state of affairs? | 3: Stakeholder Group Engagement |
| RESEARCH AREA 1: IDENTIFICATION OF METHODS/ALTERNATIVES AND ASSESSMENT OF COST FOR GREAT LAKES BALLAST WATER MANAGEMENT | **Objective 1:** Determination of Operational Characteristics of Commercial Vessels Trading within the Great Lakes System | 1. What are the typical (and more challenging) ballasting operational characteristics of United States and Canadian-flag commercial vessels that trade within the Great Lakes? | 1: Determining Operational Characteristics of Great Lakes Vessels |
| | **Objective 2:** Land-Based Evaluation of the Effectiveness of IMO Compliant and U.S. Coast Guard Type Approved BWMS in Great Lakes Water | 1. Are there existing BWMS available on the global market (either type-approved under the IMO Convention or by the U.S. Coast Guard) that can treat Great Lakes ballast water effectively to meet the current U.S. discharge standards using existing test methods (i.e., *Generic Protocol for the Verification of Ballast Water Treatment Technology; U.S. EPA, 2010*)?  
2. When evaluated at a land-based scale using the newly developed, Great Lakes-adapted protocol (see Research Area 2, Objective 3), how do these BWMS perform?  
   a. What is the level of ANS reduction that can be achieved in the Great Lakes based on land-based testing? | 2: Land-Based BWMS Evaluation |
<table>
<thead>
<tr>
<th>Research Area</th>
<th>Objective</th>
<th>Key Research Question(s) Addressed by Project</th>
<th>Project(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective 3:</td>
<td>Shipboard</td>
<td>1. Are there existing BWMS available on the</td>
<td>3: Shipboard</td>
</tr>
<tr>
<td></td>
<td>Evaluation of the Effectiveness of IMO</td>
<td>global market (either type-approved under the</td>
<td>BWMS</td>
</tr>
<tr>
<td></td>
<td>of IMO Compliant and U.S. Coast Guard</td>
<td>IMO Convention or by the U.S. Coast Guard)</td>
<td>Evaluation</td>
</tr>
<tr>
<td></td>
<td>Type Approved BWMS in Great Lakes Water</td>
<td>that can treat Great Lakes ballast water</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>effectively to meet the current discharge</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>standards using existing test methods (i.e.,</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>ETV Protocol).</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. When evaluated at a shipboard scale using</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>the newly developed, Great Lakes-adapted</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>protocol, how do these BWMS perform?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>a. What is the level of ANS reduction that</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>can be achieved based on shipboard testing?</td>
<td></td>
</tr>
<tr>
<td>Objective 4:</td>
<td>Evaluating the Effectiveness of Ballast</td>
<td>1. Can filtration technologies and practices</td>
<td>4: Ballast</td>
</tr>
<tr>
<td></td>
<td>Water Best Management Practices Including</td>
<td>be improved for ballast water management in</td>
<td>Water Filter</td>
</tr>
<tr>
<td></td>
<td>Hybrid Solutions</td>
<td>the Great Lakes?</td>
<td>Performance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. What are the efficacies of potential,</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>promising BMPs in reducing the</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>concentration of ANS in ballast water</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>discharged within the Great Lakes?</td>
<td></td>
</tr>
<tr>
<td>Objective 5:</td>
<td>Evaluating the Feasibility and Significant</td>
<td>1. What is the feasibility, economic, and</td>
<td>6: Feasibility</td>
</tr>
<tr>
<td></td>
<td>and Significant Impacts of Ballast Water</td>
<td>environmental impact of reception facilities</td>
<td>Study of</td>
</tr>
<tr>
<td></td>
<td>Reception Facilities within the Great Lakes</td>
<td>if utilized within the Great Lakes under</td>
<td>Reception</td>
</tr>
<tr>
<td></td>
<td>System</td>
<td>certain scenarios or locations?</td>
<td>Facility</td>
</tr>
<tr>
<td></td>
<td>Management Strategies on Commercial</td>
<td>compare in terms of ANS reductions and cost</td>
<td>Strategy</td>
</tr>
<tr>
<td></td>
<td>Vessels Operating Exclusively within the</td>
<td>for installation and operation?</td>
<td>Cost</td>
</tr>
<tr>
<td></td>
<td>Great Lakes System</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RESEARCH AREA 2:</td>
<td>Characterizing BWMS Challenge Conditions</td>
<td>1. What are the ranges of living organism</td>
<td>1: Characterize</td>
</tr>
<tr>
<td></td>
<td>in the Great Lakes System</td>
<td>densities/composition and water quality</td>
<td>BWMS Challenge</td>
</tr>
<tr>
<td></td>
<td></td>
<td>parameters found within Great Lakes</td>
<td>Conditions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>commercial ports where cargo off-loading/</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>ballasting occurs?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Given #1, are the minimum challenge</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>condition requirements specified in the</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>ETV Protocol appropriate (i.e., challenging,</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>but not rare natural environmental</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>conditions) for evaluating BWMS performance</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>in the Great Lakes?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1. What are the potential emerging or</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>alternative viability assessment methods for</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>BWMS biological efficacy evaluation, and</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>how effective are those methods?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>a. Are there viability assessment methods</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>that can be utilized for the Great Lakes in</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>order to evaluate treatment effects on</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>planktonic organisms?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>b. Is it feasible to implement these</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>methods during land-based evaluation of</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>BWMS?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Research Area</td>
<td>Objective</td>
<td>Key Research Question(s) Addressed by Project</td>
<td>Project(s)</td>
</tr>
<tr>
<td>---------------</td>
<td>-----------</td>
<td>---------------------------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>Research Area</td>
<td>Objective 3: Development of a Great Lakes-Adapted Protocol for Verification of BWMS</td>
<td>1. What changes to the existing ETV Protocol are appropriate for its use to evaluate BWMS effectiveness for Great Lakes vessels?</td>
<td>5: Protocol Development</td>
</tr>
<tr>
<td>Research Area 3: ACCELERATING DEVELOPMENT OF EMERGING BALLAST WATER TREATMENT TECHNOLOGIES</td>
<td>Objective 1: Acceleration of Ballast Water Treatment Technology Development</td>
<td>1. What resources exist or can be provided to accelerate bringing Great Lakes-specific solutions to market?</td>
<td>1: Accelerate Technology Development</td>
</tr>
<tr>
<td></td>
<td>Objective 2: Research and Development Testing for Emerging Ballast Water Treatment Technologies</td>
<td>1. Are there promising, emerging technologies for treating ballast water that may be candidates for undergoing Great-Lakes-specific testing, including using a Great Lakes-adapted protocol? 2. Are there promising, emerging technologies capable of treating waters in addition to Great Lakes water?</td>
<td>2: R&amp;D Testing Emerging Technologies</td>
</tr>
<tr>
<td>Research Area 4: DEVELOPMENT OF BALLAST WATER INDICATIVE MONITORING METHODS</td>
<td>Objective 1: Development of a Method to Collect Representative Ballast Water Discharge Samples Onboard Great Lakes Commercial Vessels</td>
<td>1. What are the most practical indicative monitoring methods to determine effectiveness of a variety of ballast water management strategies used by Great Lakes vessels?</td>
<td>1: Indicative Monitoring Sample Method Development</td>
</tr>
<tr>
<td>Research Area 5: ASSESSING THE RISK OF AQUATIC NUISANCE SPECIES TRANSFER FROM BALLAST WATER DISCHARGE</td>
<td>Objective 1: Establishment of Great Lakes Focal Ports to Determine Interlake Transfer</td>
<td>1. What is the risk of ANS interlake transfer via ballast water? 2. What is the relative ANS loading associated with the various vessel voyage patterns within the Great Lakes, and are there significant differences that may warrant different technologies or practices for these different situations?</td>
<td>1: Quantifying ANS Transfer</td>
</tr>
<tr>
<td>Research Area</td>
<td>Objective</td>
<td>Key Research Question(s) Addressed by Project</td>
<td>Project(s)</td>
</tr>
<tr>
<td>---------------</td>
<td>-----------</td>
<td>---------------------------------------------</td>
<td>------------</td>
</tr>
<tr>
<td><strong>Objective 2</strong>: Using Semi-Field Methodologies to Determine the Impact of ANS Reduction in Managed Ballast Water</td>
<td>1. Using existing semi-field methodologies and a variety of freshwater taxonomic groups, can the impact of ANS reduction in Great Lakes ballast water be determined under a variety of ballast water management scenarios?</td>
<td>2: Determining Impact of ANS Reduction</td>
<td></td>
</tr>
</tbody>
</table>
The Great Lakes Ballast Water R&D Plan will be implemented over a period of five federal fiscal years, approximately 01 October 2020 to 30 September 2025 (Figure 1). There are five research areas outlined in the plan, and a total of 21 projects (including the stakeholder group activities). Many of the 21 projects outlined in the R&D Plan will be designed and implemented during the first two years because the data generated in these critical years of the plan will form the foundation for subsequent projects.

![Figure 1. Great Lakes Ballast Water Research and Development Plan Five-Year Timeline by Federal Fiscal Year with Start Date, Duration (in working days), and End Date for each Proposed Project. The black bars represent the timing associated with the adjacent Research Area (duration on the right includes all projects within that Research Area), and the green bars represent the timing associated with each proposed project within that Research Area. The light-colored arrows represent links between projects within the R&D Plan.](image)
GREAT LAKES AND LAKE CHAMplain INVASIVE SPECIES PROGRAM RESEARCH COORDINATION AND REVIEW

Upon receipt of funding, the U.S. Department of Transportation Maritime Administration will assemble a GLLCISP Review Committee, that will:

1. Participate in quarterly progress meetings during the five-year implementation of this R&D Plan
2. Participate in the semi-annual U.S. Coast Guard – U.S. Naval Research Lab program review (associated with ballast water/aquatic nuisance species research)

These meetings will ensure regular communication and close coordination with agencies conducting ballast water research projects within the Great Lakes System, and eliminate any duplication of effort during project implementation.

At a minimum, the Review Committee will consist of representatives from the following organizations: U.S. EPA Office of Water, U.S. EPA Great Lakes National Program Office, U.S. Coast Guard Environmental Standards Division, U.S. Coast Guard Research and Development Center, and the Naval Research Laboratory.
STAKEHOLDER GROUP INVOLVEMENT

Given the magnitude, complexity, and importance of this Ballast Water R&D Plan, stakeholder involvement will be critical to each project’s successful design, implementation, and dissemination of project results. It is recommended that a stakeholder group be engaged as early as possible in the design of the projects proposed within this plan, and that this group be involved throughout the five-year implementation period. The overarching objectives in this plan will likely not change; however, the proposed projects outlined in this Ballast Water R&D Plan will evolve from conceptual project ideas (as currently described) to separate project plans containing scientifically defensible experimental design and fully-formed implementation details. Each of the individual project plans will incorporate feedback received from stakeholder group meetings. Members of the stakeholder group may serve as project partners and supply critical historical data that will be used to identify data gaps and research needs (see Objective 2 below). Throughout the implementation of the plan, stakeholder involvement will be strictly advisory in nature. The role of the stakeholder group is not that of a decision-making body; all project design, implementation, data interpretation decisions, and recommendations will be made by the project principal investigators in cooperation with MARAD. Stakeholder involvement will ensure that the projects described in this plan best serve the needs of the Great Lakes region. It will also promote an inclusive, transparent, and collaborative process throughout project plan development and implementation.

A. APPROACH AND OBJECTIVES

Objective 1: Formation of Ballast Water R&D Plan Stakeholder Group and Kick-Off Meeting

Key Question: Which organizations are key for input on the goals and direction of the R&D Plan?

MARAD and UW-Superior will lead the formation of the stakeholder group. The stakeholder group will include the U.S. EPA’s Office of Water and Great Lakes National Program Office (GLNPO), and the GLLCISP collaborators listed in VIDA including U.S. Fish and Wildlife Service, National Oceanic and Atmospheric Administration (including Great Lakes Environmental Research Laboratory and Great Lakes Aquatic Nonindigenous Species Information System), U.S. Geological Survey, and U.S. Coast Guard. The stakeholder group should be binational in nature, and include representation from additional organizations in the Great Lakes region, including: Transport Canada, Department of Fisheries and Oceans Canada, Tribal agencies, Great Lakes states and provinces, Great Lakes Commission (including Great Lakes Panel on Aquatic Nuisance Species), U.S. and Canadian shipping companies with vessels operating in the Great Lakes System, representatives from the ballast water equipment manufacturing industry, Great Lakes ports, St. Lawrence Seaway organizations, non-governmental/policy organizations, and academic researchers.

Within three to six months of receiving approval for public release of the R&D Plan from the U.S. EPA’s Office of Water, a stakeholder kick-off meeting will be held. This meeting will be led jointly by MARAD and UWS-LSRI, and its purpose will be to introduce the stakeholder group to the plan’s objectives and projects and solicit initial feedback from stakeholders on project design and planning with a focus on the first year of the five-year implementation period.
Objective 2: Formation of Data Working Group and Mining, Sharing, and Compiling Existing Data

Key Questions:

1. Which stakeholder member organizations should form the data working group?
2. What is the process for mining, compiling, and sharing critical historical data that will inform project design?
3. Based upon published literature and data from the working group, what are the data gaps that must be addressed through R&D Plan projects?

Ahead of the kick-off meeting, a working group will be formed consisting of stakeholder member organizations who may have data that would feed directly into the projects described in this R&D Plan. This working group will meet separately in conjunction with the kick-off meeting and will be very engaged during the first year of R&D Plan implementation. During this initial working group meeting, the process by which these data will be mined, compiled, and shared will be discussed and agreed upon. The details of this agreement will be shared with the larger group of stakeholders. Once all data from the working group has been shared, data gaps will be identified and shared with the larger group of stakeholders, and this R&D Plan will be revised to reflect any necessary changes to project design.

Objective 3: Engaging Stakeholders during R&D Plan Implementation

Key Question: Is the Ballast Water R&D Plan on track and are there any necessary updates based on the current state of affairs?

Following the initial kick-off meeting, the stakeholder group will meet twice each year over the five-year R&D Plan implementation period. The first meeting, to take place during the first quarter of each calendar year, will have a project planning and experimental design focus. Project principal investigators will outline each of the projects planned for that year and will receive input from the stakeholder group regarding research questions, data needs, experimental design, potential project partners, etc. The principal investigators will incorporate all applicable feedback into that year’s project plans. The second annual meeting, to take place during the third quarter of each calendar year, will provide an opportunity for the project principal investigators to present preliminary project results to the stakeholder group.

B. Timeline

Figure 2 outlines the planned timing for the tasks associated with the stakeholder group.

Figure 2. Timing of Tasks Associated with Stakeholder Group Involvement in the Great Lakes Ballast Water R&D Plan.
I. RESEARCH AREA 1: IDENTIFICATION OF METHODS/ALTERNATIVES AND ASSESSMENT OF COST FOR GREAT LAKES BALLAST WATER MANAGEMENT

Waterhouse et al. (2013) used ballast discharge data and voyage patterns to identify five vessel types that represent all U.S.-flag vessels operating exclusively within the Great Lakes System. Vessel types identified are as follows:

- Intermediate to Large Capacity 1000’: Primary trade route from western Lake Superior to southern Lake Michigan or Lake Erie;
- Large Capacity 1000’: Primary trade route from western Lake Superior to southern Lake Michigan and Lake Huron;
- Older, Smaller Capacity 700’ to 800’: Trading routes from southern Lake Michigan to northern Lake Huron and western Lake Erie;
- Newer, Intermediate Capacity 800’ to 900’: Trading routes vary from northern Lake Michigan and northwest Lake Huron to southern Lake Michigan, southern Lake Huron, and western Lake Erie; and
- Small Capacity River Class 600’ to 700’: Several varied long (e.g., northern Lake Michigan to western Lake Erie) and short (e.g., within western Lake Erie) trading routes.

The Laker fleet, represented by these five vessels types, has unique operating characteristics that make it distinct from the global fleet. Ballast water management options that are broadly applicable to many vessels in the global fleet may not be appropriate for the relatively small number of vessels constructed for the specific conditions in the Great Lakes that comprise the Laker fleet. Relative to seagoing vessels, voyage routes for Laker vessels are short (i.e., 8 to 72 hours), and the vessels are designed for high-efficiency cargo loading and unloading with very high-capacity ballast flow rates with respect to vessel size (i.e., 2,000 to 10,000 m³/hour; Wren et al., 2013). It is necessary to determine the operating characteristics of the five vessel types identified by (Waterhouse et al., 2013), including Canadian-flag vessels, in order to identify ballast management options that may be applicable to vessels operating exclusively in the Great Lakes System.

One study (Mueller & Dooley, 2017) found that no U.S. Coast Guard type approval testing of market-available BWMS has been conducted within the Great Lakes System. To our knowledge, there has been one land-based U.S. Coast Guard type approval test of a BWMS that took place within the Great Lakes (Cangelosi et al., 2018b), and one shipboard type approval test of a second BWMS that included two trials within the Great Lakes (Cangelosi et al., 2017). This lack of data begs the question of whether market-available, type-approved BWMS were tested under Great Lakes relevant conditions during type approval testing. Evaluation of BWMS in the Great Lakes must be conducted in order to answer this important question.

There may be approaches to Great Lakes ballast water management that could be utilized in advance of, and possibly in lieu of, successful development (and testing) of BWMS for use on board certain Great Lakes vessels. Even with installation of an operational BWMS on board a Great Lakes vessel, there may be instances of BWMS malfunction in which another approach is needed to reduce ANS discharges. There may also be situations in which a BWMS is rendered ineffective or inoperable due to challenging biological/water quality conditions within a port (e.g., during infrequent weather conditions). Increasing
frequency of extreme weather events and resulting significant overland flooding will increase the likelihood of these challenging water quality conditions within Great Lakes commercial ports in future years. Great Lakes vessel owners and operators need a suite of management options that can be effectively utilized to reduce ANS discharges. These approaches may consist of ballast water best management practices, including emergency/contingency ballast water treatment and management alternatives. It is critical that this suite of tools be supported by empirical data, collected within the Great Lakes System to ensure accurate evaluation of these management options.

In addition to on board ballast water management options, there may be alternative, shore- or barge-based reception facilities that could be utilized by Laker vessels. Wren et al. (2013) examined several options with respect to the U.S.-flag Laker fleet, including publicly-owned treatment works and dedicated reception facilities, and found that either option may be a viable solution for vessels with dedicated voyage routes. Regardless, these reception facilities would require a substantial infrastructure investment (Wren et al., 2013). A ballast lighter vessel, which is a barge or other vessel that accepts and manages ballast from a commercial vessel, is an option that has not been explored in the Great Lakes System but has been utilized elsewhere (i.e., Europe, India, and Iran; Prihoda et al., 2020 draft in review).

For all potential ballast water management options being considered by this R&D Plan, the biological efficacy data, in combination with a better understanding of environmental risk (Research Area 5), must be weighed against the cost associated with each potential management option. The data collected under Research Area 1 will allow for determination of the best management options available to Laker vessels by generating biological efficacy data on a wide variety of management strategies along with accurate cost estimates for each option being considered.

A. RESEARCH APPROACH AND OBJECTIVES

Objective 1: Determination of Operational Characteristics of Commercial Vessels Trading within the Great Lakes System

Key Question: What are the typical (and more challenging) ballasting operational characteristics of United States and Canadian-flag commercial vessels that trade within the Great Lakes?

This objective will be implemented through a foundational, one-year project (hereafter Research Area 1 – Project 1). This project will build upon the work that was done by (Waterhouse et al., 2013), and will focus on the five vessel types identified through this study. This project will focus on U.S.- and Canadian-flag vessels operating exclusively within the Great Lakes System, but will also take into consideration other vessels that load and unload cargo/ballast within the Great Lakes. The operational characteristics of U.S.- and Canadian-flag Lakers operating exclusively within the Great Lakes System will be contrasted to those of seagoing vessels that trade within the Great Lakes. In addition, data will be gathered on the number of seagoing vessels entering the Great Lakes System, including, voyage patterns within the Great Lakes, the volume of Great Lakes ballast water taken onboard these vessels annually, and the volume of ballast water discharged from seagoing vessels within the Great Lakes System annually.
Current data on Laker vessel operational characteristics will feed into several of the projects described in this R&D Plan, including all of the proposed projects in Research Area 1, development of a Great Lakes-adapted BWMS testing protocol (Research Area 2 – Project 5), and quantifying the risk of ANS transfer from ballast water of Laker vessels (Research Area 5 – Project 1). The parameters of interest in this project are as follows:

- Voyage patterns, including ballast water uptake and discharge locations within various Great Lakes ecoregions (Figure 3, as described in The Great Lakes, 1995)
- Voyage durations (ballast hold time)
- Ballast volumes and durations of ballast water uptake/discharge operations
- Ballast flow rates
- Ballasting system characterizations (pump and piping arrangements, etc.)
- Ballast water best management practices utilized

Potential project partners such as the Lake Carriers’ Association and Chamber of Marine Commerce, will be called upon for existing data (see Stakeholder Group Objective 2). Data will also be gathered through publicly available sources (e.g., National Ballast Information Clearinghouse). Through this data-gathering process, the operational characteristics of Laker vessels will be determined. This project will also examine voyage patterns in the context of the various U.S. and Canadian Great Lakes ecoregions (Figure 3, The Great Lakes, 1995). Voyages within an ecoregion (Figure 3) may not contribute greatly to secondary spread of established ANS compared to voyages between one or more Great Lakes ecoregions (Figure 3). This examination of voyage patterns in the context of ballast water discharge monitoring data to determine ANS loadings (Quantifying ANS Transfer Project, Research Area 5 – Project 1) will allow for development of science-based and adaptive ballast water management strategies.
Objective 2: Land-Based Evaluation of the Effectiveness of IMO Compliant and U.S. Coast Guard Type Approved BWMS in Great Lakes Water

Key Questions:

1. Are there existing BWMS available on the global market (either type-approved under the IMO Convention or by the U.S. Coast Guard) that can treat Great Lakes ballast water effectively to meet the current U.S. discharge standards using existing test methods (i.e., Generic Protocol for the Verification of Ballast Water Treatment Technology; U.S. EPA, 2010)?

2. When evaluated at a land-based scale using the newly developed, Great Lakes-adapted protocol (see Protocol Development Project, Research Area 2 – Project 5), how do these BWMS perform?
   a. What is the level of ANS reduction that can be achieved in the Great Lakes based on land-based testing?
This objective will be addressed through implementation of a single, five-year project (Research Area 1 – Project 2). The first two years of this project are designed to gather data on the operational and biological effectiveness of market-available BWMS under Great Lakes conditions and using existing test methods, i.e., Generic Protocol for the Verification of Ballast Water Treatment Technology (U.S. EPA, 2010), hereafter ETV Protocol. Selection of ballast water treatment technologies for land-based testing will be conducted using a similar method to Wren et al. (2013), wherein a matrix will be created to summarize the market-available technologies, manufacturer, technology type, and system description. Data from the previously described project on operating practices (Characterize Laker Vessel Operations Project, Research Area 1 – Project 1), along with input from the stakeholder group, will be used to determine which technologies from the matrix are the most promising for testing. Laker vessel operating characteristics, including holding time and ballast flow rates will be considered. In addition, only those technologies designed to treat fresh water (and ideally for a salinity <1 PSU) and very cold water will be selected. Other Laker-specific considerations, such as the potential of the treatment to cause corrosion of the ballast tanks, will factor into the ultimate selection of technologies for testing.

Promising BWMS will be obtained, either through BWMS manufacturer lending/leasing of a unit or through direct purchase. During the first two years of land-based testing, the ETV Protocol will be used to verify the selected technology’s biological efficacy and operation and maintenance. Biological efficacy will be measured against the current U.S. ballast water discharge standard. All technologies will be evaluated at the UWS-LSRI Montreal Pier Facility (Superior, WI), which is operated by the Great Waters Research Collaborative (GWRC). Three BWMS will be evaluated in Year One and three BWMS will be evaluated in Year Two.

Work conducted during Years Three to Five assumes successful development of an “ETV-like” protocol adapted for the Great Lakes, which is outlined in Research Area 2 and described by Research Area 2 – Project 5. The Great Lakes-adapted testing protocol will be finalized before the start of the third land-based testing season. Given that the Great Lakes-adapted protocol will be based on the ETV Protocol, and any new methods incorporated into this protocol will undergo validation prior to inclusion, the Great Lakes-adapted protocol will be validated prior to use.

Prior to beginning work in Year Three, the data from the six BWMS land-based evaluations will be assessed in the context of operational and biological performance outcomes to determine which BWMS should be tested in Years Three to Five. Stakeholder group input will be considered when making this determination. Those technologies that warrant further testing will be evaluated using the Great Lakes-adapted testing protocol in Years Three to Five. This second round of land-based testing will serve as a real-world verification of the newly-developed protocol, provide data on the scalability and representativeness of these land-based testing methods to a shipboard application, and will also provide data on the performance of these technologies using the validated methodology that was developed specifically for Great Lakes water quality and biological conditions. The adapted protocol will be used to verify the technology’s biological efficacy. In this case, biological efficacy will be determined as a reduction in propagules over a maximum of five test trials in addition to comparison to a discharge standard. The reduction in propagules will be applied to ballast water monitoring data from shipboard testing (Shipboard BWMS Evaluation Project) and ANS monitoring (Establishment of Focal Ports Project), in order to determine if any of the BWMS evaluated provide an acceptable level of propagule reduction while also performing reliably and predictably over time.
Objective 3: Shipboard Evaluation of the Effectiveness of IMO Compliant and U.S. Coast Guard Type Approved BWMS in Great Lakes Water

Key Questions:

1. Are there existing BWMS available on the global market (either type-approved under the IMO Convention or by the U.S. Coast Guard) that can treat Great Lakes ballast water effectively to meet the current discharge standards using existing test methods (i.e., ETV Protocol)?
2. When evaluated at a shipboard scale using the newly developed, Great Lakes-adapted protocol (see Protocol Development Project, Research Area 2 – Project 5), how do these BWMS perform?
   a. What is the level of ANS reduction that can be achieved based on shipboard testing?

Research Area 1 – Project 3 is designed to determine the biological and operational effectiveness of market-ready and type-approved BWMS onboard vessels operating in the Great Lakes System. The data generated during Objective 3 will add to existing shipboard research and development data obtained from the U.S. Coast Guard, Department of Fisheries and Oceans Canada, and others. Input during the stakeholder group meetings will ensure that lessons learned from previous Great Lakes shipboard research and development testing will be considered and addressed in the project plan. This may include the use of vessels accepted into the U.S. Coast Guard’s Shipboard Technology Evaluation Program (STEP). This project may also include vessels that are not accepted into STEP but have installed type approved or IMO compliant BWMS and have agreed to serve as a platform for shipboard biological and operational efficacy verification. This project (Research Area 1 – Project 3), which will be a five-year project involving multiple vessels, will greatly increase the data on BWMS performance under real-world operational conditions and in a variety of Great Lakes commercial ports. The data obtained during shipboard testing will feed into many proposed projects in this R&D Plan, including:

- Real-world operational characteristics of Laker vessels (Research Area 1 – Project 1)
- Filter performance (Research Area 1 – Project 4 and Research Area 1 – Project 5)
- Characterizing Great Lakes challenge conditions (Research Area 2 – Project 1)
- Development of methods for ballast water sample assessment (Research Area 2 – Project 2, - Project 3, - Project 4)
- Verification of compliance monitoring devices (Research Area 4 – Project 2)
- Assessing the risk of ANS transfer (Research Area 5 – Project 1)

At least two vessels of opportunity will be selected to participate in this project. Vessels of opportunity must trade within the Great Lakes System, have a BWMS installed or plan to have a BWMS installed, be willing to allow GWRC scientists on board the vessel for a minimum of six test trials during the five-year project period, and be willing to have water quality monitoring technology installed to automatically monitor key parameters during uptake of ballast water on all voyages. The Lake Carriers’ Association and the Chamber of Marine Commerce may have members with vessels that would be willing to serve as test platforms or may already be considering the installation of BWMS for which efficacy data are needed. Vessels of opportunity will be selected during Year One of the R&D Plan implementation, a process which will be done in cooperation with the stakeholder group. Following vessel and BWMS selection, project planning and logistics will begin.
The first two years of testing (i.e., R&D Plan Year Two and Three) are designed to gather data on the operational and biological effectiveness of market-available BWMS under normal vessel operating conditions using existing test methods (ETV Protocol). Biological efficacy will be measured against the current U.S. ballast water discharge standard. All technologies will be evaluated by GWRC staff during a maximum of five test trials conducted over two Great Lakes shipping seasons.

Following finalization of the Great Lakes-adapted testing protocol, the biological efficacy of the BWMS installed on the vessels of opportunity will again be evaluated using the adapted protocol's methods. Given that the Great Lakes-adapted protocol will be based on the ETV Protocol, and any new methods incorporated into this protocol will undergo validation prior to inclusion, the Great Lakes-adapted protocol will be validated prior to use.

Prior to beginning work in Year Three, the data from the BWMS shipboard evaluations will be assessed in the context of operational and biological performance outcomes to determine which BWMS should be tested in Years Three to Five. Stakeholder group input will be considered when making this determination. This second round of shipboard testing will only include those technologies for which it is determined that further testing is warranted. Testing will occur over two Great Lakes shipping seasons and will be comprised of a maximum of five test trials on each vessel. The adapted protocol will be used to verify the technology’s biological efficacy. In this case, biological efficacy will be determined as a reduction in propagules over a maximum of five test trials in addition to comparison to a discharge standard. The propagule reduction data will be applied to the Quantifying ANS Transfer Project (Research Area 5 – Project 1), in order to determine if any of the BWMS evaluated provide an acceptable level of propagule reduction while also performing reliably and predictably over time.

Objective 4: Evaluating the Effectiveness of Ballast Water Best Management Practices Including Hybrid Solutions

Key Questions:

1. Can filtration technologies and practices be improved for ballast water management in the Great Lakes?
2. What are the efficacies of potential, promising BMPs in reducing the concentration of ANS in ballast water discharged within the Great Lakes?

Objective 4 is comprised of two research projects wherein candidate best management practices will be selected based, in part, upon data generated during a U.S. EPA Great Lakes Restoration Initiative-funded Laker Study (“Ballast Water Management Alternatives for Great Lakes Vessels”, Prihoda et al., 2020 draft in review) conducted by GWRC and led by the U.S. Coast Guard Research and Development Center in cooperation with MARAD. This study identified limited ballast water chemical treatment, open lake ballast water exchange, and ballast water filtration as warranting further consideration and research. In the case of ballast water filtration, there are additional data gaps in terms of operational effectiveness in the context of Great Lakes vessels that must be addressed through a separate research project (Research Area 1 – Project 4). This research project will be designed to fill data gaps associated with filter performance under Great Lakes conditions of water quality and biology. This project will determine the impacts of parameters that present an operational and performance challenge to ballast water filters, e.g., ice, filamentous protists, and high concentrations of total suspended solids. The ETV Protocol
specifies an acceptable water temperature range for BWMS testing from 4 - 35°C. Great Lakes water temperatures can be consistently <4°C for several months of the shipping season, and during the winter months the presence of pack ice and freezing water could cause operability issues for BWMS. BWMS filters are typically tested with solids that have diameters in the micron range, which is substantially smaller than the diameter of floating lake ice that could be taken up during ballasting. Similarly, operation of filters at low temperatures in fresh water can also lead to icing on filter elements. Great Lakes protist populations may also cause filter performance issues. Specifically, filamentous diatoms and cyanobacteria, some of which having filaments well over 100 μm in length, taken up in ballast can rapidly clog filter systems necessitating near-constant filter backflushing and decreased ballast flow rates and cargo off-loading operations. Commercial ports with high concentrations of suspended solids may create a similar operational challenge.

A call will be made to filter manufacturers (e.g., representatives from the ballast equipment manufacturing industry) to participate in this research project, which will determine performance of market-ready filters using a standard set of operational variables under extreme, but not rare, Great Lakes-relevant conditions. Filter performance will be assessed at the UWS-LSRI Montreal Pier Facility (Superior, WI), which will allow for controlled evaluations of each filter to be conducted. Filters will be selected through a “Request for Applications” process wherein filter manufacturers apply to participate in this research in exchange for very valuable data on the performance of their filter system. A similar approach was used successfully during a previous land-based study, (Cangelosi et al., 2014), wherein performance of eight commercially-available ballast water filter systems manufactured by five companies was evaluated.

In order to determine the target concentrations of parameters that will be used to challenge each filter evaluated, data on total suspended solids and protist densities at commercial ports within the Great Lakes must first be obtained. This will be done during shipboard evaluation of BWMS (Research Area 1 – Project 3) and characterizing Great Lakes challenge conditions (Research Area 2 – Project 1). The target concentration of total suspended solids and target density of protists for this evaluation will be selected to create a “challenging but not rare” test condition. The data obtained from Great Lakes commercial ports will be evaluated as a whole, statistically, to determine the appropriate filter challenge conditions. Each filter participating in this project will undergo at least three test trials under these challenging conditions, and at the upper-end of the Montreal Pier Facility’s flow rate capacity (i.e., maximum flow rate of 340 m³/hour). The following variables will be measured during this evaluation:

- Filter back-flush frequency
- Flow rates pre- and post-filter
- Filter back-flush volume
- Filter throughput
- Duration of backflush cycle
- Pressure pre- and post-filter
- Differential pressure
- Total suspended solids removal
- Particulate organic matter removal
- Organism removal
  - Zooplankton
Protists

The impact of ice/icing on filter performance will also be evaluated on the filters participating in this research project. This evaluation will also take place at the Montreal Pier Facility while the water surrounding the pier is ice-covered. Ballast water filter systems must be operated in above-freezing temperatures; thus, each filter will be operated in an indoor heated space during this evaluation. A simulated ice pack will be created in the water adjacent to the pier, and a trash pump (i.e., portable pump designed to pump large volumes of water that contains hard and soft solids) will be used to deliver the ice-laden water to the filter system being tested. This evaluation will measure filter performance in terms of a reduced set of operational parameters compared to that previously-described (i.e., filter back-flush frequency, flow rates pre- and post-filter, filter back-flush volume, filter throughput, duration of backflush cycle, pressure pre- and post-filter, and differential pressure).

The second research project (Research Area 1 – Project 5) is designed to determine the biological effectiveness, defined here as a reduction in propagules, of promising, potential BMPs, which may include those identified in Prihoda et al. (2020 draft in review). The first step in this project is to determine the practicability of each BMP for each of the five U.S. Laker vessel types identified by Waterhouse et al. (2013), plus any additional vessel types that trade within the Great Lakes System. Selection of BMPs for evaluation will be based on data from the previously-described Characterization of Laker Vessel Operations Project, data from the Stakeholder Data Working Group, and input from the larger stakeholder group. Any issues identified with the feasibility of the proposed BMPs may be addressed experimentally, if possible. The potential BMPs listed below should not be considered final, as this list will be refined prior to conducting this research project. This multi-year project (Research Area 1 – Project 5) will involve land-based testing of each BMP identified as promising, feasible, and practicable. Land-based testing will allow for controlled, research experiments to be conducted without impacting normal vessel operations. Land-based testing of each BMP individually will be conducted at the Montreal Pier Facility (Superior, WI) as follows:

**Limited Ballast Water Chemical Treatment**

Three biocidal chemicals were identified by Prihoda et al. (2020 draft in review) as having the potential to reduce the number of live organisms in ballast water discharge: glutaraldehyde, sodium hydroxide, and ozone. As stated previously, these chemicals will be considered as potential BMPs, but final selection will be based upon data gathered during the first year of R&D Plan implementation and will include input from the stakeholder group. Regardless of final selection, in order to determine the dose of each biocide to use for land-based testing, a laboratory-based range-finding experiment will first be conducted using standard test organisms cultured at LSRI. The pathogen indicator organisms *Escherichia coli* and *Enterococcus faecium*, the green algae *Selenastrum capricornutum*, and *Daphnia magna* (cladoceran) will be used to determine the appropriate dose of each chemical. Standard operating procedures developed by LSRI for GWRC’s laboratory-based ballast water treatment testing program will be used to conduct these aquatic toxicity tests. Organisms will be exposed to a wide range of doses of each chemical individually, and organism survival at each dose will be determined. Based upon calculated LC₅₀ (concentration lethal to 50% of the population) values for each organism, an appropriate dose of each selected chemical to be used in land-based experiments will be determined. Each chemical will be tested individually in a maximum of five biological efficacy trials. The challenge conditions and test methods specified in the ETV Protocol will be used to evaluate the ability of each chemical to reduce
the number of organisms present in ballast discharge. In each trial, one-half of the ballast uptake will be treated with the pre-determined dose of the biocide and one-half of the ballast uptake will be untreated and will act as the experimental control. Treatments will be applied in-tank and the treated water will be held for 24 hours, a common voyage time for Great Lakes vessels. Prior to discharge, the concentration of each biocide in the treatment tank will be measured and the water will be neutralized if the concentration of the biocide is above the method detection limit. The reduction in live organism density in treated discharge water will be compared to that of the untreated, control tank.

Data from these experiments will feed into the development of Great Lakes-relevant whole effluent toxicity testing for ballast water treatments (Research Area 2 – Project 4). The treatment and control discharge water will be sampled for a suite of disinfection byproducts (DBPs) in order to gain a better understanding of the DBPs that are produced from different chemical treatments. The toxicity testing methods being developed during Research Area 2 – Project 4 will be validated during these experiments.

**Open Lake Ballast Water Exchange**

The goal of open lake ballast water exchange is to reduce the number of propagules in ballast discharge by exchanging organism-rich harbor water taken on during cargo off-loading with open lake water that contains a much lower concentration of organisms. The organisms released into open lake water during the exchange process have a reduced potential for survival and reproduction due to the less favorable conditions in an oligotrophic environment (e.g., offshore areas of Lake Superior, Lake Michigan, and Lake Huron).

Again, prior to conducting the experimental validation of any BMPs, the practicability of each BMP under consideration, including open lake ballast water exchange, for vessels operating within the Great Lakes System will be evaluated. In the case of open lake ballast water exchange, evaluation will include an examination of existing vessels that trade within the Great Lakes System to determine which vessels are structurally able to perform this BMP (i.e., based on data from the Determination of Operational Characteristics of GL Vessels Project, Research Area 1 - Project 1). Further, as part of this project, data will be gathered on ballast tank flushing operations, ballast water exchange operations, and mid-voyage ballasting operations that are currently conducted by U.S. and Canadian Lakers. These data, along with input from the stakeholder group, will be used to develop the project plan. The experimental design outlined below should be considered preliminary, and represents a first step in what could be a multi-step validation of this ballast water BMP.

As a first step to begin to understand the impact of open lake exchange on reduction of propagules in ballast water discharge (i.e., environmental risk reduction), this BMP will be mock-implemented at the Montreal Pier Facility. A similar exchange process was simulated successfully at the Montreal Pier Facility during a previous project that compared the effects of ocean-voyage ballast water exchange to ballast water exchange plus treatment (Briski et al., 2013).

The organism-rich harbor water will be Duluth-Superior harbor water augmented to the biological and water quality conditions specified in the ETV Protocol. The open lake water will be municipal water from the City of Superior, WI that has been neutralized with sodium thiosulfate such that there is no detectable total residual chlorine. The municipal water from City of Superior, WI is sourced from Lake Superior (i.e., is open lake water), and does contain a very low density of planktonic organisms (Great
Waters Research Collaborative, unpublished data). This proposed experimental design includes three different levels of volumetric exchange that will be tested with a maximum of five trials at each level:

1. 95% volumetric exchange (as specified by Regulation D-1 of the IMO Ballast Water Management Convention)
2. 50% volumetric exchange
3. 25% volumetric exchange

Open lake water will be prepared by adding municipal water to a 260 m$^3$ storage tank and then dechlorinating the water. Ballast water uptake for each trial will involve filling one treatment and one control holding tank to a volume of 200 m$^3$. The ballast water will be held for six hours to simulate the voyage from the port to open water, and then an appropriate volume of treatment tank water will be discharged. The volume of water that is discharged and then exchanged is proposed above, but will ultimately depend upon the current operational practices of U.S.- and Canadian-flag Laker vessels. These data will be obtained during the Determination of Operational Characteristics of GL Vessels Project (Research Area 1 – Project 1). The prepared open lake water will be added to the treatment tank to a total volume of 200 m$^3$. After a 24-hour retention time, the treatment and control tanks will be discharged and the density of live organisms in each of the three regulated size classes will be determined.

Given a vessel of opportunity, this validation could also be conducted on a Laker Vessel as a second step in this project, to provide more real-world results on the impact of open lake exchange on the density of propagules in ballast water discharge.

**Ballast Water Filtration**

The previously-described Ballast Water Filter Performance Project (Research Area 1 – Project 4) evaluated the performance of filters as a component of a BWMS. Here, ballast water filtration is being evaluated to determine the biological performance (i.e., reduction of propagules) of ballast water filtration alone (without any subsequent disinfection).

The validation of the ballast water filtration BMP will be conducted on the same filters that were evaluated as part of the Ballast Water Filter Performance Project. This land-based evaluation will be conducted at the Montreal Pier Facility (Superior, WI) using the water quality and biology challenge conditions specified in the ETV Protocol. Each filter participating in this project will undergo at least three test trials under these conditions, and at the upper-end of the Montreal Pier Facility’s flow rate capacity (i.e., maximum flow rate of 340 m$^3$/hour). The following variables will be measured during this evaluation:

- Organism removal
  - Zooplankton
  - Protists

**Objective 5: Evaluating the Feasibility and Significant Impacts of Ballast Water Reception Facilities within the Great Lakes**

**Key Question:** What is the feasibility, economic, and environmental impact of reception facilities if utilized within the Great Lakes under certain scenarios or locations?
Objective 5 will be carried out as a single, one-year project (Research Area 1 – Project 6), largely by a maritime transportation economist or natural resource/bio-economist. In a study conducted by Wren et al. (2013), which examined the feasibility of municipal treatment of ballast water and dedicated reception facilities, the authors suggest that these options may only be viable for vessels with dedicated trade routes. In addition, mathematical modeling has shown that prioritizing development of high-volume, ballast water reception facilities based on network centrality could be a potentially effective strategy for reduction of secondary spread of ANS (Kvistad, 2019). The five U.S. Laker vessel types classified by Waterhouse et al. (2013), in combination with existing literature and the vessel operating characteristics determined for U.S. and Canadian Lakers during the Determination of Operational Characteristics of GL Vessels Project (Research Area 1 – Project 1), will be examined to determine which vessel types and voyage patterns would be most conducive to utilize reception facilities for ballast water management. There may also be scenarios in which pre-treatment reception facilities could be utilized to improve BWMS performance. In all cases, the feasibility and significant impacts (i.e., cost, infrastructure needs, permitting, and environmental risk) of this alternative treatment (or pre-treatment) option (ballast water reception facilities), will be independently assessed and reported. The assessment will consider:

- All sectors of the U.S. and Canadian Great Lakes fleets, including all commercial vessel types and operations
- Scenarios in which ballast water reception facilities may be more feasible options than installation of a BWMS, such as for vessels on dedicated trade routes
- Scenarios in which pre-treatment of ballast via reception facilities may lead to improved BWMS performance

**Objective 6: Assessing the Cost of Ballast Water Management Strategies on Commercial Vessels Operating Exclusively within the Great Lakes System**

**Key Question: How do ballast water management strategies compare in terms of ANS reductions and cost for installation and operation?**

Objective 6 consists of a single project (Research Area 1 – Project 7) designed to answer the above question. This R&D Plan is designed to gather empirical biological efficacy data on a wide range of ballast water management strategies, including, best management practices and BWMS. This project will consist of an independent evaluation of the existing literature, and data from the Stakeholder Data Working Group, regarding the cost of installation and operation of a wide range of management options, including but not limited to:

- Open lake exchange
- Limited chemical treatment
- Ballast water filtration
- Market-available BWMS (as in Wren et al., 2013)
- Emerging BWMS

This cost assessment will be conducted by an experienced maritime transportation economist or natural resource economist, in collaboration with naval architecture/marine engineering firms. The evaluation will consider various classes of vessels within the Great Lakes fleet (Waterhouse et al., 2013), in addition
Great Lakes Ballast Water R&D Plan, Version 4

to voyage routes (as obtained through the Characterization of Laker Vessel Operations Project, Research Area 1 - Project 1). Following a thorough examination of the existing literature, any additional research needs for accurately assessing the cost of these management options in the Great Lakes will be identified. Additional empirical data collection may be needed in order to accurately determine the installation and operational cost associated with each management option under consideration. Factors to be considered during this independent data evaluation include:

- Management options currently available
  - Purchase cost
  - Installation cost
  - Ongoing cost, including energy requirements
- Great Lakes fleet
  - Vessel types
  - Ballast system types
  - Age of vessels
- Operational impacts of installation and operation
  - Impact on cargo loading/off-loading operations
  - Impact on available cargo space

The results from this independent cost assessment will be weighed against the environmental benefit of each management option under consideration. In this way, the most cost effective but most environmentally protective management options will be determined. This project will be conducted during the last two years of the five-year R&D Plan implementation.

B. Timeline

Figure 4 outlines the planned timing for the seven research projects identified in Ballast Water R&D Plan Research Area 2.

![Figure 4. Timing, by Federal Fiscal Year, of Projects Implemented under Research Area 1 of the Great Lakes Ballast Water R&D Plan with Project Start Date, Duration (in working days), and End Date.](image-url)
II. Research Area 2: Toward Development of a Great Lakes Relevant BWMS Testing Protocol

Two major obstacles in the development of BWMS in the Great Lakes are the lack of relevant water quality and biology “challenge” data from within Great Lakes commercial ports, and a generic testing protocol for independent land-based and shipboard BWMS evaluation that is not tailored to these Great Lakes conditions. The adequacy of the protocols used to evaluate BWMS for purposes of IMO compliance and U.S. Coast Guard type approval has long been a point of scientific debate (Kim et al., 2016; Global TestNet, 2018; Silkin et al., 2018; Reavie & Cangelosi, 2020). The ETV Protocol, which outlines the methods required to evaluate BWMS during land-based and shipboard type approval testing, may need to be adapted for Great Lakes water quality, biology, and the operational realities of the Great Lakes fleet.

In a recent publication by Reavie & Cangelosi (2020), the relevancy of land-based type approval test requirements to the Great Lakes are discussed in the context of ten years of experience with BWMS testing. Reavie & Cangelosi (2020) state that requirements related to protists are especially problematic because of the stark difference between the protist challenge condition requirement and the reality of the Great Lakes ecosystem. This focus of this publication is on the requirement that ballast uptake during land-based testing must have at least 1000 cells/mL of organisms ≥10 µm and <50 µm in minimum dimension (U.S. EPA, 2010). This size class of organisms, known as protists, is dominated by phytoplankton. Within the Great Lakes, protists are abundant in the ecosystem, forming the basis of the food chain. However, the proportion of protist propagules (either free-living cells or cells that are part of a larger colony) larger than 10 µm in minimum dimension is low. Protists in the Great Lakes System are composed of many genera of colonial forms, and although the entities themselves are well over 10 µm, the cells that comprise the entities are often less than 10 µm in minimum dimension. Figure 5 presents data from samples collected at the Montreal Pier Facility (Superior, WI) in 2013, which shows the abundance of protists in the St. Louis River Estuary of Lake Superior, and the low proportion of those protists that fit the strict definition of the size class. Protist densities ranged from 1,000 to 6,000 cells/mL, however, the proportion of that population fitting the strict definition of the size class was always less than 1,000 cells/mL (Figure 5). This trend extends from Lake Superior to the Great Lakes System. As demonstrated in Great Lakes monitoring data from 2001 – 2015, protist densities are very clearly abundant throughout the Great Lakes System, averaging well over 1000 cells/mL with a maximum density of greater than 5000 cells/mL, in samples collected in the months of April and August (n = 2145 samples; Reavie & Cangelosi, 2020). Figure 6, from Reavie & Cangelosi (2020), shows the distribution of protist cell sizes (by density) in Great Lakes monitoring samples, and clearly demonstrates that the vast majority of the propagules within these samples are <10 µm in minimum dimension.

In order to evaluate BWMS in the Great Lakes System according to the ETV Protocol requirements, a substantial proportion of the protist population is not counted (i.e., all of the cells in the grey-shaded area in Figure 5, as well as all of the “small” cells and some of the “transitional” cells in Figure 6 would be present in ballast water samples but ignored). The result is that during type approval testing, the impact of ballast water treatment is not being evaluated against these organisms, which include genera that produce harmful algal blooms (e.g., *Microcystis* and *Dolichospermum*; Figure 7). Effects of BWMS should be measured against a much larger proportion of the Great Lakes protist population than is...
currently required. In particular, effects of BWMS against microcystin-producing cyanobacteria should be measured, especially considering the impact of the microcystin toxin on the Great Lakes region’s drinking water supply.

Figure 5. Protist Densities (cells/mL) in Samples Collected from Montreal Pier Facility in Summer 2013 (Author Credit: Euan Reavie, 2013). Grey-Shaded Areas Representing Density of Protist Propagules ≥5 µm in any Visible Dimension and Black-Shaded Areas Representing Density of Protist Propagules ≥10 µm in Minimum Dimension.
Figure 6. Figure from Reavie & Cangelosi (2020) Showing the Protist Cell Size Distribution, by Density, in Samples Collected over 14 Years throughout the Great Lakes. Boxes represent the lower and upper quartiles, whiskers represent the 1.5 interquartile distance from the lower and upper quartiles, and small circles are outliers.
Moreover, this strict size class definition necessitates augmentation to increase the density of those few cells that are ≥10 µm in minimum dimension. Augmentation also increases the density of cells that do not fit the size class definition, compounding the number of protists that are present in samples but ignored during testing. The ETV Protocol was designed to evaluate BWMS under water quality and biology conditions that represent “extreme, but not rare, natural environmental conditions” (Hunt et al., 2005). However, current challenge condition requirements for protists, which are required to be measured on the minimum dimension, necessitate augmentation to such a degree that the original objective of the ETV Protocol (i.e., challenging but not rare natural environmental conditions) is difficult to achieve. Conversely, the water quality challenge condition requirements are likely underrepresenting the extreme, natural conditions within Great Lakes commercial ports.

The ETV Protocol allows for the use of new methods for sample analysis during land-based and/or shipboard evaluation of BWMS, provided those methods are sufficiently validated. This provision opens the door to methodologies that provide accurate, sensitive, and reliable data about ballast water treatment technology performance within the Great Lakes System. The VIDA redefined the term “BWMS” as equipment “that processes ballast water to kill, render nonviable, or remove organisms” (Coast Guard Reauthorization Act of 2018). There is interest in the availability of test methods and testing protocols that can accurately determine the efficacy of BWMS in rendering organisms nonviable (i.e., the organisms are permanently incapable of reproduction). There is also interest in the scientific validity and practicability of any existing methodologies used to meet international obligations to enumerate viable organisms in ballast water, and to identify different parameters with scientifically valid...
and practicable test methods that may be better suited for measuring viable organisms in ballast water. In a recent draft policy letter issued by the U.S. Coast Guard Office of Operating and Environmental Standards (26 July 2019), the U.S. Coast Guard states that there are currently no “testing protocols for BWMS that render nonviable organisms in ballast water that are based on best available science”. The draft policy letter outlines the process by which protocols for organism viability assessment may be accepted and used, laying the groundwork for a protocol to be developed, validated, and accepted for the Great Lakes. There are important method development needs regarding analysis of treated ballast water containing eggs and resting stages of planktonic organisms. Residual sediment and water are retained in ballast tanks after deballasting. Sediment retained in ballast tanks is a potential vector for benthic zooplankton ANS, including dormant life stages (resting stages) that can remain viable under adverse environmental conditions and over very long periods of time (Bailey et al., 2005; Raikow et al., 2007; Branstrator et al., 2015). Active substance-based ballast water treatments are often not efficacious against zooplankton eggs and resting stages, and the presence of sediment has been shown to reduce effectiveness by up to a factor of 20 (Raikow et al., 2007). These life stages are not commonly used in aquatic toxicology studies, and there are no standard methods available for assessing viability of eggs and dormant life stages of zooplankton. The ETV Protocol does not address analysis of these life stages. The methodology for analyzing zooplankton (i.e., organisms ≥50 µm) is based on motility, and these life stages are not motile. In addition, vital stains that are used for protist analysis (i.e., organisms ≥10 µm and <50 µm) have not been validated to be effective for analysis of cysts, eggs, and resting stages. This has led to varied approaches among test facilities globally, ranging from noting (but not counting) these life stages if they occur in samples, to counting these life stages as living if they occur in samples, to incubation of eggs and resting stages found in samples to determine viability (Global TestNet, 2018b). Within the Great Lakes, a unified and validated approach to analysis of cysts, eggs, and resting stages found in ballast water samples collected during treatment technology testing is necessary to determine whether treatments are capable of killing, inactivating, or rendering these life stages nonviable.

Great Lakes trade patterns dictate that commercial ports are largely either cargo off-loading/ballast water uptake ports or cargo loading/ballast water discharge ports, meaning that certain ports within the Great Lakes System may be impacted by ballast water discharge more than others due to the large volume of ballast water received. Data will be generated on Great Lakes voyage patterns and ballasting operations during the Determination of Operational Characteristics of GL Vessels Project (Research Area 1 – Project 1). To ensure environmental protectiveness, and human health and safety (given the Great Lakes are a drinking water source), assessing the effect of treated and neutralized ballast water that is discharged to receiving waters of the Great Lakes System is an extremely important component of any land-based and shipboard protocol. The ETV Protocol provides some very limited guidance on toxicity testing for biocide treatments for marine and brackish waters only, but no guidance regarding disinfection byproducts (DBPs) that should be targeted for analysis. There are also no recommendations in the ETV Protocol on interpretation of the toxicity test results or DBP concentrations in ballast water discharge to effectively verify environmental acceptability of ballast water treatments utilizing active substances. The U.S. Coast Guard shipboard testing requirements in 46 CFR §162.060-28(g)(4)(v) necessitate whole effluent toxicity (WET) testing must be conducted in accordance with the requirements of the U.S. EPA Vessel General Permit (VGP) effective December 2008, however, the applicability of the methodologies outlined in the 2008 U.S. EPA VGP to either land-based or shipboard testing of ballast treatment technologies is questionable. In addition, the feasibility of performing WET
testing during shipboard BWMS evaluation must be evaluated. The *Ballast Discharge Toxicity Method Development Project* will address the lack of an appropriate Great Lakes testing approach by development of guidance for (1) sample collection, handling, and analysis for freshwater chronic WET testing during land-based and shipboard BWMS evaluation, (2) selection of DBPs that should be sampled and analyzed for various types of ballast water treatments, and (3) appropriate endpoints and interpretation of the results of freshwater chronic WET testing and DBP concentrations. Data generated from multiple projects conducted under this plan (i.e., *Land-Based and Shipboard BWMS Evaluation, BMP Effectiveness*, and *R&D Testing of Emerging Technologies Projects*) will provide much-needed information on residual active substances in ballast water discharges, chronic WET of treated and neutralized ballast water, and DBP concentrations in treated and neutralized ballast water for a variety of different treatment technologies. These data will be used to inform method development and data interpretation efforts in Research Area 2.

The projects outlined in Research Area 2 allow for the development of a Great Lakes-adapted, “ETV-like” testing protocol for BWMS with application in the Great Lakes System and beyond, as these methodologies will have application to freshwater systems globally. The Great Lakes-adapted testing protocol will include additional recommendations and guidance for conducting freshwater chronic WET testing, including endpoint selection and interpretation of results.

**A. RESEARCH APPROACH AND OBJECTIVES**

Research Area 2 will consist of a data-gathering phase, followed by a decision-making phase that will lead to land-based and shipboard testing protocols that are consistent with many aspects of the *ETV Protocol*, but are adapted for Great Lakes vessel operational characteristics and Great Lakes biology and water quality conditions. The newly developed Great Lakes-adapted protocol will be used to evaluate market-available BWMS during both land-based and shipboard testing (see *Research Area 1 – Project 2* and *– Project 3*).

**Objective 1: Characterizing BWMS Challenge Conditions in the Great Lakes System**

**Key Questions:**

1. **What are the ranges of living organism densities/composition and water quality parameters found within Great Lakes commercial ports where cargo off-loading/ballasting occurs?**
2. **Given #1, are the minimum challenge condition requirements specified in the *ETV Protocol* appropriate (i.e., challenging, but not rare natural environmental conditions) for evaluating BWMS performance in the Great Lakes?**

The first objective will be accomplished through one, two-year project (*Research Area 2 – Project 1*). Through an examination of publicly-available data on Laker vessel trade patterns, including ballast water uptake and discharge locations and ballast volumes (detailed in *Research Area 1 – Project 1*), and the “connectedness” of ports within the Great Lakes shipping network (Kvistad, 2019), a list of priority commercial ports for which monitoring data are needed will be generated. For each port, biological and water quality data relevant to BWMS performance will be sourced from existing literature (e.g., peer-reviewed and published data, publicly available databases, technical reports). A call for existing data collected from Great Lakes commercial ports will be sent to members of the stakeholder working group (see “*Stakeholder Involvement*” section, Objective 2). For those priority ports for which very little
historical data exists, data will be generated through sample collection and analysis (see Research Area 1 – Project 3 and Research Area 5). In some cases, there may be existing monitoring programs (e.g., implemented by U.S. Geological Survey, Army Corps of Engineers, U.S. Fish and Wildlife Service, and/or state and local agencies) that could add the parameters of interest to their current monitoring program. This option will be explored during stakeholder group meetings. For those ports for which there is no existing data and for which current monitoring efforts cannot be augmented, a port-specific monitoring plan will be developed that outlines the parameters of interest, frequency of collection per port, and analysis methods. Monitoring will take place over the course of two Great Lakes shipping seasons (i.e., approximately late March to early January) to capture variations at each location in biology and water quality as a result of seasonal trends and weather events. Sampling will take place from within identified priority commercial ports or from ballast water uptake while a vessel is off-loading cargo in these ports.

- Biological parameters of interest:
  - Zooplankton taxonomy and size distribution
  - Protist taxonomy, functional form, and size distribution (minimum and maximum dimensions)
    - Proportion of population comprised of single-cell forms
    - Proportion of population comprised of multicellular entities, including cyanobacteria and harmful algal bloom
  - Concentration of pathogen indicator organisms, including consideration of human and fish pathogens
    - *Escherichia coli*
    - *Enterococci*
    - Replacement for *Vibrio cholerae* O1 and O139

- Water quality parameters of interest:
  - Temperature
  - Salinity/specific conductivity
  - Dissolved oxygen
  - Turbidity
  - Total suspended solids
    - Particle size distribution
  - Dissolved organic carbon
    - Composition
  - Transmittance of ultraviolet light at 254 nm
  - Particulate organic matter
    - Particle size distribution
    - Composition
  - Mineral matter

For each parameter of interest, project partners will be identified to implement sample collection and/or analysis. For example, microbiology experts may assist with identification of Great Lakes-relevant pathogen indicator organisms. Monitoring data will be incorporated into an online, publicly available Great Lakes Commercial Port Database that is currently under development by the GWRC.

This monitoring effort will also contribute to the development of environmental DNA (eDNA) markers that can be used for targeted early detection and rapid response efforts. Specimens of organisms on the
Great Lakes Aquatic Nonindigenous Species Information System Watchlist (GLANSIS Watchlist) will be provided to project partners with expertise in the development of eDNA markers.

**Objective 2: Evaluating Alternative/Emerging Sample Analysis Methods for Ballast Water Treatment Technology Testing**

**Key Questions:**

1. **What are potential emerging or alternative viability assessment methods for BWMS biological efficacy evaluation, and how effective are those methods?**
   - Are there viability assessment methods that can be utilized for the Great Lakes in order to evaluate treatment effects on planktonic organisms?
   - Is it feasible to implement these methods during land-based evaluation of BWMS?
   - Is it feasible to implement these methods during shipboard BWMS evaluation?

2. **Are there assessment methods for evaluating the mortality and/or viability of eggs and resting stages of organisms exposed to ballast water treatment?**

3. **Is there a method that can be used to accurately assess the environmental acceptability of treated and neutralized ballast water upon discharge?**
   - Is there an adequate benchmark value/environmental acceptability standard that can be used to ensure protectiveness to Great Lakes ports receiving ballast?
   - Is it feasible to implement this method during shipboard BWMS evaluation?

Objective 2 is comprised of three separate projects. In order to answer the above research questions, existing literature will be reviewed, including any literature compiled from the Stakeholder Data Working Group, to identify data gaps and needs for empirical research. In addition, recommendations from the ETV technical panel that have been compiled since completion of the existing ETV Protocol, but never incorporated, will be included for consideration. Methodologies currently accepted under the IMO Convention, in particular viability assessment methodologies, will be examined for potential feasibility within the Great Lakes System. A separate method development and validation plan will be drafted for each of the projects described below.

The first project, **Research Area 2 – Project 2** will utilize the process outlined in the U.S. Coast Guard VIDA viability draft policy letter (26 July 2019) for proposal and submission of a viability assessment method for Great Lakes ballast water samples. GWRC has experience validating a freshwater MPN-based method during a 2018 project that was led by the Naval Research Laboratory (Prihoda et al., 2019). The results from this freshwater validation will be used as a starting point to develop a Great Lakes MPN-based method. Using the validation approach developed by the U.S. EPA Office of Research and Development (2018), and considering the data requirements in the U.S. Coast Guard draft policy letter, the Great Lakes method will be developed first at the Montreal Pier Facility located in the Port of Superior, Wisconsin. Once an accurate and precise method is developed, the method will be trialed at other Great Lakes ports. The goal of this project is to develop a single method that could be utilized to assess ballast water samples from within the Great Lakes System. Land-based and shipboard testing of market-available BWMS (**Research Area 1 – Project 2** and **– Project 3**) will provide opportunities for validation of the proposed Great Lakes viability assessment method, given that many of the market-available BWMS use UV-based treatment technology. In addition, this large-scale method validation will
provide valuable data on the feasibility of implementing a viability assessment in both a land-based and
shipboard testing context.

The second proposed project, **Research Area 2 – Project 3**, will take a similar approach and start with
laboratory method development experiments. These method development experiments will examine
multiple methods for determining mortality and viability of eggs and resting stages, including the use of
commercially-available stains and incubation/grow-out of samples. Once a promising method is
developed, the methodology will be trialed at several additional Great Lakes ports. Again, land-based
and shipboard testing of market-available BWMS (**Research Area 1 – Project 2** and **– Project 3**) will allow
for large-scale, real-world validation of a proposed Great Lakes method for assessment of these life
stages in ballast water samples.

The third and final proposed project in Research Area 2 (**Research Area 2 – Project 3**) will be designed to
develop a methodology for determination of environmental acceptability of BWMS treating Great Lakes
ballast water. Environmental acceptability determination includes four factors:

1. Impact of the treatment process on ballast discharge water quality parameters (e.g., pH, salinity,
dissolved oxygen, and biochemical oxygen demand)
2. Concentration of residual active substance following treatment and neutralization
3. Concentration of disinfection byproducts resulting from treatment and neutralization
4. Toxicity of ballast water discharge to organisms in the receiving environment

The goal of this project is to develop a method to assess environmental acceptability of BWMS that may
be used to manage ballast water onboard Great Lakes vessels, and to include this methodology in the
proposed Great Lakes-adapted testing protocol. Accurate assessment of BWMS environmental
acceptability is of particular importance for the Great Lakes because vessel trade patterns dictate that
most ports are either ballasting (cargo off-loading ports) or are receiving ballast water (cargo loading
ports). This means that certain ports, i.e., Port of Duluth-Superior, receive a huge volume of ballast
water over the course of a Great Lakes shipping season. The VIDA standards developed by U.S. EPA will
likely include some limits for active substance residuals in ballast water discharges (Factor 2 above). This
research project will feed into that effort by identifying the disinfection byproducts produced by
different market-available ballast water treatment technologies, provide methodology to assess
environment risk of treatment residuals, and provide toxicity testing data from real-world testing of
BWMS within the Great Lakes. Existing literature, in combination with the data generated from land-
based and shipboard testing of BWMS (**Research Area 1 – Project 2** and **– Project 3**), and data from
evaluation of the limited chemical treatment ballast water best management practices (**Research Area 1
– Project 4**) will provide valuable information on the concentration of residual active substances and the
formation of disinfection byproducts for a variety of biocidal treatments (Factors 2 and 3 above). At the
same time, methods will be developed and validated to determine toxicity of ballast water discharge to
organisms in the receiving environment. Importantly, methods development will include a process for
interpretation of the toxicity test data in combination with the chemical analysis data.

**Objective 3: Development of a Great Lakes-Adapted Protocol for Verification of BWMS**

**Key Question:** What changes to the existing **ETV Protocol** are appropriate for its use to evaluate
BWMS effectiveness for Great Lakes vessels?
Objective 3 is the decision-making phase of Research Area 2, wherein, the results of Objectives 1 and 2 will be evaluated to determine adaptations that would be needed to the existing ETV Protocol to ensure Great Lakes applicability. Decision points will include:

- Biological challenge condition criteria, including organism type and size
- Water quality challenge condition criteria
- Acceptable hold time
- Alternative/emerging viability assessment methods
- Environmental acceptability methods and pass/fail criteria

The results from Objectives 1 and 2 will be communicated to the stakeholder group members, along with the science-based recommendations for Great Lakes adaptations to the ETV Protocol. Recommendations will be made solely by the project principal investigators in cooperation with MARAD. The stakeholder group will be given an opportunity to comment on recommendations and protocol development, and comments will be considered prior to finalization of the protocol. The deliverable from this project (RA2–Project 5) will be a Great Lakes-adapted protocol for land-based and shipboard testing.

**B. TIMELINE**

Figure 8 outlines the planned timing for each of the five projects described for Ballast Water R&D Plan Research Area 2. This figure includes the timing of the Great Lakes-adapted ballast water treatment technology testing protocol.

![Figure 8](image_url)

*Figure 8. Timing, by Federal Fiscal Year, of Projects Implemented under Research Area 2 of the Great Lakes Ballast Water R&D Plan with Project Start Date, Duration (in working days), and End Date.*
III. RESEARCH AREA 3: ACCELERATING DEVELOPMENT OF EMERGING BALLAST WATER TREATMENT TECHNOLOGIES

Creative solutions for treating ballast water within the Great Lakes continue to be developed. Often, developers are self-employed inventors, small start-up companies, or academic researchers that do not have the resources needed to obtain independent data on their technology’s biological effectiveness or scale-up their technology for required land-based and shipboard evaluation. These obstacles have become an impediment to the development of Great Lakes-applicable treatment technologies.

A. RESEARCH APPROACH AND OBJECTIVES

Objective 1: Acceleration of Ballast Water Treatment Technology Development

Key Question: What resources exist or can be provided to accelerate bringing Great Lakes-specific solutions to market?

Objective 1 will be accomplished through the implementation of one exploratory project (Research Area 3 – Project 1). Resources are required in order to accelerate the development of creative solutions for treatment of Great Lakes ballast water. The small Great Lakes market has been an obstacle to larger, more financially stable companies developing BWMS specifically for Great Lakes biology, water quality, and vessel operations. Likewise, small, start-up companies often lack the capital required to develop their technologies beyond the prototype stage. Two complementary approaches will be used to implement this project:

1. Network building
   a. Create connections that allow technology developers to tap into expertise within the Great Lakes research and shipping communities, including:
      i. Marine engineers
      ii. Marine transportation economists
      iii. Financial consultants
      iv. Naval architects
      v. Representatives from the ballast water equipment manufacturing industry

2. Development of a framework for aiding ballast water treatment technology developers, including creative solutions for:
   a. Providing incentives to support shipowner and developer partnerships, including technical support programs, warranties, and training programs
   b. Providing financial incentives to established BWMS developers to overcome the small Great Lakes market
   c. Inspiring the development of new and emerging technologies through competitive means
   d. Providing resources for scaling-up developing technologies from small, prototype units to larger, land-based-ready units to market-ready units appropriate for shipboard testing
Objective 2: Research and Development Testing for Emerging Ballast Water Treatment Technologies

Key Questions:
1. Are there promising, emerging technologies for treating ballast water that may be candidates for undergoing Great Lakes-specific testing, including using the Great Lakes-adapted protocol?
2. Are there promising, emerging technologies capable of treating waters in addition to Great Lakes water?

This objective will be implemented through one project (Research Area 3 – Project 2). The GWRC has a long-standing Great Lakes ballast water treatment technology testing program (funded by the U.S. EPA’s Great Lakes Restoration Initiative, GLRI). In the past two years, the approach to implementing this program has become a formal, standardized process that could be modeled to implement this project. The process involves an annual Request for Applications (RFA) that is advertised to developers of ballast treatment technologies, and a formal application process. Applications are reviewed and reviewers are charged with determining the appropriate scale of testing for technologies accepted into the program. The focus of treatment technology testing for those systems in early stages of development will be land-based testing. Appropriately scaled-up systems could be evaluated via the U.S. Coast Guard STEP requirements or other research method, provided there is a platform (vessel) and operator willing to install an experimental technology (note this may require a financial incentive). The STEP process was designed to facilitate development of experimental ballast water treatment technologies and presents a possible framework for Great Lakes shipboard evaluation of emerging treatment solutions.

In order to address the second research question in this objective, the ability of emerging technologies to treat waters other than Great Lakes waters, land-based testing of emerging technologies could be done at other land-based test facilities (in addition to Montreal Pier Facility) to determine biological efficacy at higher salinities. Alternatively, or additionally, shipboard testing of emerging ballast water treatment technology testing could be conducted on a seagoing vessel that trades within the Great Lakes. This would allow for operational verification of a technology to be conducted on vessels other than Laker vessels, and allow for biological efficacy to be determined in multiple salinities.

B. Timeline

Figure 9 outlines the planned timing for the two projects identified in Ballast Water R&D Plan Research Area 3.

![Figure 9](image-url)
IV. RESEARCH AREA 4: DEVELOPMENT OF BALLAST WATER INDICATIVE MONITORING METHODS

Effective ballast water management strategies for Great Lakes vessels will require monitoring of ballast water discharges. Indicative monitoring conducted for self-monitoring, research, shipboard testing (other than for type approval), and compliance monitoring needs to be done quickly with results that are accurate and representative of the ballast water discharge conditions. Challenges remain regarding how to practically sample and analyze ballast discharges from operational vessels, such as is required for indicative monitoring purposes. Large volumes of ballast water, the shape, size, and number of ballast tanks, and the heterogeneous distribution of organisms within the ballast tanks are all factors that must be considered when conducting indicative monitoring of ballast water discharge (Carney et al., 2013). Collection of representative ballast water samples is critical for evaluating performance of ballast water management strategies, and sample locations, design of in-line sampling apparatus, and design and operation of in-line sample points for land-based and shipboard type approval testing are specified in the ETV Protocol. However, this required sample approach does not apply to a rapid, indicative monitoring situation. When monitoring ballast water during a vessel’s operational discharge to determine effectiveness of a ballast water management strategy, there is an added challenge to overcome in that ballast discharge samples must be collected quickly and be representative of the volume discharged during sampling (not necessarily during the entire deballasting operation as Great Lakes vessels discharge very large volumes of ballast water during each deballasting). Just the act of collecting a sample that is representative of ballast discharge is a much more difficult undertaking than for other types of discharge monitoring.

Similar obstacles exist for indicative analysis tools used for rapid analysis of ballast water discharge as previously described for treatment technologies. Regarding the Great Lakes, low temperatures, high dissolved organic carbon, and high concentration of suspended solids can interfere with a device’s ability to accurately determine discharge characteristics. In addition, large proportions of colonial protist entities in Great Lakes water can be a substantial challenge for technologies that have only been verified using cultured, single-celled protists.

Given that VIDA redefined the term “BWMS” as equipment “that processes ballast water to kill, render nonviable, or remove organisms”, there is interest in the availability of test methods and testing protocols that can accurately determine the efficacy of BWMS in rendering organisms nonviable. For any future ballast water management systems type-approved by the USCG based on organism viability, monitoring methods must be able to assess organisms’ ability to reproduce. Therefore, it may be necessary for indicative analysis tools to distinguish between viable and non-viable organisms in discharge samples. Monitoring technology types have been found to vary widely in their ability to enumerate nonviable organisms, particularly in the ≥10 µm and <50 µm size class, in ballast water discharge samples collected and analyzed immediately after UV treatment (Bradie et al., 2018).
A. **RESEARCH APPROACH AND OBJECTIVES**

**Objective 1: Development of a Method to Collect Representative Ballast Water Discharge Samples Onboard Great Lakes Commercial Vessels**

**Key Question:** What are the most practical indicative monitoring methods to determine effectiveness of a variety of ballast water management strategies used by Great Lakes vessels?

*Research Area 4 - Project 1*, addresses the need to develop a method to sample ballast water discharge onboard Great Lakes vessels for purposes of indicative monitoring. This project will begin with a data-gathering phase, wherein recommended methods for ballast discharge sampling will be thoroughly researched for applicability to Great Lakes vessels. Literature review will include the established methodology from the International Standards Organization (ISO; ISO 11711-1:2019, ISO/DIS 11711-2). Shipboard sampling apparatus developed by private sector entities and other organizations will also be considered during the data-gathering phase of this project. Members of the stakeholder group will be asked to provide information regarding current approaches used by Great Lakes states/ports, and throughout project planning close coordination will be needed with organizations conducting similar projects within the U.S. and Canada (e.g., U.S. Coast Guard, Smithsonian Environmental Research Center, SGS, and Department of Fisheries and Oceans Canada). Finally, data will be gathered on the number of U.S. and Canadian Laker vessels with installed sample ports (19 have been installed by Great Ships Initiative and GWRC), followed by an engineering analysis to determine whether sample ports could be installed on remaining vessels within the fleet in accordance with ISO 11711-1:2019, ISO/DIS 11711-2.

Sampling methods identified as promising for Great Lakes compliance monitoring will be trialed during the *Shipboard BWMS Evaluation Project* (*Research Area 1 – Project 3*) and the *Characterize BWMS Challenge Conditions Project* (*Research Area 2 – Project 1*) and assessed for feasibility. Results will be compared to results obtained from GWRC’s shipboard sampling system, which is used to collect samples of ballast water during monitoring, research, and type approval testing.

**Objective 2: Great Lakes Verification of Ballast Water Indicative Monitoring Tools**

**Key Question:** Are indicative monitoring devices sufficiently accurate, precise, and sensitive to assess Great Lakes ballast water?

The second project under Research Area 4 (*Research Area 4 – Project 2*) is a Great Lakes verification of ballast water compliance monitoring devices. During project planning, close coordination will be needed with organizations currently conducting similar projects (e.g., U.S. Coast Guard and U.S. Naval Research Laboratory) to ensure supplemental, and not duplicative, data generation (see Great Lakes and Lake Champlain Invasive Species Research Coordination and Program Review).

This verification will take into consideration the implementation of a ballast water discharge standard based on both live/dead and viability-based standards. The GWRC is currently conducting a one-year project to verify commercially available ballast water compliance monitoring devices in Great Lakes water quality. *Research Area 4 – Project 2* could be modeled after GWRC’s approach, providing data on many more devices and providing Great Lakes-verified options to end users. Like GWRC’s ballast water
treatment technology testing program, an RFA could be opened annually to solicit device manufacturers to participate in this program. The resulting testing would be a “type approval-like” process for compliance monitoring devices, consisting of laboratory testing of single-species samples, testing with ambient Great Lakes organisms, and ending with testing of treated water samples.

Following the Great Lakes verification, device developers may need to adjust their technologies to improve performance in Great Lakes water quality. In this case, technologies will again undergo an independent verification process to determine whether adjustments were successful in improving device performance.

**B. TIMELINE**

Figure 10 outlines the planned timing for the research projects described in Ballast Water R&D Plan Research Area 4.

*Figure 10. Timing, by Federal Fiscal Year, of Projects Implemented under Research Area 4 of the Great Lakes Ballast Water R&D Plan with Project Start Date, Duration (in working days), and End Date.*
V. RESEARCH AREA 5: ASSESSING THE RISK OF AQUATIC NUISANCE SPECIES TRANSFER FROM BALLAST WATER DISCHARGE

Determination of acceptable environmental risk associated with Great Lakes ballast water discharges is a daunting task given the complexities associated with ANS establishment. Focused monitoring efforts within the Great Lakes are necessary to better understand propagule pressure (i.e., number of ANS) in Laker vessel ballast water discharge. The U.S. Coast Guard and Smithsonian Environmental Research Center (SERC) have been sampling ballast water on vessels within established “focal port/areas” for several years. The current focal port areas are Chesapeake Bay, Tampa Bay, and San Francisco Bay. The Coast Guard is working toward identifying one or more of these focal port areas within the Great Lakes System. Ballast water monitoring at established focal ports within the Great Lakes facilitates the collection of critical data on propagule pressure, which is one step toward determining the probability of ANS establishment (Figure 11). Research has shown that the number of species released in ballast water (i.e., colonization pressure) is greatly affected by die-off of more sensitive species during voyage time, reducing the number of species discharged to only those most tolerant of selection pressures within a ballast tank (Briski et al., 2012). Monitoring conducted at the Great Lakes focal ports would add to current scientific knowledge of colonization pressure in ballast discharge, and the relationship between propagule pressure and colonization pressure. In 2008, the U.S. EPA conducted a modeling effort to determine the Great Lakes ports at greatest risk for invasion, and concluded that the ports of Toledo, Ashtabula, and Sandusky, OH; Gary, IN; Duluth, MN; Milwaukee and Superior, WI; and Chicago, IL were priority ports for monitoring efforts (U.S. Environmental Protection Agency, 2008). More recent modeling efforts have found that indegree centrality, or the degree of “connectedness” between ports, is perhaps an even more important factor determining the secondary spread of ANS within the Great Lakes than ballast water discharge volume (Kvistad, 2019). This study determined the top ten most central ports within the Great Lakes are: Superior, WI; Cleveland, OH; Detroit, MI; Two Harbors, MN; Sandusky, OH; Toledo, OH; Marquette, MI; Calcite, MI; Duluth, MN; and Ashtabula, OH (Kvistad, 2019). These two studies, along with other historical data, will be used to prioritize the ports for which focal port areas should be established.

The question of how much the probability of ANS establishment is reduced given a commensurate reduction in viable organism densities in ballast water, i.e., through ballast water management, can be answered in part using semi-field (mesocosm) experiments (Aliff et al., 2018; Branstrator et al., 2019). In a mesocosm study conducted in 2013, the freshwater phytoplanktonic diatom Melosira varians was used as a surrogate to determine the risk-release relationship in multiple freshwater trials, and it was determined that the inoculation density (a proxy for propagule pressure) needed for M. varians establishment was approximately 12 cells/mL (Aliff et al., 2018). Aliff et al. suggest additional experiments be conducted with a variety of organisms and conditions in order to better understand the risk-release relationship. A mesocosm study conducted in 2015 using the nonindigenous and invasive zooplankter Bythotrephes longimanus concluded that inoculation density was the best predictor of B. longimanus reproductive output (a proxy for establishment; Branstrator et al., 2019).

While the endpoint of mesocosm experiments may provide context to a numerical discharge standard (Aliff et al., 2018 and Branstrator et al., 2019), defining an acceptable level of environmental risk for ballast discharges in the Great Lakes System may or may not include the use of a numerical discharge
A holistic, integrated approach is needed to assess the incredibly complex question of how effective a given ballast water management practice or approach must be to achieve an acceptable level of ANS reduction (decreased propagule pressure) in ballast water discharges. Research Area 5 presents an opportunity to tie all of the projects conducted in this R&D Plan together. The projects described below will quantify the number of ANS present in ballast water discharges within Great Lakes commercial ports, which has been shown to correlate with establishment success (Lockwood et al., 2005), and put those data into context of the biological efficacy associated with various management options (as presented in Research Area 1) and establishment probabilities estimated from mesocosm experiments.

**A. RESEARCH APPROACH AND OBJECTIVES**

**Objective 1: Establishment of Great Lakes Focal Ports to Determine Interlake Transfer**

**Key Questions:**

1. What is the risk of ANS interlake transfer via ballast water?
2. What is the relative ANS loading associated with various vessel voyage patterns within the Great Lakes, and are there significant differences that may warrant different technologies or practices for these different situations?

Research Area 5 – Project 1 will supplement the efforts already initiated by the U.S. Coast Guard and SERC, who have received funding from U.S. EPA Great Lakes Restoration Initiative to establish several focal port areas within the Great Lakes from which ballast water will be sampled from Great Lakes vessels. The first step in this project will be development of a plan for collaboration between U.S. Coast Guard/SERC and the agencies responsible for implementing this R&D Plan for identifying appropriate focal port sites within the Great Lakes System, considering the objectives of the current U.S. Coast Guard/SERC effort and the objectives described in this R&D Plan. Other potential project collaborators will be identified during collaboration planning.

Once the focal ports have been identified and implemented by U.S. Coast Guard/SERC, ballast water monitoring will take place using the methodology already established by the Coast Guard and SERC. Ballast water samples will be collected to determine the concentration and composition of organisms within all three regulated size classes. In addition, data on each sampled vessel’s ballast water management strategies will be collected in order to put the biological data into context. Zooplankton taxonomists at LSRI are skilled in identifying non-indigenous zooplankton in Great Lakes samples, and will analyze zooplankton samples using a methodology from previous ballast water monitoring projects (Cangelosi et al., 2018) to identify the non-indigenous zooplankton in these samples. At the same time, increased harbor monitoring in these focal port regions will take place. Sampling will be targeted to non-indigenous zooplankton, especially benthic zooplankton, which have been found previously in ballast water monitoring onboard Great Lakes vessels (Cangelosi et al., 2018).
Objective 2: Using Semi-Field Methodologies to Determine the Impact of ANS Reduction in Managed Ballast Water

Key Question: Using existing semi-field methodologies and a variety of freshwater taxonomic groups, can the impact of ANS reduction in Great Lakes ballast water be determined under a variety of scenarios?

This objective will be addressed through a multi-year project (Research Area 5 – Project 2) that utilizes existing mesocosm methodology (Aliff et al., 2018 and Branstrator et al., 2019) to better understand the risk-release relationship in a variety of freshwater organisms and under a variety of biotic and abiotic conditions. A series of mesocosm experiments will take place at the Montreal Pier Facility (Superior, WI). Researchers with expertise in invasion ecology will be critical project partners during design and implementation of this project and will assist with selection of planktonic organisms that will function as surrogate invaders. A total of 22, one-cubic meter mesocosms will be used for each risk-release relationship experiment. The mesocosms are located in a laboratory building at the Montreal Pier Facility that is climate and light controlled. The mesocosms will be filled simultaneously with 1000 L of water pumped from the Duluth-Superior Harbor. The water quality and biology (i.e., native organism concentration and composition) conditions of the water used to fill the mesocosms will be determined. The selected surrogate invader for each experiment will be added to the mesocosms in varying densities, above and below the current national ballast water discharge limits for organisms ≥50 µm or ≥10 µm and <50 µm. During the course of each experiment, duration to be determined based on taxa selection, water quality will be measured using a multiparameter water quality Sonde. At the conclusion of each experiment, reproduction of the surrogate invader (i.e., establishment) will be measured by sampling each mesocosm and analyzing each sample to determine the number of invaders present. In addition, the water quality and biology (i.e., native organism concentration and composition) conditions will be measured at the conclusion of each experiment.

The data gathered during these mesocosm experiments will provide context to the ANS data gathered from the Quantifying ANS Transfer Project (Research Area 5 – Project 1). Propagule pressure, as estimated from focal port area monitoring, will be combined with the mesocosm data estimating establishment probability of a variety of taxa (similar to Figure 11). These data will be evaluated in the context of the biological efficacy of a variety of ballast water management options investigated through this R&D Plan. Given all of these datasets, the ability to estimate the impact of various management strategies on the risk of ANS transfer through Great Lakes ballast water can be modeled.
Figure 11. Risk-Release Relationship Curves as Modified from Ruiz and Carlton (2003). Output from Research Area 5 - Project 2 will result in similar data for a variety of freshwater taxa, and these curves will be overlaid by the propagule data collected during Research Area 1 – Project 1.

B. TIMELINE

Figure 12 outlines the planned timing for the research projects described in Ballast Water R&D Plan Research Area 5.

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Year 4</th>
<th>Year 5</th>
<th>Year 6</th>
<th>Year 7</th>
<th>Year 8</th>
<th>Year 9</th>
<th>Year 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research Area 5: Assessing the Risk of Aquatic Nuisance Species Transfer from Ballast Water Discharge</td>
<td>10/1/21</td>
<td>782 days</td>
<td>9/30/24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 - 1: Quantifying ANS Transfer</td>
<td>10/1/20</td>
<td>1043 days</td>
<td>9/30/24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 - 2: Determining Impact of ANS Reduction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 12. Timing, by Federal Fiscal Year, of Projects Implemented under Research Area 5 of the Great Lakes Ballast Water R&D Plan with Project Start Date, Duration (in working days), and End Date.
VI. PROGRAMMATIC CAPABILITY AND PAST PERFORMANCE

MARAD was established in 1950 and is responsible for the waterborne transportation system in the U.S. ([maritime.dot.gov](http://maritime.dot.gov)). MARAD’s mission is to foster and promote the U.S. Merchant Marine and the U.S. maritime industry, and to strengthen the maritime transportation system, including commercial ports, shipbuilding, and labor. MARAD’s Office of Environment supports ballast water and hull fouling research and ballast water treatment and compliance technology development and testing, among many other maritime environmental issues. This support has included the design, development, and improvement of ballast water treatment testing facilities in the U.S., including the only facility located within the Great Lakes, the Montreal Pier Facility located in the Port of Superior, WI (formerly the Great Ships Initiative Research, Development, Testing, and Evaluation Facility).

The UW-Superior’s LSRI ([uwsuper.edu/lsri](http://uwsuper.edu/lsri)) was formed in 1967. Its mission is to conduct environmental research and provide services that directly benefit the people, industries, and natural resources of the Upper Midwest, the Great Lakes Region, and beyond; provide non-traditional learning and applied research opportunities for undergraduate students; and foster environmental education and outreach in the Twin Ports and surrounding communities. LSRI established an independent Quality Management System (QMS) in 1991, and is committed to a comprehensive quality assurance (QA) and quality control (QC) program in its environmental data operations. The LSRI QMS is based on U.S. EPA requirements as outlined in the *Quality Standard for Environmental Data Collection, Production, and Use by Non-EPA (External) Organizations*, CIO Standard 2106-S-02 (U.S. EPA, 2012 review draft). LSRI’s environmental data operations must adhere to the requirements outlined in the LSRI Quality Management Plan. The QA requirements of each project are met by the cooperative effort between project management and the LSRI Quality Assurance Manager.

MARAD’s relationship with UW-Superior’s LSRI began more than 10 years ago, as many LSRI staff worked on ballast water research and technology testing projects conducted under the Great Ships Initiative (Northeast-Midwest Institute; Washington, DC). In 2017, MARAD and LSRI entered into a Cooperative Agreement, the purpose of which is to support the evaluation and verification of ballast water treatment technologies and other green shipping initiatives. As a result of this agreement, the GWRC was born ([uwsuper.edu/gwrc](http://uwsuper.edu/gwrc)). The GWRC is devoted to conducting high-quality environmental research and providing independent testing services to support green shipping and promote the sustainable industrial, commercial, and public use of the great freshwater bodies of the world. The GWRC is comprised of experienced researchers with diverse expertise; the team has more than 15 years of experience working together on ballast water research within the Great Ships Initiative and now LSRI’s GWRC. GWRC is lead and managed by LSRI, with engineering services provided by AMI Consulting Engineers P.A. and protist ecology and taxonomy services provided by researchers from the Natural Resources Research Institute at the University of Minnesota-Duluth.
VII. REFERENCES


Hunt, C. D., Tanis, D. C., & Stevens, T. G. (n.d.). A protocol ready for pilot-scale testing should improve knowledge of available technologies. 8.


### VIII. GREAT LAKES BALLAST WATER R&D PLAN DELIVERABLES

<table>
<thead>
<tr>
<th>Research Area</th>
<th>Objective</th>
<th>Project(s)</th>
<th>Deliverable(s)</th>
</tr>
</thead>
</table>
2. Kick-off meeting and development of project plans for projects beginning FY1 including stakeholder input. |
| | **Objective 2:** Formation of Data Working Group and Mining, Sharing, and Compiling Existing Data | 2: Form Data Working Group/Data Mining & Sharing | 1. Formation of data working group.  
2. Agreed-upon process for data sharing among working group members.  
3. Identification of data gaps and consideration of additional research needs for inclusion into R&D Plan. |
| | **Objective 3:** Engaging Stakeholders during R&D Plan Implementation | 3: Stakeholder Group Engagement | 1. Relevant R&D Plan with separate, supporting project plans that reflect the needs of stakeholders within the Great Lakes region. |
| **RESEARCH AREA 1:** IDENTIFICATION OF METHODS/ALTERNATIVES AND ASSESSMENT OF COST FOR GREAT LAKES BALLAST WATER MANAGEMENT | **Objective 1:** Determination of Operational Characteristics of Commercial Vessels Trading within the Great Lakes System | 1: Determining Operational Characteristics of Great Lakes Vessels | 1. Current data on U.S. and Canadian-flag Laker vessel operational characteristics to inform R&D Plan projects.  
2. Data on the number of seagoing vessels that enter the Great Lakes System, and contrast of seagoing vessels’ operational characteristics with those of Laker vessels.  
3. Analysis of data and comparison to ETV Protocol requirements to determine if Great Lakes adaptations are necessary. |
<p>| | <strong>Objective 2:</strong> Land-Based Evaluation of the Effectiveness of IMO Compliant and U.S. Coast Guard Type Approved BWMS in Great Lakes Water | 2: Land-Based BWMS Evaluation | 1. Data on the operational and biological efficacy of at least six market-available BWMS in Great Lakes water quality and biology, using current methods (ETV Protocol) and Great Lakes-adapted protocol. |
| | <strong>Objective 3:</strong> Shipboard Evaluation of the Effectiveness of IMO Compliant and U.S. Coast Guard Type Approved BWMS in Great Lakes Water | 3: Shipboard BWMS Evaluation | 1. Data on the operational and biological efficacy of at least two market-available BWMS used during normal Great Lakes vessel operations, and using current methods (ETV Protocol) and Great Lakes-adapted protocol. |</p>
<table>
<thead>
<tr>
<th>Research Area</th>
<th>Objective</th>
<th>Project(s)</th>
<th>Deliverable(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5: Ballast Water BMP Effectiveness</td>
<td>1. Data on the feasibility of potential, promising ballast water best management practices, including limited chemical treatment, open lake ballast water exchange, and ballast water filtration. 2. Empirical, biological efficacy data on feasible and promising ballast water best management practices.</td>
<td></td>
</tr>
<tr>
<td><strong>Objective 5</strong>: Evaluating the Feasibility and Significant Impacts of Ballast Water Reception Facilities within the Great Lakes</td>
<td>6: Feasibility Study of Reception Facility Treatment</td>
<td>1. Identification of scenarios under which management of ballast water via reception facilities may be viable options. 2. Data on the feasibility, economic, and environmental impact of alternatives to on-board ballast water treatment.</td>
<td></td>
</tr>
<tr>
<td><strong>RESEARCH AREA 2</strong>: TOWARD DEVELOPMENT OF GREAT LAKES RELEVANT BWMS TESTING PROTOCOL</td>
<td><strong>Objective 1</strong>: Characterizing BWMS Challenge Conditions in the Great Lakes System</td>
<td>1. Water quality and biology data from Great Lakes commercial ports in a publicly-available database. 2. Analysis of data and comparison to ETV Protocol requirements to determine if Great Lakes adaptations are necessary.</td>
<td></td>
</tr>
<tr>
<td>Research Area</td>
<td>Objective</td>
<td>Project(s)</td>
<td>Deliverable(s)</td>
</tr>
<tr>
<td>------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(per VIDA Viability Draft Policy Letter, 26 July 2019).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3: Eggs/Resting Stages Method Development</td>
<td>1. Validated method for determining the mortality and/or viability of eggs and resting stages in Great Lakes ballast water discharge samples leading to more accurate determination of BWMS biological efficacy.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4: Ballast Discharge Toxicity Method Development</td>
<td>1. Validated method for determining the toxicity of treated and neutralized ballast water discharge to organisms in the receiving water, and determination of feasibility of method implementation during shipboard testing. 2. Great Lakes specific guidance on selection of disinfection byproducts according to treatment technology, sampling, and analysis as part of toxicity testing. 3. Great Lakes specific guidance on interpretation of the results of toxicity testing in combination with disinfection byproduct data to ensure protectiveness of Great Lakes adapted testing protocol.</td>
</tr>
<tr>
<td>RESEARCH AREA 3: ACCELERATING DEVELOPMENT OF EMERGING BALLAST WATER TREATMENT TECHNOLOGIES</td>
<td>Objective 1: Acceleration of Ballast Water Treatment Technology Development</td>
<td>1: Accelerate Technology Development</td>
<td>1. Network of Great Lakes specific resources and experts that technology developers can utilize to ensure future technologies are applicable to Great Lakes realities from the early stages of development. 2. Framework for aiding ballast water treatment technology developers scale up technologies and bring them to market.</td>
</tr>
<tr>
<td></td>
<td>Objective 2: Research and Development Testing for Emerging Ballast Water Treatment Technologies</td>
<td>2: R&amp;D Testing Emerging Technologies</td>
<td>1. Land-based and/or shipboard research and development testing on biological efficacy (using Great Lakes-adapted protocol), and general</td>
</tr>
<tr>
<td>Research Area</td>
<td>Objective</td>
<td>Project(s)</td>
<td>Deliverable(s)</td>
</tr>
<tr>
<td>---------------</td>
<td>-----------</td>
<td>------------</td>
<td>----------------</td>
</tr>
</tbody>
</table>
| RESEARCH AREA 4: DEVELOPMENT OF BALLAST WATER INDICATIVE MONITORING METHODS | Objective 1: Development of a Method to Collect Representative Ballast Water Discharge Samples Onboard Great Lakes Commercial Vessels  
Objective 2: Great Lakes Verification of Ballast Water Indicative Monitoring Tools | 1: Indicative Monitoring Sample Method Development  
2: GL Verification of Indicative Analysis Tools | operational performance of at least three promising ballast water treatment technologies in development.  
1. Validated method for collection of indicative monitoring samples from Great Lakes vessels.  
1. Suite of indicative monitoring devices that have been verified for use in Great Lakes water quality and biology. |
| RESEARCH AREA 5: ASSESSING THE RISK OF AQUATIC NUISANCE SPECIES TRANSFER FROM BALLAST WATER DISCHARGE | Objective 1: Establishment of Great Lakes Focal Ports to Determine Interlake Transfer  
Objective 2: Using Semi-Field Methodologies to Determine the Impact of ANS Reduction in Managed Ballast Water | 1: Quantifying ANS Transfer  
2: Determining Impact of ANS Reduction | 1. Determination of ANS transfer via Great Lakes ballast water in the context of various vessel voyage patterns.  
2. Harbor monitoring data within Great Lakes focal ports/regions identifying ANS present in samples of zooplankton and benthic zooplankton.  
1. Data on the risk-release relationship for a variety of freshwater data providing context to ballast water monitoring data.  
2. Analysis of biological efficacy of ballast water management options evaluated during R&D Plan implementation in combination with ballast water monitoring data and risk-release relationship data to determine which management options ensure a sufficient reduction in ANS in ballast water discharge. |