Great Lakes and Lake Champlain Invasive Species Program

Great Lakes Ballast Water Research and Development Plan

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Prepared for

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Office of Water

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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 GLLCISP 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. However, Laker vessels do pose a risk of accelerating the secondary spread of introduced ANS within the Great Lakes, 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 GLLCISP 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 from the International Maritime Organization (IMO) D-2 Standard, USCG regulations at 33 CFR Part 151, and EPA's 2013 Vessel General Permit (VGP). 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, personal 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 adapted methods 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. Longer term, emerging technologies may be identified that can meet the current (national) discharge standard. In the interim, there may be best management practices (BMPs), 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 Research and Development (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. Coincidentally, 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, 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 seven-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

Research Areas 3 and 4 were removed from the R&D Plan in response to public comments indicating the projects proposed within those areas were low priority. It should be noted, work on the Plan was underway prior to the decision to the remove Research Areas 3 and 4; therefore, the numbering of Research Areas will remain the same.

Research Area	Objective	Key Research Question(s) Addressed by Project	Project(s)
STAKEHOLDER GROUP INVOLVEMENT	**Objective 1:** Formation of the Ballast Water R&D Stakeholder Group and Kick-Off Meeting	1. Which organizations are key for input on the goals and direction of the R&D Plan?	1: Form Stakeholder Group/Kick-Off
	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 modifications 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

Research Area	Objective	Key Research Question(s) Addressed by Project	Project(s)
	Objective 3: Shipboard 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 discharge standards using existing test methods (i.e., *ETV Protocol*), and two approaches: a. Conducting shipboard BWMS trials onboard Laker vessels in a variety of different Great Lakes commercial ports and over at least one Great Lakes shipping season. b. Sampling ballast uptake and discharge of seagoing vessels with installed BWMS that are trading within the Great Lakes System. 2. When evaluated at a shipboard scale using the newly developed, Great Lakes-adapted protocol, how do these BWMS perform? a. What is the level of ANS reduction that can be achieved based on shipboard testing?	3: Shipboard BWMS Evaluation
	Objective 4: Evaluating the Effectiveness of Ballast Water Best Management Practices Including Hybrid Solutions	1. Can filtration technologies and practices be improved for ballast water management in the Great Lakes?	4: Ballast Water Filter Performance
		2. What are the efficacies of potential, promising BMPs in reducing the concentration of ANS in ballast water discharge within the Great Lakes?	5: Ballast Water BMP Effectiveness
	Objective 5: Evaluating the Feasibility and Significant Impacts of Ballast Water Reception Facilities within the Great Lakes	1. What is the feasibility, economic, and environmental impact of reception facilities if utilized within the Great Lakes under certain scenarios or locations?	6: Feasibility Study of Reception Facility Treatment
	Objective 6: Assessing the Cost of Ballast Water Management Strategies on Commercial Vessels Operating Exclusively within the Great Lakes System	1. How do ballast water management strategies compare in terms of ANS reductions and cost for installation and operation?	7: Management Strategy Cost
RESEARCH AREA 2: TOWARD DEVELOPMENT OF GREAT LAKES RELEVANT BWMS TESTING PROTOCOL	**Objective 1:** Characterizing BWMS Challenge Conditions in the Great Lakes System	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 data collected for #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?	1: Characterize BWMS Challenge Conditions

Research Area	Objective	Key Research Question(s) Addressed by Project	Project(s)
	Objective 2: Evaluating Alternative/Emerging Sample Analysis Methods for Ballast Water Treatment Technology Testing	1. What are the potential emerging or alternative viability assessment methods for BWMS biological efficacy evaluation, and how effective are those methods? a. Are there viability assessment methods that can be utilized for the Great Lakes in order to evaluate treatment effects on planktonic organisms? b. Is it feasible to implement these methods during land-based evaluation of BWMS? c. Is it feasible to implement these methods during shipboard BWMS evaluation?	2: Viability Assessment Method Development
		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: Eggs/Resting Stages Method Development
		3. Is there a method that can be used to accurately assess the environmental acceptability of treated and neutralized ballast water upon discharge? a. Is there an adequate benchmark value/environmental acceptability standard that can be used to ensure protection of Great Lakes ports receiving ballast? b. Is it feasible to implement this method during shipboard BWMS evaluation?	4: Ballast Discharge Toxicity Method Development
	Objective 3: Development of a Great Lakes-Adapted Protocol for Verification of BWMS	1. What changes to the existing *ETV Protocol* are appropriate for its use to evaluate BWMS effectiveness for Great Lakes vessels?	5: Protocol Development
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	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?	1: Quantifying ANS Transfer
	Objective 2: Using Semi-Field Methodologies to Determine the Impact of ANS Reduction in Managed Ballast Water	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?	2: Determining Impact of ANS Reduction

PROPOSED BALLAST WATER R&D PLAN TIMELINE

The Great Lakes Ballast Water R&D Plan will be implemented over a period of seven federal fiscal years, approximately 01 October 2020 to 30 September 2027 (Figure 1). There are four research areas outlined in version 5 of the plan, and a total of 17 projects (including the stakeholder group activities). Many of the 17 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. Shading indicates the proposed year(s) during which each project will occur.

Research Area - Project	Project Description	Year 1 10/1/20 - 9/30/21	Year 2 10/1/21 - 9/30/22	Year 3 10/1/22 - 9/30/23	Year 4 10/1/23 - 9/30/24	Year 5 10/1/24 - 9/30/25	Year 6 10/1/25 - 9/30/26	Year 7 10/1/26 - 9/30/27
Stakeholder Group Involvement								
S1	Form Stakeholder Group/Kick-Off	■						
S2	Form Data Working Group/Data Mining and Sharing	■						
S3	Stakeholder Group Engagement	■	■	■	■	■	■	■
Research Area 1: Identification of Methods/Alternatives and Assessment of Cost for Great Lakes Ballast Water Management								
1 - 1	Determining Operational Characteristics of GL Vessels	■						
1 - 2	Land-Based BWMS Evaluation	■	■	■		■	■	
1 - 3	Shipboard BWMS Evaluation	■	■	■		■	■	
1 - 4	Ballast Water Filter Performance		■	■				
1 - 5	Ballast Water BMP Effectiveness		■	■	■			
1 - 6	Feasibility Study of Reception Facility Treatment		■					
1 - 7	Management Strategy Cost					■	■	
Research Area 2: Toward Development of Great Lakes Relevant BWMS Testing Protocol								
2 - 1	Characterize BWMS Challenge Conditions		■					
2 - 2	Viability Assessment Method Development	■	■					
2 - 3	Eggs/Resting Stages Method Development	■	■					
2 - 4	Ballast Discharge Toxicity Method Development	■	■					
2 - 5	Protocol Freshwater Revision and Validation				■			
Research Area 5: Assessing the Risk of Aquatic Nuisance Species Transfer from Ballast Water Discharge								
5 - 1	Quantifying ANS Transfer		■	■	■			
5 - 2	Determining Impact of ANS Reduction	■	■	■	■			
	Final data summary and reporting/publication						■	■

Figure 1. Great Lakes Ballast Water Research and Development Plan Seven-Year Timeline by Federal Fiscal Year.

GREAT LAKES BALLAST WATER RESEARCH AND DEVELOPMENT PLAN COORDINATION AND REVIEW

Upon receipt of Year One funding, the U.S. Department of Transportation Maritime Administration and members of the GWRC will 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.

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 seven-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 (i.e., in the form of Quality Assurance Project Plans and Test Plans) containing scientifically defensible experimental design and fully-formed implementation details. 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). 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 UWS-LSRI 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. Additional experts from academia will participate in Stakeholder Group/project planning meetings on an as-needed basis.

MARAD will function as the neutral facilitator of the R&D Plan's Stakeholder Group. As the facilitator, MARAD will be responsible for convening the stakeholder group, including academic experts as needed, and providing logistical and technical support for stakeholder group meetings. MARAD will not contribute to meeting content, is non-partisan, and will not drive the direction of the R&D Plan projects.

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 seven-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 existing 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. Literature review will be an integral part of R&D Plan project planning and will be an ongoing process throughout the seven-year implementation. Therefore, the data working group will remain engaged throughout the Year One to Year Seven planning processes. 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 seven-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. One- to two-page project summaries will be sent to stakeholder group members at least one week ahead of each meeting to allow ample time for preparation.

During the seven-year implementation of the R&D Plan, impromptu meetings with the stakeholder group may be necessary. These meetings will be scheduled on an as-needed basis in order to share and discuss any critical results and decision points.

B. TIMELINE

Figure 2 outlines the planned timing for the tasks associated with the formation of a stakeholder group and future engagement activities.

Research Area - Project	Project Description	Year 1 10/1/20 - 9/30/21	Year 2 10/1/21 - 9/30/22	Year 3 10/1/22 - 9/30/23	Year 4 10/1/23 - 9/30/24	Year 5 10/1/24 - 9/30/25	Year 6 10/1/25 - 9/30/26	Year 7 10/1/26 - 9/30/27
Stakeholder Group Involvement								
S1	Form Stakeholder Group/Kick-Off							
S2	Form Data Working Group/Data Mining and Sharing							
S3	Stakeholder Group Engagement							

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

DATA MANAGEMENT, SHARING, AND AVAILABILITY

A. GREAT WATERS RESEARCH COLLABORATIVE DATA MANAGEMENT STRUCTURE AND PROCESS

All projects conducted as part of the R&D Plan must conform to the documents and records management processes outlined in the *Lake Superior Research Institute Quality Management Plan* (LSRI QMP; LSRI, 2018). Project-specific requirements above and beyond those outlined in the LSRI QMP will be detailed in each Quality Assurance Project Plan, which are prepared by the project lead(s) and reviewed by the project manager, Dr. Jen Maki.

Organization and Management of References

Literature review will be an ongoing process throughout implementation of the R&D Plan. Zotero reference management software is used exclusively to collect, organize, cite, and share references among project team members. A password-protected and private group library has been created within Zotero for the R&D Plan, and each project outlined in the R&D Plan has an individual collection within this library. As references are populated in the R&D Plan group library, they are also tagged with the corresponding research area and project. In this way, all references are searchable by research area, project, title, author, and several other search terms.

Organization and Management of Data

LSRI's Egnyte Ballast Water File Server is the storage location for all existing data gathered as part of the Data Working Group efforts and primary data generated through implementation of R&D Plan projects. This cloud-based storage is protected by Egnyte's security system, and at the user level through password protection. User names and passwords for LSRI's Egnyte Ballast Water File Server are only issued to project staff. Data within Egnyte are organized by R&D Plan project and data type.

Project data will be recorded by hand on pre-printed data collection forms and/or in bound laboratory notebooks that are uniquely identified to the R&D Plan project. All documentation is required to conform to LSRI's good documentation practices and completed data collection forms will be secured in uniquely-identified, three-ring binders specific to the project. All hand-written data will be scanned and saved to LSRI's Egnyte File Server as soon as possible after generation. All original, raw (hand-recorded) data will be archived in LSRI's secure archive room for a period of at least seven years after project completion.

B. PROJECT DATA SHARING AND AVAILABILITY

The data generated during R&D Plan project implementation will be publicly available. A tiered approach to data access will be utilized, according to the following groups:

1. Members of the R&D Plan Stakeholder Group/Stakeholder Group Organizations
2. General Public

R&D Plan Stakeholder Group Organizations

The members of the R&D Plan Stakeholder Group will be given access to preliminary, summarized project data ahead of Stakeholder Group meetings. Project data will be provided at least one week prior to each semi-annual meeting to allow enough time for members to prepare for discussion. R&D Plan

Stakeholder Group members/organizations may also request access to more detailed project data at any time during the seven-year implementation of the R&D Plan by submitting a written request to GWRC (gwrc@uwsuper.edu) for the detailed project data set. The member must specify what information/data they seek and must describe how the data will be used. Following the request, the member will be sent a unique and password-protected download link that will enable them to download a local copy of the data stored on LSRI's Egnyte File Server to their PC/laptop. This link will only allow access to the specific information/data that was requested; the member will not have access to LSRI's Egnyte File Server through this link.

General Public

The public will only be given access to final project data after publication and final presentation, and after data have undergone GWRC's data verification and validation process. Project output, in the form of a peer-reviewed publication or technical report (where appropriate), will be publicly available. If more information/data than is provided in the project output is required, a written request to GWRC (gwrc@uwsuper.edu) can be made. The request must include the requester's name and contact information, affiliation and title, what information/data they seek, justification for the request, and description of how the data will be used. Following the request, the requester will be sent a unique and password-protected download link that will enable them to download a local copy of the data stored on LSRI's Egnyte File Server to their device.

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 vessel 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 m^3/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, which tested an electro-chlorination system (Cangelosi et al., 2018b), and one shipboard type approval test of a second BWMS that included two trials within the Great Lakes, which tested a chemical-injection system (Cangelosi et al., 2017). This lack of data begs the question of whether market-available, type-approved BWMS tested under Great Lakes relevant conditions during type approval testing will still meet a discharge standard. 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/treatment 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

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 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.

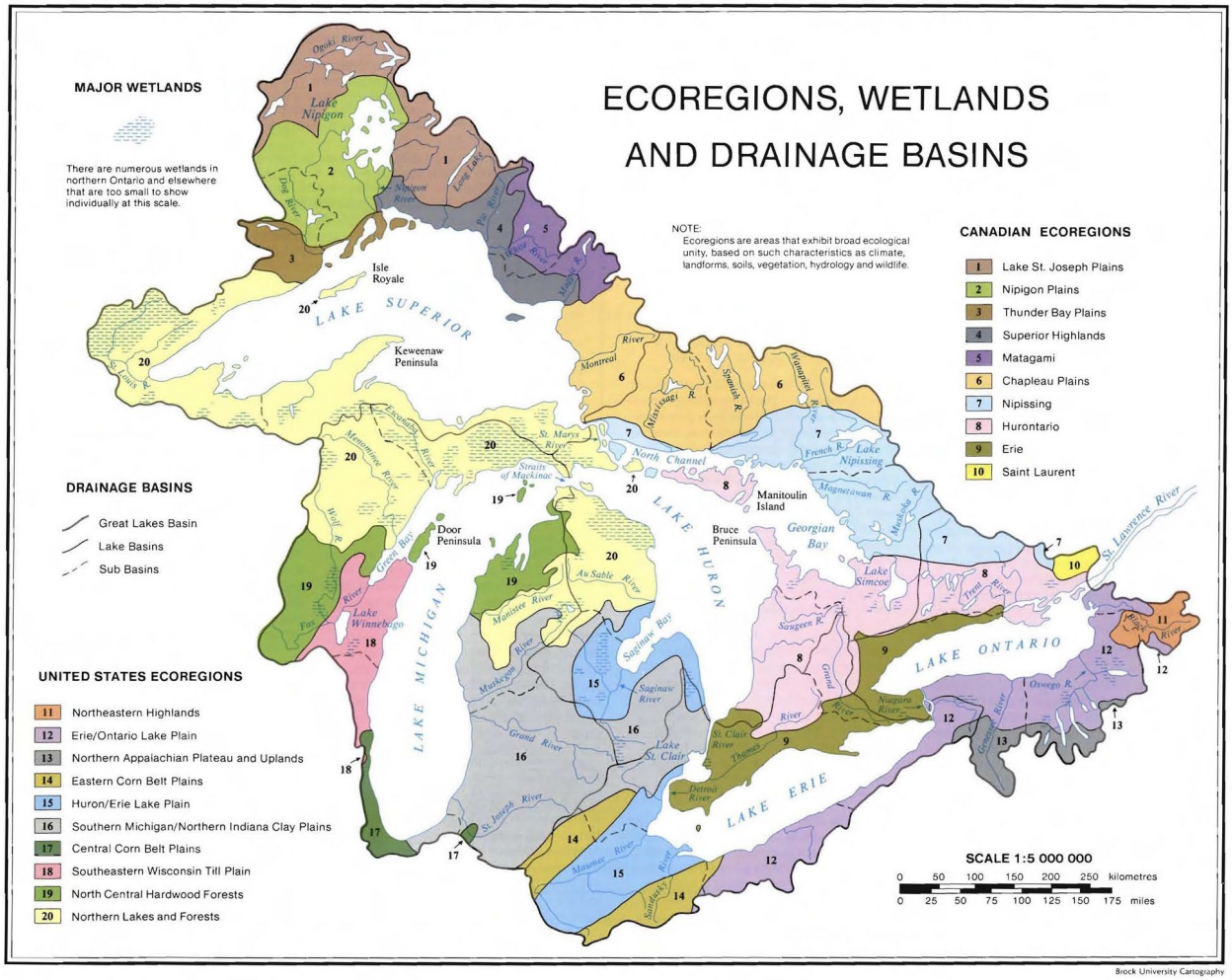

Figure 3. U.S. and Canadian Great Lakes Ecoregions from "The Great Lakes: An Environmental Atlas and Resource Book" (Government of Canada and U.S. EPA, 1995).

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, six-year project (Research Area 1 – Project 2). The first three 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, and the requirement for a source of salinity (i.e. electrolysis systems) will factor into the ultimate selection of technologies for testing. It should be noted, testing the effect of active substances on a ships structure (i.e. corrosion) is beyond GWRC's capabilities. Given successful biological efficacy and environmental acceptability testing GWRC can facilitate a discussion and make recommendations for corrosion testing.

Promising BWMS will be obtained, either through BWMS manufacturer lending/leasing of a unit or through direct purchase. During the first three 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), against challenging but realistic water quality conditions, which is operated by the GWRC. Up to three BWMS will be evaluated in each of Years One to Three.

Work conducted during Years Five and Six assumes successful development of an "ETV-like" protocol adapted for the Great Lakes in project Year Four, which is outlined in Research Area 2 and described by Research Area 2 – Project 5. The Great Lakes-adapted testing protocol will be finalized and validated before the start of Year Five.

Prior to beginning work in Year Five, the data from the 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 Five and Six. 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 Five and Six. This second round of land-based testing will provide data on the scalability and applicability 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 (Research Area 1—Project 3) and ANS monitoring (Research Area 5—Project 1), 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 six-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) Assessing the risk of ANS transfer (Research Area 5 – Project 1)

Two approaches will be used to maximize the data collection efforts:

1. Conducting shipboard BWMS evaluation trials onboard Laker vessels in a variety of different Great Lakes commercial ports and over at least one Great Lakes shipping season.
2. Sampling ballast uptake and discharge of seagoing vessels with installed BWMS that are trading within the Great Lakes System.

For the first approach, 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 six-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. Vessels of opportunity may also include mobile (port- and/or barge-based) ballast water treatment options with the potential for Great Lakes applicability. 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 over the course of the first three years of the R&D Plan implementation. Following vessel and BWMS (technologies designed to treat freshwater) selection, project planning and logistics will begin. Other Laker-specific considerations, such as the potential of the treatment to cause corrosion of the ballast tanks, and the requirement for a source of salinity (i.e. electrolysis systems) will factor into the ultimate selection.

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 and validation of the Great Lakes-adapted testing protocol in Year Four, the biological efficacy of the BWMS installed on the vessels of opportunity will again be evaluated using the adapted protocol's methods.

Prior to beginning work in Year Five, 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 Five and Six. 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, 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 compared to the *Quantifying ANS Transfer Project* (Research Area 5 – Project 1), to determine if any of the BWMS evaluated provide an acceptable level of propagule reduction while also performing reliably and predictably over time.

For the second approach, seagoing vessels with installed BWMS that are trading within the Great Lakes System will be targeted for ballast uptake and discharge sampling. Only those vessels with BWMS conducting both cargo off-loading and cargo loading operations within the Great Lakes during a single voyage will be targeted for a sampling event. Based upon data gathered by GWRC from the National Ballast Information Clearinghouse (NBIC) database, during 2015 – 2020, there were a total of 165 voyages of seagoing vessels with installed BWMS that performed ballast uptake and discharge operations within the Great Lakes System (an average of 33 voyages per year). There were only eight unique BWMS utilized on these vessels during this time frame. Therefore, GWRC will sample ballast uptake and discharge of eight different voyages, with the goal of collecting biological efficacy data on each unique BWMS represented in the 2015 – 2020 NBIC dataset. These sample collection efforts will take place over two Great Lakes shipping seasons. Planning for this work will begin approximately October 2021, and GWRC will collaborate with those shipping companies whose vessels most frequently trade within the Great Lakes System to begin targeting voyages. Sample collection efforts will take place March – December 2022 and March – December 2023. Methods outlined in the *ETV Protocol* will be followed for this work.

Objective 4: Evaluating the Effectiveness of Filtration Technologies.

Key Question:

1. **Can filtration technologies and practices be improved for ballast water management in the Great Lakes?**

Objective 4 is comprised of a research project 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 have 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), in which performance of eight commercially-available ballast water filter systems manufactured by five companies were 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, 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 m^3/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.

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

Note that mobile (land- or barge-based) treatment options are being considered as part of Research Area 1 – Project 3 (*Shipboard Evaluation of Approved BWMS in Great Lakes Water*).

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)
- Mobile (land- or barge-based) 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 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 and environmentally protective management options will be determined. This project will be conducted during Years Five and Six of the seven-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 1.

Research Area - Project	Project Description	Year 1 10/1/20 - 9/30/21	Year 2 10/1/21 - 9/30/22	Year 3 10/1/22 - 9/30/23	Year 4 10/1/23 - 9/30/24	Year 5 10/1/24 - 9/30/25	Year 6 10/1/25 - 9/30/26	Year 7 10/1/26 - 9/30/27
Research Area 1: Identification of Methods/Alternatives and Assessment of Cost for Great Lakes Ballast Water Management								
1 - 1	Determining Operational Characteristics of GL Vessels	■						
1 - 2	Land-Based BWMS Evaluation	■	■	■		■	■	
1 - 3	Shipboard BWMS Evaluation	■	■	■		■	■	
1 - 4	Ballast Water Filter Performance		■	■				
1 - 6	Feasibility Study of Reception Facility Treatment		■					
1 - 7	Management Strategy Cost					■	■	

Figure 4. Timing, by Federal Fiscal Year, of Projects Implemented under Research Area 1 of the Great Lakes Ballast Water R&D Plan.

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. The 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, the majority of which are 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 most 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. 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.

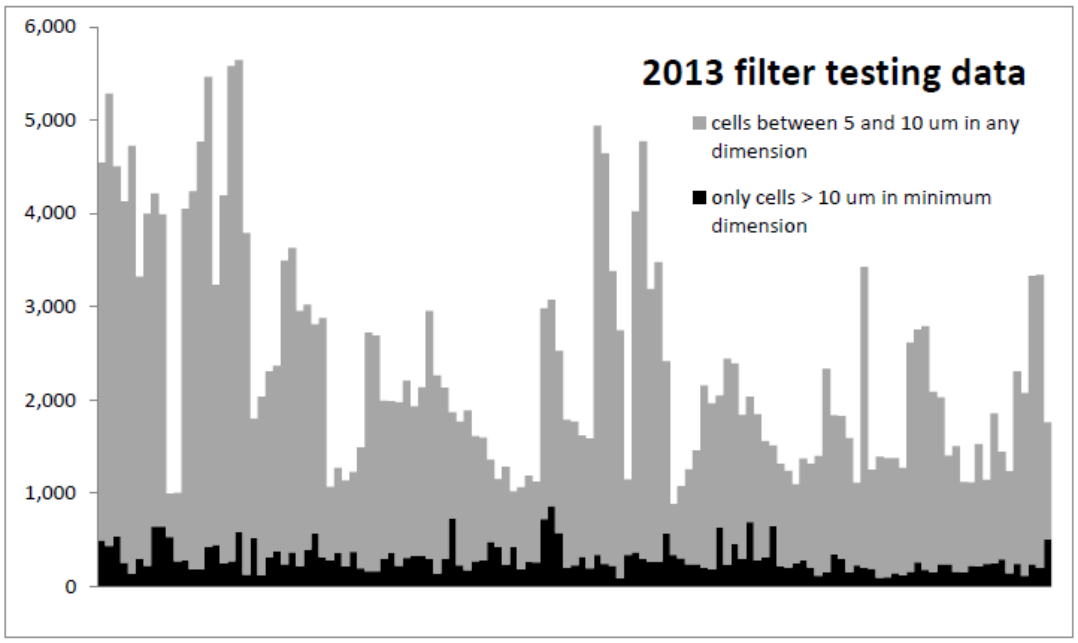

Figure 5. Protist Densities (cells/mL) in Samples Collected from Montreal Pier Facility in Summer 2013 (Author Credit: Euan Reavie, 2013). Grey-Shaded Areas Representing Density of Protist Propagules ≥5 µm in any Visible Dimension and Black-Shaded Areas Representing Density of Protist Propagules ≥10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

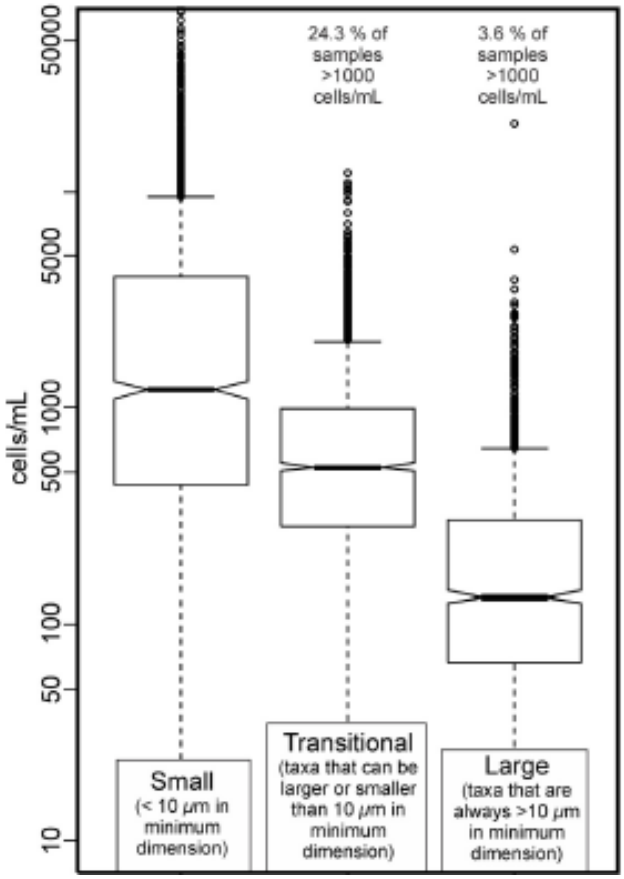

Figure 6. Figure from Reavie & Cangelosi (2020) Showing the Protist Cell Size Distribution, by Density, in Samples Collected over 14 Years throughout the Great Lakes. Boxes Represent the Lower and Upper Quartiles, Whiskers Represent the 1.5 Interquartile Distance from the Lower and Upper Quartiles, and Small Circles are Outliers.

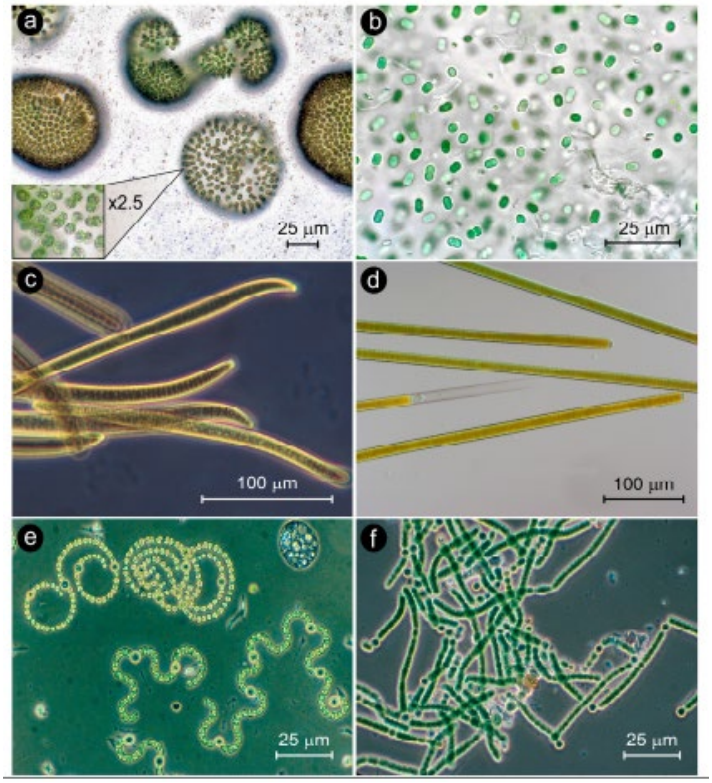

Figure 7. Photomicrographs (Paerl, 2018) of Coccoid and Filamentous Cyanobacteria Genera (a) Microcystis spp.; (b) Synechococcus sp.; (c) Oscillatoria sp.; (d) Lyngbya sp.; (e) Dolichospermum sp.; (f) Nodularia sp.

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. 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 resulted in 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 can kill, inactivate, or render 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 protection, 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 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 BWMS Evaluation, Shipboard BWMS Evaluation*, and *BMP Effectiveness*) 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 data from #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 a one-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 are 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 one Great Lakes shipping season (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*
        - *Enterococcus spp.*
        - Replacement for *Vibrio cholerae* O1 and O139
- Water quality parameters of interest:
    - Temperature
    - Salinity/specific conductivity
    - Dissolved oxygen
    - pH
    - 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 developed by GWRC.

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?**
    a. **Are there viability assessment methods that can be utilized for the Great Lakes in order to evaluate treatment effects on planktonic organisms?**
    b. **Is it feasible to implement these methods during land-based evaluation of BWMS?**
    c. **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?**
    a. **Is there an adequate benchmark value/environmental acceptability standard that can be used to ensure protectiveness to Great Lakes ports receiving ballast?**
    b. **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 complied 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 under Objective 2, 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 in Superior, WI. 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 method that could be utilized within the Great Lakes System and elsewhere, during BWMS type approval testing, to assess the viability of protists in freshwater ballast water samples. 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 under this objective, Research Area 2 – Project 4, 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. 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 environmental 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 revisions to the freshwater testing requirements in 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 revisions. The deliverable from this project will be recommendations for inclusion into a revision to the current *ETV Protocol* that captures Great Lakes realities (R&D Plan Deliverables).

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.

Research Area - Project	Project Description	Year 1 10/1/20 - 9/30/21	Year 2 10/1/21 - 9/30/22	Year 3 10/1/22 - 9/30/23	Year 4 10/1/23 - 9/30/24	Year 5 10/1/24 - 9/30/25	Year 6 10/1/25 - 9/30/26	Year 7 10/1/26 - 9/30/27
Research Area 2: Toward Development of Great Lakes Relevant BWMS Testing Protocol								
2 - 1	Characterize BWMS Challenge Conditions		■					
2 - 2	Viability Assessment Method Development	■	■					
2 - 3	Eggs/Resting Stages Method Development	■	■					
2 - 4	Ballast Discharge Toxicity Method Development	■	■					
2 - 5	Protocol Freshwater Revision and Validation				■			

Figure 8. Timing, by Federal Fiscal Year, of Projects Implemented under Research Area 2 of the Great Lakes Ballast Water R&D Plan.

III. 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 "sentinel sites" for several years. The current sentinel sites are in Chesapeake Bay, Tampa Bay, and San Francisco Bay. The Coast Guard is working toward identifying one or more of these sentinel sites 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 9). 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 sentinel sites 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 Great Lakes sentinel sites 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. (2018) suggest additional experiments be conducted with a variety of organisms and conditions 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

standard. 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 Sentinel Sites 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 sentinel sites 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 sentinel 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 within the sentinel sites 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 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 each experiment, 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 for establishment probability of a variety of taxa (like Figure 9). 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 these datasets, the ability to approximate the impact of various management strategies on the risk of ANS transfer through Great Lakes ballast water can be modeled.

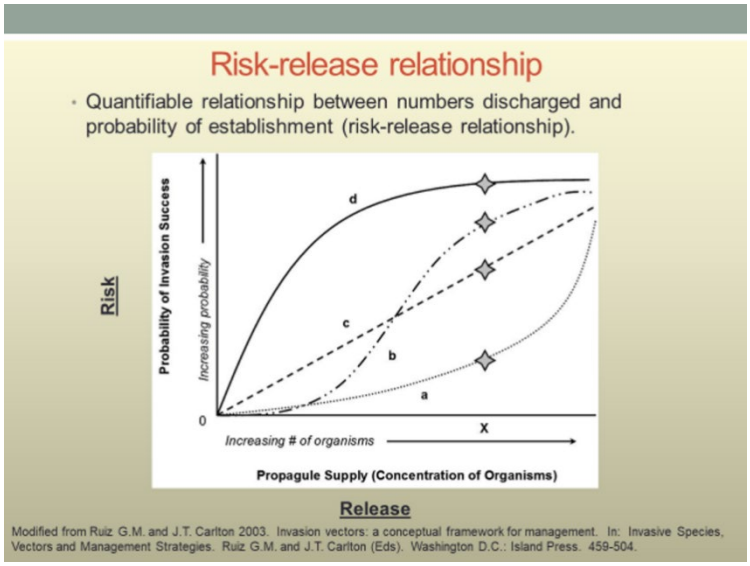

Figure 9. Risk-Release Relationship Curves as Modified from Ruiz and Carlton (2003). Output from Research Area 5 - Project 2 will result in similar data for a variety of freshwater taxa, and these curves will be overlaid by the propagule data collected during Research Area 1 – Project 1.

B. TIMELINE

Figure 10 outlines the planned timing for the research projects described in Ballast Water R&D Plan Research Area 5.

Research Area - Project	Project Description	Year 1 10/1/20 - 9/30/21	Year 2 10/1/21 - 9/30/22	Year 3 10/1/22 - 9/30/23	Year 4 10/1/23 - 9/30/24	Year 5 10/1/24 - 9/30/25	Year 6 10/1/25 - 9/30/26	Year 7 10/1/26 - 9/30/27
Research Area 5: Assessing the Risk of Aquatic Nuisance Species Transfer from Ballast Water Discharge								
5 - 1	Quantifying ANS Transfer							
5 - 2	Determining Impact of ANS Reduction							

Figure 10. Timing, by Federal Fiscal Year, of Projects Implemented under Research Area 5 of the Great Lakes Ballast Water R&D Plan.

IV. 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). 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 UWS LSRI (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 project staff.

MARAD's relationship with UWS 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, GWRC was born (uwsuper.edu/gwrc). 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.

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VI. GREAT LAKES BALLAST WATER R&D PLAN DELIVERABLES

Research Area	Objective	Project(s)	Deliverable(s)
STAKEHOLDER GROUP INVOLVEMENT	**Objective 1:** Formation of the Ballast Water R&D Stakeholder Group and Kick-Off Meeting	1: Form Stakeholder Group/Kick-Off	1. Formation of diverse, binational stakeholder group. 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.
	Objective 2: 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.
	Objective 3: Shipboard Evaluation of the Effectiveness of IMO Compliant and U.S.	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

Research Area	Objective	Project(s)	Deliverable(s)
	Coast Guard Type Approved BWMS in Great Lakes Water		using current methods (*ETV Protocol*) and Great Lakes-adapted protocol. 2. Data on the biological efficacy of BWMS as installed on seagoing vessels trading within the Great Lakes System.
	Objective 4: Evaluating the Effectiveness of Ballast Water Best Management Practices Including Hybrid Solutions	4: Ballast Water Filter Performance	1. Data on the performance of at least six market-available ballast water filters under challenging (but not rare) Great Lakes conditions. 2. Data on the impact of ice/icing on the performance of the same six filters.
		5: Ballast Water BMP Effectiveness	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.
	Objective 5: Evaluating the Feasibility and Significant Impacts of Ballast Water Reception Facilities within the Great Lakes	6: Feasibility Study of Reception Facility Treatment	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.
	Objective 6: Assessing the Cost of Ballast Water Management Strategies on Commercial Vessels Operating Exclusively within the Great Lakes System	7: Management Strategy Cost	1. Evaluation of the cost of ballast water management strategies in combination with biological efficacy data from Great Lakes testing.
RESEARCH AREA 2: TOWARD DEVELOPMENT OF GREAT LAKES RELEVANT BWMS TESTING PROTOCOL	**Objective 1:** Characterizing BWMS Challenge Conditions in the Great Lakes System	1: Characterize BWMS Challenge Conditions	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.

Research Area	Objective	Project(s)	Deliverable(s)
	Objective 2: Evaluating Alternative/Emerging Sample Analysis Methods for Ballast Water Treatment Technology Testing	2: Viability Assessment Method Development	1. Viability assessment method for analysis of Great Lakes ballast water discharge and determination of feasibility of method implementation during land-based and shipboard testing.
		3: Eggs/Resting Stages Method Development	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.
		4: Ballast Discharge Toxicity Method Development	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.
	Objective 3: Development of a Great Lakes-Adapted Protocol for Verification of BWMS	5: Protocol Development	1. Determination of changes needed to existing *ETV Protocol*, and written recommendations for adaptations to *ETV Protocol*, incorporating input from stakeholder group. 2. Great Lakes-adapted, "ETV-like" protocol for review and acceptance by U.S. EPA and U.S. Coast Guard.

Research Area	Objective	Project(s)	Deliverable(s)
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	1: Quantifying ANS Transfer	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.
	Objective 2: Using Semi-Field Methodologies to Determine the Impact of ANS Reduction in Managed Ballast Water	2: Determining Impact of ANS Reduction	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 enough reduction in ANS in ballast water discharge.