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# Great Lakes Hydrilla Risk Assessment

February 2019

Prepared for:

**U.S. ARMY CORPS OF ENGINEERS (USACE)** - Buffalo District
and the
**USACE Engineer Research and Development Center**

US Army Corps of Engineers®
Buffalo District
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**North Carolina State University**
**Texas Tech**
**University Of Toledo**

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# Risk Assessment

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**Paid for by:**
**Great Lakes Restoration Initiative**

**Prepared for:**
**U.S. ARMY CORPS OF ENGINEERS (USACE) - Buffalo District**
**and the USACE Engineer Research and Development Center**

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# List of Abbreviations and Acronyms

| | |
|---|---|
| AIS | aquatic invasive species |
| ANS | aquatic nuisance species |
| AVM | avian vacuolar myelinopathy |
| BMP | best management practice |
| BOD | biological oxygen demand |
| CY | cubic yards |
| DNR | Department of Natural Resources |
| DO | dissolved oxygen |
| E & E | Ecology and Environment, Inc. |
| EDDMapS | Early Detection and Distribution Mapping System |
| eDNA | environmental DNA |
| ERDC | Engineer Research and Development Center |
| g | gram |
| GBIF | Global Biodiversity Information Facility |
| GIS | geographic information system |
| GLAHF | Great Lakes Aquatic Habitat Framework |
| ha | hectare |
| Hydrilla | *Hydrilla verticillata* |
| IBA | important bird area |
| NAS | National Audubon Society |
| NCSU | North Carolina State University |
| NOAA | National Oceanic and Atmospheric Administration |
| NWR | National Wildlife Refuge |
| NYSDEC | New York State Department of Environmental Conservation |
| OMNRF | Ontario Ministry of Natural Resources and Forestry |
| PA DCNR | Pennsylvania Department of Conservation and Natural Resources |
| ROM | rough order-of-magnitude |

## List of Abbreviations and Acronyms (cont.)

| | |
|---|---|
| SAV | submerged aquatic vegetation |
| SDM | species distribution model |
| tubers/$m^2$ | tubers per square meter |
| USACE ERDC | U.S. Army Corps of Engineers – Buffalo District and Engineer Research and Development Center |
| USEPA | U.S. Environmental Protection Agency |
| USFWS | U.S. Fish and Wildlife Service |
| USGS | U.S. Geological Survey |

# Executive Summary

*Hydrilla verticillata* (Hydrilla) is an invasive aquatic plant introduced to the United States from Asia. There are two biotypes of Hydrilla in the United States. The dioecious Hydrilla biotype was introduced from Sri Lanka into Florida in the 1950s and has spread throughout the southeastern United States. The monoecious Hydrilla biotype was discovered in Delaware in the mid-1970s and has since expanded its distribution through the Atlantic states and northward to Maine. Recently, monoecious Hydrilla was discovered at several locations in the Great Lakes Basin, including locations in central and western New York State and in several waterbodies in Pennsylvania and Ohio near Lake Erie. These discoveries raised concerns about the spread of monoecious Hydrilla throughout the Great Lakes Basin. Where introduced, Hydrilla has considerable negative impacts due to its ability to grow and reproduce rapidly. These impacts include clogging waterways with surface mats; restricting water flow; interfering with boating, swimming, and fishing; diminishing shoreline property value; interfering with navigation, irrigation, and hydropower generation; displacing native aquatic plants; and generally disrupting submerged aquatic habitats by domination. This assessment was undertaken to identify locations in the Great Lakes Basin most vulnerable to monoecious Hydrilla invasion based on likelihood of introduction and environmental suitability, and to estimate potential impacts that could arise from establishment. In addition, this assessment provides recommendations for prevention, early detection, and rapid response to reduce risk of Hydrilla spread and identifies best management practices (BMPs) for Hydrilla control.

This assessment made use of: (1) all available Hydrilla occurrence records for North America and the world; (2) state-of-the-science methods for dispersal and distributional modeling; (3) growth studies with monoecious Hydrilla to identify critical environmental limits on monoecious Hydrilla growth and reproduction in northern waters; and (4) an evaluation of environmental parameters expected to influence Hydrilla growth and reproduction in the Great Lakes, including water temperature and depth, substrate type, and aquatic-plant distribution. The combined outputs of these project components showed that watersheds bordering Lakes Erie and Ontario in New York, Pennsylvania, and Ohio, and Lake St. Clair in southeast Michigan, are at greatest risk for Hydrilla introduction and establishment. Conversely, watersheds bordering Lake Superior are at lowest risk for Hydrilla introduction and establishment.

Within the Great Lakes proper, potential habitat for Hydrilla generally is limited to areas where water depth is less than 25 feet (due to hydrostatic pressure) and summer water temperature is 68°F or greater for two consecutive months (to allow for adequate tuber production). These limitations mean that the habitats most vulnerable to Hydrilla invasion in the Great Lakes are near-shore, littoral-zone habitats. However, not all littoral zone habitats are equally at risk. In general, shallow, near-shore areas that are sheltered from wave action, including embayments, coves, coastal wetlands, and natural and constructed harbors provide more suitable habitat for Hydrilla than open, wave-swept shorelines. Hence, shallow, sheltered areas along the south shores of Lakes Erie and Ontario and along the shoreline of Lake St. Clair are the areas considered to be most at risk from Hydrilla and, therefore, where resource managers should be most vigilant for the appearance of this aquatic invasive species.

Inland water bodies also are vulnerable to Hydrilla.  Within the Great Lakes Basin, inland waterbodies in watersheds bordering Lakes Erie and Ontario in New York, Pennsylvania, and Ohio, and Lake St. Clair in southeast Michigan, are at greatest risk from Hydrilla, whereas those in watersheds bordering Lake Superior are at lowest risk.  In general, inland water bodies are expected to be more vulnerable to a Hydrilla infestation than the Great Lakes proper because they are less turbulent, shallower, and warmer than the Great Lakes. Indeed, within the Great Lakes Basin currently, all known Hydrilla infestations exist in inland waterbodies, not in the Great Lakes proper. Inland infestations may act as sources of propagules to other inland waterbodies and to the Great Lakes and, therefore, resource managers should be especially watchful for the appearance of new Hydrilla infestations near existing infestations.

Potential economic, environmental, socio-cultural, and tribal impacts resulting from Hydrilla establishment in the Great Lakes were evaluated and found to be significant. For example, the economic loss associated with impacts on recreational fishing, beach use, recreational boating, and commercial navigation are expected to range between $70 and $500 million annually if Hydrilla becomes established in the Great Lakes.  Given the potentially large economic (and other) losses resulting from Hydrilla establishment, the costs of implementing a prevention and management program would be far less costly than controlling and managing well-established infestations.

Preventing the spread of Hydrilla in the Great Lakes Basin depends on an informed public; thus, public information and awareness are the foundation of a successful Hydrilla prevention program. Hydrilla prevention and management recommendations for the Great Lakes Basin include:

- Develop a public information campaign and post signage at access points;
- Implement watercraft inspections at boat ramps and launches in high-risk waterbodies;

- Establish active and passive detection networks to survey and monitor high-risk waterbodies for detection of new Hydrilla populations;
- Focus monitoring efforts on areas in and around existing infestations;
- Implement early coordination with regulatory agencies for rapid response, including identifying and eliminating pathways to and from new infestations;
- Close access points in proximity to Hydrilla infestations to minimize spread;
- Consider the use of quarantine options where applicable and appropriate; and
- For long-term sustained control, use chemical control agents (aquatic herbicides) for Hydrilla management along with additional measures as necessary to control isolated patches that survive treatment or re-sprout from the tuber bank.

In addition to the recommendations summarized above, this risk assessment presents BMPs for Hydrilla detection, treatment, and monitoring. Lastly, the results of this assessment are being shared with stakeholders and other interested parties throughout the Great Lakes Basin and elsewhere, thereby contributing to the management of Hydrilla in the Great Lakes Basin by identifying high-risk areas and encouraging adoption of the recommendations and BMPs developed as part of the assessment.

# Summary Report

## SR.1 Background

*Hydrilla verticillata* (Hydrilla) is an invasive aquatic plant introduced to the United States from Asia. There are two biotypes of Hydrilla in the United States (Shearer 2014). The dioecious Hydrilla biotype was introduced from Sri Lanka into Florida in the 1950s and has spread throughout the southeastern United States. The monoecious Hydrilla biotype was discovered in Delaware in the mid-1970s and has since expanded its distribution through the Atlantic states and northward to Maine. Recently, monoecious Hydrilla was discovered at several locations in the Great Lakes Basin, including Cayuga Lake in central New York State; Tonawanda Creek in western New York State; Tinker Nature Park near Rochester, New York; and several waterbodies in Ohio near Lake Erie. These discoveries raised concerns about the spread of monoecious Hydrilla throughout the Great Lakes Basin. Where introduced, Hydrilla has considerable negative impacts due to its ability to grow and reproduce rapidly. These impacts include clogging waterways with surface mats; restricting water flow; interfering with recreational activities such as boating, swimming, and fishing; diminishing shoreline property value; interfering with navigation, irrigation, and hydropower generation; displacing native aquatic plants; and generally disrupting submerged aquatic habitats by domination (Langeland 1996; Netherland and Greer 2014; Shearer 2014; Dayan and Netherland 2005). This risk assessment was undertaken to understand the potential for introduction and establishment of monoecious Hydrilla in the Great Lakes Basin and estimate potential impacts from establishment.

## SR.2 Objectives

The principal objective of the Great Lakes Hydrilla risk assessment was to identify locations in the Great Lakes Basin most vulnerable to invasion based on likelihood of introduction and environmental suitability. Other key components of the project were to: (1) develop an improved understanding of the effects of photoperiod, temperature, and interspecies competition on growth of monoecious Hydrilla through laboratory and field mesocosm studies; (2) assess economic, socioocultural, and environmental impacts of Hydrilla establishment in the Great Lakes; (3) provide recommendations for prevention, early detection, and rapid response to reduce risk of Hydrilla spread; and (4) identify best management practices (BMPs) for Hydrilla control.

## SR.3 Risk Assessment Framework

The risk assessment framework for aquatic nuisance species (ANS) proposed by Suedel et al. (2007) was adopted for this project. Their framework was modeled after the ecological risk assessment framework developed by the U.S. Environmental Protection Agency (USEPA) and includes four main elements: (1) Problem Formulation; (2) Analysis, including Characterization of Exposure and Effects; (3) Risk Characterization, and (4) Risk Management (USEPA 1997). Figure SR-1 shows the ANS risk assessment framework of Suedel et al. (2007) made specific to the Great Lakes Hydrilla risk assessment project. Problem Formulation included:

1. Defining the problem (see Section SR.1);
2. Setting objectives (see Section SR.2);
3. Defining the project extent, which, for this project, was the Great Lakes themselves and inland waterbodies in the Great Lakes Basin (see Section SR.2); and
4. Defining focus, which, for this project, was monoecious Hydrilla because this Hydrilla biotype was discovered recently in the Great Lakes Basin and is well adapted to growing and reproducing in cool-water environments (see Section SR.5).

The row of five boxes at the top of the Analysis step in Figure SR-1 comprise the Exposure Assessment, and included:

1. Creating a Hydrilla occurrence database, to document where Hydrilla occurs in the Great Lakes Basin and elsewhere in the United States and globally (see Section SR.6.1.1);
2. Distributional modeling, to identify suitable habitats for Hydrilla in the Great Lakes Basin (see Section SR.6.1.2);
3. Evaluating Great Lakes habitat features, such as water temperature and depth, to help better identify suitable Hydrilla habitats in the Great Lakes (see Section SR.6.1.3);
4. Dispersal modeling, to forecast where Hydrilla can be transported to from where it is now and identify important transport mechanisms (see Section SR.6.1.4); and
5. Hydrilla growth studies, to better understand how monoecious Hydrilla performs in cool water habitats and competes with aquatic plant species currently established in the Great Lakes Basin (see SR.6.1.5).

The results from these five activities allowed the project team to map the location and extent of areas vulnerable to Hydrilla invasion and establishment in the Great Lakes Basin. Once these areas were identified and mapped, the potential economic, socio-cultural, and environmental impacts of Hydrilla establishment in the Great Lakes Basin were estimated.

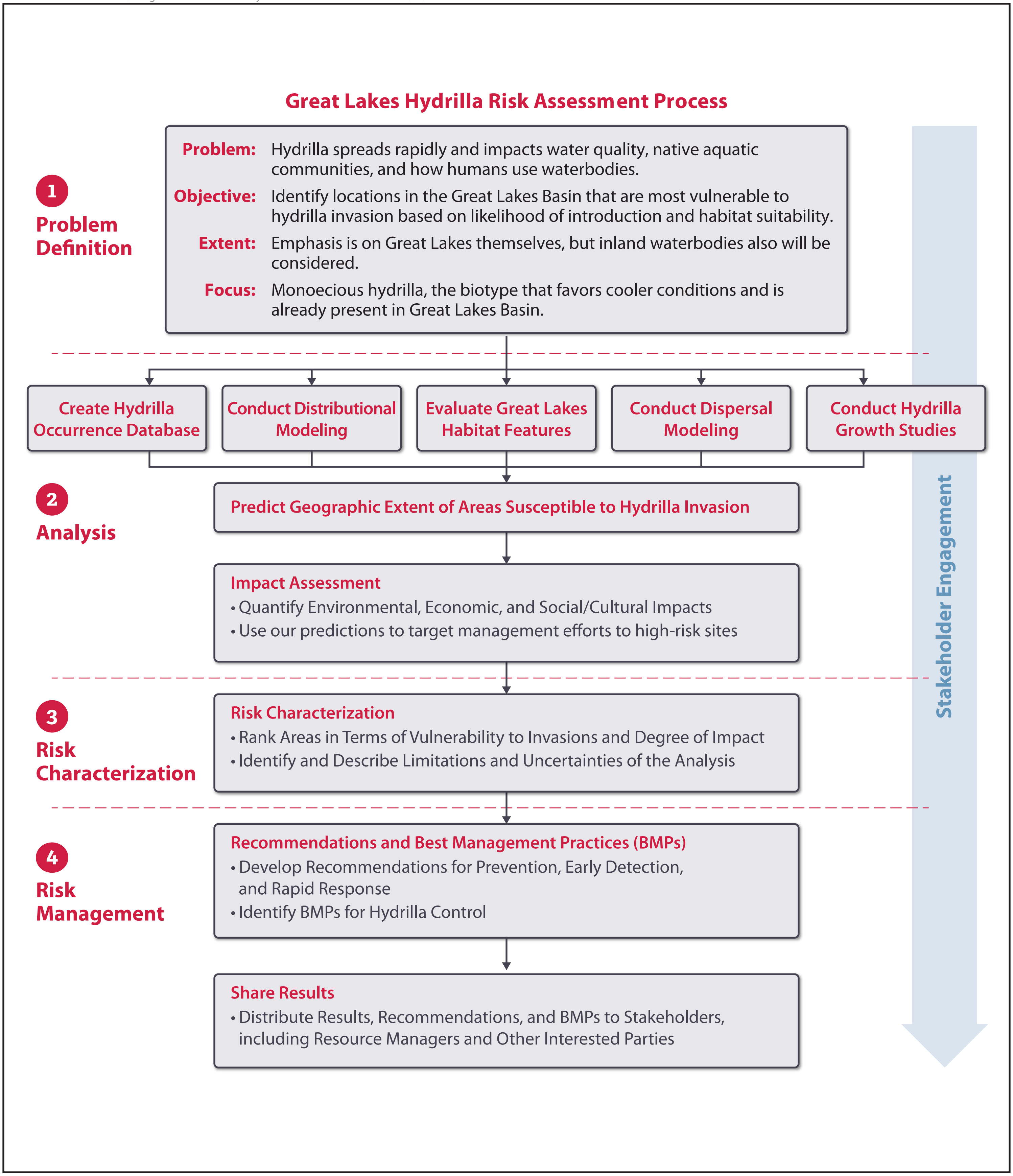


**Figure SR-1 Great Lakes Hydrilla Risk Assessment Process**

The Analysis Phase was followed by Risk Characterization (see Figure SR-1), in which areas were ranked based on vulnerability to invasion and potential for impact, and key uncertainties in the risk-assessment process were identified and discussed.

Following Risk Characterization, relevant material was reviewed to provide guidance in support of effective Risk Management (see Figure SR-1), which included developing recommendations for prevention, early detection, and rapid response, and developing BMPs for Hydrilla control. An important element of risk management was sharing results, recommendations, and BMPs with resource managers and other stakeholders in the Great Lakes Basin.

As recommended by Suedel et al. (2007) and shown in Figure SR-1, stakeholder engagement should occur throughout the ANS risk assessment process to ensure that the outputs of the assessment are useful to resource managers and others that need to make decisions about ANS management.

## SR.4 Stakeholder Engagement

Stakeholder engagement occurred throughout the risk assessment process, both to incorporate existing knowledge and information from Hydrilla specialists into the risk assessment process, and share results of the assessment with stakeholders across the Great Lakes Basin (see Figure SR-1). Stakeholders were defined as individuals or organizations with a demonstrated interest in Hydrilla management, with emphasis on management practitioners. At the outset of the project, a *Stakeholder Coordination and Outreach Playbook* was developed to guide stakeholder engagement activities throughout the assessment. Key activities prescribed by the playbook include stakeholder identification, information gathering from Hydrilla specialists within and outside the Great Lakes Basin, and additional stakeholder communications focused on announcing the risk assessment and disseminating project information and conclusions.

A preliminary set of stakeholders was identified that included individuals and organizations within the Great Lakes Basin, including all Great Lakes states, as well as stakeholders in non-Great Lakes states with known Hydrilla infestations. The preliminary stakeholder list was compiled from various sources, including previous project experience, Internet research, and a review of available technical literature. Focus was placed on the identification of representative Hydrilla management practitioners and outreach specialists in Great Lakes states, as well as entities involved with past and present Hydrilla management efforts in other states. Additional stakeholders were identified at the local, state, and federal levels; within applicable academic and non-governmental organizations; and from federally recognized tribes in states that border the Great Lakes and various intertribal organizations, which may also have an interest in the project.

Stakeholders across the Great Lakes Basin and in other areas were interviewed for information about Hydrilla infestations in their jurisdictions, management of those infestations, and early detection and rapid response programs to prevent Hydrilla spread. Additional stakeholder engagement activities were focused on increasing awareness of this risk assessment through distribution of project fact sheets and making presentations at relevant technical conferences. Stakeholder engagement at the conclusion of the risk assessment included dissemination of the final risk assessment report and targeted outreach activities to communicate the findings of the assessment with respect to colonization potential in specific areas of the Great Lakes Basin and promote implementation of recommended actions and BMPs for prevention, early detection, rapid response, and long-tern management to minimize and mitigate damages from Hydrilla within the basin.

## SR.5 Problem Formulation

Problem formulation, the first step in the risk-assessment process, identifies the objectives and focus of the assessment, stressors, sources of stressors, complete and potentially complete exposure pathways, and receptors. In the Great Lakes Hydrilla risk assessment, the stressor is Hydrilla, sources are locations that release Hydrilla (i.e., current infestations), receptors are the valued natural and manmade resources that may be adversely impacted by Hydrilla, and exposure pathways are mechanisms by which Hydrilla can be transported from sources to receptor locations (e.g., movement of contaminated watercraft). Once exposed, receptors interact with Hydrilla in several ways, both direct and indirect (e.g., habitat alteration, interference with recreational activities, and elimination of native species). As part of problem formulation, a conceptual model was developed that summarized the relationships between the stressor (Hydrilla) and potential receptors. The conceptual model for the Great Lakes Hydrilla risk assessment is shown in Figure SR-2. Transport by recreational watercraft is thought to be the primary means by which Hydrilla moves within a waterbody and into new waterbodies; however, the other means of transport are possible (see Figure SR-2) and may be significant in certain situations.

## SR.6 Analysis

The analysis step was the longest and most detailed step in the assessment. As shown in Figure SR-1, the analysis step included: (1) five components designed to characterize current and future exposure of the Great Lakes to Hydrilla; (2) integration of results from these components to identify areas most vulnerable to invasion based on likelihood of introduction and environmental suitability; and (3) characterization of economic, socio-cultural, and environmental impacts from Hydrilla establishment.

### SR.6.1 Exposure Assessment Components

As shown in Figure SR-1, five activities were undertaken to understand current and future exposure of the Great Lakes to Hydrilla; (1) Hydrilla Occurrence Database Development; (2) Distributional Modeling; (3) Evaluation of Great Lakes Habitats Features; (4) Dispersal Modeling; and (5) Hydrilla Growth Studies. Each of these activities is discussed in turn in the following subsections.

02:1003025.0025.03.06-B4869\01 Figure SR-2 Conceptual Site Model.ai-1/24/19-GRA

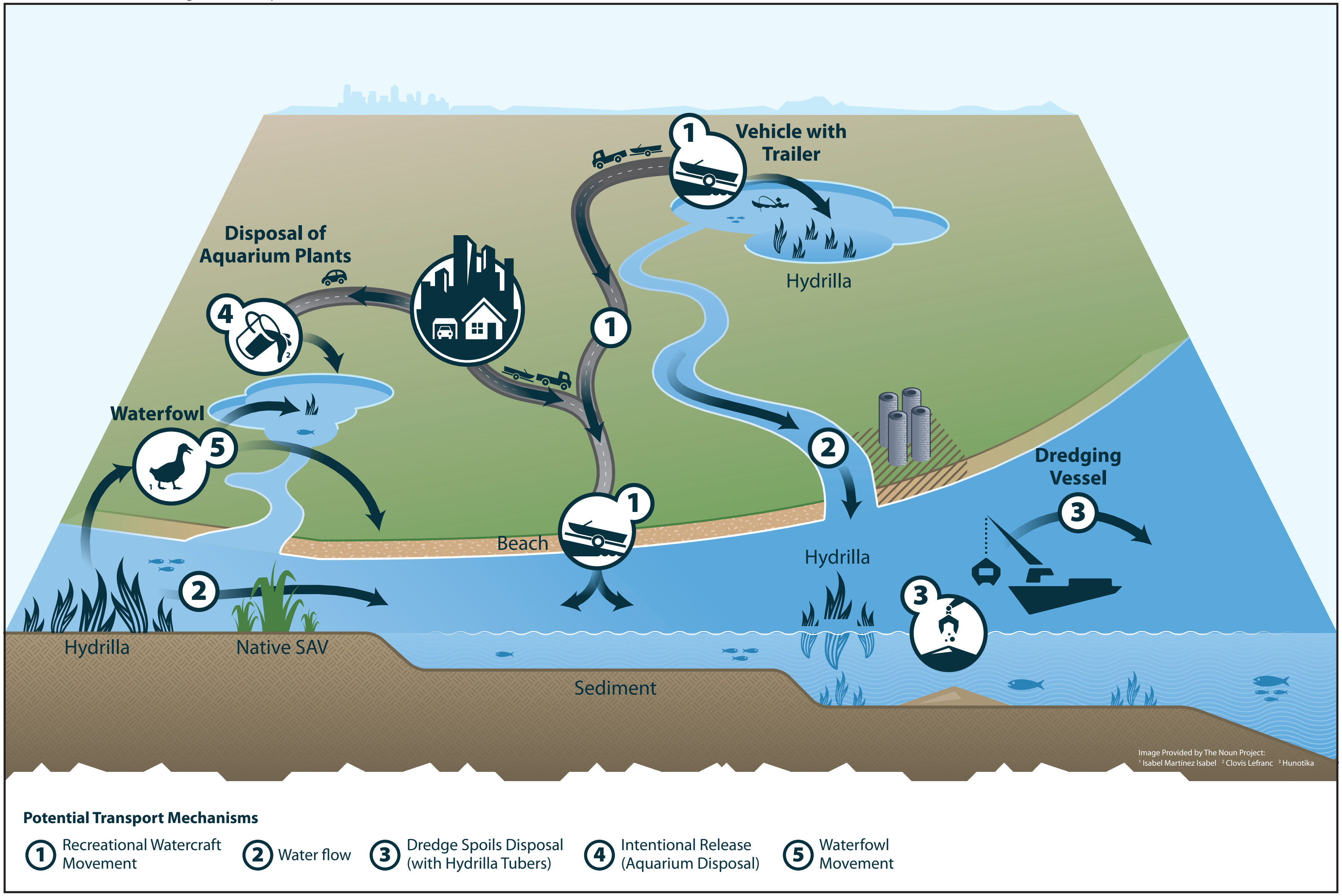


**Figure SR-2 Conceptual Model Illustrating Potential Means of Hydrilla Movement in a Typical Great Lakes Environment**

Transport by recreational watercraft (1) is thought to be the primary means by which Hydrilla moves into new waterbodies; however, the other means of transport (2 to 5) cannot be ruled out and may be signifiant in certain situations.

### SR.6.1.1 Hydrilla Occurrence Database Development

To model where Hydrilla may find suitable habitat in the Great Lakes Basin and identify key Hydrilla transport mechanisms, it was necessary to know where Hydrilla occurs elsewhere in the United Sates and globally, and how the distribution of Hydrilla has changed over time. For this reason, a comprehensive database of documented Hydrilla occurrences for the United States and world was developed.

The database encompassed the distribution of both native and invasive populations of Hydrilla, including the distribution of monecious and dioecious Hydrilla in the United States, and was the foundation for the distributional and dispersal modeling conducted for this project. The Hydrilla occurrence database was developed by combining Hydrilla occurrence data from the Early Detection and Distribution Mapping System, Global Biodiversity Information Facility, published literature, and stakeholders in the Great Lakes Basin. The Hydrilla occurrence database was used to create maps depicting the current distribution of Hydrilla in the Great Lakes Basin (see Figure SR-3), elsewhere in the United States, and globally. The Hydrilla occurrence database was also used to help understand past spread patterns of Hydrilla in the United States and identify likely transport pathways and vectors.

### SR.6.1.2 Distributional Modeling

Species distribution models (SDMs) predict sites with suitable habitat capable of supporting new populations of a given species. This is accomplished by relating known species occurrences with local environmental conditions to understand habitat requirements for that species across wide landscapes and matching suitability. The main question that distributional modeling is used to answer is: *Can the site support a self-sustaining population*? Two distributional modeling methods, Maxent and Maxlike, were used to generate forecasts of habitat suitability for Hydrilla. Maxent is one of the most widely used SDM methods. Maxent output is commonly interpreted as *habitat suitability* and provides a geographically explicit estimate of local probability of establishment following introduction. In contrast, Maxlike estimates probability of occurrence, producing output that is a geographically explicit map of *likelihood of occurrence*. Distributional modeling for this project was done by Texas Tech University, Lubbock, Texas.

Multiple distributional models were created with Maxent and Maxlike, using North American only and global Hydrilla occurrence data, and with and without partitioning Hydrilla occurrence data by biotype. For two reasons, it was decided that the Maxent global model based on the global occurrence dataset (not partitioned by biotype) was the best model for identifying potential Hydrilla habitat in the Great Lakes Basin. First, Maxent is the most widely used and reliable SDM method presently available. Second, a model based on the global occurrence dataset better captures the range of environments that Hydrilla may find suitable. The North American models created for this project were trained on occurrence data for the United States only and, therefore, may not depict the full range of potential Hydrilla habitats present in the Great Lakes Basin because the Hydrilla invasion in North America is ongoing.

Figure SR-4 shows the Maxent global model results for the Great Lakes Basin. Maxent generates a logarithmic score from 0 to 1 for each 10 by 10 km grid cell across the area being modeled. The results typically are presented as heat maps with warm colors (red and orange) representing the highest scores and cool colors (blue) representing the lowest scores. A score near 1 (hottest colors) implies that there is high confidence that the answer is *Yes* to the main question being asked by distributional modeling; that is, *Can the site support a self-sustaining population?* In contrast, a score near 0 (coldest colors) suggest that the answer to this question likely is *No*. Within the Great Lakes Basin, the Maxent global model indicated that the areas with the most suitable habitat for Hydrilla are Lake Erie, southeast Lake Michigan, and the Finger Lakes region in central New York State (see Figure SR-4). For reference, Figure SR-4 also shows locations of current Hydrilla infestations in the Great Lakes Basin and the Maxent habitat-suitability scores for those locations. Maxent predictions of highly suitable Hydrilla habitat generally were focused near known Hydrilla occurrences.

The Maxent global model was used for two purposes in this risk assessment. First, is was used as an input to the dispersal model (see Section SR.6.1.4) to inform that model regarding habitat suitability for Hydrilla in the Great Lakes Basin and elsewhere in the United States. Second, the Maxent global model output was used along with other measures of habitat suitability (see Section SR.6.1.3) to identify areas of the Great Lakes Basin that include suitable Hydrilla habitat and help rank those areas for further consideration in the risk assessment (see Section SR.6.2).

#### SR.6.1.3 Great Lakes Habitats Features

Geographic information system (GIS) layers for a wide range of parameters potentially useful for inferring habitat suitability for Hydrilla in the Great Lakes were evaluated, including water depth, water temperature, sediment composition, nutrient levels, photoperiod, wave action, and coverage by other submerged aquatic plants, including Eurasian watermilfoil (*Myriophyllum spicatum*). Online resources were queried and subject-matter experts were contacted to obtain spatial data for the above-mentioned parameters. Spatial data for these parameters were overlaid with the Maxent distributional modeling results to refine predicted suitable habitats for Hydrilla in the Great Lakes. In this regard, water depth and surface-water temperature were found to be the most useful parameters and also were available as GIS layers that could be applied across the Great Lakes Basin. Available information on Hydrilla biology and ecology suggests that Hydrilla is likely to be limited to water depths of approximately 25 feet or less as a result of hydrostatic pressure (less if light penetration is < 25 feet) and requires water temperatures of 68°F or greater for at least two months to develop dense, problematic infestations. Figure SR-5 shows areas of the Great Lakes where these conditions are met.

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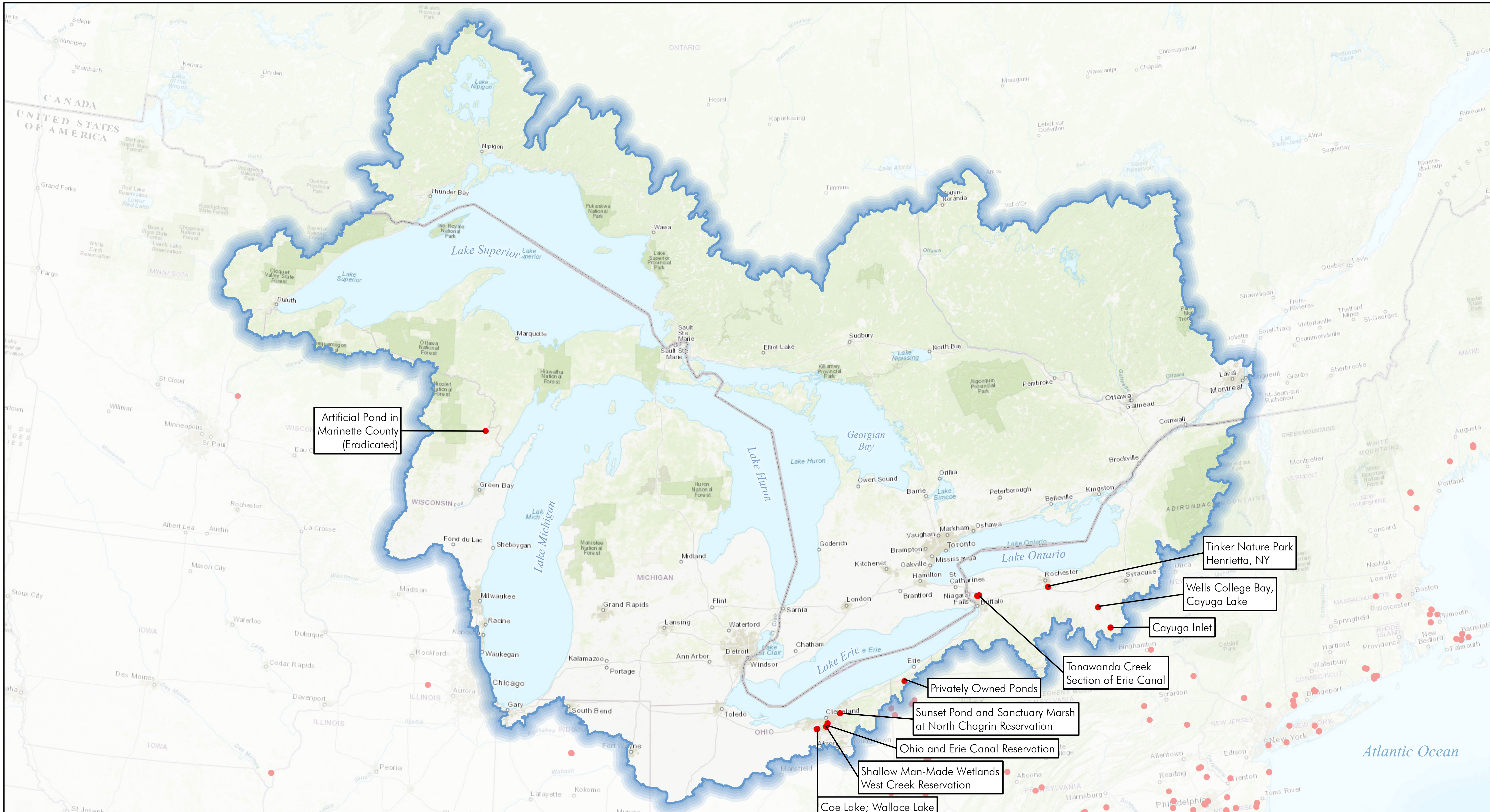


KEY:

- Hydrilla – Documented Occurrences
- Great Lakes Basin

Figure SR-3

**Documented Hydrilla Occurrences in the Great Lakes Basin**

Great Lakes Basin Distribution

Occurrences as of February 2018

N

0 50 100 200

Miles

Data Source: ESRI 2015; Barnes 2014; EDDMaps 2015; GBIF 2012, 2015; GLIN 2015; Ecology and Environment, Inc. 2018.

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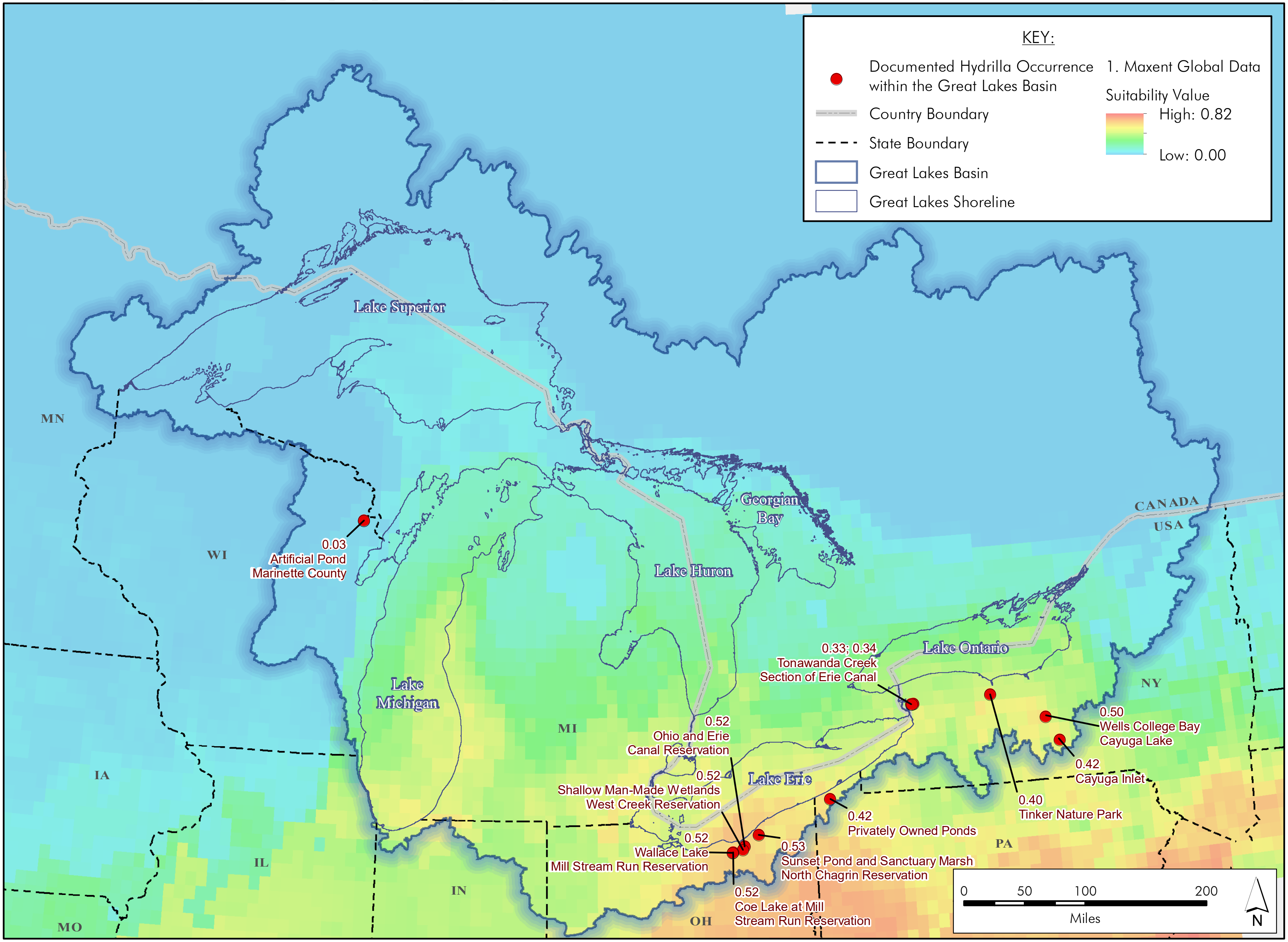
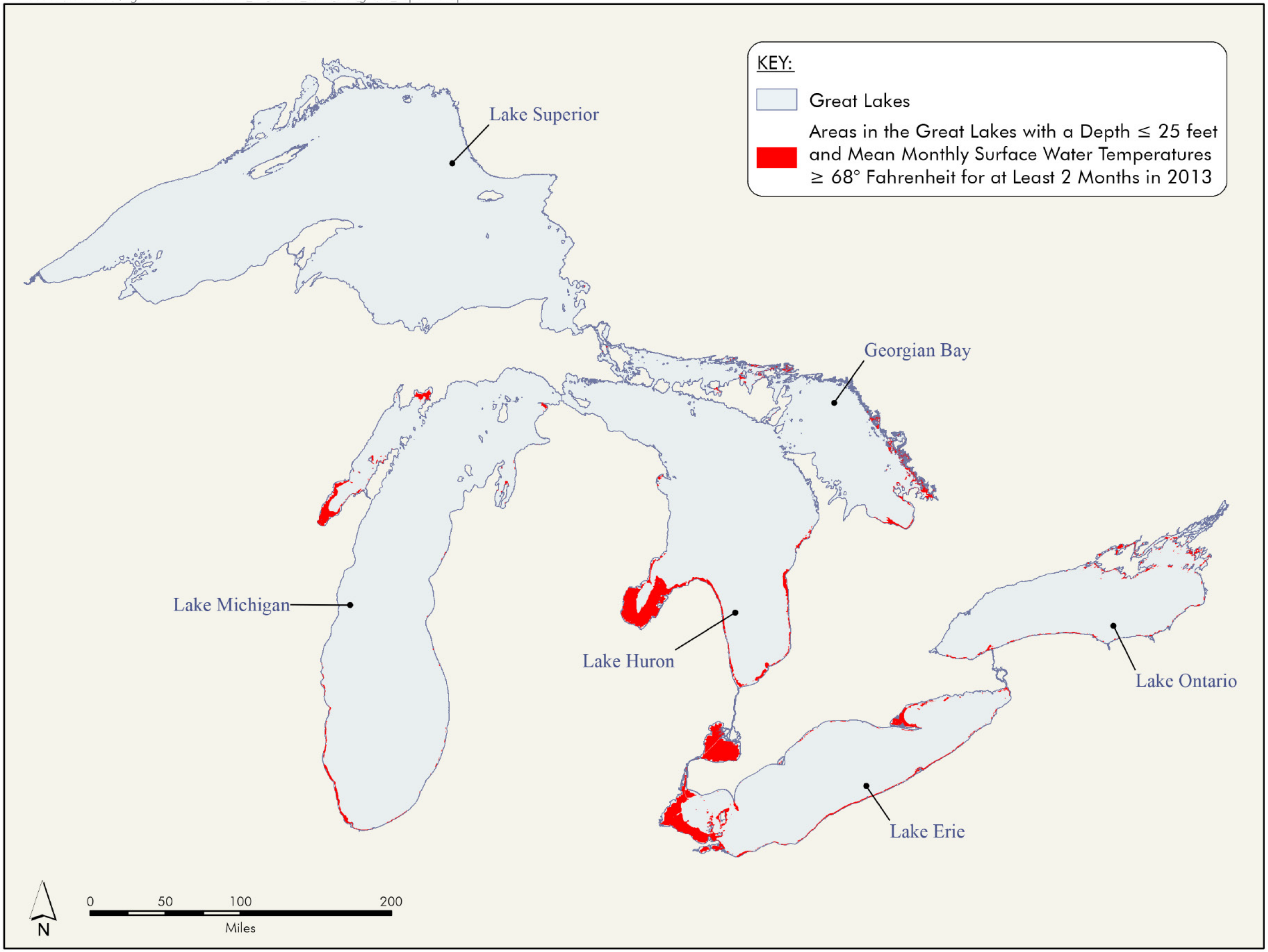



**Figure SR-4 Maxent Global Model Output Zoomed to Extent of Great Lakes Basin**

**Occurrences as of 2/26/2016**

02:1003025.0025.01\Figure SR-5 Areas inthe Great Lakes - 68 degrees Depth 25ft.pdf




Data Source: ESRI 2012; GLAHF 2013, 2015.

**Figure SR-5 Areas in the Great Lakes with Water Depths Less Than or Equal to 25 Feet and Water Temperatures Less Than or Equal to 68°F for At Least Two Months**

### SR.6.1.4 Dispersal Modeling

Dispersal modeling is used to understand the likelihood of introduction and subsequent dispersal of an invasive species into new habitats. The primary question that dispersal modeling is used to answer is: *Can the invasive species get there?* The primary objective of the dispersal modeling was to predict the potential spread of Hydrilla to the Great Lakes Basin via recreational watercraft and boat trailers and identify high risk areas for introduction. According to the literature, recreational boating is the human-mediated pathway most often responsible for the spread of aquatic invasive species. Dispersal modeling for this project was done by the University of Toledo, Toledo, Ohio.

The type of dispersal model developed for this project is known as a gravity model. Gravity models use spatial interactions to predict potential spread based on distance and attraction (Bossenbroek et al. 2001). A climate-matching component was included in the model by incorporating the distributional modeling results (see Section SR.6.1.2). The model was built for the continental United States and included 210 total watersheds, including those in the southeastern United States where Hydrilla is most established, and the 18 watersheds of interest in the Great Lakes Basin. Model inputs included: county boater registrations, watershed boundaries, waterbody data (major lakes, reservoirs, rivers, and streams), and known Hydrilla occurrences (see Section SR.6.1.1). A foundation assumption is that the model assumes recreational boat movement is the primary vector for Hydrilla spread.

The gravity model was developed using the following general steps: (1) estimate number of boaters traveling from each watershed; (2) estimate the proportion of those boats that will travel from watersheds infested with Hydrilla; (3) assign new infestations based on a watershed's habitat suitability and the number of boaters traveling to a watershed from infested locations; and (4) estimate the area of lakes and rivers that are newly infested in each watershed each year. The current Hydrilla occurrence database for the United States was used to parameterize and calibrate the model. This resulted in a model that best fit the current Hydrilla distribution in the United States and could mimic actual spread patterns from the first known infested watershed in 1953 to 2015, providing confidence that the model could predict the future spread of Hydrilla. Using the best-fit parameters, the model was run forward from 2015 to 2025 for 1,000 iterations.

Hydrilla is expected to continue to spread throughout the continental United States and into the Great Lakes Basin over the next 10 years. In general, watersheds that currently have infestations of Hydrilla are at the highest risk for further infestation. In addition, watersheds with large areas of water and high boater registration in or near watersheds with established Hydrilla populations are also at high risk for Hydrilla infestation. The gravity model results were used to rank the Great Lakes Basin watersheds based on the future proportion of waterbody area infested with Hydrilla in 2025. The top five watersheds in the Great Lakes Basin predicted by the model to have the greatest future proportion of infested waterbody area are Southeastern Lake Ontario (5.1% [29,434 hectares (ha)]), St. Clair-

Detroit (3.9% [2,755 ha]), Western Lake Erie (3.7% [14,837 ha]), Southern Lake Erie (3.4% [20,879 ha]), and Southwestern Lake Ontario (1.3% [4,369 ha]) (see Figure SR-6).

### SR.6.1.5 Hydrilla Growth Studies

Most Hydrilla research has been conducted on dioecious Hydrilla in warmer climates. Because monoecious Hydrilla growth in northern waters is not well understood, an important component of this project was to develop a greater understanding of the effects of photoperiod, temperature, and interspecies competition on growth of monoecious Hydrilla in northern conditions through laboratory and field research. The research was conducted by the Department of Crop Science at North Carolina State University in Raleigh, North Carolina. The objectives of the research were to: (1) document monoecious Hydrilla phenology in simulated northern conditions; (2) compare monoecious Hydrilla growth rate in northern versus southern conditions; (3) document growth of monoecious Hydrilla alone and in competition with other cool-climate submerged aquatic plants; and (4) determine the impact of prolonged cold exposure on viability of Hydrilla tubers. To investigate the growth behavior of monoecious Hydrilla in different climates, outdoor mesocosm trials were conducted at two separate research locations: (1) Laurel Springs, North Carolina (elevation 3,215 feet), representing cooler, northern conditions; and (2) Raleigh, North Carolina (elevation 288 feet), representing warmer, southern conditions.

Regarding the first objective, it was found that plants in the cooler climate reached all life stages, including tuber sprouting, floral initiation, and senescence, at a cooler mean water temperature than those grown in the warmer climate. These results suggest that monoecious Hydrilla can adapt its phenology to the shorter growing season in cooler areas. Plants grown in the cooler climate produced less tubers than those in the warmer climate, but tuber density at both climates was more than adequate to allow significant regrowth of Hydrilla biomass in the spring following fall senescence.

To address the second and third objectives, monoecious Hydrilla plants were grown in outdoor mesocosms alone or together with Eurasian watermilfoil, elodea (*Elodea canadensis*), or eelgrass (*Vallisneria americana*). Eurasian watermilfoil and elodea suppressed Hydrilla biomass production and tuber production in cool-climate mesocosms, but not in warm climate mesocosms. When grown alone in aboveground mesocosms, Hydrilla biomass production was greater (by about 20%), and tuber production was lower (by about 20%), in the cool-climate conditions compared with the warm-climate conditions. Although tuber production was lower under cool-climate conditions, tuber density still was adequate to support spring regrowth of Hydrilla, in agreement with the results from objective 1.

02:1003025.0025.01-B4869\Figure SR-6 Top Five Watersheds.pdf

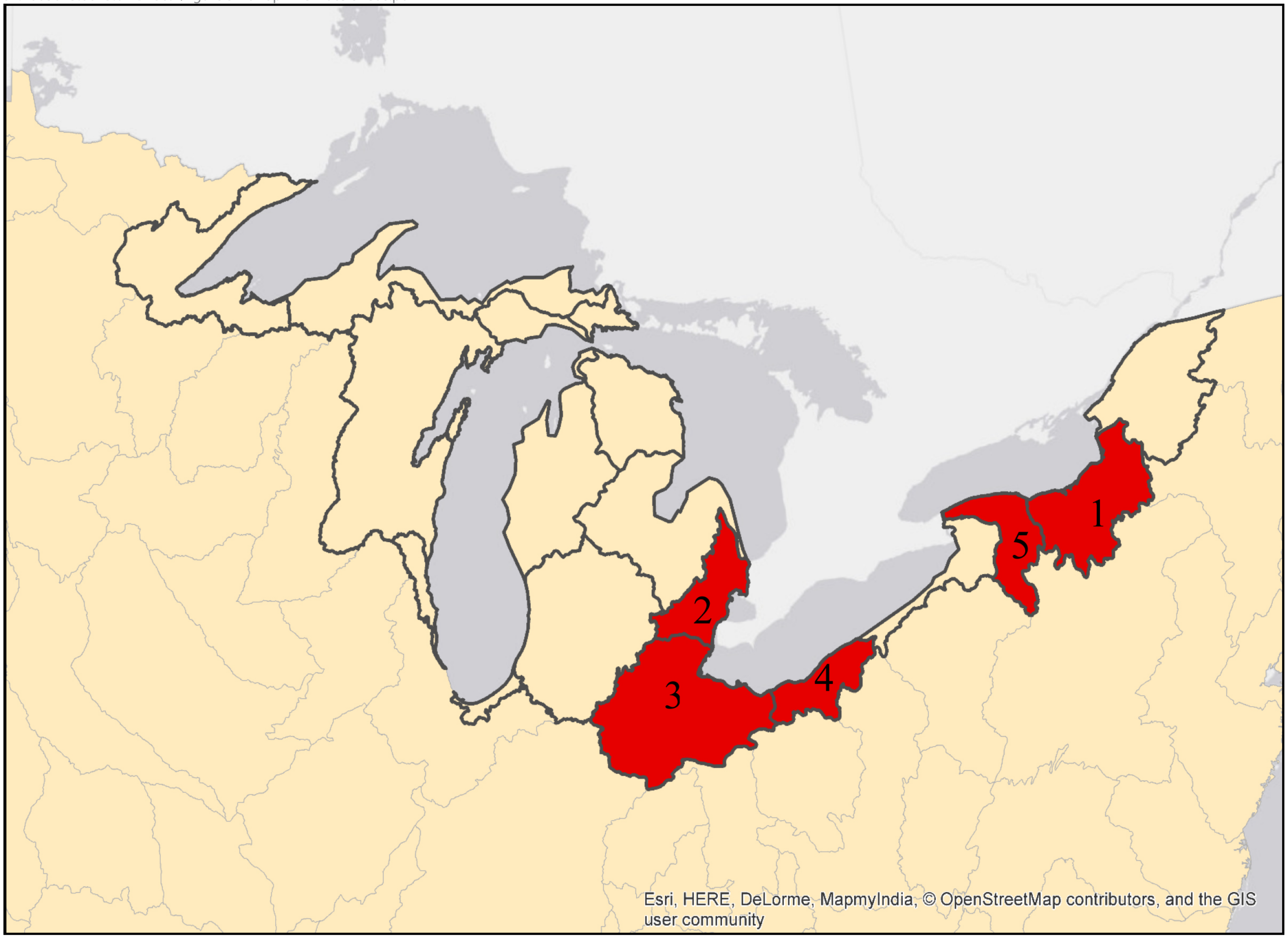



**Figure SR-6 Top Five Watersheds in Great Lakes Basin Predicted by Modeling to Have the Greatest Future Proportion of Hydrilla-Infested Waterbody Area: Southeastern Lake Ontario (1), St. Clair-Detroit (2), Western Lake Erie (3), Southern Lake Erie (4), and Southwestern Lake Ontario (5)**

To address objective 4, tubers were harvested from plants grown at Raleigh, NC (warmer climate) and Laurel Springs, North Carolina (cooler climate) and overwintered at air temperatures of 4, 0 and -3°C. Temperature during Hydrilla development and overwintering temperature affected tuber viability. Tubers produced in the cooler climate were heavier, averaging 0.113 g compared to 0.096 g in the warmer climate. Also, tubers produced in the cooler climate had higher viability, averaging 89% when overwintered at 4°C and 20% when overwintered at 0°C, while the warmer climate Hydrilla tubers had an average viability of 63% when overwintered at 4°C, and 0% when overwintered at 0°C.

### SR.6.2 Integration

As noted above, the principal objective of the Great Lakes Hydrilla risk assessment was to identify areas in the Great Lakes Basin most vulnerable to invasion by Hydrilla based on likelihood of introduction and environmental suitability. This objective was addressed by combining the distributional and dispersal modeling results and water-depth and temperature requirements for Hydrilla. The integration of these results is shown in Figure SR-7 and explained below.

Areas of suitable habitat for Hydrilla in the Great Lakes Basin were identified by overlying the water-depth (< 25 feet) and water-temperature (two months at 68°F) requirements for monoecious Hydrilla establishment (see Figure SR-5) on the distributional modeling results, specifically the Maxent global model results (see Figure SR-4). To forecast habitat suitability for Hydrilla, the Maxent model used atmospheric temperature data, not water-depth or water-temperature data; hence, it was necessary to overlay the water-depth and water-temperature requirements for Hydrilla on the Maxent heat map to appropriately exclude areas in the Great Lakes that are too deep or too cold to serve as Hydrilla habitat.

The dispersal model results were used to quantify likelihood of introduction. For each watershed in the Great Lakes Basin, the dispersal model provided the acreage and proportion of inland waterbodies and Great Lakes shoreline with a relative high probability of being colonized by Hydrilla in 2025 due to recreational watercraft and trailer movement. It should be noted that the results of the dispersal model are at the watershed scale, which is larger than the 10 x 10 km scale used for the Maxent model. Nonetheless, the watershed boundaries can be superimposed on the Maxent heat map and the watersheds ranked based on the future proportion of infested waterbody area, as shown in Figure SR-7. Doing so effectively represents the dispersal model results and habitat suitability information for Hydrilla.

Figure SR-7 shows that the watersheds in the Great Lakes Basin with the greatest potential for Hydrilla introduction also provide the best habitat for Hydrilla. For example, the watersheds bordering Lakes Erie and Ontario in New York, Pennsylvania, and Ohio have high ranks for introduction potential (1 to 6) and also contain favorable Hydrilla habitat (orange, yellow, and yellow-green coloration). The potential severity of a Hydrilla infestation in these watershed can be understood by relating the habitat suitability scores (and colors) from Maxent with the severity of known Hydrilla infestations in those watersheds. For example, the habitat suitability scores for the grid cells in Ohio and New York where current Hydrilla infestations are present range from 0.32 to 0.52 (yellow to light orange). The infestations at these locations are dense and require treatment to minimize Hydrilla spread. Other grid cells in the Great Lakes Basin with similar Maxent scores (and colors) could potentially develop a similar level of infestation if Hydrilla were introduced to those locations, all other things being equal. In theory, SDMs are not equipped to provide a measure of species performance; however, in practice, a positive correlation has been found between Maxent scores and species performance or functional traits for a number of invasive plants and animals (Wittmann et al. 2016).

### SR.6.3 Impact Analysis

Negative impacts on aquatic resources from Hydrilla are generally known from literature and include: clogging waterways with surface mats; restricting water flow; interfering with recreational activities; diminishing shoreline property value; interfering with navigation, irrigation, and hydropower generation; and generally disrupting submerged aquatic habitats by domination. In addition to summarizing known impacts based on literature, this assessment also estimated future potential impacts to the Great Lakes resulting from the introduction and establishment of Hydrilla. Four types of potential impacts were assessed: economic, socio-cultural, environmental, and tribal.

The impact evaluations conducted for this project were focused on the Great Lakes proper because of their uniqueness and regional importance as a resource for recreational, commercial, industrial, and other uses. Because of the large size of the Great Lakes and abundance of shoreline resources, the evaluation of potential economic, socio-cultural, and tribal resources was conducted for six representative watersheds and, within those watersheds, was further focused on shoreline areas that offered the best potential habitat for Hydrilla. The six selected watersheds were considered representative of all watersheds within the Great Lakes Basin. Likewise, the focus areas considered within each selected watershed were considered representative of all waterbodies (shoreline or interior) in each selected watershed and also in watersheds not selected for detailed analysis. Potential environmental impacts on the Great Lakes from Hydrilla were evaluated more generally on a basin-wide basis.

#### SR.6.3.1 Potential Economic Impacts

The economic-impact evaluation concluded that the introduction and establishment of Hydrilla in the Great Lakes Basin would generate a significant negative economic impact on individuals and local, regional, and national economies. The negative economic impacts would include both additional costs that would be incurred as a result of the establishment of Hydrilla, such as increased dredge disposal costs and costs associated with the removal of Hydrilla from water intakes, and the loss of well-being or loss of utility associated with decreased enjoyment

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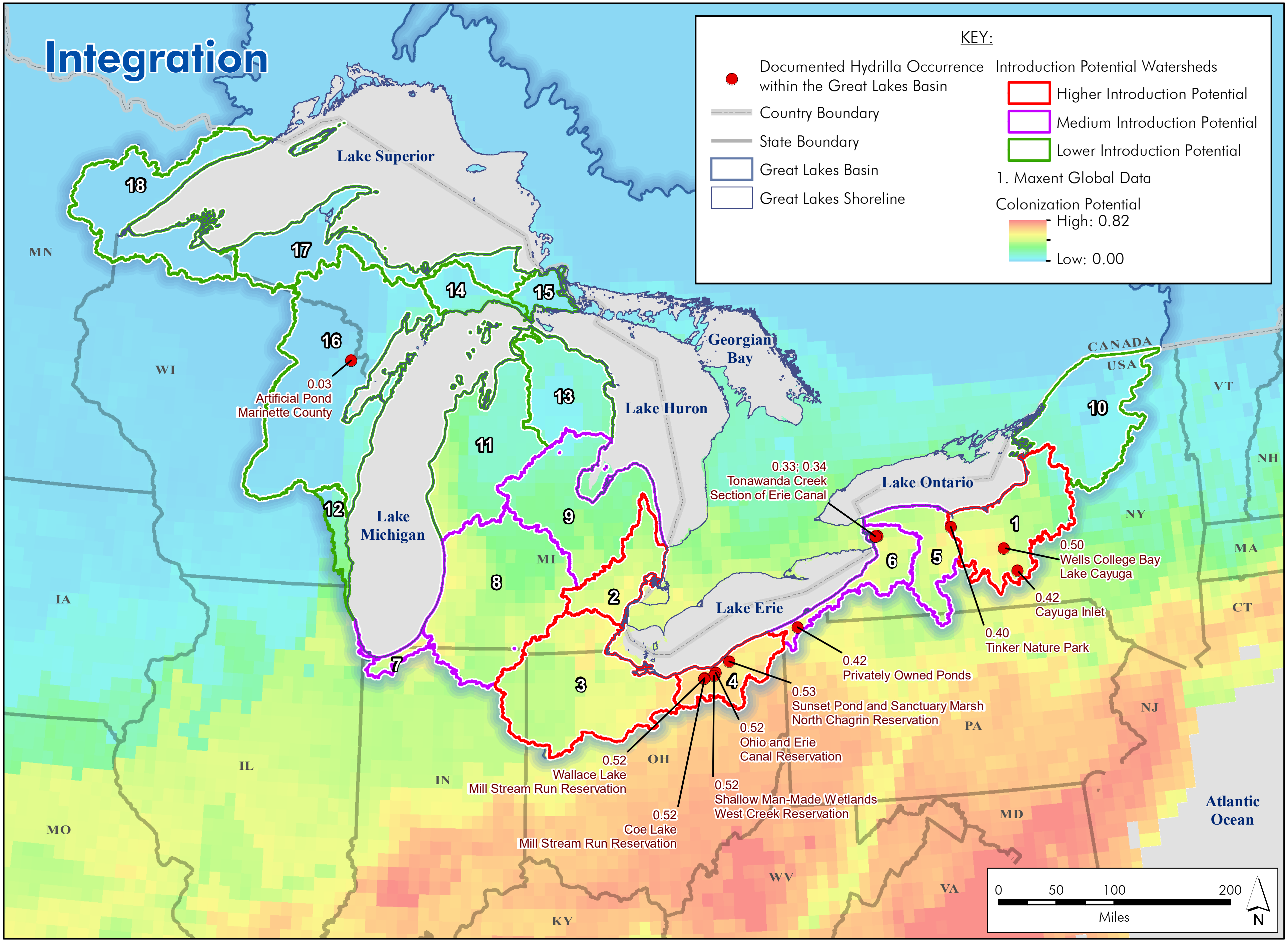


**Figure SR-7 Integration of Maxent Model Results, Water-Depth and Water-Temperature Requirements, and Dispersal Model Results for Hydrilla**

Occurrences as of 2/26/2016

from recreational activities, such as fishing, boating, and beach use on the Great Lakes. In terms of dollars, the economic loss associated with the impacts on recreational fishing, beach use, recreational boating, and commercial navigation are expected to range between $70 and $500 million annually if Hydrilla were to become established in the Great Lakes.

The estimates developed for this assessment include only the direct loss in economic well-being associated with the uses mentioned above. The overall macroeconomic impacts on the tourism industry and the recreational fishing and boating industries have not been included. Hence, any loss of sales, employment, or earnings associated with the decline in recreational use of the Great Lakes would be an additional economic loss to local and regional communities.

Given the potentially large economic losses that would occur if Hydrilla were to become established in the Great Lakes, the costs of implementing a prevention and management program would be far less costly than controlling and managing well established infestations. Any money spent to prevent the spread of Hydrilla to the Great Lakes or to eradicate Hydrilla before it became established in the Great Lakes would be more than offset by the economic losses avoided.

#### SR.6.3.2 Potential Socio-Cultural Impacts

The analysis of potential impacts to socio-cultural resources from the introduction and establishment of Hydrilla in the Great Lakes Basin provided a sense of what the potential impacts on community character and socio-cultural setting could be. Ten general categories of natural and socio-cultural features were identified in the focus areas from the representative watersheds and are considered physical representations of community character and socio-cultural setting. Those categories of features were: natural features; private businesses; communities; public parks and other public facilities; built resources; organizations; conservation areas; governmental facilities; industrial facilities; and camps/retreats. Potential impacts of Hydrilla introduction and establishment on these features, and on public perception of these features, were considered to identify potential socio-cultural impacts.

Various potential impacts that could result from Hydrilla introduction and establishment included: (1) impacts on natural shoreline features; (2) impacts on socio-cultural features that have water-dependent or water-related uses; (3) impacts to water-dependent or water-related uses of natural and socio-cultural features; (4) impacts on community perceptions of natural and socio-cultural features and water-dependent and water-related uses; and (5) impacts on community character in areas or watersheds affected by Hydrilla infestations.

Overall, the evaluation of potential socio-cultural impacts found that the establishment of Hydrilla in the Great Lakes Basin has the potential to result in long-term (permanent), direct and indirect, negative impacts on natural and socio-cultural features and their associated water-dependent and water-related uses that comprise the socio-cultural setting of watershed in the Great Lakes Basin. Similar impacts would be expected on the perceptions of these features and uses. Collectively, these impacts would represent long-term, indirect, negative impacts on the community character of the Great Lakes Basin in general, and on the community character and associated socio-cultural setting of specific affected areas within the Great Lakes Basin.

### SR.6.3.3 Potential Environmental Impacts

The evaluation of potential environmental impacts to the Great Lakes from the introduction and successful establishment of monecious Hydrilla was based in part on a review of scientific journals, aquatic management plans, and interviews with natural resource managers. This effort provided a sense of *what* the impacts may be. Additionally, the impact evaluation attempted to understand *where* in the Great Lakes Basin environmental impacts from Hydrilla may occur and how extensive those impacts may be in the future, specifically in 2025. The latter was accomplished through a desktop analysis using GIS combined with the dispersal modeling results, specifically the results for the future proportion of waterbody area per watershed predicted to contain Hydrilla in 2025. Potential environmental impacts were organized into five general categories: water quality and aquatic plant communities, fisheries and benthic macroinvertebrates, pathogens, waterfowl and wildlife, and hydrology.

The literature review provided an indication of the types and magnitude of environmental impacts that occur when Hydrilla is introduced into an aquatic system with suitable habitat and develops over time into an infestation. These impacts are largely due to the ability of Hydrilla to grow and reproduce rapidly once introduced, thereby clogging waterways, restricting water flow, modifying sunlight and temperature within the water column, lowering dissolved oxygen levels, and generally disrupting submerged aquatic habitats by domination. In contrast, positive impacts on fish and waterfowl have been reported in situations where Hydrilla density was low, but such benefits are expected to be short-lived and limited to the early stages of Hydrilla invasion.

A desktop GIS analysis provided a means to locate areas in the Great Lakes Basin that may be more susceptible to Hydrilla introduction and establishment, and a way to predict possible extents of future infestations on a smaller scale. This analysis identified waterbodies, coastal wetlands, fish spawning and nursery sites, wildlife refuges, national wildlife refuges, and important birding areas that are potentially susceptible to Hydrilla introduction and establishment and worst-case extent of those potential impacts in 2025. In general, the extent and severity of potential impacts to these resources from Hydrilla are likely to be greatest in the more southerly Great Lakes Basin watersheds where Hydrilla introduction potential and habitat suitability are greatest based on dispersal and distributional modeling.

### SR.6.3.4 Potential Tribal Impacts

To begin to understand potential impacts of Hydrilla on resources of interest or concern to federally recognized Indian tribes, it was necessary to identify tribes located in the Great Lakes Basin as well as tribes now located outside the Great Lakes basin but that have a historical or cultural interest in areas within the Great Lakes Basin, and summarized available information regarding species of interest or concern to the tribes, either economically, culturally, or for other management purposes from a desktop analysis of publicly available sources of information. Overall, this information provided a sense of the level of outreach and consultation that would be necessary to engage these tribes in the management of Hydrilla.

A total of 61 federally recognized tribes from 12 states (Delaware, Indiana, Iowa, Michigan, Minnesota, Montana, Nebraska, New York, North and South Dakota, Oklahoma, Wisconsin) were identified. Information on official tribal websites resulted in the identification of a number of aquatic and terrestrial animal and plant species of interest or concern. Most tribal websites identify specific species of interest or concern, and often reasons for their significance. A total of 144 different species, or families of species, were identified from tribal websites, including: 37 fish species; 86 wildlife species, including mammals, birds, waterfowl, furbearers, and game species; and 21 plant species. Many of these species are managed by tribes for economic purposes, but they may also be of traditional cultural significance. However, information regarding the traditional cultural significance of a given species is generally not provided on official tribal websites. Therefore, it is possible that the results of the desktop analysis underestimates the number of species of cultural significance to current and former resident tribes within the Great Lakes Basin.

The establishment of Hydrilla in the Great Lakes Basin has the potential to disrupt traditional tribal ways of life and affect customary tribal nourishment practices, as well as spiritual beliefs. Such impacts would be likely if dense Hydrilla infestations were to develop in aquatic habitats traditionally used by one or more of the tribes identified in this analysis. Fishing continues to be essential to many tribes for both subsistence and economic reasons. Although not as essential to survival as in the past, subsistence hunting also is still an important aspect of tribal life. Members of the majority of tribes in the Great Lakes Basin hunt traditional waterfowl and game species as their ancestors did generations ago. Various plant species also remain economically, culturally, and spiritually important to tribal life. In particular, wild rice remains an essential component of many tribes' economic and cultural practices. The potential for Hydrilla to affect aquatic habitats where harvesting of wild rice is conducted presently in the Great Lakes basin is possible if Hydrilla were to be introduced into those habitats.

## SR.7 Risk Characterization

### SR.7.1 Relative Risks for Watersheds in the Great Lakes Basin

The principal objective of the Great Lakes Hydrilla risk assessment was to identify areas in the Great Lakes Basin most vulnerable to Hydrilla invasion based on likelihood of introduction and environmental suitability (see Section SR.2). This objective was addressed by combining the distributional modeling results, dispersal modeling results, and water-depth and water-temperature requirements for Hydrilla, as described in Section SR.6.2 and shown in Figure SR-7. Combining this information shows that watersheds bordering Lakes Erie and Ontario in New York, Pennsylvania, and Ohio, and Lake St. Clair in southeast Michigan, have the greatest Hydrilla introduction potential and most suitable habitat for Hydrilla. Conversely, watersheds bordering Lake Superior have the lowest Hydrilla introduction potential and lowest habitat suitability. Watersheds around Lakes Michigan and Huron have intermediate values for Hydrilla introduction potential and habitat suitability. The impact assessments suggest that all watersheds in the Great Lakes Basin include abundant socio-cultural, economic, environmental, and tribal resources that may be adversely affected by Hydrilla, regardless of introduction potential or habitat suitability, as would be expected.

Based on the totality of analyses conducted for this assessment (see Section SR.6), it was concluded that the watershed ranks presented in Figure SR-7 based on introduction potential (i.e., proportion of waterbody area per watershed infested with Hydrilla in 2025) are the best predictor of the potential risk that Hydrilla poses to watersheds in the Great Lakes Basin. Using introduction potential to assign relative risks is logical and appropriate for two reasons. First, introduction potential is an estimate of exposure and, without exposure, there is no risk. Second, habitat suitability varies directly with introduction potential, which implies that Hydrilla is most likely to develop into problematic infestations in the same areas in the Great Lakes Basin where it is mostly likely to arrive. The relationship between habitat suitability and introduction potential is partly due to the inclusion of a habitat suitability term in the dispersal model equations. However, the relationship also exists because Hydrilla is approaching the Great Lakes Basin from the south and the southern Great Lakes are warmer and thus provide conditions more favorable for monoecious Hydrilla growth.

### SR.7.2 Vulnerable Great Lakes Areas

Within the Great Lakes proper, potential habitat for Hydrilla generally is limited to areas where water depth is less than 25 feet (due to hydrostatic pressure) and summer water temperature is at least 68°F for two consecutive months (see Section SR.6.1.3). Also, if light penetration is less than 25 feet, then the effective depth to which Hydrilla can grow will be correspondingly less. These limitations mean that the habitats most vulnerable to Hydrilla invasion in the Great Lakes are near-shore, littoral-zone habitats. However, not all littoral zone habitats are equally at risk. In general, shallow, near-shore areas that are sheltered from wave action, including embayments, coves, coastal wetlands, and natural and constructed harbors provide more suitable habitat for Hydrilla than open, wave-swept shorelines. Hence, shallow, sheltered areas along the south shores of Lakes Erie and Ontario and along the shoreline of Lake St. Clair are the areas considered to be most at risk from Hydrilla and, therefore, where resource managers should be most vigilant for the appearance of this aquatic invasive species.

### SR.7.3 Vulnerable Inland Areas

The relative risk ranks shown in Figure SR-7 also apply to inland waterbodies in the 18 Great Lakes watersheds. Hence, inland waterbodies in watersheds bordering Lakes Erie and Ontario in New York, Pennsylvania, and Ohio, and Lake St. Clair in southeast Michigan, are at greatest risk from Hydrilla, whereas those in watersheds bordering Lake Superior are at lowest risk. In general, inland waterbodies are expected to be more vulnerable to a Hydrilla infestation than the Great Lakes proper because they are less turbulent, shallower, and warmer than the Great Lakes. Indeed, within the Great Lakes Basin currently, all known Hydrilla infestations exist in inland waterbodies, as shown in Figure SR-7, not in the Great Lakes proper. Inland infestations may act as sources of propagules to other inland waterbodies and to the Great Lakes and, therefore, resource managers should be especially watchful for the appearance of new Hydrilla infestations near existing infestations.

Although introduction potential and habitat suitability are low for Hydrilla in the northern portion of the Great Lakes Basin, it is worth noting that at least one Hydrilla infestation has been reported from this region, in an artificial pond in northeast Wisconsin (see Figure SR-7). The occurrence of this infestation indicates that potential risks from Hydrilla to this portion of the Great Lakes Basin still are present despite the very low modeled habitat suitability and introduction potential for Hydrilla in this area. Hence, resource managers in the northern portion of the Great Lakes Basin still should be watchful for Hydrilla, especially given the large number of small inland lakes and ponds in this region.

### SR.7.4 Other Hydrilla Risk Assessments

Other entities have conducted risk assessments or similar evaluations for Hydrilla including the New York State Department of Environmental Conservation (NYSDEC) and Ontario Ministry of Natural Resources and Forestry (OMNRF). NYSDEC (2008) completed their *Invasiveness Ranking Form* for Hydrilla and concluded that Hydrilla was likely to be very highly invasive in New York State. The OMNRF (2016) prepared a risk assessment for Hydrilla using methodology they developed and concluded that the overall risk for invasion and impacts in Ontario is very high.

Recent publications from the peer-reviewed literature also suggest that the invasion potential for Hydrilla is likely to be high. Zhu et al. (2017) reached this conclusion generally for North and South America and presented Maxent heat maps showing habitat-suitability for Hydrilla that are similar to those generated for this project. Using a different SDM ("range bagging"), Wittmann et al. (2017) focused their work on the Great Lakes and concluded that climatic and habitat conditions in the Great Lakes were suitable for Hydrilla in several of the lakes, including Lakes Erie, Michigan, and Huron. Overall, the findings of the above-mentioned assessments and publications are consistent with this assessment and support the general conclusion that Hydrilla poses a serious potential risk to the Great Lakes region, especially the southerly Great Lakes region.

## SR.8 Risk Management Recommendations

Recommendations were developed for prevention, detection, and response and were based on a review of existing information pertaining to early detection and rapid response programs and numerous Hydrilla control projects, as well as outreach with stakeholders involved in the prevention, detection, and management of Hydrilla across the country. The recommendations also take into account the results of the distributional and dispersal modeling and Hydrilla growth studies undertaken for this risk assessment.

Preventing the spread of Hydrilla depends on an informed public; thus public information and awareness are the foundation of a successful Hydrilla prevention program. Hydrilla prevention and management recommendations for the Great Lakes Basin include:

- Develop a public information campaign and post signage at access points;
- Implement watercraft inspections at boat ramps/launches in high-risk waterbodies;
- Establish active and passive detection networks to survey and monitor high-risk waterbodies for detection of new Hydrilla populations;
- Focus monitoring efforts on areas in and around existing infestations;
- Implement early coordination with regulatory agencies for rapid response, including identifying and eliminating pathways to and from new infestation;
- Close access points in proximity to Hydrilla infestations to minimize the potential for spread;
- Consider the use of quarantine options where applicable; and
- For long-term sustained control, use chemical control agents (aquatic herbicides) for Hydrilla management along with additional measures, as necessary, to control isolated patches and satellite populations that survive treatment or re-sprout from the tuber bank.

In addition to the recommendations summarized above, the risk assessment presents BMPs for Hydrilla detection, treatment, and monitoring.

The final step in the risk assessment process is sharing the results of the assessment with stakeholders and other interested parties, thereby contributing to the management of Hydrilla in the Great Lakes Basin by identifying high-risk watershed and encouraging the implementation of the recommendations and BMPs discussed above. Stakeholder outreach activities anticipated to be conducted within six months of the completion of the risk assessment report include presenting the findings of the assessment in fact sheets, at stakeholder meetings in high-risk watersheds, and on webinars, and sharing the Great Lakes Hydrilla risk assessment report on the Great Lakes Hydrilla Collaborative website (www.Hydrillacollaborative.com).

# 1 Introduction

This risk assessment for *Hydrilla verticillata* (Hydrilla) in the Great Lakes Basin was prepared by Ecology and Environment, Inc. (E & E) for the U.S. Army Corps of Engineers–Buffalo District and Engineer Research and Development Center (USACE ERDC) under Contract Number W912P4-10-D-0002. The assessment was undertaken to evaluate the potential for introduction and establishment of Hydrilla in the Great Lakes Basin and estimate potential impacts from establishment.

## 1.1 Background

Hydrilla is an invasive aquatic plant introduced to the Unites States from Asia. There are two biotypes of Hydrilla in the United States (Shearer 2014). The dioecious Hydrilla biotype was introduced from Sri Lanka into Florida in the 1950s and has spread throughout the southeastern United States (Langeland 1996). The monoecious Hydrilla biotype was first discovered in Delaware in 1976 and expanded its distribution through the Atlantic states and northward to Maine (True-Meadows et al. 2016). Recently, monoecious Hydrilla was discovered at several locations in the Great Lakes Basin, including Cayuga Lake in central New York State (2011), Tonawanda Creek in western New York State (2013), Tinker Nature Park near Rochester, New York (2015), and several waterbodies in Ohio near Lake Erie. These discoveries raised concerns about the spread of monoecious Hydrilla throughout the Great Lakes Basin. Where introduced, Hydrilla has considerable impacts, including: reducing water flow; interfering with recreational activities such as boating and swimming; displacing native plants through competition for light and other resources; diminishing shoreline property value; and interfering with navigation, irrigation, and hydropower generation (Langeland 1996). The New York State Department of Environmental Conservation (NYSDEC) evaluated the potential threat that Hydrilla poses to waterbodies in New York State and found it to be “very high” (NYSDEC 2008).

## 1.2 Objectives

The principal objective of the Great Lakes Hydrilla risk assessment was to identify locations in the Great Lakes Basin most vulnerable to invasion based on likelihood of introduction and environmental suitability. Other key components of the project were to: 1) develop an improved understanding of the effects of photoperiod, temperature, and interspecies competition on growth of monoecious Hydrilla through laboratory and field mesocosm studies; 2) assess economic, sociocultural, and environmental impacts of Hydrilla establishment in the Great Lakes; 3) provide recommendations for prevention, early detection, and rapid response to reduce risk of Hydrilla spread; and 4) identify best management practices (BMPs) for Hydrilla control.

## 1.3 Risk Assessment Methodology and Framework

The risk assessment framework for aquatic nuisance species (ANS) proposed by Suedel et al. (2007) was adopted for this project (see Figure 1-1; E & E 2015). Their framework is modeled after the Ecological Risk Assessment Guidance for Superfund (U.S. Environmental Protection Agency [USEPA] 1997) and includes four main elements: 1) Problem Formulation; 2) Analysis, which includes Characterization of Exposure (i.e., Exposure Assessment) and Characterization of Effects (i.e., Effects Assessment); 3) Risk Characterization, and (4) Risk Management. In the risk assessment framework for ANS developed by Suedel et al. (2007), communication with the risk manager and other stakeholders occurs throughout the process to ensure that the outputs of the assessment are useful to resource managers and others that need to make decisions about ANS management.

Figure 1-2 shows the ANS risk assessment framework of Suedel et al. (2007) made specific to the Great Lakes Hydrilla risk assessment project. Again, there are four main elements: Problem Formulation, Analysis, Risk Characterization, and Risk Management. Problem Formulation included:

- Defining the problem (see Section 1.1);
- Setting objectives (see Section 1.2);
- Defining the project extent, which, for this project, was the Great Lakes themselves and inland waterbodies in the Great Lakes Basin (see Section 2.1); and
- Defining focus, which, for this project, was monoecious Hydrilla because this Hydrilla biotype was discovered recently in the Great Lakes Basin and is well adapted to growing and reproducing in cool-water environments, whereas the dioecious biotype appears to be limited by colder environments (see Section 2.2).

The row of five boxes at the top of the Analysis step in Figure 1-2 comprised the Exposure Assessment, and includes:

- Creating a Hydrilla occurrence database, to document where Hydrilla occurs in the Great Lakes Basin and elsewhere in the United States and globally (see Section 3.1.2);
- Distributional modeling, to identify suitable habitats for Hydrilla in the Great Lakes Basin (see Section 3.1.3);
- Evaluating Great Lakes habitat features, such as water temperature and depth, to help better identify suitable Hydrilla habitats (see Section 3.1.4);
- Dispersal modeling, to forecast where Hydrilla can be transported to from where it is now and identify important transport mechanisms (see Section 3.1.5); and

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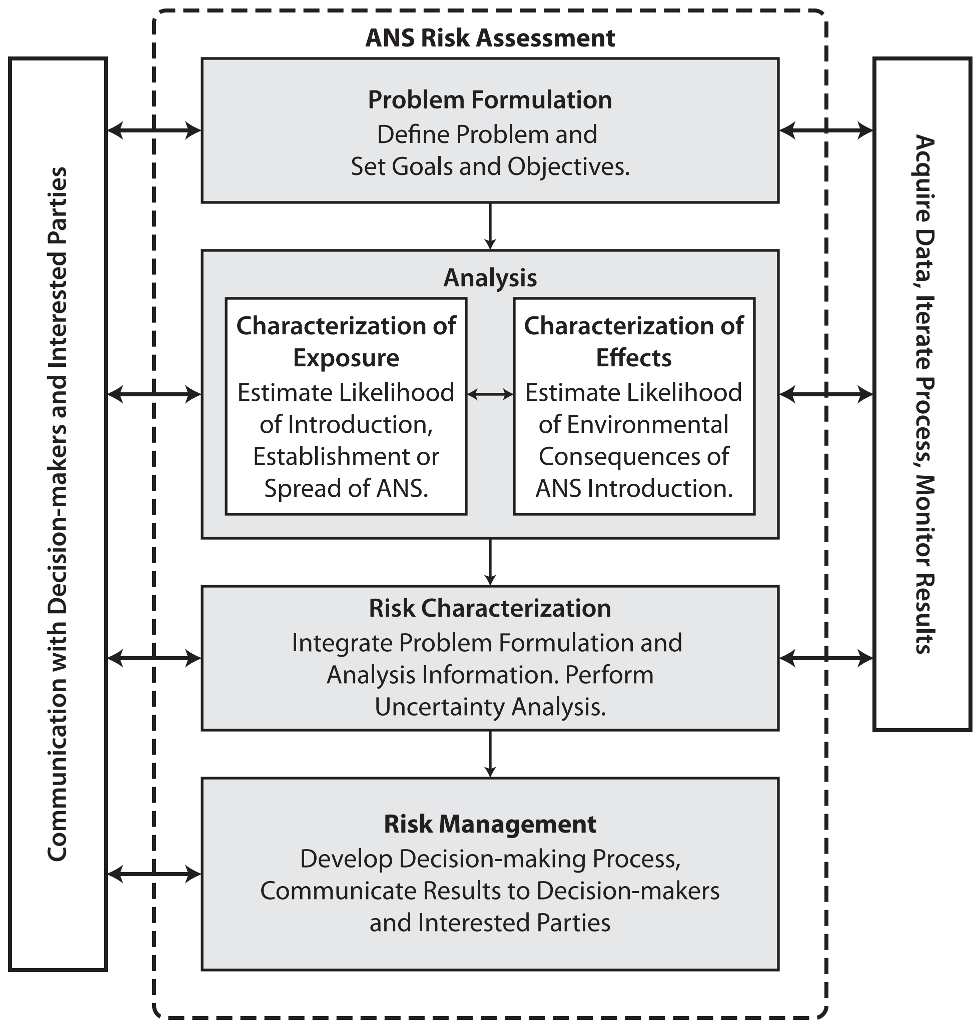


**KEY:**
**ANS:** Aquatic Nuisance Species

**Figure 1-1 Risk Assessment Framework for Aquatic Nuisance Species (Suedel et al. 2007)**

02:1003025.0025.03-B4869\Figure ES-1 Great Lakes Hydrill Risk Assessment Process.ai-4/17/18-GRA

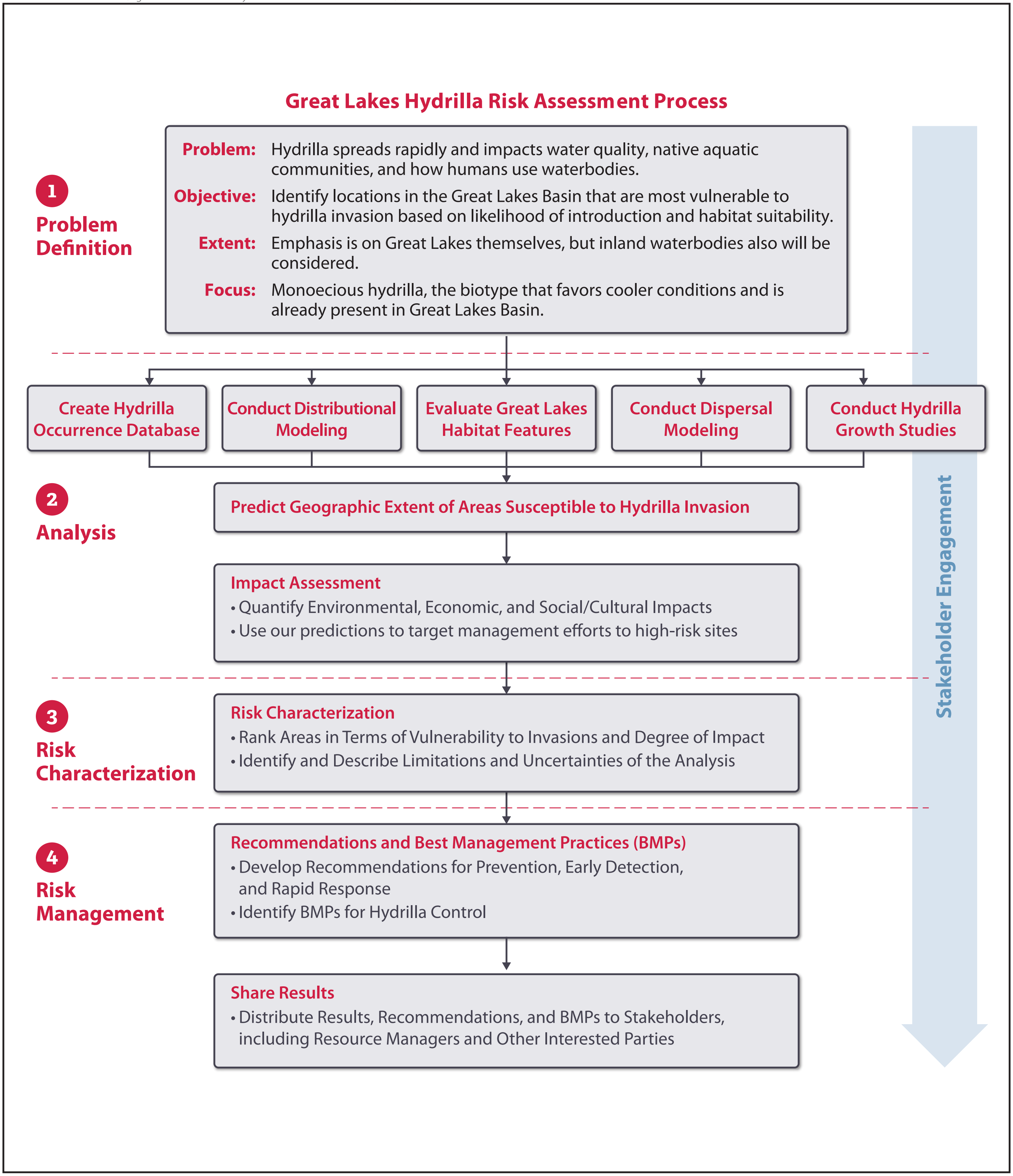


**Figure 1-2 Great Lakes Hydrilla Risk Assessment Process**

- Hydrilla growth studies, to better understand how monoecious Hydrilla performs in cool water habitats and competes with aquatic plant species currently established in the Great Lakes Basin (see Section 3.1.6).

The results from these five activities allowed E & E to map the location and extent of areas vulnerable to Hydrilla invasion and establishment in the Great Lakes Basin. Once these areas were identified and mapped, the potential economic, socio-cultural, and environmental impacts of Hydrilla establishment in the Great Lakes Basin were estimated (see Section 3.3).

The Analysis Phase was followed by Risk Characterization (see Figure 1-2), in which areas were ranked based on vulnerability to invasion and degree of impact, and key uncertainties in the risk-assessment process were identified and discussed (see Section 4).

Risk Characterization was followed by Risk Management (see Figure 1-2), which included developing recommendations for prevention, early detection, and rapid response, and developing BMPs for Hydrilla control. An important element of risk management was sharing results, recommendations, and BMPs with resource managers and other stakeholders in the Great Lakes Basin (see Section 5).

## 1.4 Risk Assessment Team

In order to formulate an appropriate framework for this investigation, and to be able to conduct the necessary predictive analyses, it was clear from the beginning of this effort that the Project Team needed to be comprised of a number of specialists. Consequently, E & E and USACE Buffalo set out to locate experts in the fields of predictive modeling with regard to potential spread and suitability of Hydrilla into and throughout the Great Lakes. Expertise was also required regarding Hydrilla biology, previous and ongoing Hydrilla research and control, and impact and risk assessment. Through the search to compile the Project Team, a number of agencies and universities to were invited to support the assessment, as noted below:

- The USACE–Buffalo District was responsible for setting overall project goals and objectives, leading peer reviews of the many portions of the Risk Assessment, and administering the project;
- The USACE Engineer Research Development Center supported the project by making available a number of their experts on Hydrilla biology, ecology, and management;
- Texas Tech University, Lubbock, Texas, conducted Hydrilla distributional/colonization potential modeling;
- University of Toledo, Toledo, Ohio, conducted Hydrilla dispersal modeling;
- North Carolina State University (NCSU) conducted growth and competition studies with monoecious Hydrilla for this project; and

- E & E conducted the Hydrilla database compilation, habitat suitability analyses, data integration, literature reviews, impact assessment, risk formulation, and the preparation of this document.

## 1.5 Document Organization

The remained of this report is organized as follows:

- Section 2 presents the problem formulation for the Great Lakes Hydrilla risk assessment;
- Section 3 presents the analysis step of the assessment, including a description of the five main components of the exposure assessment, integration of results from those components, and description of the economic, socio-cultural, and environmental impacts resulting from establishment of Hydrilla in the Great Lakes Basin;
- Section 4 provides the risk characterization step of the assessment, including the ranking of areas in the Great Lakes Basin relative to vulnerability to invasion and degree of impact and discusses uncertainties in the risk-assessment process; and
- Section 5 describes risk management, including recommendations, BMPs, and future stakeholder-outreach activities.

# 2 Problem Formulation

Problem formulation, the first step in the risk-assessment process, identifies the goals, breadth, and focus of the assessment (USEPA 1997, 1998). The problem formulation step also identifies stressors, locations of stressors, and complete and potentially complete exposure pathways, and receptors. A conceptual model is then developed to summarize the relationships between stressors and receptors. In an ANS risk assessment, sources are locations that release ANS (e.g., sites of current infestations) and receptors are the valued natural resources, including habitats and wildlife, which may be adversely impacted by ANS. Exposure pathways are mechanisms by which ANS can be transported from sources to receptor locations (e.g., water currents and movement of watercraft). Once exposed, receptors interact with ANS in several ways, both direct and indirect (e.g., habitat alteration, interference with navigation, and elimination of native species). This section presents the Problem Formulation for the Great Lakes Hydrilla risk assessment. It states the goals, breadth, and focus of the assessment; generally describes the potential adverse impacts that Hydrilla may have on the Great Lakes watershed based on available literature; and presents a conceptual model that identifies and illustrates the relationships between potential Hydrilla sources, transport pathways, and vectors, and receptors.

## 2.1 Goals, Breadth, and Focus

As stated in Section 1, the principal objective of the Great Lakes Hydrilla risk assessment is to identify locations in the Great Lakes watershed most vulnerable to invasion based on likelihood of introduction and environmental suitability. Although the focus of the assessment was the Great Lakes themselves, the potential for Hydrilla to become established in inland waterbodies also was considered. The Great Lakes watershed includes thousands of inland waterbodies, and it was important to consider these waterbodies for several reasons. For example, an infestation in a small waterbody near one of the Great Lakes may result in an ongoing source of propagules and, therefore, an outsized economic impact for control if it leads to continued introduction of Hydrilla into a Great Lake. Conversely, continued spread to inland waterbodies from an established Hydrilla infestation in a Great Lake also could have ongoing economic impacts. However, given the size of the Great Lakes Basin and the large number of inland waterbodies therein, this assessment was only able to describe differences in susceptibility at a watershed scale, not at the level of individual waterbodies. Finally, this assessment was focused on monoecious Hydrilla, the biotype that favors colder waters and already has been found at some locations in the Great Lakes Basin.

## 2.2 Hydrilla Biotypes and Impacts of Hydrilla Infestations

As noted above, there are two Hydrilla biotypes in the United States (Shearer 2014). The female dioecious Hydrilla biotype was introduced from Sri Lanka to Florida in the 1950s. It has spread throughout the southeastern United States, as far west as Texas and into parts of California. Monoecious Hydrilla was first discovered in Delaware in 1976 and expanded its distribution through the Atlantic States and northward to Maine. Other locations where monoecious Hydrilla have been reported in Iowa, Ohio, Indiana, Wisconsin, Kansas, Missouri, California, and Washington State. The Washington State population was eradicated and it is thought that the populations in Iowa and Wisconsin also have been eradicated (Shearer 2014). The most recent invasions have appeared in Cayuga Lake and the Erie Canal in North Tonawanda, both in upstate New York, and in Pymatuning Reservoir on the Pennsylvania-Ohio border. Also, there was a recent confirmation of Hydrilla presence in Monroe County, New York. Based on earlier distributional modeling (Barnes et al. 2014) and observations of monoecious Hydrilla at northern locations (Maine and Wisconsin) it seems possible that much of the Great Lakes Basin may provide suitable habitat for monoecious Hydrilla.

Hydrilla possesses several characteristics that allow it to spread rapidly, displace other aquatic plants, and form dense single-species infestations. These characteristics include:

- Hydrilla can reproduce in four ways: tubers, turions, fragmentation, and seeds. The first three mechanisms are asexual and are the primary means by which Hydrilla expands into new environments and regrows after exposure to adverse environmental conditions.
  - Tubers are produced below the sediment surface and are viable for years, allowing the plant to regrow at a given location when all aboveground parts of the plant are destroyed (Langeland 1996; True-Meadows et al. 2016).
  - Turions are compact dormant buds produced by the above-sediment portion of the plant. When fully formed, they are released from the parent plant and are carried downstream by water currents, or settle to the surrounding sediment to grow (True-Meadows et al. 2016).
  - Fragmentation is a process in which nodes of the parent plant break away into buoyant fragments that disperse through the system by water currents. Fragmentation occurs naturally due to wave action and currents. Anthropogenic activities, such as boating, can increase fragmentation and transport plant fragments to other waterbodies (Langeland 1996).
- Hydrilla can absorb nutrients from water and sediment. This ability allows plant fragments to remain viable and grow while floating in the water column (Madsen and Owens 2000).

- Hydrilla can photosynthesize and grow under low light levels, giving it a competitive advantage over other aquatic plants in the same environment (Madsen and Owens 2000; Balciunas et al. 2002; True-Meadows et al. 2016).
- Hydrilla grows rapidly compared with many native aquatic plants, allowing it to displace native species (Langeland 1996).

In short, Hydrilla is a species particularly effective at staying alive, reproducing through a variety of mechanisms, and spreading much more rapidly than native aquatic plants.

Where introduced, Hydrilla has considerable impacts, including reduction of water flow, interference with recreational activities, and displacement of native plants through competition for light and other resources (Langeland 1996). Consequently, the introduction and establishment of Hydrilla in the Great Lakes Basin is considered to pose a threat to the ecological integrity of existing aquatic communities; recreational use of waterbodies; and use of waterbodies for irrigation, hydropower generation, and other purposes. These adverse impacts are largely due to the ability of Hydrilla to grow and reproduce rapidly once introduced, thereby clogging waterways, restricting water flow, modifying sunlight and temperature within the water column, lowering dissolved oxygen (DO) levels, and generally disrupting submerged aquatic habitats by domination (Netherland and Greer 2014; Shearer 2014; Dayan and Netherland 2005).

## 2.3 Conceptual Site Model

Currently, monoecious Hydrilla is present at several locations in the Great Lakes watershed (see Figure 2-1). The transport mechanisms responsible for these introductions are not specifically known. Possible transport mechanisms include: 1) movement of recreational watercraft containing Hydrilla among lakes; 2) water flow; 3) accidental release (e.g., disposal of aquarium contents); 4) waterfowl transport of plant fragments, tubers, or turions; and 5) disposal of dredged sediment containing plant fragments, tubers, or turions. Figure 2-2 presents a conceptual model showing how Hydrilla may be transported within a waterbody and between different waterbodies by these mechanisms in a typical Great Lakes environment; however, the five potential transport mechanisms mentioned above are not all equally responsible for Hydrilla movement. In general, it is thought that Hydrilla transport by recreational watercraft is a primary means by which this invasive species moves into new waterbodies (NCSU 2017). Nonetheless, the other means of transport cannot be ruled out, and may be significant in certain situations. For example, the spread of Hydrilla along several hundred miles of the Ohio River between Ohio and West Virginia was likely due in part to downstream transport of plant fragments, tubers, or turions.

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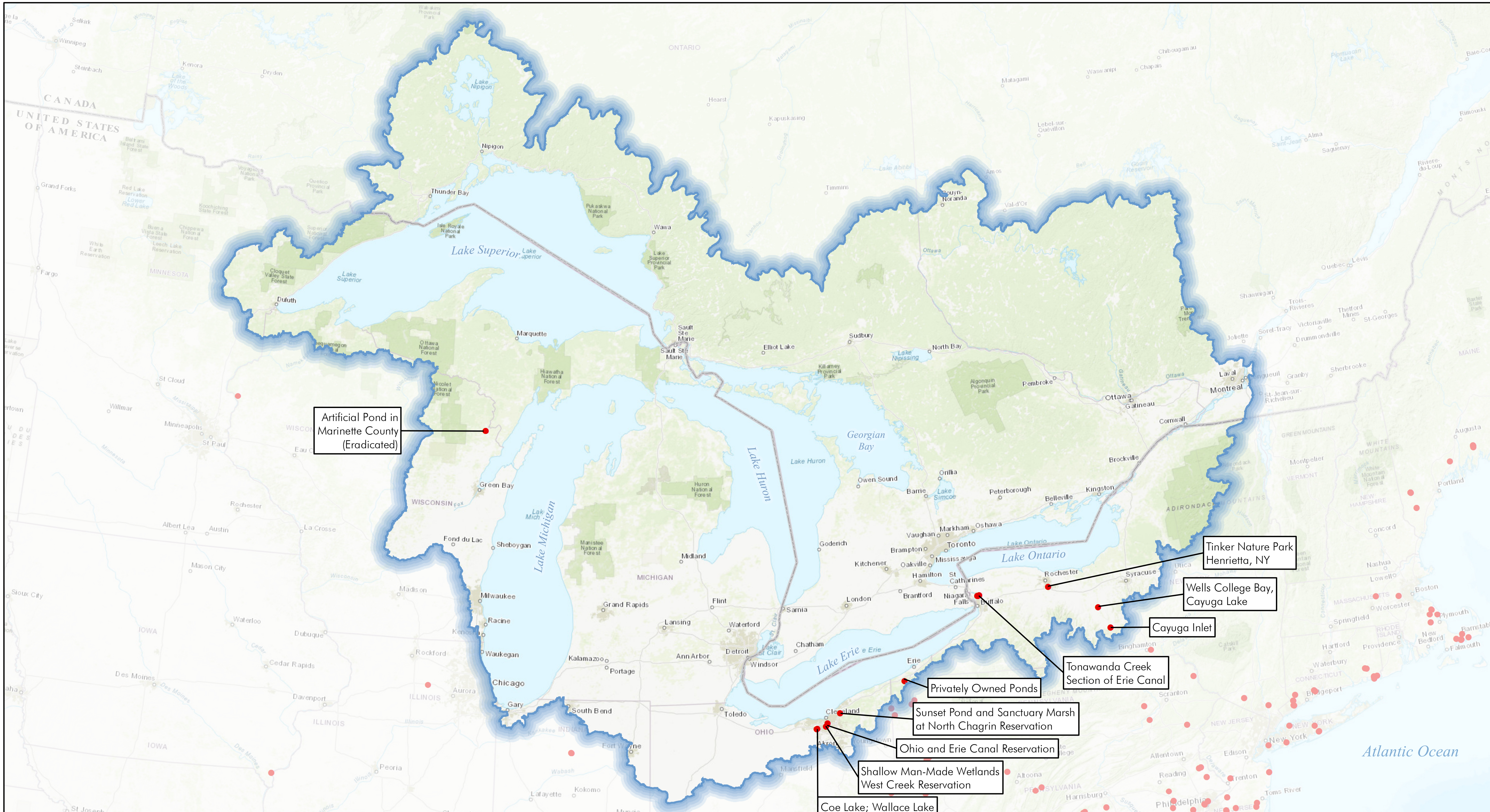



KEY:

- Hydrilla – Documented Occurrences
- Great Lakes Basin

Figure 2-1

**Documented Hydrilla Occurrences in the Great Lakes Basin**

Great Lakes Basin Distribution

Occurrences as of February 2018

N

0 50 100 200

Miles

Data Source: ESRI 2015; Barnes 2014; EDDMaps 2015; GBIF 2012, 2015; GLIN 2015; Ecology and Environment, Inc. 2018.

02:1003025.0025.03.06-B4869\Figure 2-2 Conceptual Site Model.ai-1/10/19-GRA

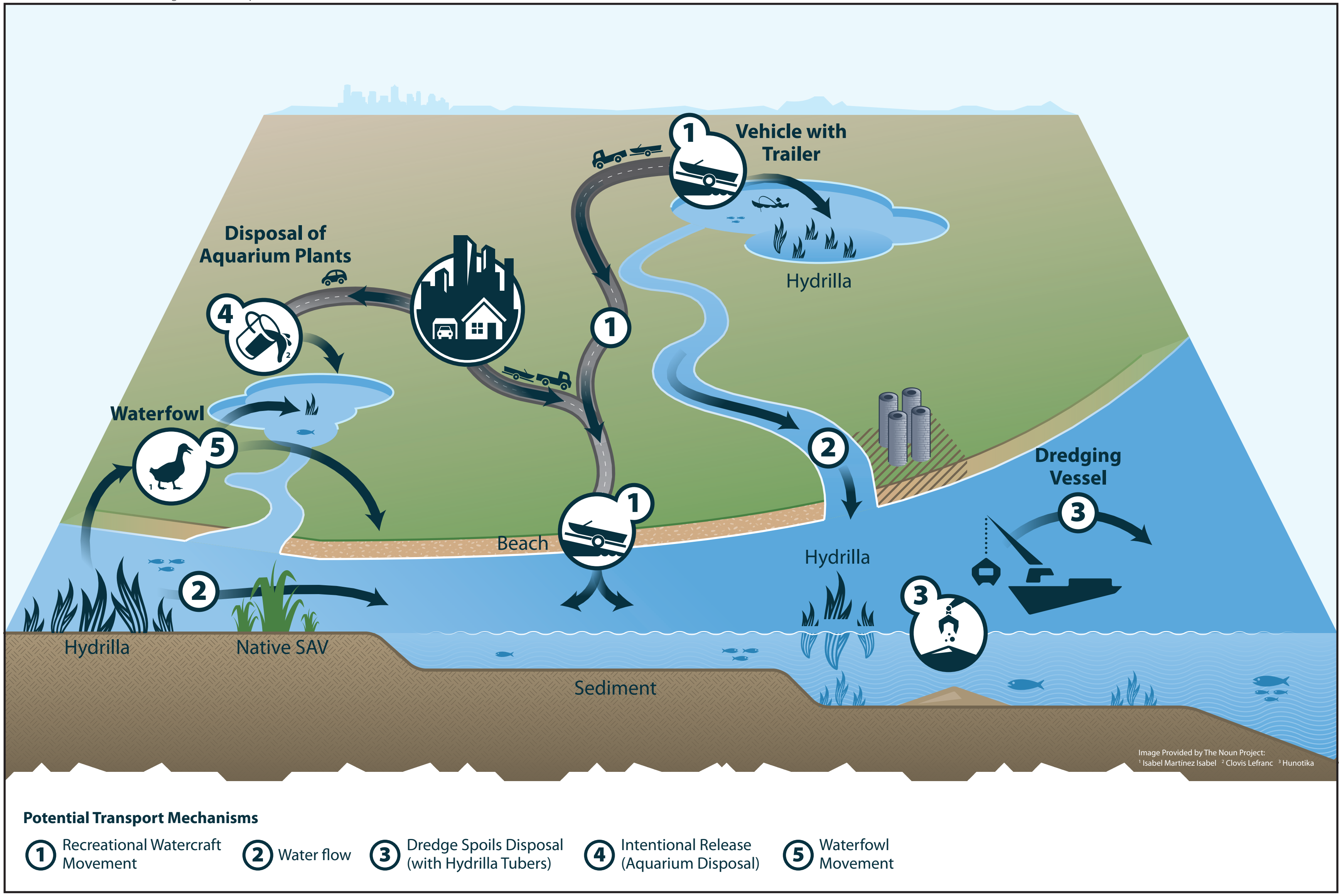



**Figure 2-2 Conceptual Site Model Illustrating Potential Means of Hydrilla Movement in a Typical Great Lakes Environment**

Transport by recreational watercraft (1) is thought to be the primary means by which Hydrilla moves into new waterbodies; however, the other means of transport (2 to 5) cannot be ruled out and may be signifiant in certain situations.

# 3 Analysis

This section presents the analysis step of the Great Lakes Hydrilla risk assessment. The analysis step is the longest and most detailed step in the risk-assessment process. As shown in Figure 1-2, the analysis step includes the following:

- Five components designed to characterize current and future exposure of the Great Lakes to Hydrilla (see Section 3.1);
- Integration of results from these components to identify areas most vulnerable to invasion based on likelihood of introduction and environmental suitability (see Section 3.2); and
- Characterization of economic, cultural, and environmental impacts from Hydrilla establishment (see Section 3.3).

Because stakeholder engagement is an important element of the risk-assessment process for invasive species, stakeholder engagement activities also are discussed in this section.

## 3.1 Critical Project Components

This section describes the work undertaken to engage stakeholders and characterize current and future exposure of the Great Lakes to Hydrilla. These topics are discussed under six main headings: (1) Stakeholder Engagement; (2) Hydrilla Occurrence Database Development; (3) Distributional Modeling; (4) Great Lakes Habitats Features; (5) Dispersal Modeling; and (6) Hydrilla Growth Studies.

### 3.1.1 Stakeholder Engagement

#### 3.1.1.1 Purpose

Project stakeholder engagement occurred at various stages of completing the risk assessment process, both to incorporate existing knowledge and information from Hydrilla specialists into the risk assessment process, and to share the results of the assessment with stakeholders across the Great Lakes Basin (see Figure 1-2). Stakeholders have been regularly engaged throughout the project, as effective coordination and outreach is critical in communicating the importance of managing the spread of Hydrilla throughout the Great Lakes Basin. The term “stakeholder” for this project is defined as an individual or organization with a demonstrated interest in the management of Hydrilla, with emphasis on management practitioners.

#### 3.1.1.2 Methods and Results

At the outset of the risk assessment, a Stakeholder Coordination and Outreach Playbook was developed to guide stakeholder engagement activities throughout the assessment. While the specific sequencing of events conceived of during the writing of Playbook were not exactly followed, the general approach was followed. Key activities conduced and prescribed by the playbook and described below include stakeholder identification, information gathering from Hydrilla specialists within and outside the Great Lakes Basin, and additional stakeholder communications focused on announcing the risk assessment and disseminating project information and conclusions.

#### 3.1.1.3 Stakeholder Identification

A preliminary set of stakeholders was identified including individuals and organizations within the Great Lakes Basin, including all Great Lakes states, as well as stakeholders in non-Great Lakes states with known Hydrilla infestations. The preliminary stakeholder list was compiled from various sources, including previous project experience, Internet research, and a review of available technical literature. Focus was placed on the identification of representative Hydrilla management practitioners and outreach specialists in Great Lakes states, as well as entities involved with past and present Hydrilla management efforts in other states. Additional stakeholders were identified at the local, state, and federal levels; within applicable academic and non-governmental organizations; and from federally recognized tribes in states that border the Great Lakes and various intertribal organizations, which may also have an interest in the project.

#### 3.1.1.4 Stakeholder Interviews

Interviews were conducted with more than 20 natural resource management practitioners responsible for addressing local Hydrilla infestations and state-level managers able to speak regarding statewide concerns (e.g., response readiness and available budget) and public policy issues (e.g., rules for boaters and restrictions on the sale and distribution of aquatic plants). Table 3-1 lists the agencies and groups represented by these interviewees and their respective states.

The individuals who were interviewed were identified based on their geographic dispersion and their known or presumed responsibilities relating to the management of Hydrilla infestations and/or prevention and detection of new occurrences. At least one management practitioner and/or state agency representative was interviewed within each Great Lakes state to gain a basic familiarity with Hydrilla-related activities within each state, to contribute to the collection of Hydrilla occurrence data for the Hydrilla occurrence database (see Section 3.1.2), and to facilitate indirect connections with other interested parties in each state through both the established and more informal professional networks of each interviewee.

**Table 3-1 Stakeholder Agencies and Organizations Interviewed for the Great Lakes Hydrilla Risk Assessment**

| Agency or Organization | State |
|---|---|
| **Great Lakes States** | |
| Illinois Department of Natural Resources | IL |
| Northeast Illinois Invasive Plant Partnership | IL |
| Indiana Department of Natural Resources | IN |
| Michigan Department of Environmental Quality - Aquatic Invasive Species Program | MI |
| Minnesota Department of Natural Resources - Aquatic Invasive Species Advisory Committee | MN |
| Cornell Cooperative Extension of Tompkins County | NY |
| Finger Lakes Partnership for Regional Invasive Species Management (PRISM) | NY |
| New York State Department of Environmental Conservation - Bureau of Water Assessment and Management | NY |
| New York State Department of Environmental Conservation - Office of Invasive Species Coordination (OISC) | NY |
| Cleveland Metroparks | OH |
| Ohio Division of Wildlife | OH |
| Pennsylvania Department of Conservation and Natural Resources - Bureau of State Parks | PA |
| Wisconsin Department of Natural Resources | WI |
| **Other States** | |
| California Department of Food and Agriculture | CA |
| Florida Fish and Wildlife Conservation Commission | FL |
| Georgia Power | GA |
| Maine Department of Environmental Protection - Bureau of Land and Water Quality | ME |
| Maryland Department of Natural Resources | MD |

The individuals interviewed from non-Great Lakes states were selected with input from the USACE ERDC based on their knowledge and experience with management or eradication of individual occurrences of monoecious and/or dioecious Hydrilla or related statewide programs.

Most interviews were conducted during spring 2015. Interviews were conducted by telephone and generally lasted 30 to 60 minutes. Each interview began with an introduction to the project followed by a discussion generally guided by the topics and questions shown in Table 3-2. Questions were modified or omitted within each interview based on the knowledge and experience of the interviewee.

**Table 3-2 Summary of Primary Information Gathering Questions for Resource Managers and Application to the Risk Assessment**

| Information Gathering Topics/Questions | Potential Application to the Risk Assessment |
| --- | --- |
| ■ What are the responsibilities of your position with regard to invasive species? | General Application and Future Outreach |
| ■ What, if any, are your [state or organization's] current research priorities with respect to monoecious Hydrilla? How do you see these priorities contributing to progress toward the management and control of Hydrilla? | Plant Biology and Ecology Studies |
| ■ Are there peer-reviewed studies or published papers that you feel would be helpful to E & E to review as part of the risk assessment? | General Application |
| ■ What data are you aware of that may speak to the habitat preferences of monoecious Hydrilla (e.g., nutrient levels and plant associations)? | Colonization Potential |
| ■ What data or papers are you aware of that speak to the environmental impacts of Hydrilla infestations? Do these data sources provide an indication of the geographic extent and severity of those impacts? | Environmental Impacts |
| ■ Have you had to quantify environmental impacts as a result of Hydrilla infestation? This may be related to fisheries, submerged aquatic vegetation, water quality, wildlife, human uses (e.g., swimming, boating, and fishing), hydrology, etc. If so, can you share the data? | Environmental Impacts |
| ■ Do you have any documentation/mapping of current and historical infestations and detections? We would like to obtain data to include date of first detection, rate of establishment, severity of infestation, existence of control efforts, extent of infestation (acres), type of aquatic environment (e.g., flowing system, stream, or lake) and source. Do you know others who may have similar data? | Occurrence Database |
| ■ What control measures (physical, mechanical, biological, chemical) have you employed and on what biotype of Hydrilla (monoecious or dioecious)? Do you have data to speak to the efficacy of these measures, or any case studies to share which might highlight successful/unsuccessful management techniques? | BMPs/Recommendations |
| ■ In what types of systems (e.g., lakes, flowing systems) have you managed Hydrilla and how have your techniques varied to reflect the system? | BMPs/Recommendations |
| ■ What kind of post-treatment monitoring or assessment activities have you been involved with and how have those helped to shape management/control activities? | BMPs/Recommendations |
| ■ What has been your experience with early detection and rapid response measures? What technologies do you utilize to detect new infestations and for rapid response? | BMPs/Recommendations |

**Table 3-2 Summary of Primary Information Gathering Questions for Resource Managers and Application to the Risk Assessment**

| Information Gathering Topics/Questions | Potential Application to the Risk Assessment |
|---|---|
| ■ What cost data do you have that could help in estimating the control costs of future management efforts? | Economic Impacts |
| ■ What are the key Hydrilla pathways (e.g., transport on recreational watercraft and boat trailers, downstream flow) that you have identified in your own work or would suggest that this project include? | Pathway Analysis |
| ■ What questions do you have about Hydrilla that may be addressed through this risk assessment? | General Application |
| ■ What other specialists should we contact? | Stakeholder Engagement |
| ■ Who are the key stakeholders associated with your research and projects? | Stakeholder Engagement |
| ■ Are you aware of any submerged aquatic vegetation mapping initiatives in the Great Lakes and inland waters, as well as bathymetric data in nearshore areas? | Colonization Potential |
| ■ Are there efforts in your state or region to limit sales of non-native aquatic species for personal aquaria or water gardens that could become invasive if released? | BMPs/Recommendations |
| ■ Does your state have an Early Detection/Rapid Response plan for Hydrilla? | BMPs/Recommendations |

Key:
BMP = best management practice

A contact report was prepared for each interview, and a summary of the results of all stakeholder interviews was shared with the USACE ERDC.

A summary of noteworthy results and issues identified during stakeholder interviews is provided below:

- Confirmation that Hydrilla has not been found in the states of Michigan, Illinois, or Minnesota. Among states that border on the Great Lakes, Hydrilla has been found in New York, Pennsylvania, Ohio, Indiana, and Wisconsin. Discussions with stakeholders resulted in the identification of several occurrences not included in the online databases and more detail concerning occurrences already identified, such as more information about treatment schedules, costs, and suspected pathways.
- While Hydrilla is not present in every Great Lakes state, within each state there is awareness and concern about the spread of Hydrilla on the part of state agency managers, and there are efforts to detect and limit the risk of introduction of Hydrilla through outreach efforts.
- Fluridone (marketed as SePRO Sonar) and Endothall are the most commonly used herbicides for the treatment of Hydrilla. It is not uncommon for managers to convene expert panels to review and refine annual treatment plans. The

additional use of contact herbicides is not unusual. Other treatment methods (e.g., benthic mats, diver-assisted suction harvesting, use of sterile grass carp [*Ctenopharyngodon idella*], and hand removal) have been tried in certain cases, but treatment with chemical herbicides is the most common and is considered to be the best available method.

- There is substantial variation in available funding for managing and reducing the spread or risk of spread of Hydrilla across the Great Lakes states. For instance, there is a strong contrast between staff and funding available in Wisconsin, where the aquatic invasive species (AIS) program receives about $4.5 million annually and distributes about $4 million (for research, planning, control, rapid response, outreach, etc.), and the staff and funding available in Pennsylvania, where the Pennsylvania Department of Agriculture has responsibility for addressing noxious and invasive plants, but, for example, is not providing direction or funding to the Pennsylvania Department of Conservation and Natural Resources (PA DCNR) to combat Hydrilla in Pymatuning Reservoir.
- The suspected pathway mentioned most often in interviews was transfer of Hydrilla on boats, props, or boat trailers. Other suspected pathways mentioned include waterfowl eating and regurgitating Hydrilla tubers, waterfowl carrying stems on feet, individuals throwing away personal aquaria where Hydrilla was in the tank, and the natural spread within waterbodies and downstream when stems are carried by currents. The contacts in California also noted the possibility for seaplanes to carry stems in their floats.
- Most natural resource agencies in affected states are not funding academic research related to Hydrilla, but there is strong interest in the possibilities associated with genetic research, such as the ability to detect the presence of Hydrilla in a waterbody based on water sampling. This method would be an early detection method that could potentially support identification of early entry of Hydrilla into a system prior to established infestation.
- State managers generally have little-to-no data available regarding impacts on other species caused by the introduction of Hydrilla or the use of chemical herbicides.
- Regular communication occurs between members of the informal network of practitioners responsible for the management of Hydrilla in Great Lakes states.
- The decades-long experiences with Hydrilla management in California and Florida offer contrasting scenarios that may be informative for the future of Hydrilla in the Great Lakes Basin. While California remains committed by state law to the eradication of Hydrilla in its waterbodies, activities related to Hydrilla in Florida are geared toward long-term management and acknowledgment of a vocal angling community that finds Hydrilla a suitable habitat for certain types of fish and would be opposed to the eradication of Hydrilla. Florida's management approach probably is due to the fact that Florida was the beachhead for the Hydrilla invasion in North America and the problem

> was not recognized until Hydrilla was too widespread to make eradication practical. In contrast, the introduction of Hydrilla to California came many years later and was recognized early on, thereby allowing California to take timely steps to prevent, detect, and rapidly respond to Hydrilla's spread.

Much of the input summarized above has been used to inform or corroborate elements of the risk assessment.

#### 3.1.1.5 Stakeholder Communications

Additional stakeholder engagement activities conducted during the development of the Great Lakes Hydrilla risk assessment focused on increasing awareness of the assessment and collecting information to support the analysis step (Step 2 in Figure 1-2).

Two versions of a general fact sheet were developed for the assessment and distributed to stakeholders: a longer, more detailed (eight-page) version intended for informed stakeholders, and a shorter (two-page) version for the general public. Both versions were distributed in June 2016 via emails to identified stakeholders that also included a general project update, and via emails from USACE ERDC personnel to their respective networks. Fact sheets and announcements were also provided at relevant events attended by the USACE ERDC and/or E & E including a presentation about the Great Lakes Hydrilla risk assessment project that was made at the Aquatic Plant Management Society's annual conference in July 2016 in Grand Rapids, Michigan.

Additional direct stakeholder outreach was conducted on a limited basis to support development of the Hydrilla occurrence database (see Section 3.1.2) and assess potential economic, environmental, and cultural/social impacts of Hydrilla in the Great Lakes Basin (see Section 3.3).

Stakeholder engagement at the conclusion of the risk assessment process, including dissemination of the final risk assessment report and targeted outreach activities to communicate the findings of the assessment with respect to colonization potential in specific geographic areas and promote adoption of recommended steps and activities pertaining to risk management, are described in Section 5.3.

### 3.1.2 Hydrilla Occurrence Database Development

#### 3.1.2.1 Purpose

In order to model where Hydrilla may find suitable habitat in the Great Lakes Basin and identify key Hydrilla transport mechanisms, it is necessary to know where Hydrilla occurs elsewhere in the United States and across the world, and how the distribution of Hydrilla has changed over time. For this reason, a comprehensive database of documented Hydrilla occurrences for the United States and the world was created for this project. The database encompasses the distribution of both native and invasive populations of Hydrilla and was the foundation for the distributional and dispersal modeling conducted for this project.

#### 3.1.2.2 Methods and Results

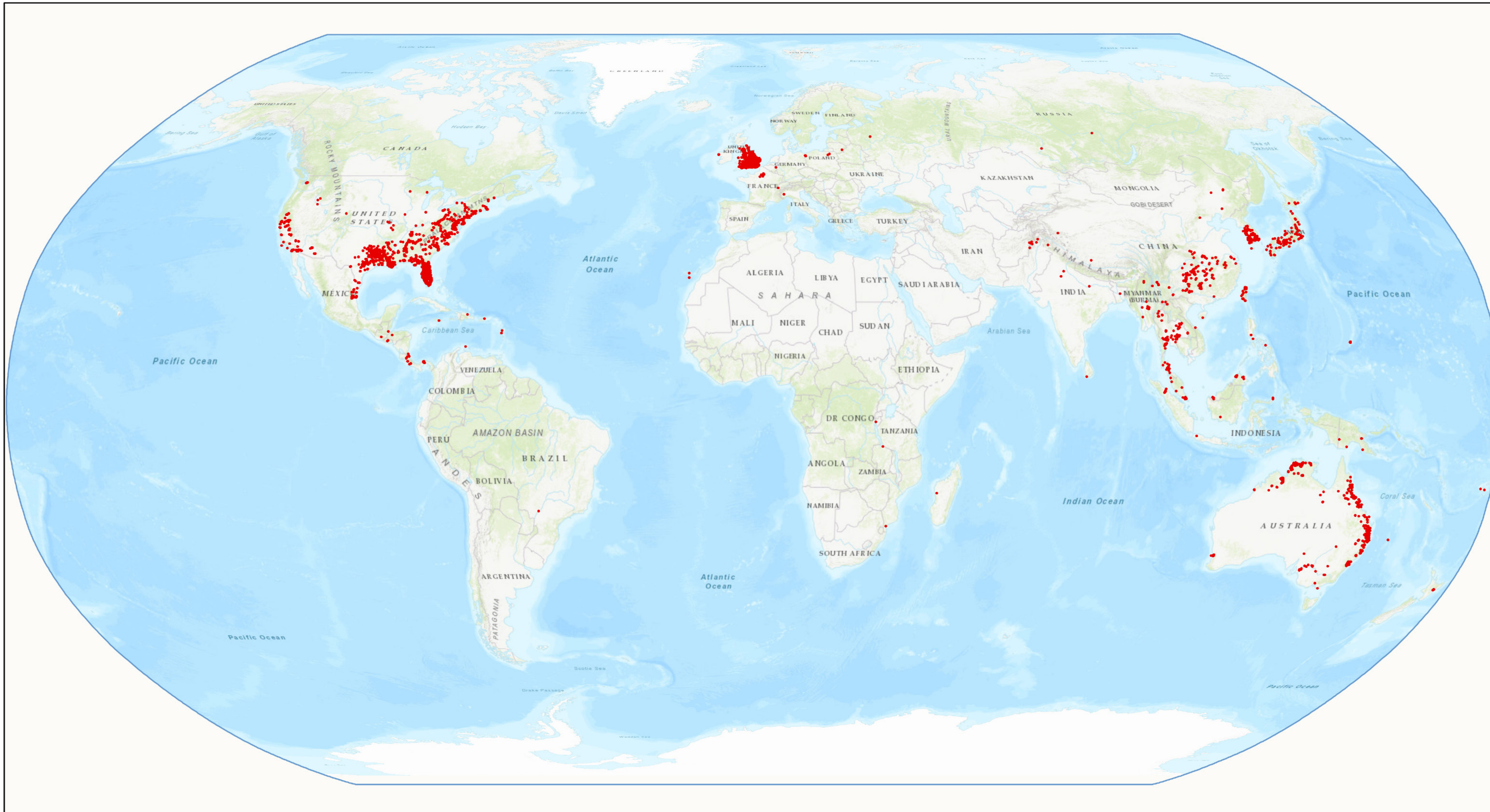
The Hydrilla occurrence database was developed by combining four datasets exported from different sources and merging them into a single dataset with a set schema. The datasets used and their hierarchy are listed below:

1. Early Detection and Distribution Mapping System (EDDMapS). 2015. [U.S. OCCURRENCES]. University of Georgia - Center for Invasive Species and Ecosystem Health. Available online at http://www.eddmaps.org/; original data export on March 23, 2015, and checks for recent additions were conducted on July 7, 2015, December 14, 2015, and February 26, 2016.
2. Global Biodiversity Information Facility (GBIF). 2015. [GLOBAL OCCURRENCES] Available online at www.gbif.org/; original data export on March 17, 2015, and checks for recent additions were conducted on July 7, 2015, December 14, 2015, and February 26, 2016.
3. "Barnes Other." [GLOBAL OCCURRENCES]. Barnes et al. (2014) provided coordinate data in their Appendix S2, with 316 records attributed to unpublished data from Zhang, Purcell, and Ding (Hydrilla native range), and one record attributed to Anderson et al. (2005) (South America).
4. GBIF 2012. [GLOBAL OCCURRENCES] Barnes et al. (2014) provided coordinate data for over two thousand records in their Appendix S2, with the majority of records attributed to data exported from GBIF in March 2012. Because their Appendix S2 lacked ancillary information (e.g., date, biotype, acres infested, rate of spread, control efforts) Barnes provided E & E with the original data export so whatever ancillary information was downloaded from GBIF in 2012 was available for review.

Each dataset was appended to the primary dataset (EDDMapS) in a hierarchical manner, based on the amount of ancillary information provided. Forty-one additional records were added manually to the database by E & E. The additional records represented recent reports of Hydrilla in Great Lakes states acquired through personal communication with stakeholders, smaller-scale, on-line resources such as iMapInvasives (https://www.imapinvasives.org/), and older literature reports of Hydrilla at northern latitudes in Eurasia. Further details regarding creation of the Hydrilla occurrence database are provided in Appendix A. The final version of the database provided to Texas Tech University and the University of Toledo for modeling purposes was last updated on February 26, 2016. That version of the database contained 6,694 records, of which 5,604 had coordinate data. Records were rarified for the distributional modeling to prevent over-representation of well-documented areas and infestations (see Section 3.1.3).

#### 3.1.2.3 Application

Using a geographic information system (GIS), the February 26, 2016, version of the database was used to create maps depicting the global distribution of Hydrilla (see Figure 3.1.2-1), Hydrilla occurrences in the United States (see Figure 3.1.2-2), and Hydrilla occurrences in the Great Lakes Basin (see Figure 2-1). In addition to mapping Hydrilla locations, the Hydrilla occurrence database was




KEY:

● Hydrilla - Known Occurrence

N

0 1,000 2,000 4,000

Miles

**Figure 3.1.2-1**
**Hydrilla Locations Derived from Ecology and Environment, Inc. Assembled Hydrilla Occurrence Database Worldwide Distribution**

Data Source: ESRI 2015; Barnes 2014; EDDMaps 2015; GBIF 2012, 2015; Ecology and Environment, Inc. 2015.

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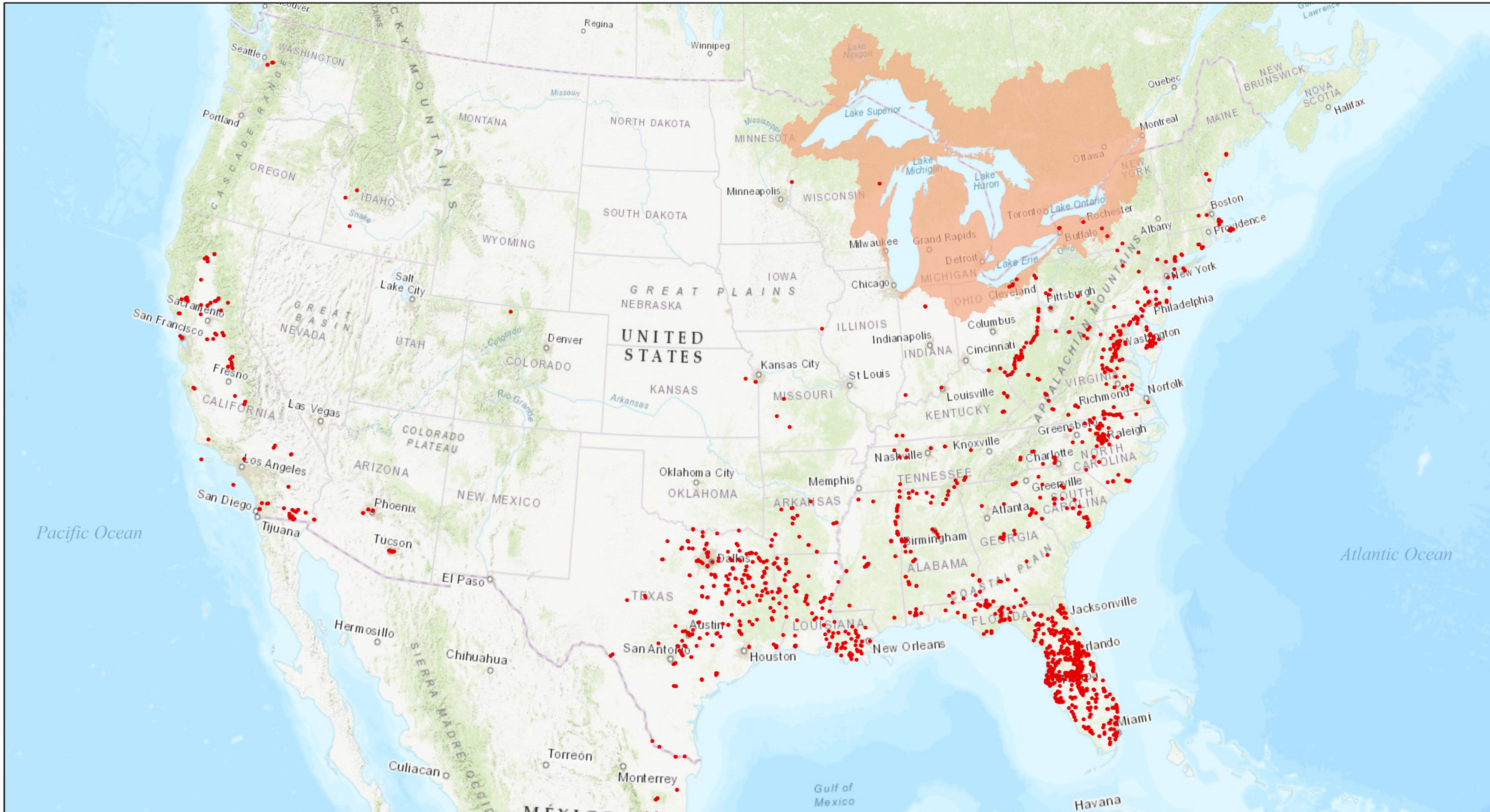


KEY:

- Hydrilla - Known Occurrence
- Great Lakes Basin

N

0 250 500 1,000

Miles

**Figure 3.1.2-2**
**Hydrilla Locations Derived from Ecology and Environment, Inc. Assembled Hydrilla Occurrence Database**
**United States of America Distribution**

Data Source: ESRI 2015; Barnes 2014; EDDMaps 2015; GBIF 2012, 2015; GLIN 2015; Ecology and Environment, Inc. 2015.

used to: understand past spread patterns of Hydrilla in the United States, identify likely transport pathways and vectors, and support dispersal and distributional modeling (see Sections 3.1.3 and 3.1.5, respectively).

### 3.1.3 Distributional Modeling

#### 3.1.3.1 Purpose

Species distribution models (SDMs) predict sites with suitable habitat capable of supporting new populations of a given species. This is accomplished by relating known occurrences of a species with local environmental conditions to understand habitat requirements for that species across wide landscapes and matching suitability. The main question that distributional modeling is used to answer is: *Can the site support a self-sustaining population*? Hydrilla distributional modeling for this project was conducted by Matthew Barnes, Ph.D. and Sasha Soto, Department of Natural Resources Management, Texas Tech University, Lubbock, Texas. A complete description of the distributional modeling work done for this project is provided in Appendix B (Soto 2017). A summary of the work is provided below.

#### 3.1.3.2 Methods and Results: Global Models

Two distributional modeling methods, Maxent and Maxlike, were used to generate forecasts of habitat suitability for Hydrilla. Maxent is one of the most widely used SDM methods. Maxent makes predictions using the maximum entropy principle to calculate the most uniform distribution within the environmental variables and constraints given. In its logistic form, Maxent output is commonly interpreted as “habitat suitability” and provides a geographically explicit estimate of local probability of establishment following introduction. In contrast, Maxlike estimates probability of occurrence by assuming the average occurrence probability is near the true occurrence probability using the maximum likelihood method (Fitzpatrick et al. 2013; Merow and Silander 2014), producing output that is a geographically explicit map of “likelihood of occurrence.” Because the two methods take different approaches to data analysis and prediction, combining them contributes to a “weight of evidence” approach for understanding habitat suitability.

The Hydrilla occurrence database described in Section 3.1.2 was used as input for the Maxent and Maxlike models. Prior to use, the occurrence data were rarefied as per recommendations from McDowell et al. (2014) to remove potential spatial bias due to uneven sampling effort. Thus, a total of 2007 Hydrilla occurrences were part of the global dataset. These Hydrilla occurrences were compared with Bioclim environmental layers, specifically global atmospheric data describing temperature patterns (Hijmans et al. 2005; WorldClim 2016), in the Maxent and Maxlike models. Although Hydrilla is an aquatic plant, aquatic environmental data layers such as water temperature are not available at an appropriate scale for species distribution modeling. However, atmospheric variables have been shown to be viable proxies for aquatic conditions at large scales when aquatic layers are unavailable and therefore were used in place of aquatic data layers in the Maxent and Maxlike models (Reshetnikov and Ficetola 2011).

Maxent and Maxlike generate a logarithmic score from 0 to 1 for each 10- by 10-kilometer grid cell across the model area. The results typically are presented as heat maps with warm colors (red and orange) representing the highest scores and cool colors (blue and aqua) representing the lowest scores. A score near 1 (hottest colors) implies that there is high confidence that the answer is *yes* to the main question being asked by distributional modeling; that is, *Can the site support a self-sustaining population*? In contrast, a score near 0 (coldest colors) suggest that the answer to this question likely is *no*.

**Maxent Results:** The Maxent global model predicted areas of high habitat suitability for Hydrilla in the southeast United States, southern Brazil, Argentina, northern and eastern Australia, southeastern Asia, South Korea, Japan, the Mediterranean, and England (see Figure 3.1.3-1). Within the Great Lakes Basin, the Maxent global model indicated that the areas with the most suitable habitat for Hydrilla are Lake Erie, southeast Lake Michigan, and the Finger Lakes region in central New York State (see Figure 3.1.3-2). For reference, Figure 3.1.3-2 also shows locations of current Hydrilla infestations in the Great Lakes Basin and the Maxent habitat suitability scores for those locations. In general, Maxent predictions of highly suitable Hydrilla habitat were focused near known Hydrilla occurrences.

**Maxlike Results:** The Maxlike global model predicted approximately two-thirds of the world's surface as potential habitat for Hydrilla (see Figure 3.1.3-3), a much greater extent of suitable habitat than predicted by the Maxent global model (see Figure 3.1.3-1). Within the Great Lakes Basin, the areas predicted by the Maxlike global model to offer suitable habitat for Hydrilla (see Figure 3.1.3-4) were generally similar to those predicted to be suitable habitat by the Maxent global model (see Figure 3.1.3-2). However, for any given location in the Great Lakes Basin, the habitat suitability score and color warmth typically were greater for the Maxlike global model than the Maxent global model (compare Figures 3.1.3-2 and 3.1.3-4).

**Comparing Maxent and Maxlike Results:** Hastie and Fithian (2013) recommend interpreting presence-only model results (such as the Maxent and Maxlike projections of Hydrilla habitat) as visualizations of relative occurrence rate rather than absolute occurrence rate. Additionally, the finding of Fitzpatrick et al. (2013) that the suitability indices output by Maxent and Maxlike were poorly correlated with one another overall may lead to the expectation that the two modeling approaches would produce different predictions of suitable Hydrilla habitat in the Great Lakes Basin. Therefore, it is notable that the two approaches yielded strikingly similar results (see Figures 3.1.3-2 and 3.1.3-4). Both models identified relatively suitable Hydrilla habitats in most of Lake Erie as well as the southern basin of Lake Michigan. Although the quantitative outputs of the two models are not directly comparable, Maxlike models produced higher output at each site of documented Hydrilla occurrence within the basin than did Maxent, which agrees with previous findings that Maxent tends to underpredict within a known species range (e.g., Royle et al. 2012). Maxlike may not be as successful as Maxent when

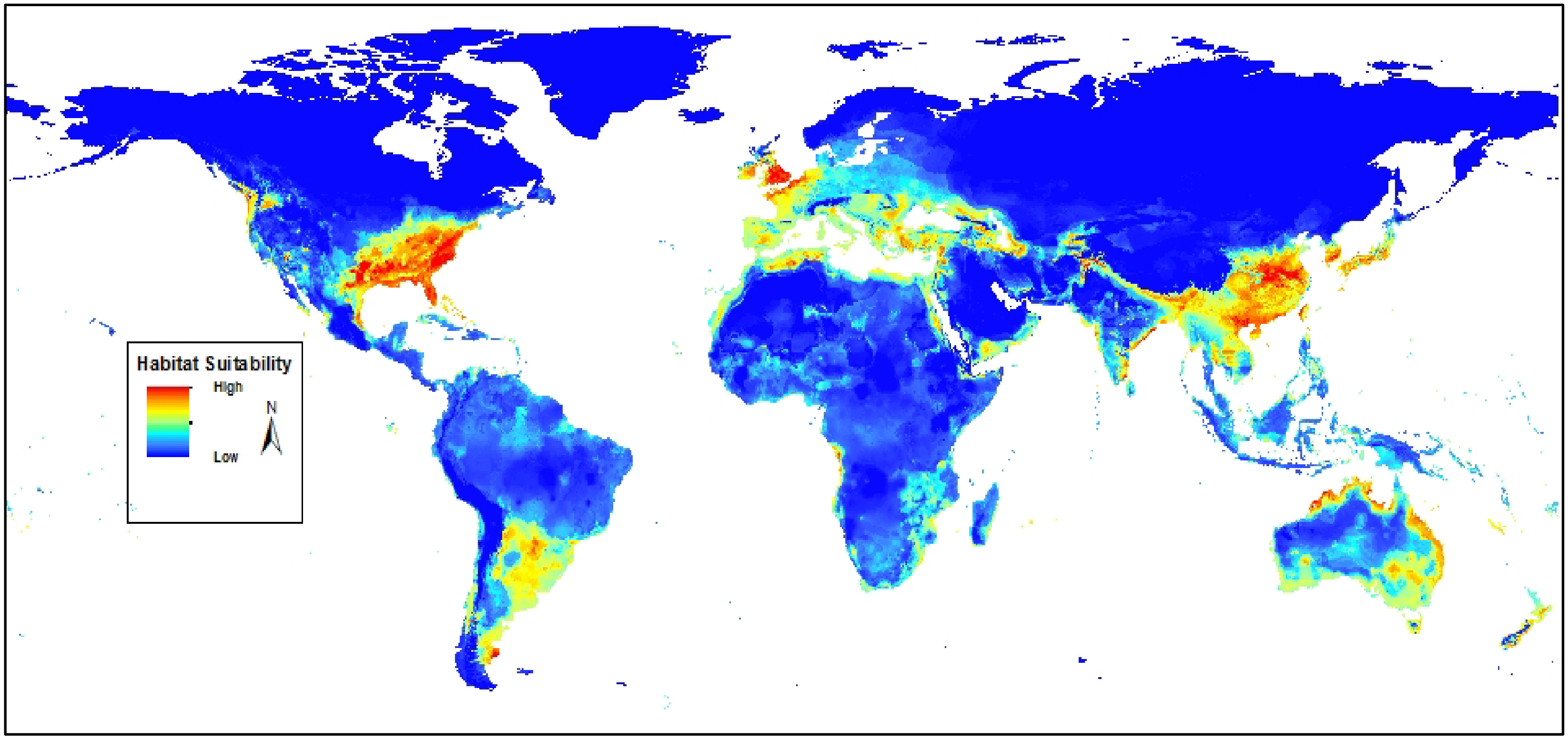


**Figure 3.1.3-1 Maxent Global Model for *Hydrilla verticillata* based on Global Hydrilla Occurrence Database (both biotypes combined)**

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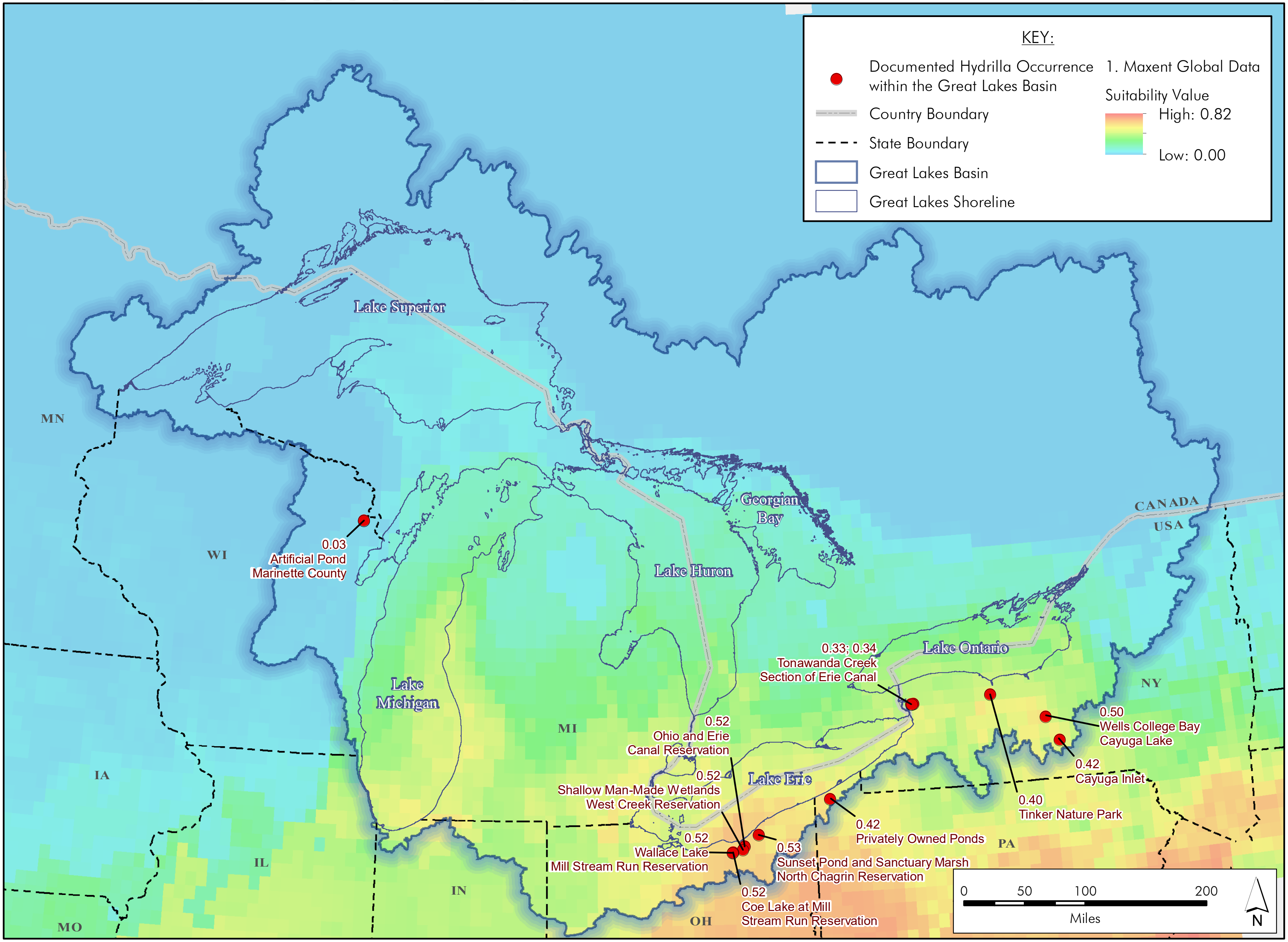


**Figure 3.1.3-2 Maxent Global Model Output Zoomed to Extent of Great Lakes Basin**

**Occurrences as of 2/26/2016**

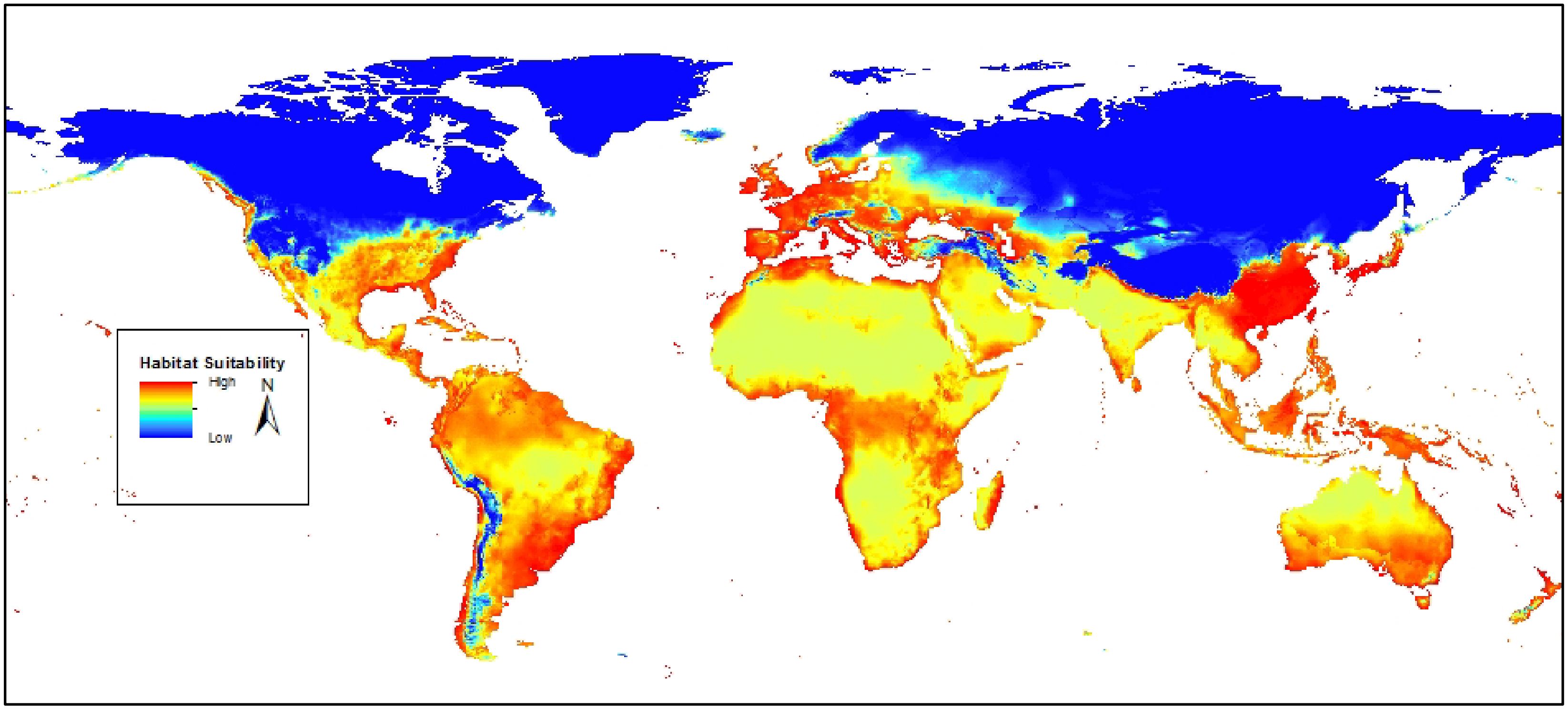


**Figure 3.1.3-3 Maxlike Global Model for *Hydrilla verticillata* based on Global Hydrilla Occurrence Database (both biotypes combined)**

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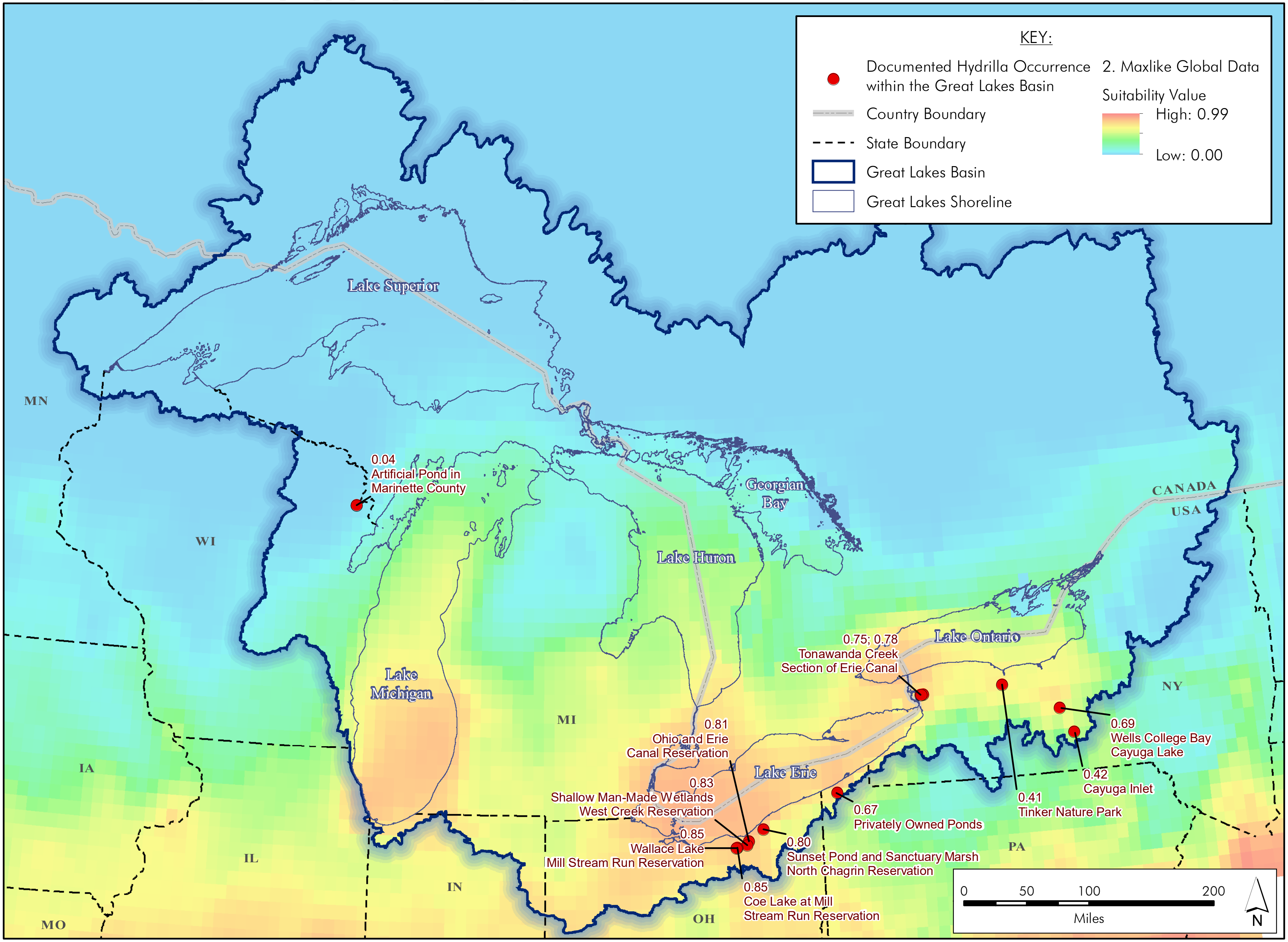


**Figure 3.1.3-4 Maxlike Global Model Output Zoomed to Extent of Great Lakes Basin**

**Occurrences as of 2/26/2016**

it comes to predicting suitable habitat beyond the known species' range (Fitzpatrick et al. 2013), so it is noteworthy that the Maxent models made stronger predictions of habitat suitability in the northern portion of Michigan's lower peninsula than did Maxlike. Similar patterns were observed in Georgian Bay and southern portions of Lake Superior (although Lake Superior scored very low suitability levels by both models). The strong prediction values for southern Lake Michigan in the Maxlike model are comparable to the strong predictions around known occurrences near Lake Erie, which could suggest high suitability of this region for invasion.

#### 3.1.3.3 Methods and Results: North American Biotype-Specific Models

Monoecious and dioecious Hydrilla possess traits based on genetic and physiological differences that may influence their invasion potential. To evaluate whether biotype may influence the Maxent and Maxlike model predictions, models were created using data partitioned by biotype and compared (see Figure 3.1.3-5). Hydrilla occurrence records that include biotype are restricted to the United States, Mexico, and Canada (U.S. Geological Survey [USGS] 2016). After being rarified as per McDowell et al. (2014), the biotype-specific dataset contained 751 total Hydrilla occurrences: 203 monoecious and 548 dioecious records in the United States. The biotype-specific Hydrilla occurrences were compared with Bioclim temperature-based atmospheric data layers in Maxent and Maxlike, as was done for the global models. Four approaches were employed with both Maxent and Maxlike:

1. Restricting occurrence data to monoecious Hydrilla (monoecious-only model);
2. Restricting occurrence data to dioecious Hydrilla (dioecious-only model);
3. Combining monoecious and dioecious occurrences (all-data model); and
4. An additive model created by combining the monoecious-only and dioecious-only forecasts using raster math.

**Maxent Results:** The monoecious-only Maxent model predicted suitable habitat in the northeastern United States, but not south to Florida in dioecious-Hydrilla territory (see Figure 3.1.3-6). The dioecious-only Maxent model predicted suitable habitat in the southern United States, with hot spots in Florida and Louisiana, and sparingly in the western United States (see Figure 3.1.3-7). The all-data model predicted potential Hydrilla habitat in the southern and eastern United States with large hotspots (red color) in Florida and Louisiana where dioecious Hydrilla is currently prevalent and a smaller hotspot in the eastern United States in the current range of monoecious Hydrilla (see Figure 3.1.3-8). The Maxent additive model also predicted potential Hydrilla habitat in the southern and eastern United States with large hotspots in Florida and Louisiana, but also predicted a large hotspot of suitable habitat in the eastern United States that coincides with the region where monoecious Hydrilla is known to occur (see Figure 3.1.3-9). Compared with the additive model, the all-data model failed to emphasize the habitat of the less populous biotype, monoecious Hydrilla. Lastly, the Maxent monoecious-only, all-data, and additive models show that the southern portion of the Great Lakes Basin may provide suitable Hydrilla habitat.

**Maxlike Results:** The Maxlike monoecious-only, all-data, and additive models produced similar results, all predicting suitable habitat for Hydrilla in the current ranges of monoecious and dioecious Hydrilla and along much of the North American coasts, including British Columbia, southeastern Alaska, and around the Gulf of Mexico (see Figures 3.1.3-10, 3.1.3-11, and 3.1.3-12). These three models also indicated that suitable habitat for Hydrilla may exist in the southern Great Lakes Basin, especially in or near Lake Erie and southern Lake Michigan. The Maxlike dioecious model (see Figure 3.1.3-13) identified suitable habitat for Hydrilla in the southeast United States where dioecious Hydrilla currently is prevalent, around the Gulf of Mexico, and in limited locations along the west coast of North America. Overall, it appeared that the Maxent model was able to distinguish between biotypes better than the Maxlike.

To summarize, the biotype-specific models show that partitioning input data by biotype influences model predictions. Modeling biotypes separately and combining the resulting predictions (Approach 4) improved overall model predictions, especially with Maxent, by better identifying locations where monoecious and dioecious Hydrilla presently are known to occur.

#### 3.1.3.4 Application

As described above, multiple distributional models were created for this project with Maxent and Maxlike, with global and North American occurrence datasets, and with and without partitioning the datasets by biotype. For two reasons, it was decided that the Maxent global model based on the global occurrence dataset (not partitioned by biotype) was the most appropriate model for identifying potential Hydrilla habitat in the Great Lakes Basin. First, Maxent is the most widely used and reliable SDM program presently available. A summary of the existing literature on the strengths and weaknesses of both Maxlike and Maxent is presented in Section 4.4.2.1. Second, a model based on the global occurrence dataset better captures the range of environments that Hydrilla may find suitable. The North American biotype models were trained on occurrence data for the United States only and therefore may not depict the full range of Hydrilla habitats present in the Great Lakes Basin because the Hydrilla invasion in North America is not yet complete (see Section 4.4.2.2).

The Maxent global model was used for two purposes in this risk assessment. First, is was used as an input to the dispersal model (see Section 3.1.5) to inform that model regarding habitat suitability for Hydrilla in the Great Lakes Basin and elsewhere in the United States. Second, the Maxent global model output for the Great Lakes Basin (see Figure 3.1.3-2) was used along with other measures of habitat suitability (see Section 3.1.4) to identify areas of the Great Lakes Basin that include suitable Hydrilla habitat and help rank those areas for further consideration in the risk assessment (see Section 3.2 for details).

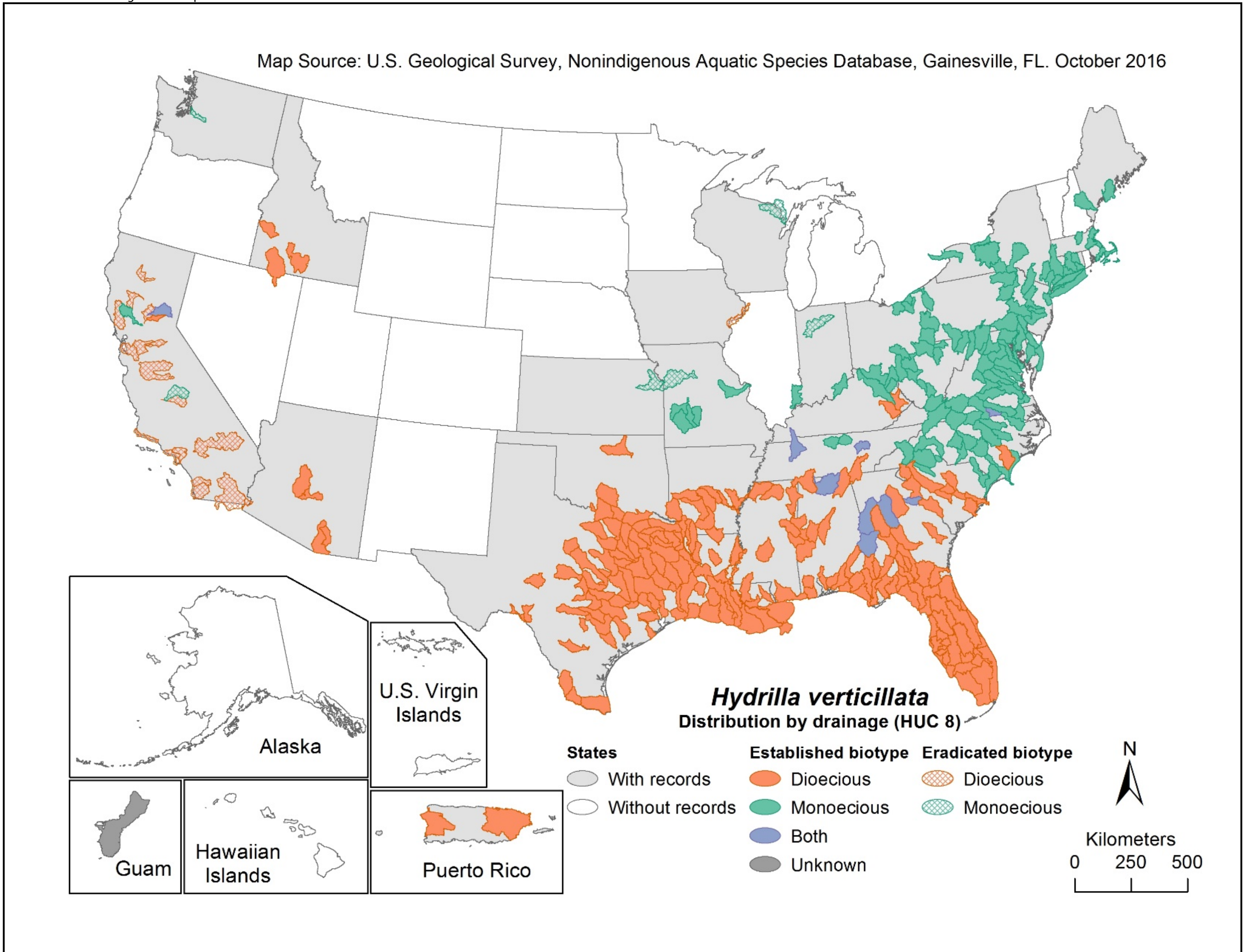


**Figure 3.1.3-5** ***Hydrilla verticillata*** **Distribution in the United States as of October 2016 (USGS)**

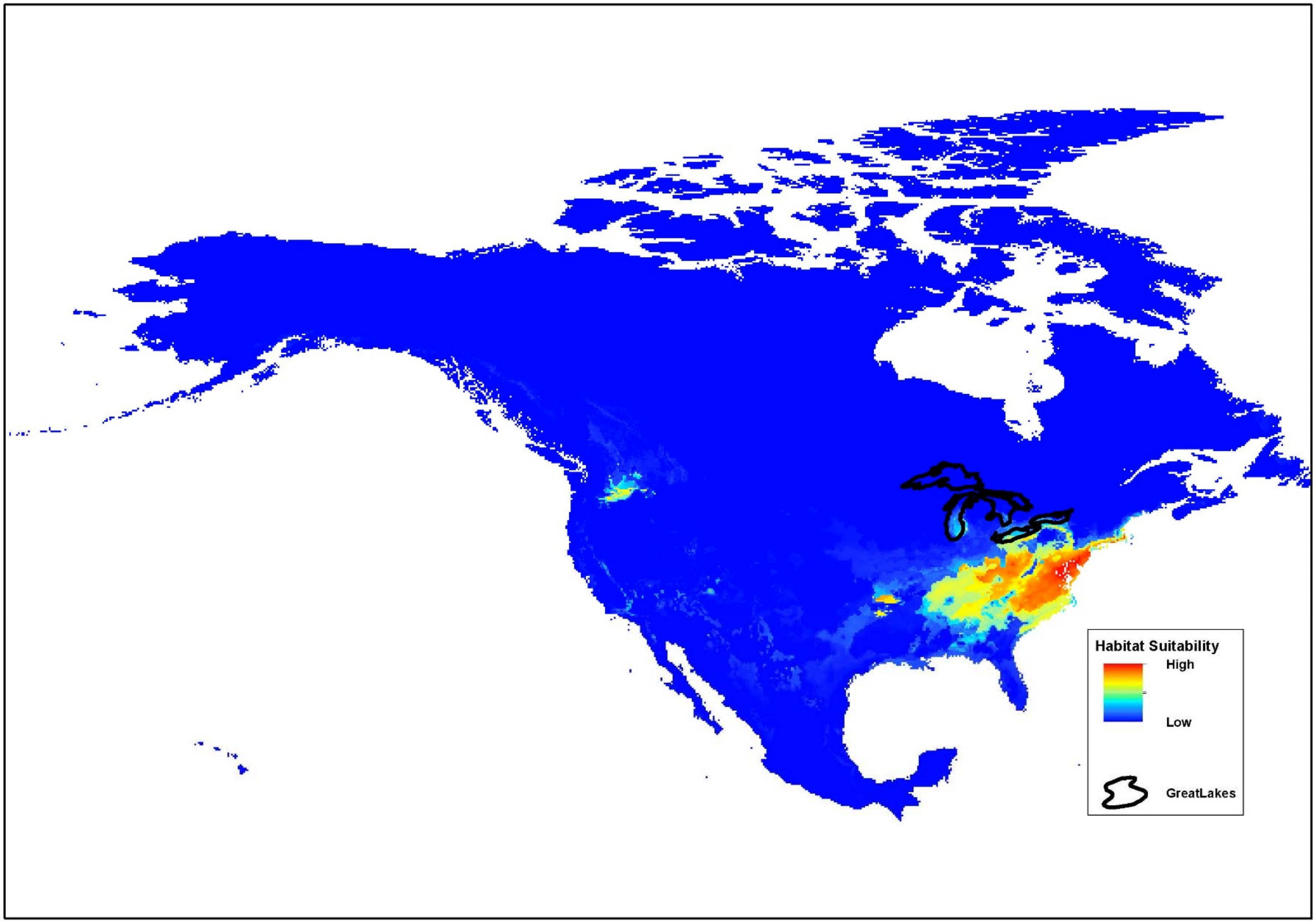


**Figure 3.1.3-6 Maxent Monoecious-Only Model Results**

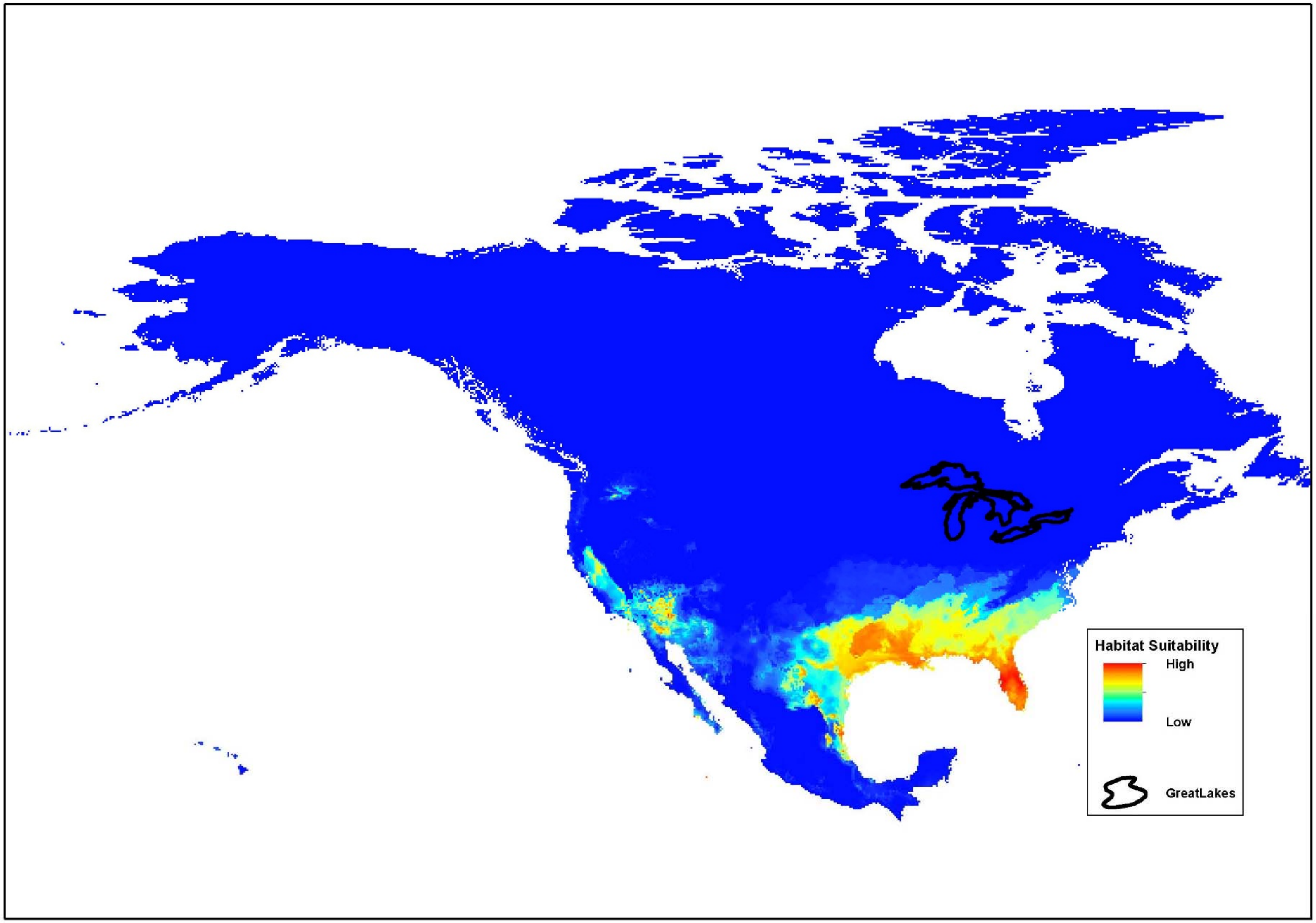


**Figure 3.1.3-7 Maxent Dioecious-Only Model Results**

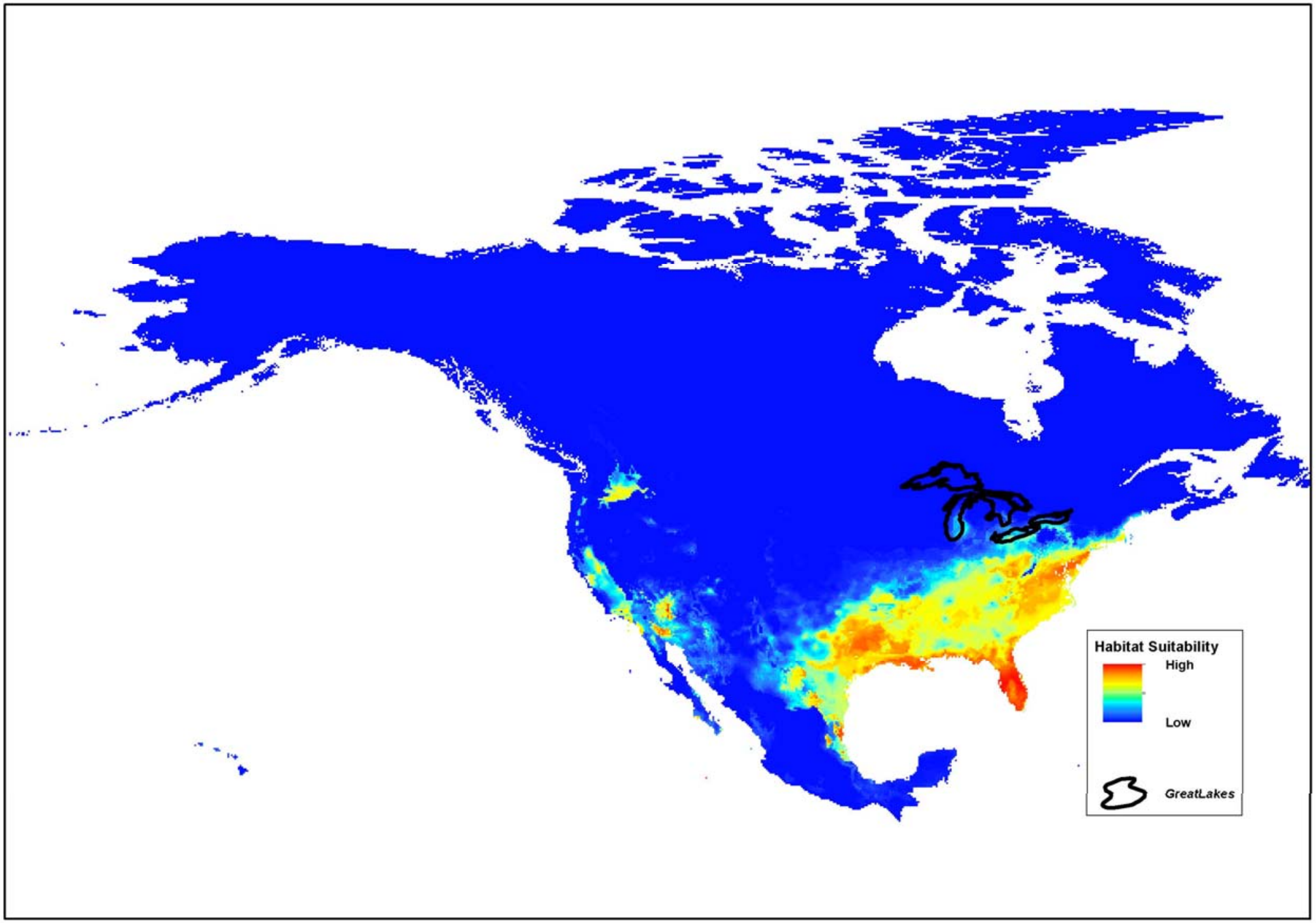


**Figure 3.1.3-8 Maxent All-Data Model Results**

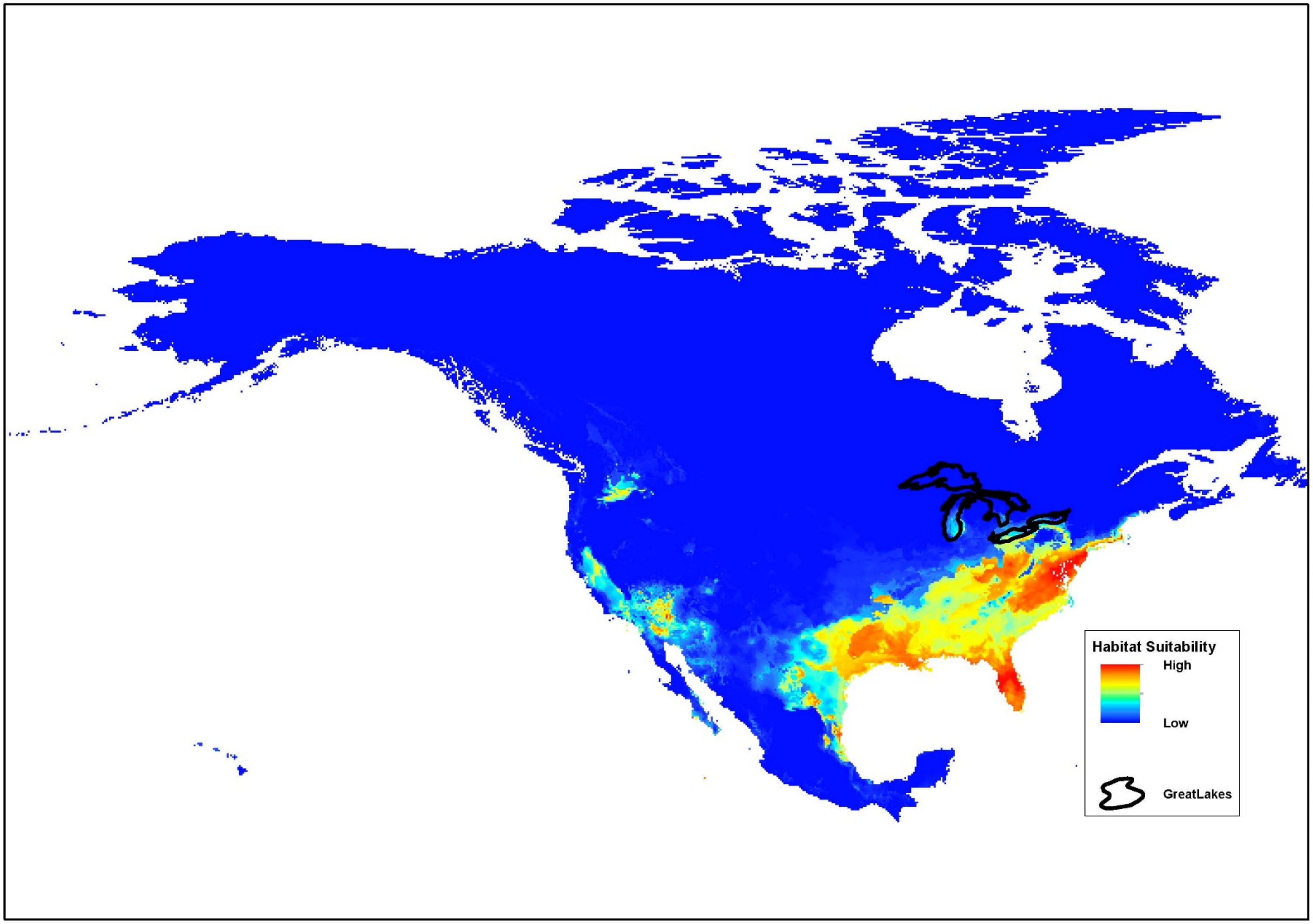


**Figure 3.1.3-9 Maxent Additive Model Results**

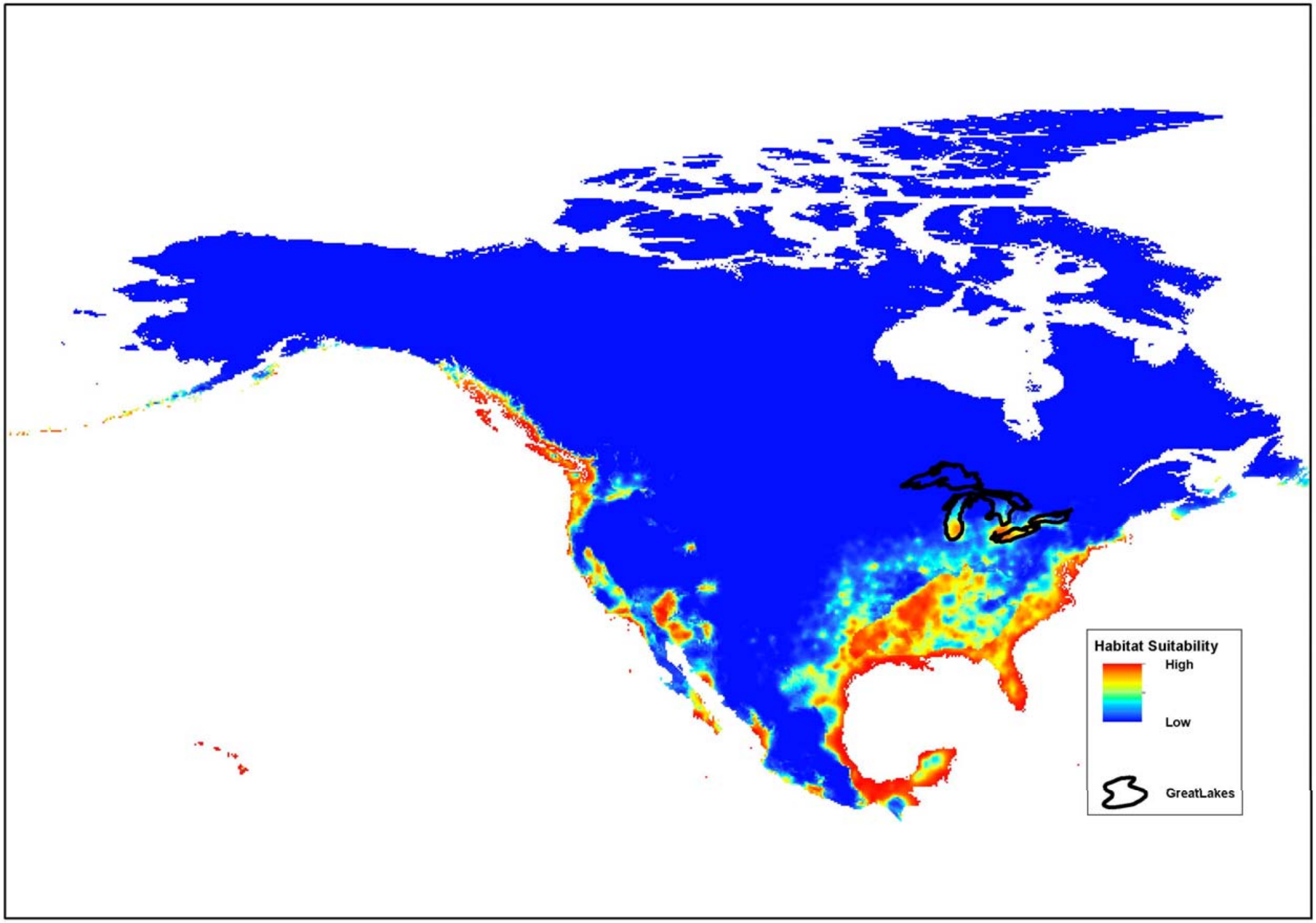


**Figure 3.1.3-10 Maxlike Monoecious-Only Model Results**

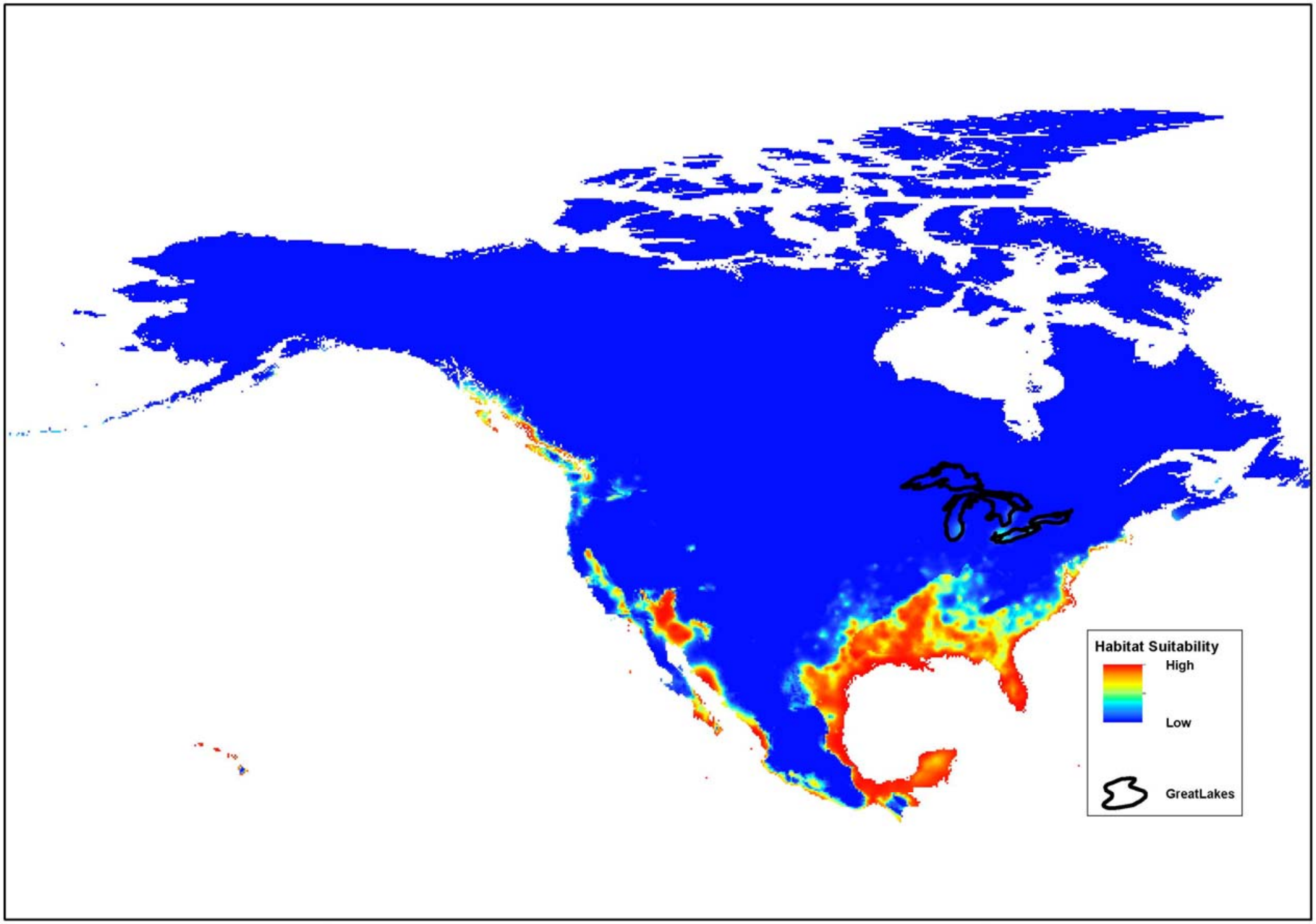


**Figure 3.1.3-11 Maxlike Dioecious-Only Model Results**

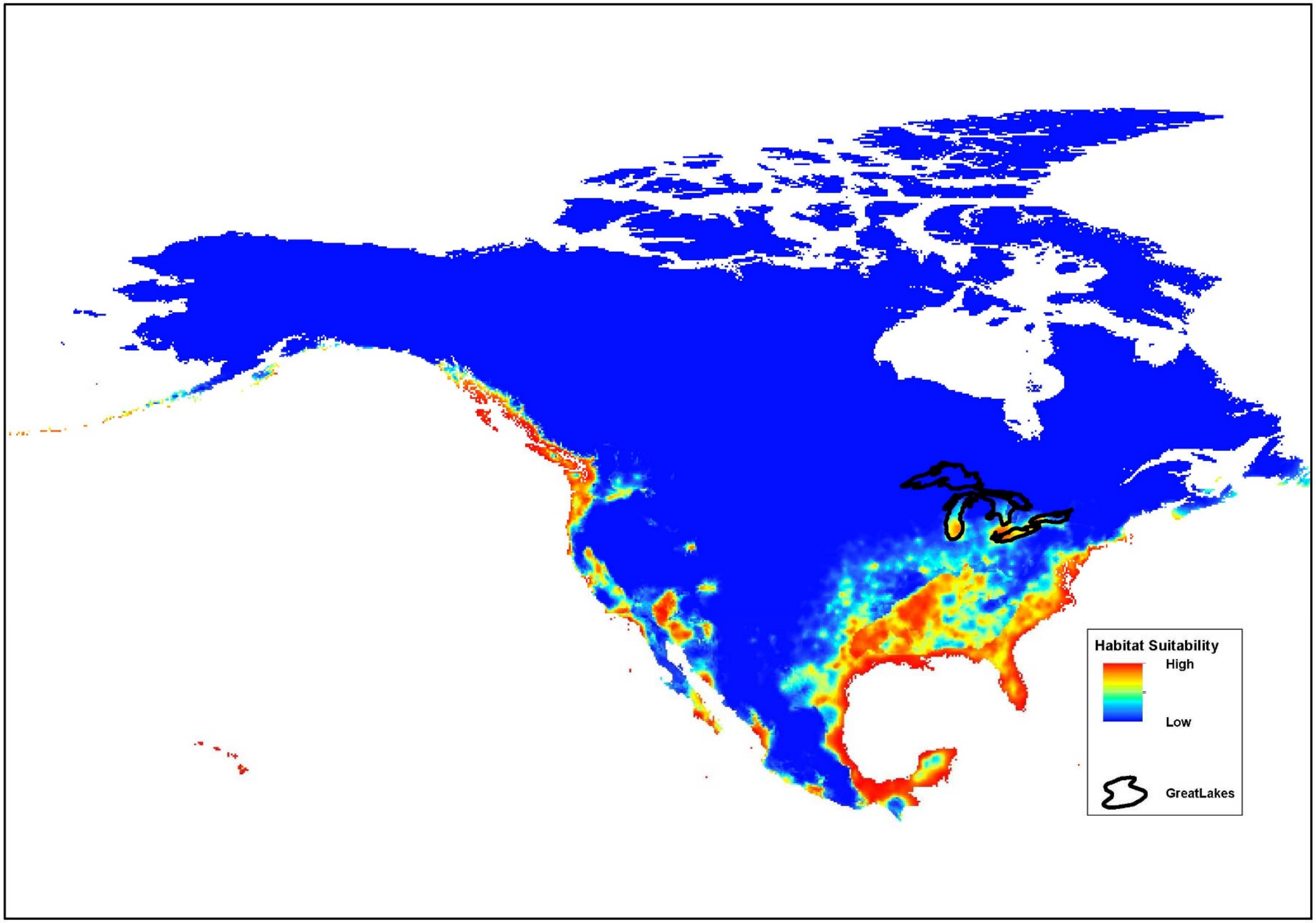


**Figure 3.1.3-12 Maxlike All-Data Model Results**

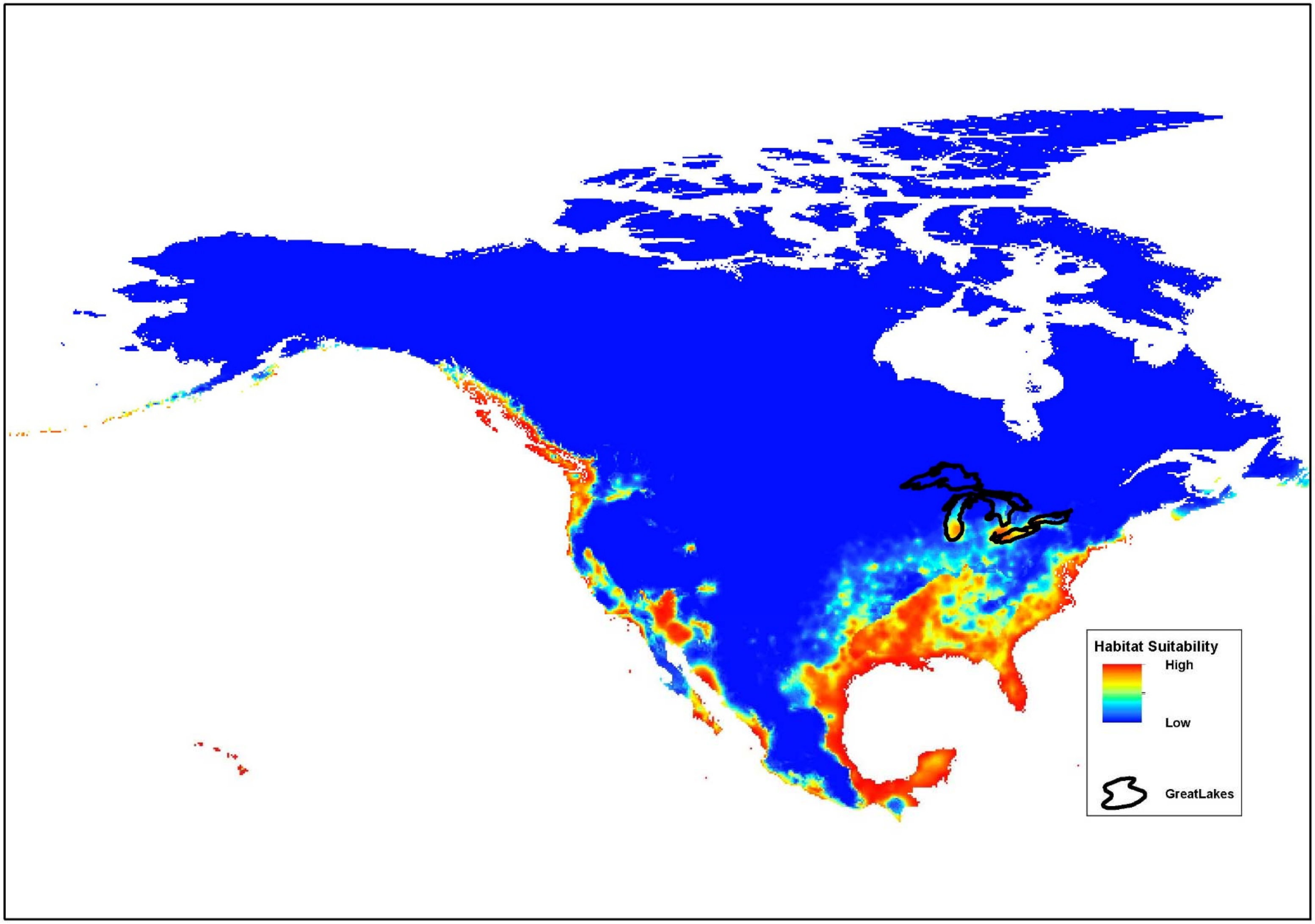


**Figure 3.1.3-13 Maxlike Additive Model Results**

### 3.1.4 Great Lakes Habitat Features

#### 3.1.4.1 Purpose

Based on recommendations from the USACE ERDC, the Project Team identified and evaluated environmental data layers potentially useful for inferring the suitability of aquatic habitats in the Great Lakes for Hydrilla. According to USACE ERDC and other sources, in-lake variables, such as light penetration, water depth, sediment composition, and exposure to wave action would likely be important in determining where Hydrilla might successfully establish and expand. Also, information on locations of current and historic submerged aquatic vegetation (SAV) communities in the Great Lakes was evaluated as an indicator for sites that may be able to support Hydrilla. Collectively, the spatial data for several of these variables were useful for refining the Hydrilla spread and distribution models developed for this project. Two additional Great Lakes environmental variables, Eurasian water-milfoil presence and shoreline embayments, were used at a more local scale for potential impact analyses (see Section 3.1.4.2).

#### 3.1.4.2 Methods and Results

As described in Appendix C, online resources were queried and subject-matter experts were contacted to obtain spatial data for in-lake variables potentially useful for inferring the suitability of aquatic habitats in the Great Lakes for Hydrilla. Spatial data for relevant environmental factors were overlaid with the distributional modeling outputs to refine predicted suitable habitats of Hydrilla within the Great Lakes. In this regard, water depth and surface water temperature (which should be related to atmospheric temperatures already implemented into SDMs) were found to be the most useful parameters, but the value of several other environmental variables also was evaluated, as discussed below.

**Water depth:** Project collaborators considered water depth to be one of the most important factors for Hydrilla growth. The Project Team used a recommendation from Michael Netherland, Ph.D. (Center of Aquatic and Invasive Plants, University of Florida) of a maximum threshold depth of 25 feet, as hydrostatic pressure at greater depths limits Hydrilla growth. Water depth is correlated with light penetration, which is another important factor as light limits where Hydrilla can successfully photosynthesize.

**Water temperature:** The second most relevant factor for potential Hydrilla habitat in the Great Lakes was water temperature. Wood (2017) reported in growth chamber studies and mesocosm studies that sprouted monoecious Hydrilla tubers had limited growth after four weeks at temperatures less than 66°F (19°C) but demonstrated significant biomass production when temperatures increased to approximately 68°F (20°C). Regan (2017) reported that shoot lengths of sprouted propagules were significantly reduced in 64°F (17.6˚C), which corroborates the limiting effects of lower temperatures on Hydrilla growth. According to Netherland (2019), problematic growth of Hydrilla requires two months or more of water temperatures of 68°F (20°C) or greater. Great Lake waters that do not reach this temperature for this duration would be unlikely to support dense infestations of Hydrilla. Both bathymetry data and surface water temperature data for the

Great Lakes were available online through the Great Lakes Aquatic Habitat Framework (GLAHF). Figure 3.1.4-1 depicts areas in the Great Lakes with water depth less than or equal to 25 feet and at least two months of water temperatures at 68°F (20°C) or greater.

**Eurasian water-milfoil:** This plant is another highly invasive, rooted, submerged aquatic plant that coexists and competes with Hydrilla where their introduced ranges overlap, which may indicate similar habitat preferences. Eurasian water-milfoil is not expected to be a perfect predictor for Hydrilla, but its preference for higher latitudes makes it a good match for monoecious Hydrilla. In addition, Wood (2017) found that the buoyancy of fragments of monoecious Hydrilla was more similar to Eurasian water-milfoil buoyancy than dioecious Hydrilla. Both Eurasian water-milfoil and monoecious Hydrilla are well documented in the Mid-Atlantic States and around the Ohio River. There are more infestations of Eurasian water-milfoil within the Great Lakes Basin than Hydrilla (see Figure 3.1.4-2).

Documentation of milfoil presence at a site provides an indicator of both potential habitat for Hydrilla and the existence of vectors of introduction. Eurasian water-milfoil location data were obtained from the EDDMapS resource developed by the University of Georgia's Center for Invasive Species and Ecosystem Health, which was also the primary resource for compiling the Hydrilla occurrence database.

**Embayments:** Exposure to wave action is another useful indicator of potential Hydrilla habitat in the Great Lakes. As a rooted aquatic plant, it would be anticipated that sites protected from wave action, notably embayments along the Great Lakes shoreline, would provide more favorable habitat for Hydrilla growth than exposed shorelines. Thus, embayments received special consideration in the potential socio-cultural and economic impact analyses. While a useful variable, identifying embayments had to be completed manually; while possible for small-scale analyses, it was not practical to apply at the scale of the entire Great Lakes. An alternative resource to assess wave action that was investigated was wave action models for the nearshore areas of the Great Lakes developed by USACE ERDC Wave Information Studies (available online through GLAHF). However, the outputs provided by the models were not readily applicable to the impact analyses or large-scale spatial analysis.

Additional variables were examined as potential data layers to infer the suitability of aquatic habitats in the Great Lakes for Hydrilla, but not ultimately used in the current assessment, including:

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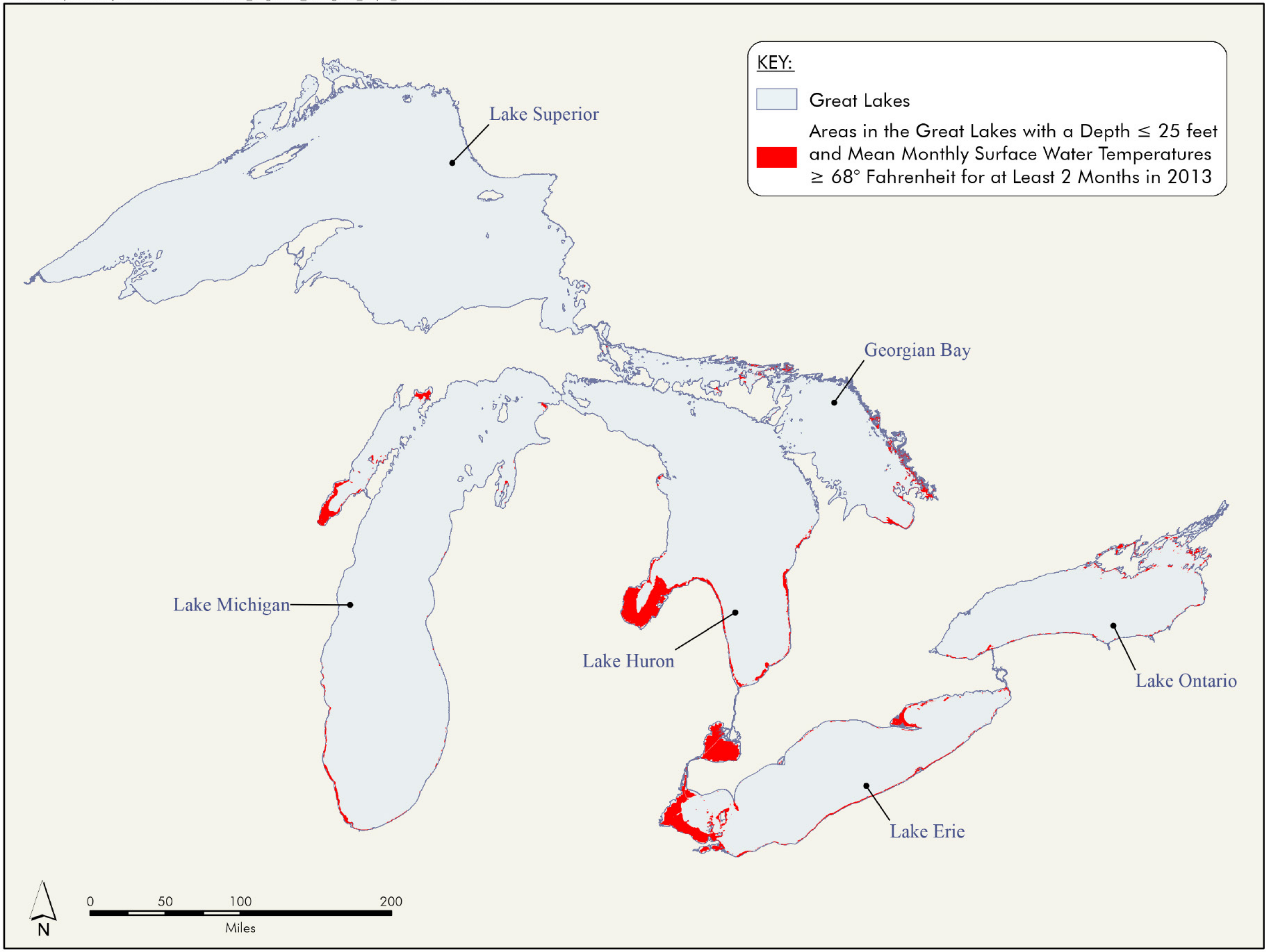


Data Source: ESRI 2012; GLAHF 2013, 2015.

**Figure 3.1.4-1 Areas in the Great Lakes with Water Depths Less Than or Equal to 25 Feet and Water Temperatures Less Than or Equal to 68°F for At Least Two Months**

02:1003025.0025.01-B4869\Figure 3.1.4-2.ai-2/8/18-GRA

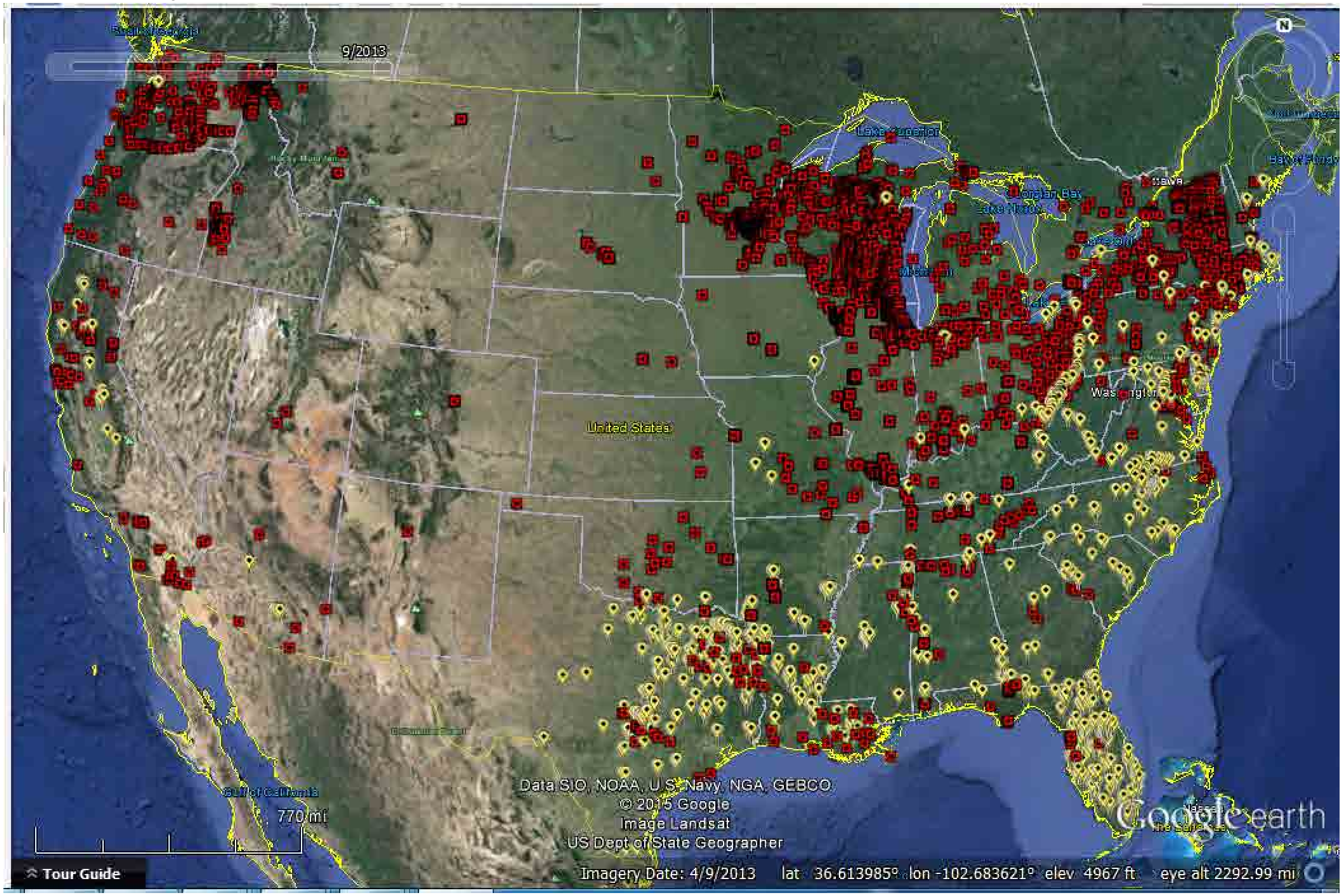


**Figure 3.1.4-2 Eurasian Water-milfoil (red points) Distribution in the United States Compared to the Distribution of Hydrilla (yellow points)**

- **Sediment composition:** Although several studies have considered substrate type preferences for monoecious Hydrilla (Spencer et al. 1992; Poovey and Kay 1998), and substrate data was available for the Great Lakes, it was a more conservative approach to assume that Hydrilla could grow at least moderately in all substrates. For example, sand is typically a low-nutrient substrate, but not in all locations, and Hydrilla has been reported to grow in a wide range of substrates, including gaps in hard, rocky substrate. Over time Hydrilla can engineer its own favorable habitat even in unvegetated areas.
- **Nutrient loading:** While nutrients influence Hydrilla growth, there are too many uncertainties regarding the response of Hydrilla to nutrients to make the use of nutrient data practical in the current assessment, particularly when interactions with other plant species are considered. For example, while high phosphorous levels encourage Hydrilla growth, they also encourage phytoplankton growth. As phytoplankton increase, light penetration decreases, thereby reducing growth of submersed plants such as Hydrilla.
- **Photoperiod:** There was not a large enough gradient in photoperiod across the Great Lakes to make some areas more favorable than others for Hydrilla growth and tuber production.
- **Current and historic SAV communities:** Spatial data of native SAV communities was very limited. Michigan Tech Research Institute conducted an extensive effort to map SAV in the Great Lakes using aerial and satellite imagery and found that the majority of SAV detected was composed of *Cladophora* (a filamentous algae) attached to hard or rocky surfaces. Because of biological differences between *Cladophora* and Hydrilla, *Cladophora* is likely a poor surrogate for identifying potential Hydrilla habitat beyond identifying areas sufficiently shallow for light penetration. However, as noted above, Eurasian water-milfoil was used as an alternate indicator of potential Hydrilla habitat.

#### 3.1.4.3 Application

Of the variables discussed above, water temperature and depth have the greatest influence on Hydrilla growth and also are available as GIS layers that can be applied across the Great Lakes. Consequently, these two variables were overlain with the distributional modeling output for the five Great Lakes to help delineate areas of suitable Hydrilla habitat and eliminate areas too deep and/or cold to support Hydrilla within the lakes (see Section 3.2). These two factors incorporate physiological limitations on the plant's growth and thus numerical thresholds could be identified and applied across the Great Lakes; discrete thresholds were not as readily determinable for other investigated environmental variables.

Two additional Great Lakes environmental variables, Eurasian water-milfoil presence and shoreline embayments, were used at a more local scale for analysis of potential social and cultural impacts (see Section 3.3.1) and potential economic impacts (see Section 3.3.2). These variables were not applied to the entire Great Lakes, but only to selected example watersheds used in the analyses. Unlike water depth or temperature, these variables would not be effective at excluding areas from consideration as possible Hydrilla habitat, but they were useful for qualitatively identifying areas of particularly favorable or unfavorable growing conditions for Hydrilla.

### 3.1.5 Dispersal Modeling

#### 3.1.5.1 Purpose

Dispersal modeling is used to understand the likelihood of introduction and subsequent dispersal of an invasive species into new habitats. The primary question that dispersal modeling is used to answer is: Can the invasive species get there? Hydrilla dispersal modeling was conducted by Jon Bossenbroek, Ph.D. and Kristen Hebebrand, Department of Environmental Sciences, University of Toledo, Toledo, Ohio.

The goal was to analyze the current distribution of Hydrilla in the United States and identify the likelihood of introduction into the Great Lakes Basin via overland recreational boat transport. According to the literature (see Appendix D and references therein), recreational boating is the human-mediated pathway most often responsible for the spread of AIS. The primary objectives of the dispersal modeling were to:

1. Predict the potential spread of Hydrilla to the Great Lakes Basin via recreational watercraft and boat trailers and identify high risk areas for introduction; and
2. Assess the current distribution of Hydrilla to determine likely vectors of spread.

#### 3.1.5.2 Methods and Results: Recreational Watercraft Dispersal Predictions

Hebebrand and Bossenbroek (2017) developed a gravity model to predict recreational watercraft and boat trailer movement in order to predict the spread of Hydrilla to the Great Lakes Basin and identify areas at risk for introduction. They also performed a proximity and connectedness analysis to evaluate natural dispersal by water flow. A complete copy of Hebebrand and Bossenbroek (2017) is provided in Appendix D. A summary of the work is provided here.

Gravity models use spatial interactions to predict potential spread by recreational boaters based on distance and attraction (Bossenbroek et al. 2001). Hebebrand and Bossenbroek (2017) included a climate-matching component in the model predictions by incorporating the results of the distributional modeling (see Section 3.1.4).

The dispersal model was built for watersheds in the continental United States based on four-digit Hydrological Unit Codes developed by the USGS. The model was comprised of 210 watersheds, including those in the southeastern United States, where Hydrilla is most established, and the 18 watersheds of interest in the Great Lakes Basin. Gravity model inputs included: county boater registrations, watershed boundaries, waterbody data (major lakes, reservoirs, rivers, and streams), and known Hydrilla occurrences (see Section 3.1.2).

Hebebrand and Bossenbroek (2017) developed the model using the following steps:

1. Estimate number of boaters traveling from each watershed;
2. Estimate the proportion of those boats that will travel from watersheds infested with Hydrilla;
3. Assign new infestations based on a watershed's habitat suitability and the number of boaters traveling to a watershed from infested locations; and
4. Estimate the area of lakes and rivers that are newly infested in each watershed each year.

The mathematical framework for the model is described in Appendix D. The model was parameterized using least squares sum analysis to test input parameter values and find best-fit values for each model parameter (see Appendix D for details). The current Hydrilla occurrence database for the United States (see Section 3.1.2) was used for the parameterization routine. This resulted in a model that best fit the current Hydrilla distribution in the United States and could mimic actual spread patterns from the first known infested watershed in 1953 to 2015, providing confidence that the model could predict the future spread of Hydrilla. Using the best-fit parameters, the model was run forward from 2015 to 2025 for 1,000 iterations.

Based on model simulations, Hydrilla is expected to continue to spread throughout the continental United States and into the Great Lakes Basin over the next 10 years. From 1953 to 2015, Hydrilla spread an average of 123 hectares (ha) per infested watershed per year. The dispersal model predicted a future infestation rate of about 609 ha per watershed per year (2015 to 2025), with infested area per watershed referring to the total area of waterbodies containing Hydrilla infestations, not the area of Hydrilla infestations themselves. Section 4.4.4 presents the range of dispersal model outputs and discusses some of the model limitations.

Watersheds that are currently infested with Hydrilla are at the highest risk for further infestation (see Figure 3.1.5-1). In addition, watersheds with large areas of water and high boater registration in or near watersheds with established Hydrilla populations are also at high risk for Hydrilla infestation.

Hebebrand and Bossenbroek (2017) ranked the Great Lakes Basin watersheds based on the future proportion infested with Hydrilla from the gravity model results (see Table 3.1.5-1). Of the currently infested area in the continental United States, 17,182 ha (1.1%) is within the Great Lakes Basin. The dispersal model predicts an increase from 17,182 ha infested in 2015 to 95,744 ha in 2025. The overall range of infested area predicted in 2025 over 1,000 trials for the Great Lakes Basin was 62,183 ha to 132,183 ha (standard deviation of 11,933 ha). The top five watersheds in the basin predicted by the model to have the greatest future (in 2025) proportion of infested waterbody area are Southeastern Lake Ontario, St. Clair-Detroit, Western Lake Erie, Southern Lake Erie, and Southwestern Lake Ontario (see Table 3.1.5-1 and Figure 3.1.5-2). And, the top five watersheds surrounding the Great Lakes Basin predicted by the model to have the greatest future proportion of infested waterbody area are Upper Ohio, Scioto, Muskingum, Great Miami, and Susquehanna (see Figure 3.1.5-3). It is important to recognize the potential for introduction and spread of Hydrilla in these watersheds and monitor for Hydrilla accordingly because these watershed appear to be the main gateway for Hydrilla entry into the Great Lakes Basin.

**Table 3.1.5-1 Gravity Model Results for all Great Lakes Basin Watersheds Ranked on Overall Proportion Future Infested Area of Water to Total Area of Water within that Watershed**

| Watershed Name | Current Area (ha)[a] | Current Proportion [b] | 2025 Area (ha)[c] | 2025 Proportion [d] |
|---|---|---|---|---|
| 1. Southeastern Lake Ontario | 17,166.90 | 0.03 | 29,434.11 | 0.0514 |
| 2. St. Clair-Detroit | 0 | 0 | 2,755.31 | 0.0392 |
| 3. Western Lake Erie | 0 | 0 | 14,837.34 | 0.0365 |
| 4. Southern Lake Erie | 15.70 | 0.00 | 20,879.03 | 0.0338 |
| 5. Southwestern Lake Ontario | 0 | 0 | 4,369.41 | 0.0134 |
| 6. Eastern Lake Erie-Lake Erie | 0 | 0 | 6,694.21 | 0.0128 |
| 7. Southwestern Lake Michigan 2 | 0 | 0 | 5,553.05 | 0.0099 |
| 8. Southeastern Lake Michigan | 0 | 0 | 8,753.82 | 0.0088 |
| 9. Southwestern Lake Huron- Lake Huron | 0 | 0 | 843.34 | 0.0069 |
| 10. Northeastern Lake Ontario- Lake Ontario-St. Lawrence | 0 | 0 | 508.01 | 0.0015 |
| 11. Northeastern Lake Michigan-Lake Michigan 2 | 0 | 0 | 312.81 | 0.0014 |
| 12. Southwestern Lake Michigan 1 | 0 | 0 | 190.19 | 0.0009 |
| 13. Northwestern Lake Huron 2 | 0 | 0 | 362.87 | 0.0004 |
| 14. Northeastern Lake Michigan-Lake Michigan 1 | 0 | 0 | 147.64 | 0.0002 |
| 15. Northwestern Lake Huron 1 | 0 | 0 | 72.57 | 0.0001 |
| 16. Northwestern Lake Michigan | 0 | 0 | 17.52 | 0.0001 |
| 17. Southern Lake Superior-Lake Superior | 0 | 0 | 12.51 | 0.0001 |
| 18. Western Lake Superior | 0 | 0 | 0 | 0 |

Source: Hebebrand and Bossenbroek 2017.

Notes:
[a] Current infested area (ha) is the current infested area of water within that watershed.
[b] Current proportion of infested waterbodies per watershed is the current infested area of water to the overall area of water within that watershed.
[c] 2025 Area (ha) is predicted area of infestation based on 10-year model results per watershed.
[d] 2025 Proportion is the proportion of the predicted area of infestation to total area of water within that watershed.

Key:
ha = hectare

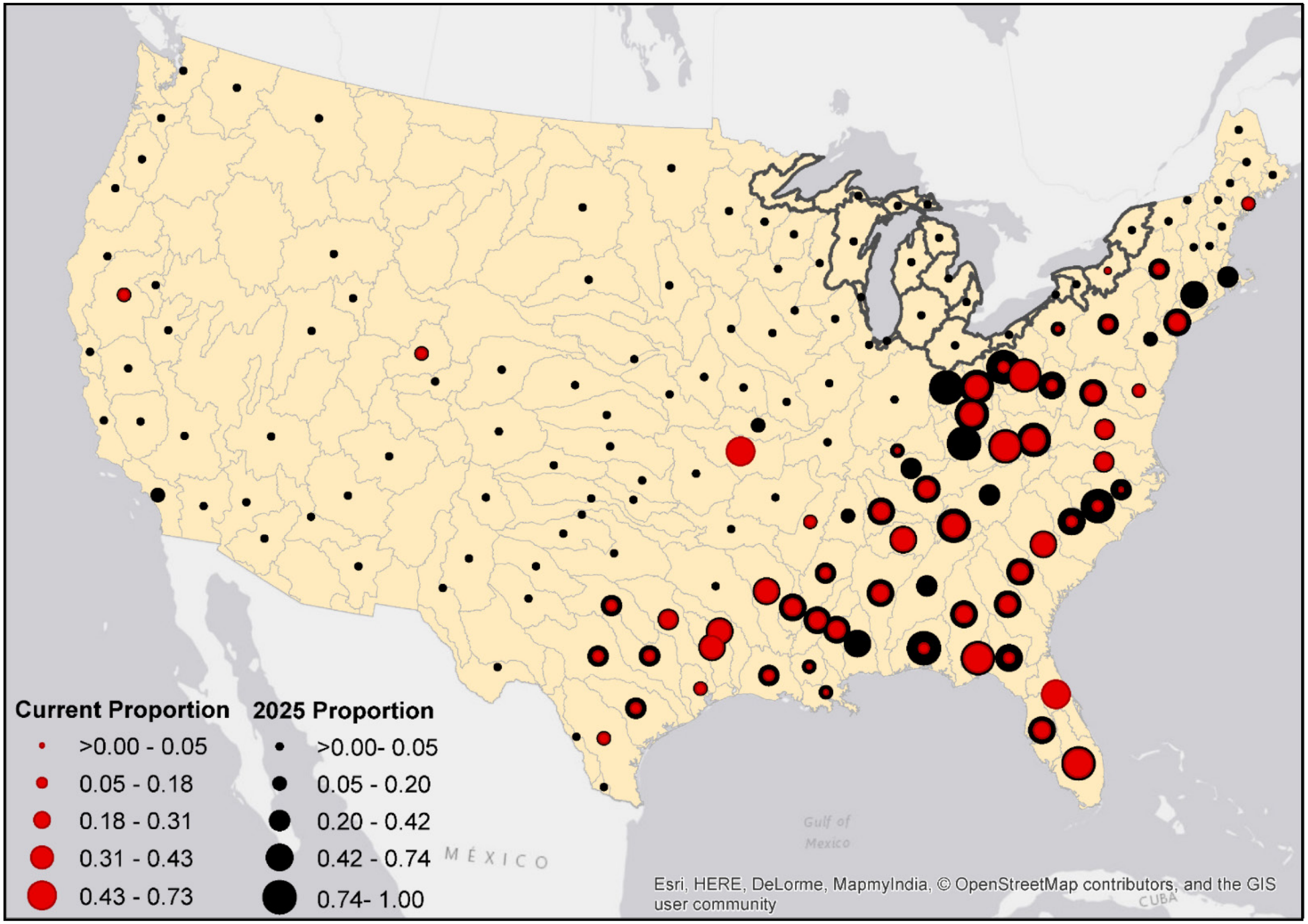


**Figure 3.1.5-1 Comparison of Current and Future (2025) Proportion of Total Waterbody Area per Watershed Infested with Hydrilla**

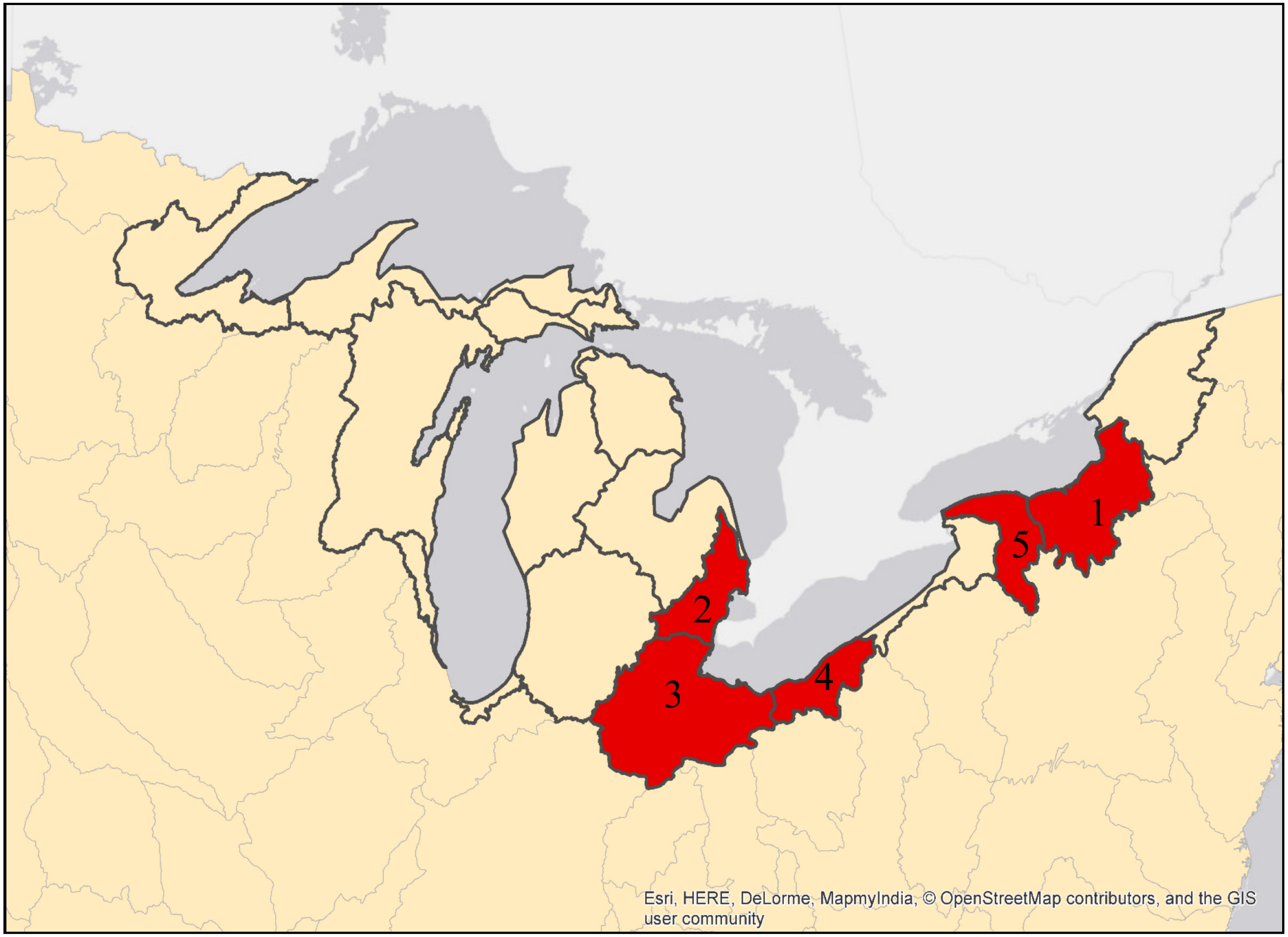


**Figure 3.1.5-2 Top Five Watersheds in Great Lakes Basin Predicted by Modeling to Have the Greatest Future Proportion of Hydrilla-Infested Waterbody Area: Southeastern Lake Ontario (1), St. Clair-Detroit (2), Western Lake Erie (3), Southern Lake Erie (4), and Southwestern Lake Ontario (5)**

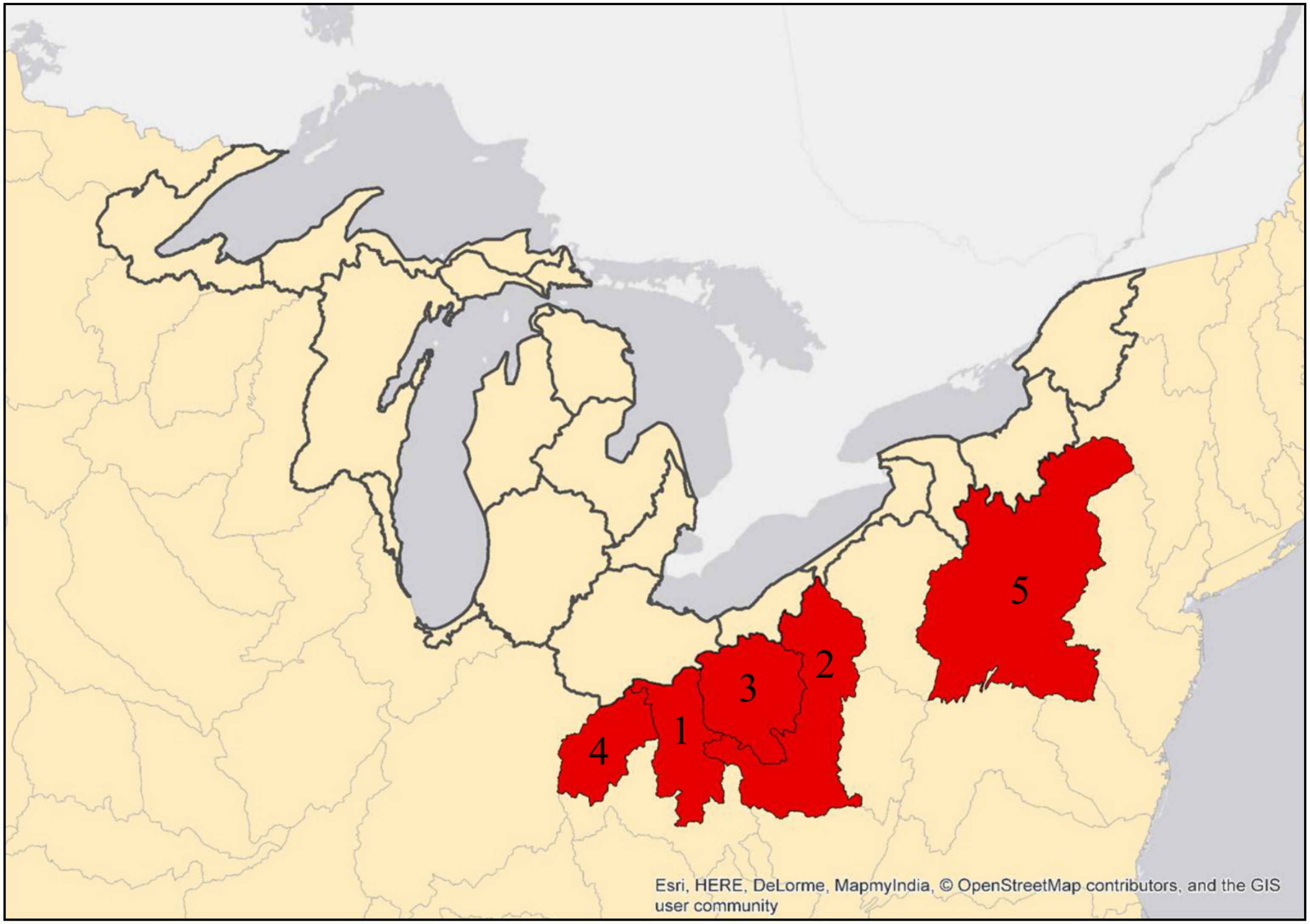


**Figure 3.1.5-3 Top Five Watersheds Surrounding Great Lakes Basin Predicted by Modeling to Have the Greatest Future Proportion of Hydrilla-Infested Waterbody Area: Upper Ohio (1), Scioto (2), Muskingum (3), Great Miami (4), and Susquehanna (5)**

The model suggests an increase in infestation rate over the next 10 years compared to the past for two reasons. First, as sources of Hydrilla increase, more boats will likely transport Hydrilla to new areas. Second, the observed current distribution of Hydrilla may underestimate the true distribution because Hydrilla may be unreported in regions where it is already present.

#### 3.1.5.3 Methods and Results: Natural Dispersal Analysis

Potential natural mechanisms for the spread of aquatic invasive plants include water flow, animal mediated dispersal, the latter including aerial dispersal by waterfowl (Keller 2009). Based on literature regarding possible mechanisms contributing to the spread of Hydrilla, water flow was determined to be a possible natural dispersal mechanism. To evaluate the potential importance of this dispersal mechanism for Hydrilla, Hebebrand and Bossenbroek (2017) selected a random subset of 22 upstream lakes that were both infested and connected to another lake downstream. They followed the downstream flow and categorized downstream lakes/reservoirs as infested or not infested/not detected. They measured distance between connected lakes and looked for trends in Hydrilla dispersal versus distance. They hypothesized that downstream lakes close to infested upstream lakes would be more likely to be infested than downstream lakes distant from infested upstream lakes. However, the results from their analysis did not support this hypothesis, suggesting that surface water flow between connected waterbodies was not an important natural dispersal mechanism for Hydrilla, at least in the waterways they evaluated. This finding may be related to fact that surface connections between lakes are infrequent in regions where Hydrilla is established currently. However, the role of natural dispersal by water flow should not be entirely discounted in the Great Lakes Basin. In areas around the Great Lakes, waters often are highly connected, and proximity to infested lakes has influenced spread of other AIS such as zebra mussels (Bobeldyk et al. 2005).

#### 3.1.5.4 Application

The dispersal modeling results were key to addressing the principal objective of the Great Lakes Hydrilla risk assessment; namely, identifying locations in the Great Lakes Basin most vulnerable to invasion based on likelihood of introduction and environmental suitability. The dispersal modeling results addressed the first element of that objective by quantifying likelihood of introduction. As discussed in Section 3.2 the dispersal modeling results were integrated with the distributional modeling results, evaluation of Great Lakes habitat features, and other project elements to fully address the principal project objective. Specifically, the dispersal modeling results presented in Table 3.1.5-1 were used to group the 18 Great Lakes Basin watersheds into high, medium, and low categories for Hydrilla introduction potential based on apparent breaks in the predicted proportion of infested waterbodies in 2025 (see Section 3.2). The watershed rankings were used along with other lines of evidence to select example watersheds to examine for analysis of economic and socio-cultural impacts (see Section 3.3). Finally, the 2025 predicted proportions were used to assess potential environmental impacts to existing natural resources in the Great Lakes Basin, such as habitats important to fish and wildlife (see Section 3.3.3)

### 3.1.6 Hydrilla Growth Studies

#### 3.1.6.1 Purpose

Most Hydrilla research has been conducted on dioecious Hydrilla in warmer climates. Because monoecious Hydrilla growth in northern waters is not well understood, an important component of this project was to develop a greater understanding of the effects of photoperiod, temperature, and interspecies competition on growth of monoecious Hydrilla in simulated northern conditions through laboratory and field research. The research was conducted by the Department of Crop Science at NCSU in Raleigh, North Carolina. The objectives of the research were to:

1. Document monoecious Hydrilla phenology in northern (cooler) conditions;
2. Compare monoecious Hydrilla growth rate in northern (cooler) versus southern (warmer) conditions;
3. Document growth of monoecious Hydrilla alone and in competition with selected cool climate submerged aquatic plants; and
4. Determine impact of prolonged cold exposure on viability of Hydrilla tubers.

To investigate the growth behavior of monoecious Hydrilla in different climates, outdoor mesocosm trials were conducted at two separate research locations: (1) Laurel Springs, North Carolina (elevation 3,215 feet), representing northern conditions; and (2) Raleigh, North Carolina (elevation 288 feet), representing southern conditions. Laurel Springs has a annual mean temperature similar to Albany, New York, and Ann Arbor, Michigan. The annual mean air temperature of Raleigh is 16.1°C, while Laurel Springs, Albany, and Ann Arbor, are 9.8°, 9.0°, and 9.7°C, respectively (Arguez et al. 2010). A complete description of methods and results of the work are included in Appendix E.1, Monoecious Hydrilla (*Hydrilla verticillata*) Growth and Phenology in Two Dissimilar Climates (Henry 2017). A summary of the work is provided in Section 3.1.6.2.

Additional studies with monoecious Hydrilla were conducted to provide added insight into the effects of water temperature on propagule sprouting and growth. A complete description of the methods and results of the studies are included in Appendix E.2, Factors Affecting Monoecious Hydrilla (*Hydrilla verticillata*) in Dynamic Systems (Regan 2017). A summary of the work is provided in Section 3.1.6.3.

#### 3.1.6.2 Methods and Results: Growth and Phenology of Monoecious Hydrilla in Two Dissimilar Climates

**Objective 1 – Monoecious Hydrilla Phenology**

Monoecious Hydrilla tubers were grown in six outdoor mesocosms in Raleigh, North Carolina, and six outdoor mesocosms in Laurel Springs, North Carolina, from May to November 2015, with 30 Hydrilla plants at each site. All Hydrilla plants in the study were collected as unsprouted tubers from a reservoir in Wake County, North Carolina.

Hydrilla growth was measured biweekly to note the timing of six different life stages (see list in Table 3.1.6-1) as part of the phenology studies. In November 2015, five plants at each location were destructively harvested to measure seasonal propagule production, while the other 25 plants were allowed to overwinter in the outdoor mesocosms. Bi-weekly observations began in spring 2016 to document propagule sprouting date, followed by another destructive harvest. Two-sample t-tests were used to make comparisons between Hydrilla grown at the two locations.

The study demonstrated that climatic conditions influenced Hydrilla growth and timing of life-stage events. Throughout the study, both water and ambient air temperatures were lower in Laurel Springs. In the warmer climate, turions and tubers sprouted earlier in the year and at warmer water temperatures than plants in the cooler climate (see Table 3.1.6-1). There was a two-week window between turion and tuber sprouting in the warmer climate, while there was a one-week window between these two events in the cooler climate. The length of time of new propagule sprouting was the same between locations, but offset two weeks. Turion formation also occurred earlier in the year in the warmer climate (see Table 3.1.6-1).

In contrast, floral initiation and plant senescence occurred earlier in the cooler climate (see Table 3.1.6-1). Although both male and female flowers were observed, no seed or fruit production was observed at either location. It was demonstrated that plants in the cooler climate reached all six of the physiological life stages at a cooler mean water temperature than those grown in the warmer climate (see Table 3.1.6-1). This observation, along with earlier timing of floral initiation and senescence, demonstrated that monoecious Hydrilla, even collected from the same location, was able to adapt its phenology to the shorter growing season of the cooler climate.

**Table 3.1.6-1 Timing and Water Temperatures of Hydrilla Life-Stage Occurrence in Northern versus Southern Conditions from March through December 2016**

| | Northern Conditions | | Southern Conditions | |
|---|---|---|---|---|
| Life Stage | Date | Mean Water Temperature (Range) (°C) | Date | Mean Water Temperature (Range) (°C) |
| Turion sprouting | Apr 3 | 7.0 (2.0 - 14.6) | Mar 23 | 12.4 (2.1 - 21.6) |
| Tuber sprouting | Apr 10 | 10.1 (2.4 - 15.3) | Apr 8 | 15.0 (-0.1 – 25.4) |
| Female floral initiation | Jul 24 | 25.9 (22.8 - 29.1) | Aug 7 | 27.7 (25.7 – 33.9) |
| Male floral initiation | Aug 21 | 23.1 (19.3 - 27.5) | Aug 28 | 23.9 (18.9 – 31.7) |
| Turion formation | Sep 18 | 20.1 (17.8 - 23.1) | Sep 6 | 24.2 (18.8 – 32.2) |
| Plant senescence | Dec 4 | 7.5 (3.5 – 14.9) | Dec 30 | 8.5 (1.1 – 8.0) |

Plants grown in the warmer climate produced a greater number of tubers than in the cooler climate. However, all mesocosms at both locations had tuber densities that were much greater than 11 tubers per square meter (tubers/$m^2$), which Nawrocki et al. (2016) demonstrated was an adequate density to support significant re-growth in Hydrilla biomass in the spring following fall senescence.

### Objectives 2 and 3 – Monoecious Hydrilla Growth Rates Alone and With Competition

The competition study was conducted in outdoor mesocosms at the Raleigh (warmer climate) and Laurel Springs (cooler climate), North Carolina sites. Monoecious Hydrilla plants were grown in aboveground and belowground mesocosms alone or together with the invasive plant Eurasian watermilfoil (*Myriophyllum spicatum*), native plant elodea (*Elodea canadensis),* or native plant eelgrass (*Vallisneria americana).* All competitor plants were planted at a density of two plants, and were grown with a density of zero, two, or four Hydrilla plants. All Hydrilla plants used in the study were collected as unsprouted tubers from a reservoir in Wake County, North Carolina.

Regarding Objective 2, mesocosm type and location affected the growth and development of Hydrilla. When grown alone in aboveground mesocosms, average Hydrilla biomass in the cooler climate was greater than the warmer climate (72.17 and 57.13 g, respectively; see Figure 3.1.6-1). However, grown alone in belowground mesocosms, average Hydrilla biomass was very low in the cooler climate compared to the warmer climate (1.94 and 40.80 g, respectively; see Figure 3.1.6-1). Grown alone in aboveground mesocosms, average tuber density was not significantly different between the cooler and warmer climates (794 and 971 tubers/$m^2$, respectively; see Figure 3.1.6-2). The very low biomass produced in belowground mesocosms in the cooler climate resulted in correspondingly lower tuber density compared to the warmer climate (3 and 629 tubers/$m^2$, respectively; see Figure 3.1.6-2).

Regarding Objective 3, *M. spicatum* and *E. canadensis* grown with Hydrilla suppressed Hydrilla growth and development in aboveground mesocosms at the cool climate compared to Hydrilla alone. Hydrilla dry weight from aboveground mesocosms in the cool climate was 24.60 to 35.73 grams (g) with *M. spicatum* and 0.78 to 7.04 g with *E. canadensis*, compared to 72.17 g when grown alone (see Figure 3.1.6-1). Hydrilla tuber production ranged from 90 to 120 tubers/$m^2$ when grown with *M. spicatum* and from 15 to 65 tubers/$m^2$ when grown with *E. canadensis*, compared with 794 tubers/$m^2$ when grown alone (see Figure 3.1.6-2). Planting combination did not suppress Hydrilla growth or tuber production in either mesocosm type at the warm climate location.

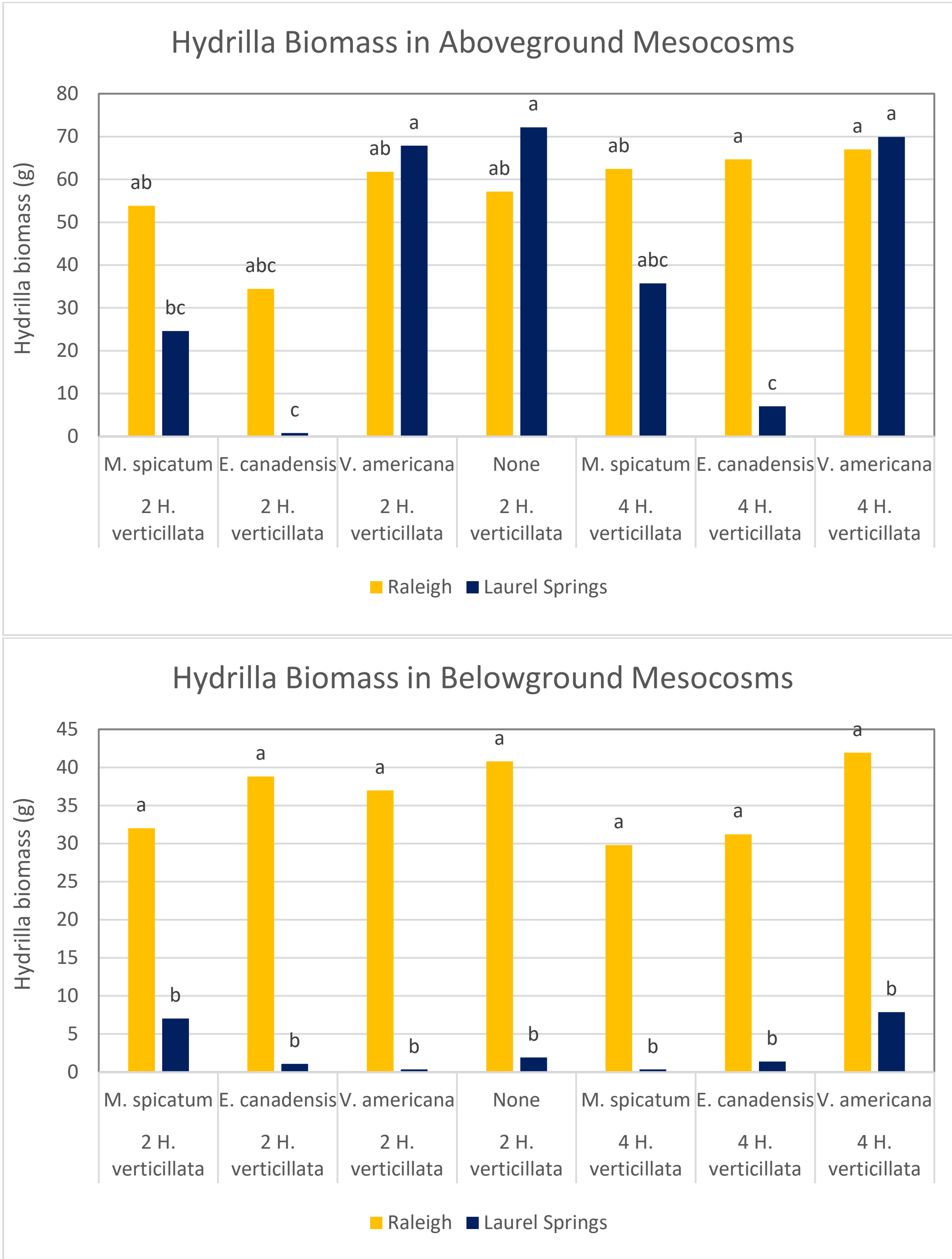


**Figure 3.1.6-1 Raleigh (warmer climate) versus Laurel Springs (cooler climate) 2016 Above- and Belowground Mesocosms Monoecious *Hydrilla verticillata* Shoot Biomass Results**

Source: Henry 2017.

Note: Mean monoecious Hydrilla biomass (dry weight) produced in one growing season at a planting density of two or four Hydrilla plants with three competitor species. Values with the same letter are not significantly different within the same planting combination according to Tukey's honest significant difference (HSD) test with probability $p < 0.05$.

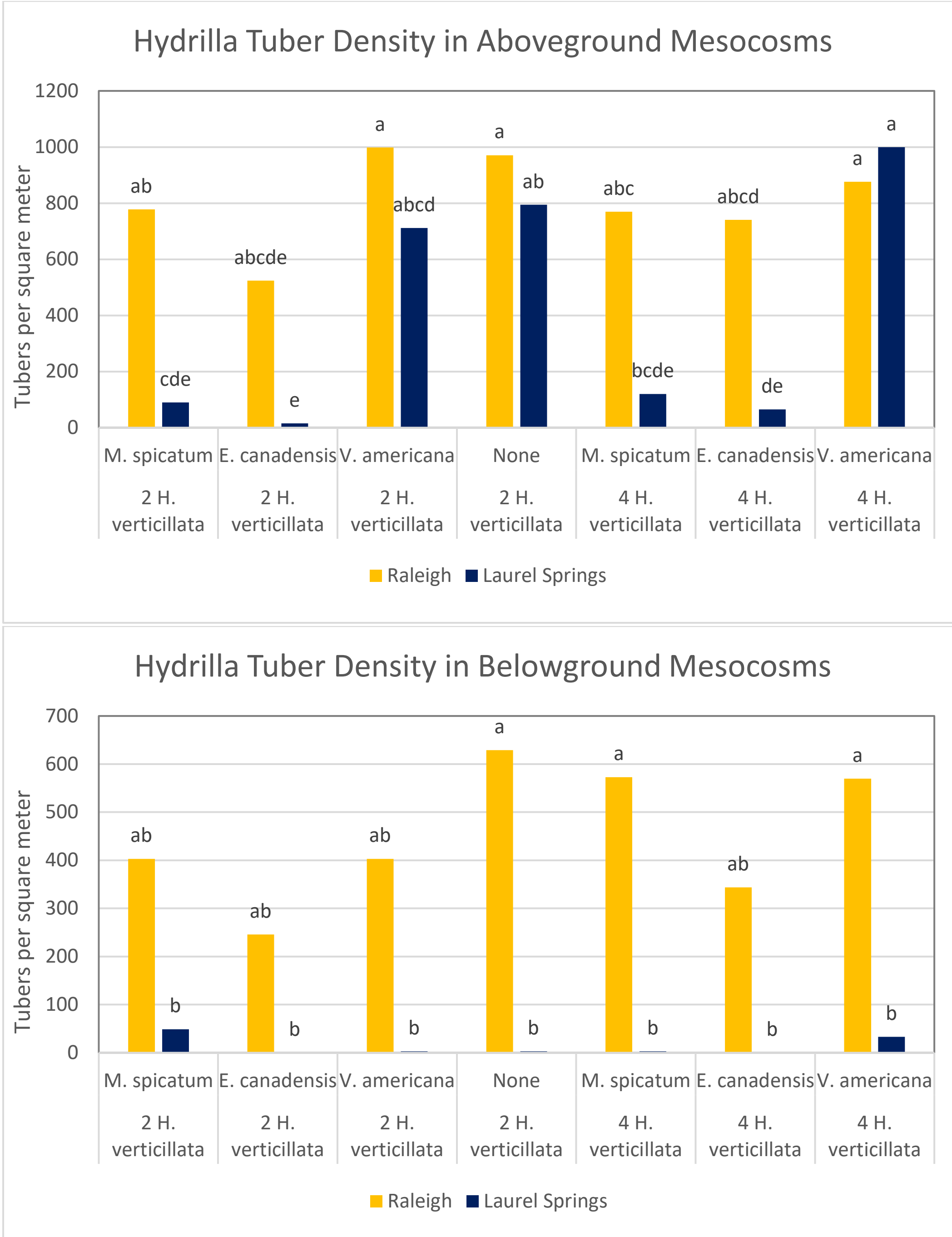


**Figure 3.1.6-2 Raleigh (warmer climate) versus Laurel Springs (cooler climate) 2016 Above- and Belowground Mesocosms Monoecious *Hydrilla verticillata* Tuber Production Results**

Source: Henry 2017.

Note: Mean number of monoecious Hydrilla tubers produced in one growing season at a planting density of two or four Hydrilla plants with three competitor species. Values with the same letter are not significantly different within the same planting combination according to Tukey's honest significant difference (HSD) test with probability $p < 0.05$.

### Objective 4 – Effects of Prolonged Cold Exposure on Hydrilla Tubers

Monoecious Hydrilla tubers were sprouted then grown in outdoor nursery pots at Raleigh (warmer climate) and Laurel Springs (cooler climate), North Carolina, from May until natural senescence in November or December 2015, with a total 164 Hydrilla plants at each site. All Hydrilla plants in the study were collected as unsprouted tubers from a reservoir in Wake County, North Carolina.

Following senescence, aboveground biomass in 144 pots at each location was removed and the pots were evenly divided in three different cooling chambers with air temperature set at 4, 0, and -3°C. The remaining pots were left to overwinter in ambient weather conditions at each location. Starting in March 2016, indoor and outdoor pots were monitored to determine emergence date of sprouting tubers. After outdoor pots had sprouted, a sample of pots from each cooling chamber temperature was destructively harvested every month for six months starting in early May 2016 at Laurel Springs and mid-April at Raleigh. Turions and tubers collected from each harvest were counted, measured, and used in a viability study to monitoring sprouting and determine average viability rates for each overwintering temperature at the two locations.

The study demonstrated that temperature during Hydrilla development and overwintering temperature affected tuber production and viability. Tubers produced in the cooler climate had a greater weight, averaging 0.113 g per tuber (average weight by harvest ranged from 0.104 to 0.118 g per tuber) compared to 0.096 g per tuber (average weight by harvest ranged from 0.093 to 0.104 g per tuber) in the warmer climate. Also, tubers produced in the cooler climate had greater viability, averaging 89% when overwintered at 4°C and 20% when overwintered at 0°C, while the warmer climate Hydrilla tubers had an average viability of 63% when overwintered at 4°C, and 0% when overwintered at 0°C. Tuber densities differed between locations, with the cooler climate averaging 823 tubers/$m^2$, while the warmer climate averaged 2,142 tubers/$m^2$.

### Application

**Objective 1** (**Monoecious Hydrilla Phenology).** Applying management practices at specific times is vital to controlling Hydrilla (True-Meadows et al. 2016). The mesocosm studies demonstrated that climatic conditions, especially water temperature, influence the timing of important Hydrilla life-cycle events, including tuber sprouting and production, shoot-elongation, and senescence, and that monoecious Hydrilla can adapt its life-cycle to the shorter growing season of cooler climates. These temperature effects were considered when developing recommendations and BMPs for Hydrilla (see Section 5.2).

Plants grown in the warmer climate produced a greater number of tubers than in the cooler climate. However, all mesocosms at both locations had tuber densities that were much greater than 11 tubers/$m^2$ (Nawrocki et al. 2016), producing more than adequate tubers to recover Hydrilla biomass in the spring following fall senescence. Thus, even though tuber densities might be lower in northern climates, they still are great enough to pose a management problem. In addition, because tubers overwintering in cooler water temperatures retain high sprouting viability, relying on cooler temperatures to reduce tuber viability is not a valid management strategy, as noted in Section 5.

**Objective 2** (**Monoecious Hydrilla Growth Rates Alone)**. Hydrilla plasticity was demonstrated by the changes in biomass accumulation and tuber production based on both temperature and mesocosm type. Cooler temperatures at Laurel Springs (the site more similar to regions around the Great Lakes) and lower light levels in belowground mesocosms likely created a less suitable environment for Hydrilla growth. At Laurel Springs, lower light levels in below ground mesocosms compared to aboveground mesocosms may have led to the greatly reduced Hydrilla biomass and propagule production in the below ground mesocosms. However, it has been found that Hydrilla can grow at extremely low light levels (Van et al. 1976), so it is more likely that interactions between light levels and other factors at Laurel Springs explains the limited growth of Hydrilla in belowground mesocosms at that location. It is also important to note that the lower dry weights of Hydrilla in this study compared to natural systems can be explained by limited expansion potential, as Hydrilla reached growing capacity quickly in the mesocosms, especially in the warmer climate site. Overall, the adaptability and plasticity of monoecious Hydrilla suggests that it is capable of surviving under a wide range of conditions, an important attribute that may allow it to establish itself in a wide range of environments across the Great Lakes Basin, if introduced.

**Objective 3 (Monoecious Hydrilla Growth Rates With Competition)**. The results from the cooler-climate location show that water temperature affected the competitive abilities of both monoecious Hydrilla and three competitor plants. In cooler conditions, *M. spicatum* and *E. canadensis* were able to negatively affect Hydrilla growth and competitiveness. This affect was less pronounced under warmer conditions. These results suggest that Hydrilla has the potential to become established in natural systems despite the presence of competitor species, although the development of an infestation may be at a slower rate, perhaps when under cooler conditions when *M. spicatum* and *E. canadensis* are present. The results of the competition study are relevant for informing management actions for Hydrilla prevention and control and protection of native aquatic plant communities (see Section 5).

Ensuring that waterbodies have a healthy and diverse aquatic plant community may influence the impact Hydrilla can have on aquatic ecosystems in Great Lakes Basin. The competition study results suggest that *V. americana* cannot compete effectively against Hydrilla in either warm or cool climates. Therefore, planting *V. americana* to discourage establishment of Hydrilla would not be an effective management strategy. This competition study suggests *E. canadensis* would be a better selection of a native plant to fill any empty niches in the environment.

**Objective 4** (**Effects of Prolonged Cold Exposure on Hydrilla Tubers)**. The overwintering study demonstrated that temperature during Hydrilla development and overwintering affects production and viability of Hydrilla tubers. Tubers produced in the cooler climate were able to withstand air temperatures maintained at 0°C for seven months, while tubers produced in the warmer climate did not remain viable at this temperature. Tubers produced in the cooler climate were fewer in number but heavier compared to those produced in the warmer climate. The greater weight of cooler-climate tubers may have been the reason that they were able to withstand more intense environmental stress and remain viable. As noted above, because overwintering tubers in the cooler climate still retained high sprouting viability, relying on colder temperatures to reduce tuber viability is not an effective management strategy.

#### 3.1.6.3 Methods and Results: Factors Affecting Monoecious Hydrilla in Dynamic Systems (Regan 2017)

##### Water Temperature Effects on Tubers and Turions

Hydrilla plants in the study were collected as unsprouted tubers from a reservoir near New Hill, North Carolina. Timing of sprouting and growth rates were evaluated for monoecious Hydrilla turions and tubers across a water temperature gradient over a period of 12 days. Propagules were floated in glass jars and placed on a thermal gradient table in rows, with rows corresponding to six different temperatures (in °C): 41.0; 34.9; 29.3; 24.0; 17.6; and 12.3. Neither turions nor tubers sprouted in the warmest or coldest water temperatures of 41.0 and 12.3°C. Optimum growth for both propagules types occurred at 29.3°C. Shoot lengths were significantly reduced for both propagule types at 17.6°C. Timing of sprouting was not significantly different between turions and tubers.

##### Application

**Water temperature effects on tubers and turions.** Sprouting appears to be at least partly a function of water temperature, which has practical implications for the timing of management actions, such as herbicide application. Low temperatures that delay sprouting and subsequent growth should also delay herbicide applications. Failure to monitor sediment temperatures or identify temperature gradients in a waterbody could lead to reduced control and/or wasted resources. Hydrilla surveys should not be conducted until benthic water temperature reaches 17°C for at least two weeks.

Also, these results are applicable in the context of refining the distributional modeling results (see Section 3.1.3). For example, the finding that monoecious Hydrilla growth is greatly limited at water temperatures of 17°C or lower corroborates results presented in Wood (2017). These two studies informed the water temperature criteria used to exclude the cooler regions of the Great Lakes as potential Hydrilla habitat, despite some of these areas being identified as potential habitat by distributional modeling, thus further improving our understanding of potentially suitable habitats for Hydrilla in the Great Lakes Basin.

## 3.2 Integration of Results

As noted in Section 1, the principal objective of the Great Lakes Hydrilla risk assessment is to identify areas in the Great Lakes Basin most vulnerable to invasion based on likelihood of introduction and environmental suitability. This objective was addressed by combining the distributional and dispersal modeling results and water-depth and temperature requirements for Hydrilla (see flowchart in Figure 3.2-1). The product of the integration of these results is shown in Figure 3.2-2 and explained in this section.

Areas of suitable habitat for Hydrilla in the Great Lakes Basin were identified by overlying the water-depth (< 25 feet) and water-temperature (two months at 68°F) requirements for monoecious Hydrilla establishment (see Figure 3.1.4-1) on the distributional modeling results, specifically the Maxent global model results (see Figure 3.1.3-2). For reasons discussed in Section 3.1.3, the Maxent models used atmospheric temperature data, not water-depth or water-temperature data, to forecast habitat suitability for Hydrilla. Hence, it was necessary to overlay the water-depth and water-temperature requirements for Hydrilla on the Maxent heat map to appropriately exclude areas in the Great Lakes that are too deep or too cold to serve as Hydrilla habitat.

The dispersal model results were used to quantify likelihood of introduction. For each watershed in the Great Lakes Basin, the dispersal model provided the acreage and proportion of inland waterbodies and Great Lakes shoreline expected to be colonized by Hydrilla in 2025 due to recreational watercraft and trailer movement (see Table 3.2-1). It should be noted that the results of the dispersal model are at the watershed scale, which is larger than the 10- by 10-kilometer scale used for the Maxent model. Nonetheless, the watershed boundaries can be superimposed on the Maxent heat map and the watersheds ranked based on the future proportion of infested waterbody area, as shown in Figure 3.2-2. Doing so effectively represents the dispersal model results and habitat suitability information for Hydrilla on a single figure. Note that the distribution model (Maxent global model output) informed the dispersal model as to areas of potentially suitable habitat.

The watersheds bordering Lakes Erie and Ontario in New York, Pennsylvania, and Ohio all rank high or medium in terms on introduction potential and also contain favorable Hydrilla habitat (orange, yellow, and yellow-green coloration; see Figure 3.2-2). The potential severity of a Hydrilla infestation in these watersheds can be understood by relating the habitat suitability scores (and colors) from Maxent with the severity of known Hydrilla infestations in those watersheds. For example, the habitat suitability scores for the grid cells in Ohio and New York where current Hydrilla infestations are present range from 0.32 to 0.52 (yellow to light orange). The infestations at these locations are dense and require treatment to minimize Hydrilla spread. Other grid cells in the Great Lakes Basin with similar Maxent scores (and colors) could potentially develop a similar level of infestation if Hydrilla were introduced to those locations, all other things being equal. In

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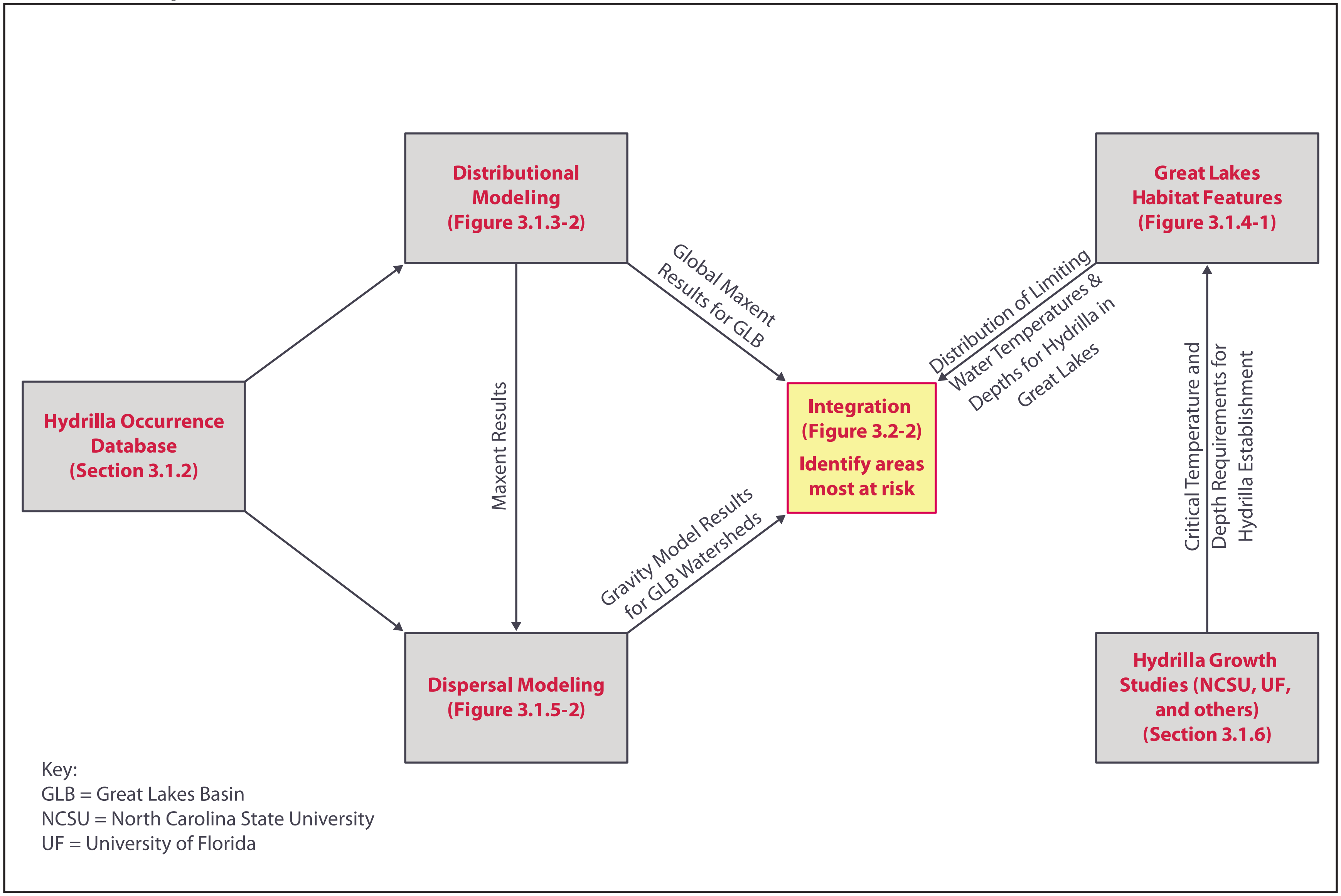


**Figure 3.2-1 Flowchart Showing Integration of Results from Modeling and Other Analysis Components**

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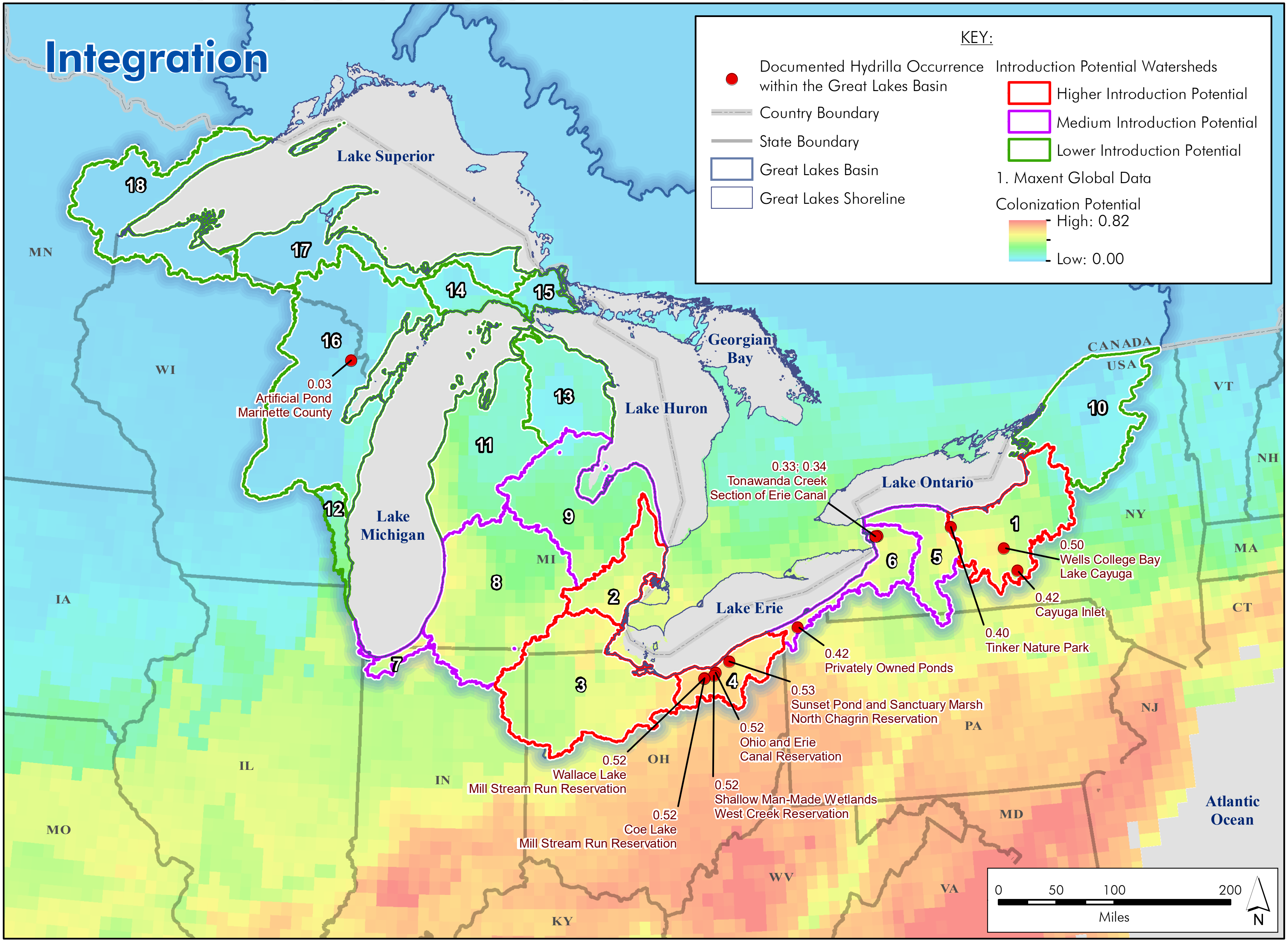


**Figure 3.2-2 Integration of Maxent Model Results, Water-Depth and Water-Temperature Requirements, and Dispersal Model Results for Hydrilla**

Occurrences as of 2/26/2016

theory, SDMs are not equipped to provide a measure of species performance; however, in practice, a positive correlation has been found between Maxent scores and species performance or functional traits for a number of invasive plants and animals (Wittmann et al. 2016).

## 3.3 Impact Analysis

To conduct the analyses for potential socio-cultural and economic impacts on the Great Lakes from Hydrilla, six representative watersheds were selected with high-to-medium potential for future Hydrilla introduction as defined in Section 3.2 and Table 3.2-1. Those watersheds (and their introduction potentials and ranks) are:

- Southeastern Lake Ontario (high, 1);
- Western Lake Erie (high, 3);
- Southern Lake Erie (high, 4);
- Eastern Lake Erie (medium, 6);
- Southwestern Lake Michigan (medium, 7); and
- Southwestern Lake Huron (medium, 9).

These six watersheds were selected to be the focus of a more detailed analyses as examples. Potential economic and socio-cultural impacts in these six watersheds were then used to infer potential impacts in the remaining Great Lakes Basin watersheds within the United States. The impact analyses focused on Great Lakes shoreline habitat and not inland waterbodies, given the importance of the Great Lakes as a regional public resource. It should be noted that if there were to be similar suitable habitat along the Canadian shoreline that impacts would like be greater than estimated in the impact analyses provided herein.

The reasons for selecting the watersheds ranked 1, 3, and 4 for detailed impact analysis are:

- High potential for Hydrilla introduction;
- High to medium habitat suitability;
- Located along the southern shores of two Great Lakes (Ontario and Erie); and
- Locations include large population centers (Syracuse/Oswego/Rochester, Cleveland, and Sandusky/Toledo/Detroit, respectively).

The reasons for selecting the watersheds ranked 6, 7, and 9 for detailed impact analysis are:

- Medium potential for Hydrilla introduction;
- Medium to low habitat suitability;

**Table 3.2-1 Dispersal Model Results for Great Lakes Basin Watersheds Ranked on Overall Proportion of Future Infested Waterbody Area per Watershed[a]**

| Watershed Name | Current Area (ha) Infested | Current Proportion Infested | 2025 Area (ha) Infested | 2025 Proportion Infested |
|---|---|---|---|---|
| 1. Southeastern Lake Ontario | 17,167 | 0.03 | 29,434 | 0.0514 |
| 2. St. Clair-Detroit | 0 | 0 | 2,755 | 0.0392 |
| 3. Western Lake Erie | 0 | 0 | 14,837 | 0.0365 |
| 4. Southern Lake Erie | 15.7 | 0.00 | 20,879 | 0.0338 |
| 5. Southwestern Lake Ontario | 0 | 0 | 4,369 | 0.0134 |
| 6. Eastern Lake Erie-Lake Erie | 0 | 0 | 6,694 | 0.0128 |
| 7. Southwestern Lake Michigan 2 | 0 | 0 | 5,553 | 0.0099 |
| 8. Southeastern Lake Michigan | 0 | 0 | 8,754 | 0.0088 |
| 9. Southwestern Lake Huron- Lake Huron | 0 | 0 | 843 | 0.0069 |
| 10. Northeastern Lake Ontario- Lake Ontario-St. Lawrence | 0 | 0 | 508 | 0.0015 |
| 11. Northeastern Lake Michigan- Lake Michigan 2 | 0 | 0 | 313 | 0.0014 |
| 12. Southwestern Lake Michigan 1 | 0 | 0 | 190 | 0.0009 |
| 13. Northwestern Lake Huron 2 | 0 | 0 | 363 | 0.0004 |
| 14. Northeastern Lake Michigan- Lake Michigan 1 | 0 | 0 | 148 | 0.0002 |
| 15. Northwestern Lake Huron 1 | 0 | 0 | 72.6 | 0.0001 |
| 16. Northwestern Lake Michigan | 0 | 0 | 17.5 | 0.0001 |
| 17. Southern Lake Superior-Lake Superior | 0 | 0 | 12.5 | 0.0001 |
| 18. Western Lake Superior | 0 | 0 | 0 | 0 |

Note:
[a] See Section 3.1.5 for discussion to modeling methods and results.

Key:
(red) = High Introduction Potential
(purple) = Medium Introduction Potential
(green) = Low Introduction Potential
ha = hectare

- Located along three Great Lakes (Erie, Michigan, and Huron); and
- Locations include large population centers (Buffalo/Erie, Gary/Chicago, and Detroit, respectively).

In summary, these six watersheds capture representative areas along four Great Lakes where dispersal and habitat-suitability models intersect for the introduction and possible establishment of Hydrilla and where large population centers are present that rely in the lakes for commercial, industrial, municipal, recreational, and other purposes.

The resolution of the distributional and dispersal model outputs were sufficient for analysis of potential environmental impacts, but were too broad to be readily used for analysis of potential socio-cultural and economic impacts.  It was not practical to evaluate the entire length of shoreline of each example watershed at the level of detail required for analysis of such impacts. Consequently, focus areas were selected within each example watershed to simplify collecting the detailed, site-specific information required for the socio-cultural and economic impact analyses.  Shoreline areas that included habitats and features assumed to be favorable to Hydrilla establishment were selected as focus areas and were manually identified from aerial imagery based on the presence of the following:

1. Contours in the shoreline representing embayments;
2. Ponds and lakes adjacent to the shoreline, or in rare cases up to one mile inland;
3. Documented Eurasian water-milfoil infestations;
4. Breakwalls;
5. River and stream outlets into the Great Lakes, often in conjunction with other features that affected habitat suitability for Hydrilla; and
6. Coastal wetlands, often in conjunction with other factors influencing habitat quality and evidence of surface water in multiple years.

Selecting focus areas in this manner reduced the length of shoreline requiring evaluation, thereby making the socio-cultural and economic impact analyses more manageable.  For example, for the southeastern Lake Ontario watershed, approximately 100 miles of shoreline fell within focus areas and was analyzed for socio-cultural and economic impacts, not the full 220 miles of shoreline in that watershed.  The number of focus areas selected within the six example watersheds ranged from 17 to 53 (see Table 3.3-1).  When considering all of the waterbody area within the example watersheds, the percentage of that area that the focus areas represents ranged from 0.4% to 6.6% (see Table 3.3-1).

Lastly, focus areas were not used for analysis of potential environmental impacts from Hydrilla establishment in the Great Lakes Basin (see Section 3.3.3).  Environmental impacts were evaluated at a larger scale using information that was readily available on a basin-wide basis and, therefore, the evaluation was not constrained by the resolution of the dispersal and distributional model results.

**Table 3.3-1 Example Watersheds and Focus Areas**

| Watershed Name | Hydrilla Introduction Potential (and Rank)[a] | Number of Focus Areas | Acreage of Focus Areas | Total Acreage of Waterbodies in Watershed[b] | Focus Area Acreage as Percentage of Total Waterbody Acreage in Watershed (%) |
|---|---|---|---|---|---|
| Southeastern Lake Ontario | High (1) | 30 | 11,908 | 572,646 | 2.1 |
| Western Lake Erie | High (3) | 49 | 26,717 | 406,502 | 6.6 |
| Southern Lake Erie | High (4) | 17 | 2,531 | 617,723 | 0.4 |
| Eastern Lake Erie | Medium (6) | 31 | 8,992 | 522,985 | 1.7 |
| Southwestern Lake Michigan | Medium (7) | 26 | 4,844 | 560,914 | 0.9 |
| Southwestern Lake Huron | Medium (9) | 53 | 4,937 | 122,223 | 4.0 |

Notes:
[a] From Table 3.2-1.
[b] Calculated from information in Appendix D (Dispersal Modeling Report).

### 3.3.1 Potential Socio-Cultural Impacts Summary

#### Summary of Reviewed Literature

Reviewed literature indicates that researchers have not substantively studied the effects of invasive species in general on socio-cultural features or the character of communities as reflected by these socio-cultural features (Connecticut Envirothon 2017; Ewing 2009; Fitzgerald and Wilkinson 2009; Pejchar and Mooney 2009; U.S. Department of the Interior 2003). With regard to the few identified studies that have considered the effects of Hydrilla on socio-cultural aspects of communities, they have primarily focused on socio-economic factors or on traditional (native or indigenous) economic activities (Ciruna et al. 2004; Monterroso 2005).

Reviewed literature also indicates that while there are various methodologies for evaluating social impacts, they all consider socio-economic impacts rather than socio-cultural impacts (U.S. Department of Commerce 1994; Fox 1999; Turnley 2002; Quinlan et al. 2007; USACE 2012). Therefore, there appear to be no standardized methodology for the assessment of impacts on socio-cultural features or community character as a result of invasive species.

To address this lack of methodology, it was decided that named natural and socio-cultural features would be considered physical representations of community character and socio-cultural setting. Because of the size of the Great Lakes Basin, research focused on identifying various socio-cultural features within specific focus areas for six selected watersheds (see Table 3.3.1-1). The six selected watersheds were considered generally representative of all the watersheds within the Great Lakes Basin. The focus areas considered within each selected watershed were all located along the shoreline of the respective Great Lake, but contained socio-cultural features that were considered generally representative of all water-bodies (shoreline or interior) within each selected watershed and for those watersheds not selected for this analysis.

**Table 3.3.1-1 Areas Evaluated for Socio-Cultural Impacts from Hydrilla**

| Watershed Name (Rank)[a] | Description of Shoreline | Description of Conditions suitable for Hydrilla[b] | Number of Focus Areas Evaluated along Shoreline of Watershed |
|---|---|---|---|
| Southeastern Lake Ontario (1) | Located at the eastern end of Lake Ontario; entirely within northwestern New York State; over portions of five counties: (from west to northeast) Monroe, Wayne, Cayuga, Oswego, and Jefferson | Highest potential for introduction of Hydrilla; moderate potential for establishment of Hydrilla in suitable nearshore aquatic habitat if introduced | 31 |
| Eastern Lake Erie (6) | Located at eastern end of Lake Erie; within western New York, northwestern Pennsylvania, and Northwestern Ohio; over portions of five counties: (from northeast to southwest) Niagara, Erie, and Chautauqua counties, New York; Erie County, Pennsylvania; and Ashtabula County, Ohio | High potential for introduction of Hydrilla; moderate potential for establishment of Hydrilla in suitable nearshore aquatic habitat if introduced | 30 |
| Southern Lake Erie (4) | Located along southern side of Lake Erie; entirely within northeastern Ohio; over portions of four counties: (from east to west) Ashtabula, Lake, Cuyahoga, and Lorain | High potential for introduction of Hydrilla; moderate potential for establishment of Hydrilla in suitable nearshore aquatic habitat if introduced | 17 |
| Western Lake Erie (3) | Located at western end of Lake Erie; within northwestern Ohio and southeastern Michigan; over portions of five counties: (from east to northwest) Erie, Lucas, Ottawa, and Sandusky counties, Ohio; and Monroe County, Michigan | High potential for introduction of Hydrilla; moderate potential for establishment of Hydrilla in suitable nearshore aquatic habitat if introduced | 49 |
| Southwestern Lake Huron (9) | Located at eastern end of Lake Huron; entirely within eastern Michigan; over portions of six counties: (from east to west) Sanilac, Huron, Tuscola, Bay, Arenac, and Iosco | Medium potential for introduction of Hydrilla; low potential for establishment of Hydrilla in suitable nearshore aquatic habitat if introduced | 52 |
| Southwestern Lake Michigan (7) | Located at southern end of Lake Michigan; within portions of southwestern Michigan, northwestern Indiana, and northeastern Illinois; over portions of five counties: (from east to west) Berrien Count, Michigan; La Porte, Porter, and Lake counties, Indiana; and Cook County, Illinois | Medium potential for introduction of Hydrilla; moderate potential for establishment of Hydrilla in suitable nearshore aquatic habitat if introduced | 26 |
| **Total** | | | **205** |

Notes:
[a] Rank for introduction potential based on dispersal modeling (see Sections 3.1.5 and 3.2).
[b] Based on dispersal and habitat-suitability modeling (see Sections 3.1.3, 3.1.5, and 3.2).

### Desktop Analysis: Socio-Cultural Features in the Great Lakes Basin Potentially Subject to Impacts as a Result of Hydrilla Infestation

The desktop analysis conducted for the focus areas within the six representative watersheds provides a sense of what the potential impacts on community character and socio-cultural setting may be. The results of this analysis are considered applicable to: (1) areas along the shoreline of the Great Lakes in the studied watershed; (2) waterbodies located in interior portions of the studied watersheds, and (3) Great Lakes shoreline and interior waterbodies in unstudied watersheds. This section summarizes the collective results of the desktop analysis. The analysis conducted for the shoreline focus areas in each of six representative watersheds is discussed in greater detail in Appendix F.

Named natural and socio-cultural features in focus areas in the six representative watersheds were identified from information included in overlays for Google Earth and identified on 7.5-minute USGS topographic quadrangles and/or coastal maps maintained in the National Oceanic and Atmospheric Administration's (NOAA's) Office of Coast Survey Historical Map and Chart Collection. The various named natural and socio-cultural features were then grouped into a total of 10 categories, as shown in Table 3.3.1-2 for the southeast Lake Ontario watershed, for example. Collectively, the named natural and socio-cultural features identified for the focus areas within each studied watershed were considered the physical representations of the watersheds' community character and socio-cultural setting.

With the information for the named natural and socio-cultural features within the focus areas for each representative watershed, various potential impacts that could result from Hydrilla introduction and establishment were considered:

- Impacts on natural features (considered primarily in terms of changes to physical conditions as a result of ecological changes caused by Hydrilla);
- Impacts on socio-cultural features, considered in terms of direct impacts where the purpose for, or use of, these natural or socio-cultural features is water-dependent, or indirect, where the purpose for, or use of, these socio-cultural features is water-related;
- Impacts on water-dependent or water-related uses of natural and socio-cultural features, again considered in terms of direct impacts where the purpose for, or use of, these natural or socio-cultural features is water-dependent, or indirect, where the purpose for, or use of, these socio-cultural features is water-related;
- Impacts on community perceptions of natural and socio-cultural features and water-dependent and water-related uses;
- Impacts on the collective community character of each of the focus areas studied for each of the six representative watersheds; and
- Impacts on the community character of each of the six representative watersheds (see Appendix F).

**Table 3.3.1-2 Categories of Natural and Socio-Cultural Features within the 31 Focus Areas along the Lake Ontario Shoreline in the Southeast Lake Ontario Watershed**

| Resource Category | Description |
|---|---|
| Natural features | Named natural features located along the shoreline of Lake Ontario. |
| Private businesses | Private enterprises related to a variety of water-dependent or water-related recreational uses and activities along the shoreline of Lake Ontario. |
| Communities | Named cities (including named neighborhoods), towns or villages, or hamlets located along the shoreline of Lake Ontario. |
| Public parks and other public facilities | State, county, and town parks and beaches located along the shoreline of Lake Ontario. |
| Built resources | Specific buildings, structures, objects, or other built features located along the shoreline of Lake Ontario. |
| Organizations | Public or private enterprises related to a variety of water-dependent or water-related recreational activities associated with the use of the shoreline of Lake Ontario. |
| Conservation areas | Federal, state, local, and private natural areas, nature/underwater preserves, and wildlife management areas located along the shoreline of Lake Ontario. |
| Governmental facilities | Federal, state, or local government facilities located along the shoreline of Lake Ontario. |
| Industrial facilities | Industrial facilities such as power plants or water treatment plants located along the Lake Ontario shoreline. |
| Camps/Retreats | Public or private facilities specifically identified as camps or retreats located along the shoreline of Lake Ontario. |

With regard to the first four types of impacts (impacts on natural features, socio-cultural features, water-dependent and water-related uses, and community perceptions of affected natural and socio-cultural features and associated water-dependent and water-related uses), the results of analysis indicates that impacts from the introduction and establishment of Hydrilla have the potential to be long-term (permanent), direct and/or indirect, and negative. Specifically, these impacts would likely be:

- Long-term (permanent) because it is unlikely that Hydrilla could be completely eliminated once it became widely established in a conducive environment;
- Indirect, in that while the introduction and establishment of Hydrilla would result in changes to the conditions of affected features or uses, it is the perceptions of these affected features or uses that could change; and
- Negative where the perceptions of affected features or uses conclude that such features and uses are less deserving of being protected, managed, created, improved, enhanced, or developed.

Additionally, these impacts could be cumulative under certain conditions, such that the long-term (permanent), indirect, negative impacts would be exaggerated or exacerbated. Cumulative impacts on the affected features or uses, and on community perceptions of them, from the introduction and establishment of Hydrilla could occur where associated waterbodies, marshes, or wetlands:

- Already contain other established invasive or alien aquatic plant species, such as Eurasian watermilfoil or spike watermilfoil; and/or
- Have existing water quality issues.

These conditions would tend to result in similar physical changes to waterbodies, such that the indirect impacts on affected features or uses and on community perceptions of them, from introduction and establishment of Hydrilla would occur at a faster rate or be greater, resulting in a cumulative impact.

The above conclusions of the socio-cultural impact assessment were based upon a scenario that once Hydrilla became introduced and established in a location, the spread in areas where there are suitable conditions would expand until the entire extent of suitable habitat had been colonized. It is unlikely that Hydrilla could be removed completely from suitable habitat, once it has become widely established. Therefore, continued treatment would be necessary to control the growth of Hydrilla. The continued treatments would likely minimize or control long-term (permanent), direct or indirect, negative impacts on natural or socio-cultural features and their associated water-dependent or water-related uses. While treatment might be unlikely to completely eliminate or reverse the impacts of the introduction and establishment of Hydrilla, treatment would likely receive considerable support by communities, governmental units, state and federal agencies, stakeholders, special interest groups, and seasonal users in an effort to avoid or minimize impacts on the perceptions of affected features and uses.

However, with regard to the last two types of impacts (impacts on the collective community character of each of the focus areas and impacts on the community character of each of the six representative watersheds), the long-term (permanent), direct and/or indirect, and negative impacts of the introduction and establishment of Hydrilla on community character would be perceived differently by different groups of people. For example, local individuals and groups that comprise the affected communities and governmental units would recognize direct and indirect impacts on natural and socio-cultural features and their associated water-dependent and water-related uses. However, they may be reluctant to acknowledge the changes to their community character that would occur as a result of these direct and indirect impacts and slow to participate in necessary revisions to the management of affected natural and socio-cultural features and their associated water-dependent or water-related uses.

Conversely, state or federal agencies and special interest groups that operate regionally or nationally likely would recognize the impacts and would accept such changes to the affected features and uses. However, they also may be slow to participate in necessary revisions to the management of affected features and uses for any number of administrative reasons (e.g., limited manpower, limited budget, and limited regulatory authority).

Finally, seasonal users would be likely to recognize the impacts, and while reluctant to accept the changes to community character, may abandon those areas that contain affected natural and socio-cultural features and their associated water-dependent and water-related uses. Changes to their seasonal use of affected areas may be either in favor of other similar areas that remain unaffected by the introduction and establishment of Hydrilla or may represent a greater shift in favor of other areas with features and uses that would never be affected by the introduction and establishment of Hydrilla.

The introduction and establishment of Hydrilla in the Great Lakes Basin, as considered through the analysis of focus areas within six representative watersheds, has the potential to result in long-term (permanent), direct and indirect, negative impacts on natural and socio-cultural features and their associated water-dependent and water-related uses. Similar impacts would be expected on the perceptions of these features and uses. Collectively, these impacts would represent long-term, indirect, negative impacts on the community character of the Great Lakes Basin in general, and on the community character and associated socio-cultural setting of specific affected areas within the Great Lakes Basin.

### 3.3.2 Potential Economic Impacts

The potential economic costs associated with the possible introduction of Hydrilla into the Great Lakes U.S. watershed could be significant. It is noted that similar suitable habitat along the Canadian shoreline could have similar economic impacts, thereby increasing total impacts around the entire Great Lakes. The Great Lakes basin provides a wide assortment of benefits and environmental services to residents and businesses located throughout the region and the nation as a whole. The potential spread of Hydrilla throughout the basin could impact a large number of diverse activities, including recreational uses such as, recreational fishing and angling, beach use, and pleasure boating as well as affect navigation, water supply, and hydropower production. The following sections attempt to estimate the economic costs associated with possible introduction and spread of Hydrilla throughout the Great Lakes. The analysis includes a discussion of the costs to individuals and businesses as well as estimates of the value of these industries to the regional economy as a whole.

Given the levels of uncertainty associated with the physical, ecological, and economic forecasts used throughout this analysis and the numerous assumptions that were made to make these forecasts, the estimates provided within should be viewed as rough order-of-magnitude (ROM) estimates. A ROM analysis gives a range of estimates and attempts to identify the most likely outcomes, given the uncertainties associated with subject. These estimates are based on the most current scientific knowledge and the most up-to-date economic data available.

#### 3.3.2.1 Methodology

In an effort to forecast the economic effects of the possible introduction of Hydrilla into the Great Lakes watershed, existing cost data and economic valuation studies were utilized throughout. No new economic surveys or econometric studies were completed for this analysis. For this analysis, heavy reliance has been on state and federal reports, academic economic literature, and actual cost data from Hydrilla abatement projects.

As described in previous sections, the Great Lakes Basin was divided into 18 watersheds for which Hydrilla introduction potential and habitat suitability were evaluated. For the purposes of this economic analysis, six representative watersheds, including three in eastern, western, and southern Lake Erie and one each in southeastern Lake Ontario, southwestern Lake Huron, and southwestern Lake Michigan were selected for more in-depth analysis. These watersheds represent areas that have a high or medium probability that Hydrilla could become established if it were introduced. These watersheds were also selected so that a wide range of communities would be represented in the analysis. No watersheds in Lake Superior were selected because it is unlikely that Hydrilla could become established in the lake due to water temperature and depth conditions. Throughout this economic analysis, these six representative watersheds have been utilized as case studies for the rest of the Great Lakes.

Within these representative watersheds, detailed analyses were focused on locations considered optimal for Hydrilla introduction and growth (i.e., theoretical infestation sites) to narrow the analysis to a manageable level and facilitate site-specific data collection, as discussed in Section 3.3. Theoretical infestation sites included shoreline areas situated within embayments, near river/creek entrances, and protected from wave action.

As discussed previously, Hydrilla typically grows in water depths less than 25 feet. Therefore, this economic analysis focuses on potential impacts on uses located on the shore and near shore areas that would occur within water depths of less than 25 feet and where water temperatures are at or above 68°F for at least two months (see Section 3.1.4.2 for discussion on suitability variables).

#### 3.3.2.2 Recreational Fishing and Angling

Recreational fishing is a major activity on the Great Lakes. According to the *2011 National Survey of Fishing, Hunting, and Wildlife-Related Activities*, conducted by the United States Fish and Wildlife Service (USFWS) in conjunction with the United States Census Bureau, approximately 1.7 million anglers fish in the Great Lakes annually. These anglers make an estimated 15.2 million fishing trips for 19.7 million fishing days. In addition, these anglers spend more than $1.9 billion annually on trip and equipment expenditures for Great Lake fishing (USFWS 2014a).

Table 3.3.2-1 shows estimates of the total number of anglers, total number of fishing trips, and total days fishing in the Great Lakes for the eight bordering states in 2011, the latest year for which complete data are available. As shown in the table, Michigan and New York account for the largest number of total fishing days in 2011 with 11 million and 4.5 million fishing days, respectively. In contrast, Indiana and Illinois had the fewest fishing days out of any state bordering the Great Lakes in 2011 (see Table 3.3.2-1).

**Table 3.3.2-1 Total Number of Anglers, Fishing Trips, and Days Fishing in the Great Lakes by State in 2011[a]**

| State | Total Number of Anglers | Total Fishing Trips | Total Days Fishing |
|---|---|---|---|
| New York | 332,000 | 2,143,000 | 4,485,000 |
| Pennsylvania[b] | 120,000 | …[c] | 387,000 |
| Ohio | 344,000 | 1,702,000 | 2,161,000 |
| Michigan | 650,000 | 9,898,000 | 10,987,000 |
| Illinois[b] | 70,000 | …[c] | 148,000 |
| Minnesota[b] | 46,000 | …[c] | 207,000 |
| Wisconsin | 178,000 | 879,000 | 1,246,000 |
| Indiana[b] | 27,000 | …[c] | 114,000 |

Sources: USFWS 2014b-i; American Sportfishing Association 2013.

Notes:
[a] Due to USFWS reporting methods and rounding issues, totals for the Great Lakes as a whole may differ slightly from the aggregate of each state
[b] Data on total number of anglers and total days of fishing in the Great Lakes for Pennsylvania, Illinois, Minnesota, and Indiana are from the American Sportfishing Association.
[c] Sample size too small to reliably report data.

In addition to being a popular recreational pastime, fishing in the Great Lakes is an important economic driver for the region. In 2011, 1.7 million people fished in the Great Lakes and spent an average of $1,121 on this activity. Trip-related expenditures totaled $1.1 billion with nearly $375 million spent on food and lodging; approximately $250 million spent on transportation; and $465 million spent on other items such as guide fees, equipment rentals, and bait. In addition, equipment purchased to fish on the Great Lakes totaled $777 million with $223 million of this total spent on fishing equipment such as rods and reels; $83 million spent on auxiliary equipment such as camping gear, binoculars, and related items; and $471 million spent on special equipment such as boats and trailers (USFWS 2014a).

Overall anglers in the Great Lakes spent an average $655 on fishing trip expenditures each year or $55 per day fished (USFWS 2014a).

Table 3.3.2-2 provides a breakdown of fishing trip and equipment expenditures for use on the Great Lakes for the states with the largest total expenditures. As shown on the table, average trip expenditures for a day of fishing on the Great Lakes ranged from a low of $43 in Michigan to a high of $98 in Ohio (see Table 3.3.2-2).

**Table 3.3.2-2 Total Expenditures Made for Fishing Trips and Equipment Used on the Great Lakes by Expenditure Category for Selected States[a]: 2011**

| Expenditure Category | New York | Ohio | Michigan | Wisconsin |
|---|---|---|---|---|
| Food and Lodging | $90,799,000 | $74,135,000 | $165,828,000 | $23,852,000 |
| Transportation | $41,286,000 | $49,198,000 | $121,667,000 | $21,491,000 |
| Other Trip Costs | $132,095,000 | $89,345,000 | $185,114,000 | $30,536,000 |
| Equipment | $95,657,000 | … | $622,884,000 | … |
| **Total Expenditures[b]** | **$359,836,000** | **$241,022,000** | **$1,095,493,000** | **$86,398,000** |
| **Average Annual Expenditures per Angler[c]** | **$191** | **$180** | **$628** | **$69** |
| **Average Trip Expenditures per Day of Fishing in the Great Lakes[c]** | **$59** | **$98** | **$43** | **$61** |

Sources: USFWS 2014b-i.

Notes:
Sample size too small to reliably report data.

[a] Due to small sample size, data are not available for Pennsylvania, Illinois, Indiana, or Minnesota.
[b] Due to estimation errors associated with small sample sizes and non-disclosure of data, total expenditure figures do not always equal the sum of the expenditure components.
[c] "Average Expenditure per Angler" and "Average Trip Expenditure per Day of Fishing in the Great Lakes" statistics are as reported in the *2011 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation.* These figures cannot be derived directly from the "Total Expenditures Made on Fishing Trips and Equipment Used in the Great Lakes" and "Total Anglers in the Great Lakes." Different definitions for the total number of anglers and fishing expenditures were utilized when calculating these statistics.

According to an analysis completed by the American Sportfishing Association, the direct, indirect, and induced impacts of the expenditures on fishing the Great Lakes created nearly $7.2 billion in economic output; supported an estimated 49,298 jobs; generated approximately $2.2 billion in wages and salaries, and generated $408.8 million in state and local tax revenues and $509.3 million in federal tax revenues (see Table 3.3.2-3; American Sportfishing Association 2013).

**Table 3.3.2-3 Economic Impact of Recreational Fishing in the Great Lakes by State: 2011**

| Economic Impact | New York | Pennsylvania | Ohio | Michigan | Illinois |
|---|---|---|---|---|---|
| Jobs | 6,787 | 891 | 7,048 | 19,805 | 786 |
| Wages and Salaries (in $ millions) | $340.8 | $31.9 | $207.7 | $774.9 | $34.4 |
| Economic Output (in $ millions) | $1,030.0 | $95.4 | $760.0 | $2,231.5 | $105.4 |
| State and Local Taxes (in $ millions) | $75.0 | $7.3 | $52.0 | $142.9 | $6.6 |
| Federal Taxes (in $ millions) | $79.2 | $7.9 | $54.1 | $173.3 | $7.9 |
| **Economic Impact** | **Minnesota** | **Wisconsin** | **Indiana** | **All Other States** | **Total Impact in U.S. from Great Lakes Fishing[a]** |
| Jobs | 1,494 | 1,883 | 213 | 10,391 | 49,298 |
| Wages and Salaries | $51.4 | $56.9 | $7.1 | $700.1 | $2,205.2 |
| Economic Output (in $ millions) | $154.3 | $186.5 | $27.9 | $2,636.4 | $7,227.4 |
| State and Local Taxes (in $ millions) | $11.0 | $12.5 | $1.7 | $99.8 | $408.8 |
| Federal Taxes (in $ millions) | $12.7 | $13.8 | $1.8 | $158.6 | $509.3 |

Source: American Sportfishing Association 2013.

Note:

[a] Total Impact on the United States from Great Lakes Fishing includes the economic impacts from purchases made in non-Great Lake states for the purpose of fishing in the Great Lakes.

### Impacts of Hydrilla

Introduction and establishment of Hydrilla into the Great Lakes ecosystem could have a detrimental impact on sport fishing in the affected areas in several ways:

- Hydrilla forms dense mats that create an unpleasant appearance and, when decomposing at the end of the growing season, can create an unpleasant odor, thereby reducing some of the enjoyment related to sport fishing;
- Hydrilla mats also decrease the amount of DO in the water, which negatively affects habitat quality and may result in fish kills in extreme situations;

- The size and weight of sport fish, such as largemouth bass, are also negatively affected. For example, areas infested by Hydrilla tend to have relatively smaller and lighter sport fish than unaffected areas (NYSDEC 2017a);
- Hydrilla infestations create a physical impediment to fishing by increasing the likelihood of snags. Areas with dense Hydrilla infestations would be expected to be unfishable; and
- Large infestations can limit shoreline access and result in recreational boats being stuck and entangled in the mats.

Depending on the level of infestation, some positive impacts on sporting fishing in the Great Lakes could also occur as a result of the presence of Hydrilla in the watershed. Some studies have shown that the existence of approximately 50% plant cover would be beneficial to some fish species by offering a refuge from predation. Hydrilla has been known to colonize areas that are deeper than some native macrophytes, thereby potentially increasing habitat. However, if Hydrilla were able to establish a dense monoculture these areas would be less suitable habitat for young fish. Given the complex nature of the relationship between Hydrilla and its effect on sport fishing, Section 5.2 suggests a BMP that includes educating angler groups on the specifics of these potential impacts.

### Quantity of Fishing Trips/Fishing Days Affected

Table 3.3.2-4 provides an estimate of the total fishing effort in open waters (i.e., fishing from a boat) versus fishing from shore of the Great Lakes for representative watersheds in the Great Lakes, as expressed in angler hours per year.

Currently, given the many unknowns, there is no conclusive way to predict what impact the introduction of Hydrilla into the Great Lakes would have on total sport fishing days or total sport fishing effort, or ultimately what the resulting economic impact would be. However, ROM estimates can be made by examining possible scenarios to bind some of the potential impacts.

In an attempt to quantify the potential economic effects of the introduction of Hydrilla on sport fishing in the Great Lakes, Ready et al. (2016) developed three potential scenarios that could describe possible effects of Hydrilla on recreational sport fishing activity. The first scenario assumed that Hydrilla would not affect recreational fish populations; therefore, no further analysis was completed. The second scenario (H-2) assumed that Hydrilla would lead to a 15% decrease in yellow perch, largemouth bass, pike, and muskellunge throughout the Great Lakes with steeper declines in areas currently exhibiting high productivity. The third scenario assumed that introduction of Hydrilla would lead to a 15% increase in yellow perch, largemouth bass, pike, and muskellunge throughout the Great Lakes (Ready et al. 2016).

**Table 3.3.2-4 Fishing Boat Survey and Fishing Effort Statistics in Selected Watersheds in the Great Lakes**

| Watershed | Total Recreational Fishing Effort in Open Waters of the Great Lakes (expressed in angler hours) 2014 | 2015 | 2016 |
|---|---|---|---|
| Southeast Lake Ontario[a] | 751,454 | 672,076 | 589,616 |
| Eastern Lake Erie[b] | 371,372 | 368,851 | 363,423 |
| Southern Lake Erie[c] | 1,509,229 | 1,312,692 | 1,162,530 |
| Western Lake Erie[d] | 1,975,161 | 1,986,014 | 2,066,757 |
| Southwestern Lake Huron | NA | NA | NA |
| Southwestern Lake Michigan | NA | NA | NA |

Sources: NYSDEC 2015, 2016a, 2016b, 2017b; Ohio Department of Natural Resources 2017.

Notes:

[a] Total Recreational Fishing Effort for the Southeast Lake Ontario Watershed figures were calculated by prorating the total boat angler hours for the entire Lake Ontario by the percent of fishing boat trips that occurred in the geographical areas II, III, and IV during that year as defined by the NYSDEC Lake Ontario fishing boat survey.

[b] Total Recreational Fishing Effort in the Eastern Lake Erie Watershed only includes estimates for the fishing effort in the New York State portion of the watershed**.** The Commonwealth of Pennsylvania does not conduct creel studies in Lake Erie and the portion of the Eastern Lake Erie Watershed located in the state of Ohio is minor. The fishing effort statistics for the Ohio portion of the Eastern Lake Erie Watershed is included in the statistics reported for the Southern Lake Erie Watershed.

[c] Total Recreational Fishing Effort for the Southern Lake Erie Watershed include data from Districts 2 and 3 as defined in the Ohio Department of Natural Resources Creel Study.

[d] Total Recreational Fishing Effort for the Western Lake Erie Watershed includes data from District 1 as defined in the Ohio Department of Natural Resources Creel Study.

Key:
NA – No data available.

Table 3.3.2-5 also shows the study's results for Scenario H-3, under which it is assumed that the presence of Hydrilla would increase sport fish in the Great Lakes by 15%. Under these assumptions, the authors determined that there would be an increase of 86,584 fishing days in the Great Lakes and the total consumer surplus would increase by approximately $29.6 million.

Table 3.3.2-5 shows the results of the Ready study (Ready et al. 2016), including the potential impact on the total number of fishing days in the Great Lakes as well as the total and the average change in consumer surplus per angler. Consumer surplus is a measurement of economic utility that attempts to quantify the benefit or value an individual receives from an activity. According to the authors, a 15% decrease in sport fish in the Great Lakes due to Hydrilla (Scenario H-2) is expected to result in an annual loss of consumer surplus of more than $34.8 million. Table 3.3.2-5 also shows the study results for each state within the Great Lakes.

**Table 3.3.2-5 Impacts on the Consumer Surplus of Anglers in the Great Lakes Upon Introduction of Hydrilla: Two Scenarios**

| State | Anglers in State | Change in Total Fishing Days | Change in Consumer Surplus per Angler (average) | Total Change in Consumer Surplus |
|---|---|---|---|---|
| **Scenario H-2 (15% reduction in sport fish)** | | | | |
| Illinois | 605,649 | -16,548 | -$9.31 | -$5,639,325 |
| Indiana | 332,061 | -2,933 | -$3.02 | -$1,002,296 |
| Michigan | 805,792 | -39,882 | -$16.88 | -$13,599,721 |
| Minnesota | 1,024,003 | -460 | -$0.15 | -$156,416 |
| New York | 589,557 | -9,577 | -$5.56 | -$3,278,738 |
| Ohio | 520,789 | -19,557 | -$12.85 | -$6,693,482 |
| Pennsylvania | 635,577 | -1,174 | -$0.64 | -$404,588 |
| Wisconsin | 728,604 | -11,844 | -$5.54 | -$4,039,912 |
| **Total** | **5,242,032** | **-101,975** | **-$6.64** | **-$34,814,477** |
| **Scenario H-3 (15% increase in sport fish)** | | | | |
| Illinois | 605,649 | 15,948 | $8.97 | $5,433,287 |
| Indiana | 332,061 | 3,030 | $3.12 | $1,035,619 |
| Michigan | 805,792 | 26,884 | $11.38 | $9,172,911 |
| Minnesota | 1,024,003 | 452 | $0.15 | $153,702 |
| New York | 589,557 | 9,677 | $5.62 | $3,313,218 |
| Ohio | 520,789 | 19,472 | $12.80 | $6,666,761 |
| Pennsylvania | 635,577 | 1,228 | $0.67 | $423,490 |
| Wisconsin | 728,604 | 9,893 | $4.63 | $3,375,020 |
| **Total** | **5,242,032** | **86,584** | **$5.64** | **$29,574,008** |

Source: Ready et al. 2016.

### 3.3.2.3 Beach Use

Travel and tourism is an important economic industry throughout the Great Lakes region. Recreational uses of the lakes and beaches are a major draw. According to NOAA's National Ocean Service, in 2014 the Great Lakes supported approximately 12,000 travel and tourism establishments that employed nearly 229,000 workers in the industry. Approximately $4.3 billion in wages and $9.4 billion in gross domestic product were created by Great Lakes travel and tourism annually. See Table 3.3.2-6 for a state-by-state breakdown of these figures.

While no national surveys have been conducted on beach use activities, several smaller local and regional economic studies have been completed to estimate the economic value of a day at the beach. In 2005, the United States Forest Service conducted a comprehensive analysis of economic literature to estimate the use values for various outdoor recreational activities. In this study, the United States Forest Service found that in the Northeast United States the average consumer surplus per person per day for a beach day was $56.74 in 2017 dollars. In other words, on average, a person valued or was willing to pay $56.74 (2017 dollars) a day to go to the beach. This figure was derived by analyzing 22 economic studies that estimated the use value of a day at the beach in the Northeast (Loomis 2005).

**Table 3.3.2-6 Economic Impacts of Travel and Tourism on the Great Lakes by State: 2014**

| State | Establishments | Employment | Wages (in $ millions) | GDP (in $ millions) |
|---|---|---|---|---|
| Ohio | 2,165 | 37,925 | $610.4 | $1,307.6 |
| Michigan | 3,163 | 51,153 | $776.3 | $1,570.9 |
| Illinois | 2,373 | 64,402 | $1,817.0 | $4,204.1 |
| Minnesota | 347 | 7,039 | $109.1 | $232.8 |
| Wisconsin | 1,747 | 32,765 | $481.4 | $1,036.7 |
| Indiana | 384 | 7,022 | $91.4 | $185.5 |
| **Total Great Lakes** | **11,985** | **228,571** | **$4,337.0** | **$9,435.9** |

Source: NOAA 2017.

Note: State data for New York and Pennsylvania were not provided on this table because statewide totals also included Atlantic Ocean tourism. Data for these states for the Great Lakes portion of their tourism impact have been included in the Great Lakes totals.

Key:
GDP = gross domestic product

### Impacts from Hydrilla

Impacts from the introduction and establishment of Hydrilla near beaches on the Great Lakes would have a negative impact on beach use and attendance in the following ways:

- Swimming would become a less desirable activity as Hydrilla mats could entangle swimmers and increase the possibility of drowning; and
- Large decomposing mats of Hydrilla would negatively affect the aesthetics of the beach as unpleasant odors and unsightly clumps of vegetation would detract from the recreational experience.

### Quantity of Beaches/Beach Attendance Impacted

There are a total of 1,049 beaches encompassing a total of 665 miles of shoreline located along the Great Lakes. Table 3.3.2-7 provides a breakdown of beaches by state in the Great Lakes region. The figures on Table 3.3.2-7 represent all public and private beaches for which the USEPA collects water quality monitoring data.

**Table 3.3.2-7 Total Number of Beaches[a] and Length of Beach in the Great Lakes by State**

| State | Total Number of Beaches | Total Length of Beach (miles) |
|---|---|---|
| New York | 50 | 18.80 |
| Pennsylvania | 13 | 3.12 |
| Ohio | 62 | 44.30 |
| Michigan | 575 | 449.64 |
| Illinois | 60 | 17.69 |
| Minnesota | 79 | 57.32 |
| Wisconsin | 185 | 51.06 |
| Indiana | 25 | 23.32 |
| **Total Great Lakes** | **1,049** | **665.25** |

Source: USEPA 2017.

Note:
[a] Includes all public and private beaches in the USEPA water quality monitoring database.

In an effort to quantify the potential number of beach days impacted by the introduction and establishment of Hydrilla into the Great Lakes ecosystem, several representative watersheds were analyzed. Table 3.3.2-8 identifies beaches that have physical characteristics (i.e., located near embayments, protected from wave action, located in warm shallow waters) that would be suitable habitat for Hydrilla within the six representative watersheds. In addition, the table provides annual attendance figures for these potentially impacted beaches.

**Table 3.3.2-8 Beaches Located in Suitable Habitat for Hydrilla and Annual Attendance Statistics in Selected Watersheds in the Great Lakes Basin**

| Beach Name | Beach Front Distance (in miles) | Acres of Parkland | Annual Attendance |
|---|---|---|---|
| **Southeast Lake Ontario Watershed** | | | |
| Durand Eastman Beach | 1.34 | 19 | 31,000 |
| Fair Haven Beach State Park | 0.82 | 1,141 | 320,000 |
| Sandy Island Beach State Park | 0.39 | 229 | 39,000 |
| Selkirk Shores State Park | 0.24 | 980 | 80,000 |
| Sodus Point Beach Park | 0.10 | NA | 9,000 – 10,000 |
| Southwick Beach State Park | 3.41 | 464 | 129,000 |
| **Total Watershed** | **6.30** | **2,833** | **608,000 – 609,000** |

**Table 3.3.2-8 Beaches Located in Suitable Habitat for Hydrilla and Annual Attendance Statistics in Selected Watersheds in the Great Lakes Basin**

| Beach Name | Beach Front Distance (in miles) | Acres of Parkland | Annual Attendance |
|---|---|---|---|
| **Eastern Lake Erie Watershed** | | | |
| Buffalo Harbor-Gallagher Beach State Park[a] | 0.29 | 1.93 | NA |
| Lake Shore Park, Town of Ashtabula | 0.20 | 2.75 | 122,000 |
| **Total Watershed** | **0.49** | **4.68** | **122,000** |
| **Southern Lake Erie Watershed** | | | |
| Cleveland Lakefront Reservation[b] | 0.34 | 4.15 | 1,651,000 |
| Fairport Harbor Lakefront Park Beach | 0.26 | 4.87 | 346,000 |
| Lakeview Park | 0.28 | 5.42 | 782,000 |
| Miller Road Park – City of Avon Park[c] | 0.29 | 1.64 | 5,000 – 8,000 |
| North Townline Park | 0.05 | 0.21 | 12,000 |
| **Total Watershed** | **1.22** | **16.29** | **2,796,000 – 2,799,000** |
| **Western Lake Erie Watershed** | | | |
| Maumee Bay State Park Beach | 0.30 | 5.37 | 40,000 – 50,000 |
| Zeller's Beach Park (Private)[d] | 0.09 | 0.21 | NA |
| **Total Watershed** | **0.39** | **5.58** | **40,000 – 50,000** |
| **Southwestern Lake Huron Watershed** | | | |
| Lincoln Memorial Park | 0.13 | 1.92 | 10,000 – 12,000 |
| Bay County Pinconning Park | 0.07 | 0.62 | 14,500 |
| Bird Creek Park | 0.20 | 2.11 | 12,000 – 15,000 |
| Tawas Bay Beach Resort[e] | 0.13 | 1.65 | NA |
| **Total Watershed** | **0.53** | **6.3** | **36,500 – 41,500** |
| **Southwestern Lake Michigan Watershed** | | | |
| Grand Mere State Park | 1.94 | 21.03 | 45,000 |
| **Total Watershed** | **1.94** | **21.03** | **45,000** |

Sources: NYS Office of Parks, Recreation and Historic Preservation 2017; Hass 2017; Hazel 2017; Wayman 2017; Hentschl 2017; McGonigal 2017; Tomczak 2017; Buehler 2017; Wruble 2017; Michigan Department of Natural Resources and Environment, Recreation Division 2010; McLaughlin 2017; James G. Zupka, CPA, Inc. 2017; Lorain County Metro Parks 2017.

Notes:
[a] Attendance figures for the Buffalo Harbor – Gallagher Beach State Park are not available due to the newness of the park and the fact that swimming is not yet permitted.
[b] Attendance figures for the Cleveland Lakefront Reservation include annual attendance at Edgewater Park and Villa Angela/Wildwood/Euclid Beach.
[c] No attendance figures were kept for Miller Road Park; attendance was estimated at 5,000 to 8,000 visitors based on special event visitations rates.
[d] Zeller's Beach Park is a private facility. Attendance figures are not publicly available.
[e] Tawas Bay Beach Resort is a private facility. Attendance figures are not publicly available.

Key:
NA = data are not available

As shown on the table, visitation rates at beaches suitable for the establishment of Hydrilla vary greatly by watershed. For instance, in the southwestern Lake Michigan, southwestern Lake Huron, and western Lake Erie watersheds annual attendance figures at beaches that are suitable for the establishment of Hydrilla total between 36,000 and 45,000 visits per year. In contrast, suitable beaches in the eastern Lake Erie watershed average approximately 122,000 visits per year; suitable beaches in the southeast Lake Ontario watershed average approximately 610,000 visits per year, while suitable beaches in the southern Lake Erie watershed average approximately 2.8 million visits per year.

Currently there are not enough scientific or economic studies to provide sufficient information for accurately estimating the impact of Hydrilla establishment on annual beach days in the Great Lakes. Therefore, in an effort to provide ROM estimates for the potential economic impact of Hydrilla on beach recreation in the Great Lakes, three scenarios were developed and analyzed. These scenarios were completed assuming that 5%/10%/15% of all visitor days to suitable beaches would be lost if Hydrilla were to become established in the Great Lakes.

In addition, there are no readily available studies that provide estimates on the total number of beach days in the Great Lakes. Therefore, beach attendance figures for suitable beaches in the six representative watersheds were used as an estimate for the entire Great Lakes. Due to the variability of beach attendance figures in the six watersheds, it was determined that there was no accurate way to utilize this information to forecast attendance figures at suitable beaches in the remaining watersheds. While this approach may underestimate the number of beach days lost, the six representative watersheds do cover the majority of the Great Lakes that is expected to experience high or medium likelihood for Hydrilla introduction and establishment. All of the watersheds in Lake Superior and several watersheds in Lake Michigan and Lake Huron are not expected to have habitat suitable for establishment of Hydrilla.

Table 3.3.2-9 shows the expected impacts on consumer surplus under the low (5% reduction), medium (10% reduction), and high (15% reduction) scenarios.

#### 3.3.2.4 Recreational Boating

Recreational boating is a popular activity in the Great Lakes. In 2012 more than 4 million recreational boats were registered in the states bordering the Great Lakes. Annual recreational-boating expenditures totaled nearly $15.4 billion in those states and nearly 7,200 business establishments sold boats, engines, and accessories or provided boat building or boating services. In total, an estimated 288,000 jobs in the eight states were supported either directly or indirectly by recreational boating activities and $11.9 billion in labor income was created (see Table 3.3.2-10).

**Table 3.3.2-9 Estimated Annual Decrease in Consumer Surplus from Reduction in Beach Use in the Great Lakes Caused by Potential Hydrilla Infestation by Scenario**

| | Low Scenario (5% Reduction in Beach Days) | | Medium Scenario (10% Reduction in Beach Days) | | High Scenario (15% Reduction in Beach Days) | |
|---|---|---|---|---|---|---|
| | Minimum | Maximum | Minimum | Maximum | Minimum | Maximum |
| Average Annual Beach Days at Beaches Suitable for Hydrilla | 3,647,500 | 3,666,500 | 3,647,500 | 3,666,500 | 3,647,500 | 3,666,500 |
| Reduction in the Average Annual Beach Days by Scenario | 182,375 | 183,325 | 364,750 | 366,650 | 547,125 | 549,975 |
| Average Consumer Surplus per Beach Day | $56.74 | $56.74 | $56.74 | $56.74 | $56.74 | $56.74 |
| Estimated Annual Loss of Utility Due to Establishment of Hydrilla | $10,348,000 | $10,402,000 | $20,670,000 | $20,804,000 | $31,044,000 | $31,206,000 |

### Impacts from Hydrilla

The possible introduction and establishment of Hydrilla in the Great Lakes would have a negative impact on recreational boating in those areas where introduction occurred and conditions were suitable for growth and spread. If established, thick mats of Hydrilla would be expected to cover warmer, shallow waters near boat slips and marinas. Hydrilla would have a negative impact on recreational boating in the following ways:

- When left uncontrolled, Hydrilla has been known to grow so thick that it can clog outboard motors and stop the forward propulsion of smaller recreational boats; and
- The aesthetic character of the boating experience could be reduced as large mats of floating vegetation, which would reduce the enjoyment associated with recreational boating.

### Quantity of Marinas/Boating Days Impacted

In a 2008 study, the USACE ERDC studied the economic impact of recreational boating in the Great Lakes. As part of this analysis, the USACE ERDC collected information on the number of recreational boats using the Great Lakes and the number of marinas and boat slips located on the lakes. Using this and other data collected during their analysis, the USACE ERDC developed estimates of the annual number of recreational boat days that occurred on the lakes. Table 3.3.2-11 provides this information by state and for the entire Great Lakes system.

**Table 3.3.2-10 Economic Impact of Recreational Boating in States Bordering the Great Lakes: 2012**

| Economic Impact | New York | Pennsylvania | Ohio | Michigan | Illinois |
|---|---|---|---|---|---|
| Number of Recreational Boats | 477,436 | 365,678 | 453,487 | 771,439 | 425,168 |
| Jobs | 46,303 | 24,835 | 28,921 | 58,863 | 31,077 |
| Labor Income (direct, indirect, and induced) (in $ millions) | $1,919.1 | $1,025.7 | $1,197.0 | $2,430.1 | $1,287.1 |
| Recreational Boating Businesses | 1,856 | 573 | 771 | 1,404 | 648 |
| Annual Recreational Boating-Related Expenditures (in $ millions) | $2,400.0 | $1,300.0 | $1,500.0 | $3,200.0 | $1,700.0 |
| **Economic Impact** | **Minnesota** | **Wisconsin** | **Indiana** | | **Total Great Lakes[a]** |
| Number of Recreational Boats | 758,255 | 560,580 | 229,985 | | 4,042,028 |
| Jobs | 42,668 | 37,233 | 17,732 | | 287,632 |
| Labor Income (direct, indirect, and induced) (in $ millions) | $1,763.9 | $1,535.2 | $734.5 | | $11,892.6 |
| Recreational Boating Businesses | 676 | 798 | 431 | | 7,157 |
| Annual Recreational Boating-Related Expenditures (in $ millions) | $2,300.0 | $2,000.0 | $955.8 | | $15,355.8 |

Source: National Marine Manufacturers Association 2015.

Note:
[a] Total Great Lakes includes economic impacts from inland purchases for all states and also includes purchases on the Atlantic Coast for New York and Pennsylvania.

In 2008 there were more than 1,200 marinas and nearly 120,000 boat slips available on the Great Lakes (see Table 3.3.2-11). An estimated 17.3 million boating days occurred on the Great Lakes each year (see Table 3.3.2-11).

**Table 3.3.2-11 Number of Marinas, Boat Slips, and Annual Boating Days on the Great Lakes: 2008**

| State | Total Marinas[a] | Total Slips | Annual Boating Days (in 1,000 days) |
|---|---|---|---|
| New York | 181 | 15,787 | 1,970 |
| Pennsylvania | 23 | 3,224 | 230 |
| Ohio | 275 | 35,367 | 2,053 |
| Michigan | 642 | 49,271 | 5,853 |
| Illinois | 8 | 5,900 | 1,400 |
| Minnesota | 4 | 276 | 1,786 |
| Wisconsin | 63 | 6,683 | 2,828 |
| Indiana | 16 | 2,883 | 1,176 |
| **Total Great Lakes** | **1,212** | **119,391** | **17,296** |

Source: USACE 2008.

Note:
[a] Figure includes marinas, yacht clubs, boatyards, campgrounds, and boat condominiums.

The study also found that the average spending per boat day for boats located in a marina ranged from $101 for vessels less than 21 feet; $163 for vessels 21 to 27 feet; $180 for vessels 28 to 40 feet; and $285 for vessels greater than 40 feet (USACE 2008).

In an effort to quantify how the annual number of boat days would be affected by Hydrilla, representative watersheds were analyzed. Table 3.3.2-12 shows the total number of marinas and slips located in each watershed and determines how many of these are located in habitats likely to support Hydrilla. Factors such as physical geography, likelihood for wave action, and water depth were considered when determining if an area's habitat was likely suitable for Hydrilla.

In an effort to provide ROM estimates for the potential economic impact of Hydrilla on recreational boating in the Great Lakes, three scenarios were developed and analyzed. Currently there is not sufficient scientific evidence to estimate the impact of Hydrilla on annual boat days in the Great Lakes. Therefore, an analysis was completed assuming that 5%/10%/15% of boater days would be lost if Hydrilla were to become established in the Great Lakes. Table 3.3.2-13 shows the expected economic impacts under each of these scenarios. To be conservative the expenditures per boat day were calculated using the two lowest expenditures levels (i.e., those for boats under 21 feet and for boats 21 to 27 feet) reported in the USACE report. If the expenditures patterns for larger boats were considered, the economic impact from each of these scenarios would be greater.

**Table 3.3.2-12 Number of Marinas and Boat Slips in Selected Watersheds in Habitats Suitable for Hydrilla**

| | Habitat Likely Suitable for Hydrilla | | Habitat Likely Unsuitable for Hydrilla | | Total | |
|---|---|---|---|---|---|---|
| | Marinas | Slips | Marinas | Slips | Marinas | Slips |
| Southeast Lake Ontario Watershed | 49 | 3,958 | 0 | 149 | 49 | 4,007 |
| Eastern Lake Erie Watershed | 51 | 7,385 | 2 | 675 | 53 | 8,060 |
| Southern Lake Erie Watershed | 15 | 4,090 | 1 | 109 | 16 | 4,199 |
| Western Lake Erie Watershed | 80 | 19,478 | 4 | 434 | 84 | 19,902 |
| Southwestern Lake Huron | 25 | 2,918 | 6 | 781 | 31 | 3,699 |
| Southwestern Lake Michigan Watershed | 15 | 7,144 | 1 | 829 | 16 | 7,973 |

**Table 3.3.2-13 Estimated Annual Decrease in Consumer Surplus in the Great Lakes Caused by Potential Hydrilla Infestation by Scenario**

| | Low Scenario (5% Reduction in Recreational Boating) | | Medium Scenario (10% Reduction in Recreational Boating) | | High Scenario (15% Reduction in Recreational Boating) | |
|---|---|---|---|---|---|---|
| Average Annual Boat Days - Baseline | 17,296,000 | | 17,296,000 | | 17,296,000 | |
| Reduction in Average Annual Boat Days by Scenario | 864,800 | | 1,729,600 | | 2,594,400 | |
| | Minimum | Maximum | Minimum | Maximum | Minimum | Maximum |
| Average Spending per Boat Day | $101 | $163 | $101 | $163 | $101 | $163 |
| Estimated Annual Losses in Utility Due to Hydrilla | $87,344,800 | $140,962,400 | $174,689,600 | $281,924,800 | $262,034,400 | $422,887,200 |

#### 3.3.2.5 Great Lakes Commercial Navigation

Great Lakes navigation is an important economic driver for the local, regional, and national economy. In 2017, the most recent time for which these economic estimates are available, an estimated 49,400 jobs in the United States were tied directly to the movement of cargo via U.S. ports and marine terminals on the Great Lakes – St. Lawrence Seaway System. The economic activity generated by the movement of cargo supported an additional 98,100 indirect and induced jobs. In total, approximately 147,500 jobs were tied to Great Lakes commercial navigation. In addition, commercial shipping on the Great Lakes directly created approximately $2.6 billion in employee earnings as well as an additional $2.5 billion in indirect employee earnings and $5.3 billion in induced employee earnings annually. Likewise, activities related to Great Lakes navigation generated approximately $1.3 billion in state and local taxes and $3.4 billion in federal taxes per year (Martin Associates 2018).

Table 3.3.2-14 provides a breakdown of the economic impacts of cargo moving via U.S. ports and marine terminals on the Great Lakes-St. Lawrence Seaway System by state. As shown on the table, Indiana, Ohio, and Michigan are the states that receive the largest economic stimulus from Great Lakes navigation. More than 66,000 jobs; $4.9 billion in personal income; $11.3 billion in business income; $623 million in state and local tax revenues; and $1.6 billion in federal tax revenues in the state of Indiana are tied to the movement of cargo from U.S. ports and marine terminals along the Great Lakes (see Table 3.3.2-14).

In an effort to promote and enhance waterborne commerce throughout the region, the USACE is responsible for operating and maintaining U.S. shipping channels, ports, harbors, and locks throughout the Great Lakes system. In fiscal year 2016, the USACE's Great Lakes Navigation Program was appropriated $142.8 million for operation and maintenance activities throughout the Great Lakes system. More than 40% ($59.2 million) of this total was earmarked for dredging and dredged material management (USACE 2016).

Approximately 3.3 million cubic yards (CY) of dredge material needs to be removed from federally designated commercial and recreational shipping channels, ports, and harbors in the Great Lakes each year to maintain safe navigation. However, the amount of material removed by the USACE ERDC from the Great Lakes varies by year and funding availability. For example, in fiscal year 2012 only approximately 1.9 million CY of dredge material was removed throughout the system. In contrast, nearly 5.3 million CY of dredge material was removed in fiscal year 2009 (USACE 2016).

**Table 3.3.2-14 Economic Impact of Cargo Moving via U.S. Ports and Marine Terminals on the Great Lakes – St. Lawrence Seaway System by State in 2017**

| Economic Impact | New York | Pennsylvania | Ohio | Michigan | Illinois |
|---|---|---|---|---|---|
| **Jobs** | | | | | |
| Direct | 691 | 291 | 9,398 | 11,180 | 2,943 |
| Indirect | 116 | 237 | 15,221 | 6,436 | 880 |
| Induced | 542 | 229 | 8,549 | 8,294 | 2,654 |
| **Total Jobs** | **1,349** | **757** | **33,168** | **25,910** | **6,476** |
| **Personal Income (in $ millions)** | | | | | |
| Direct | $38.1 | $12.7 | $475.0 | $536.6 | $130.8 |
| Indirect | $6.0 | $9.6 | $710.6 | $272.3 | $46.0 |
| Induced | $63.5 | $27.2 | $1,025.2 | $966.4 | $345.2 |
| **Total Personal Income** | **$107.6** | **$49.6** | **$2,210.8** | **$1,775.3** | **$522.0** |
| **Business Revenues (in $ millions)** | **$78.3** | **$63.6** | **$2,720.0** | **$3,194.3** | **$485.7** |
| **State and Local Taxes (in $ millions)** | **$14.8** | **$6.4** | **$216.7** | **$205.2** | **$64.9** |
| **Federal Taxes (in $ millions)** | **$27.1** | **$14.1** | **$622.0** | **$558.1** | **$137.8** |

| Economic Impact | Minnesota | Wisconsin | Indiana | Total United States |
|---|---|---|---|---|
| **Jobs** | | | | |
| Direct | 2,176 | 3,198 | 19,518 | 49,395 |
| Indirect | 2,134 | 1,970 | 27,208 | 54,201 |
| Induced | 1,852 | 2,316 | 19,432 | 43,868 |
| **Total Jobs** | **6,161** | **7,484** | **66,158** | **147,464** |
| **Personal Income (in $ millions)** | | | | |
| Direct | $99.3 | $147.2 | $1,202.0 | $2,641.7 |
| Indirect | $100.5 | $87.7 | $1,252.8 | $2,485.5 |
| Induced | $213.5 | $245.2 | $2,441.2 | $5,327.4 |
| **Total Personal Income** | **$413.4** | **$480.1** | **$4,895.9** | **$10,454.6** |
| **Business Revenues (in $ millions)** | **$1,270.2** | **$1,185.7** | **$11,285.5** | **$20,283.5** |
| **State and Local Taxes (in $ millions)** | **$69.5** | **$71.5** | **$623.1** | **$1,272.2** |
| **Federal Taxes (in $ millions)** | **$160.5** | **$169.6** | **$1,682.7** | **$3,371.9** |

Source: Martin Associates 2018.

Note: Tables may not sum due to rounding.

Typically, the USACE ERDC receives federal funding for maintenance dredging at commercial, deep draft harbors throughout the Great Lakes system. Federal funding, however, is more sporadic for the shallow recreational ports and harbors located in the Great Lakes; state and local entities often provide a portion of the funding required to dredge these areas. Figure 3.3.2-1 shows federally designated commercial and recreational harbors throughout the Great Lakes (USACE 2016).

### Impacts of Hydrilla

The introduction of Hydrilla into the Great Lakes would not have a direct effect on the movement of commercial deep draft vessels throughout the system. The size of these vessels would ensure that even dense vegetation mats would have little or no impact on propulsion. Likewise, the water depths required to accommodate these vessels would limit the likelihood that Hydrilla could establish itself within deep draft commercial harbors and channels. However, shallow draft recreational harbors and channels and deep draft recreational harbors and channels with depths less than 25 feet are potentially vulnerable to Hydrilla infestation.

While not directly affecting the commercial shipping, the introduction of Hydrilla into the Great Lakes would substantially increase the costs associated with maintaining and operating the Great Lakes Navigation system. If Hydrilla were to become established in or near harbors and channels throughout the Great Lakes, the costs associated with dredging activities, particularly dredge disposal activities would greatly increase.

If Hydrilla fragments or tubers were potentially within dredge material, some form of upland disposal would be required, thereby greatly increasing disposal costs. In an effort to provide ROM estimates of the potential impact on dredging costs, data from the USACE Dredging Program were analyzed for fiscal years 2011 to 2016. Average dredging costs per CY of dredge material by disposal type were calculated for 836 dredging contracts that occurred throughout the United States during this time.

For this analysis the dredging costs for the upland disposal were compared to the average per unit dredging costs for overboard and open water and wetland nourishment disposal methods. Costs associated with confined, underwater confined, and mixed-type disposal were excluded from the analysis because these methods are typically utilized for contaminated sediments and, therefore, have higher cost structures than those associated with uncontaminated sediments. Additionally, beach nourishment and beach and upland disposal methods were not included in the analysis because these methods also have different cost structures. The open and upland disposal methods and the unknown disposal methods were also excluded from the analysis as there was not enough detail in the data to accurately determine the volume of dredge material by disposal type.

It should be noted that due to the complexities associated with dredging activities there is substantial variation between per unit costs among projects. Given the relatively few dredging contracts that are awarded each year by the USACE, this variation can lead to a significant differences year-to-year. Therefore, the six-year average of the dredging costs were also calculated and presented on Table 3.3.2-15. As shown on Table 3.3.2-15 dredging that utilized wetland nourishment and overboard and open water disposal methods were the cheapest dredge disposal methods. The average cost per CY of dredge material removed ranged from $2.72 to $4.20 per CY for wetland nourishment disposal between fiscal year 2011 to fiscal year 2016. The six-year average per unit cost was $3.74 for dredging that utilized the wetlands nourishment disposal method. For dredging activities that utilized overboard and open water disposal methods, the average costs per CY of dredge material removed ranged from $4.01 to $5.94 per CY. The six-year average per unit cost was $4.93 for dredging that utilized the overboard and open water disposal method (see Table 3.3.2-15).

In contrast, during the same time period dredging activities that utilized upland disposal methods typically had higher per unit costs. The average costs to remove a CY of dredge material ranged from $4.20 to $10.00 per CY of material. The six-year average per unit cost was $7.69 for dredging that utilized upland disposal methods (see Table 3.3.2-15).

Establishment of Hydrilla in areas needing dredging is expected to increase the costs by an estimated $3.95 per CY of dredge material for areas that would otherwise have been able to use the wetlands nourishment disposal method. Establishment is expected to increase the costs by an estimated $2.76 per CY of dredge material for areas that would have otherwise been able to use the overboard and open water disposal methods. Therefore, dredging costs are expected to increase by more than 50% to 110% in the event Hydrilla becomes established within the Great Lakes.

### Dredge Quantities

In an effort to provide ROM forecasts for the amount of dredge material likely contaminated with Hydrilla, several representative watersheds were analyzed in greater detail.

As shown on Table 3.3.2-16 there are 47 federally designated harbors in the six representative watersheds. All but three of these harbors (Toledo Harbor, Burns Waterway Harbor, and Calumet Harbor) have water depths and physical features that lend themselves to establishment of Hydrilla if it were introduced into the area. Table 3.3.2-16 also provides information on the amount of material dredged and the frequency at which dredging occurs in these harbors. In addition to the federal harbors, there are numerous other non-federal marinas, boat slips, and docks throughout the watershed that may need dredging on occasion.

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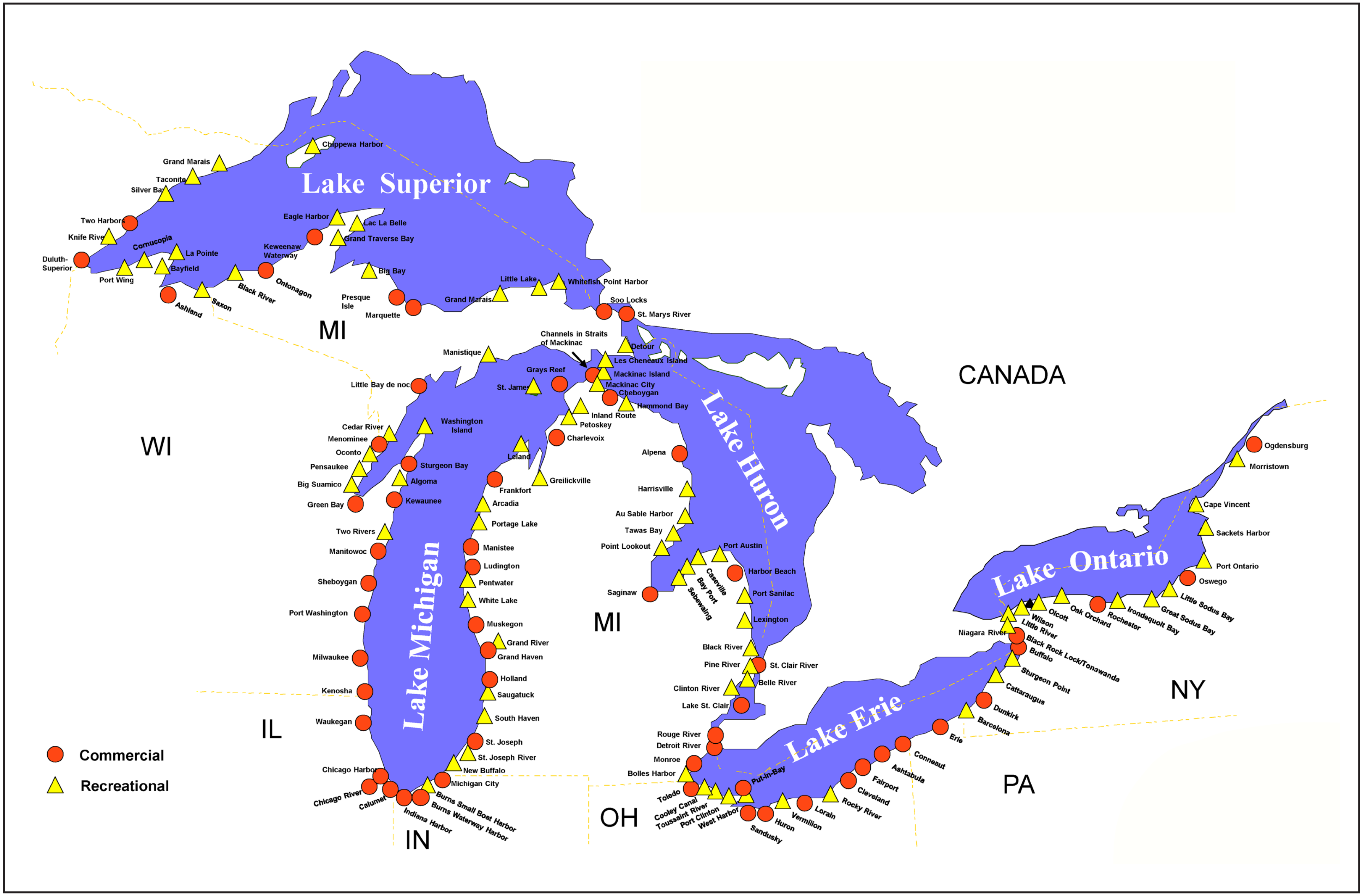



SOURCE: US Army Corps of Engineers, February 2015

**Figure 3.3.2-1** **Federally Designated Commercial and Recreational Harbors on the Great Lakes**

**Table 3.3.2-15 Average Dredging Costs per Cubic Yard of Material by Disposal Type for Fiscal Years 2011 to 2016**

| Disposal Type | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2011 to 2016 Average |
|---|---|---|---|---|---|---|---|
| **Overboard and Open Water** | | | | | | | |
| Contracts | 39 | 49 | 33 | 51 | 44 | 26 | |
| CY (Bid) | 40,743,151 | 66,197,974 | 30,497,727 | 34,149,162 | 35,303,644 | 51,695,443 | |
| Dollars (Bid) | $181,826,743 | $325,726,280 | $181,192,056 | $186,888,901 | $191,667,095 | $207,090,973 | |
| **Cost/CY** | **$4.46** | **$4.92** | **$5.94** | **$5.47** | **$5.43** | **$4.01** | **$4.93** |
| **Wetland Nourishment** | | | | | | | |
| Contracts | 6 | 5 | 3 | 7 | 5 | 5 | |
| CY (Bid) | 11,981,217 | 17,216,652 | 8,043,672 | 24,625,065 | 11,166,205 | 20,044,509 | |
| Dollars (Bid) | $35,522,649 | $72,274,720 | $28,019,609 | $66,980,352 | $64,530,384 | $80,364,728 | |
| **Cost/CY** | **$2.96** | **$4.20** | **$3.48** | **$2.72** | **$5.78** | **$4.01** | **$3.74** |
| **Upland** | | | | | | | |
| Contracts | 15 | 20 | 16 | 30 | 31 | 15 | |
| CY (Bid) | 10,087,701 | 5,887,385 | 13,707,000 | 28,653,756 | 26,294,325 | 17,152,710 | |
| Dollars (Bid) | $63,775,027 | $109,524,952 | $57,605,889 | $167,529,321 | $262,912,380 | $121,514,053 | |
| **Cost/CY** | **$6.32** | **$18.60** | **$4.20** | **$5.85** | **$10.00** | **$7.08** | **$7.69** |

Source: USACE, Navigation DataCenter 2016.

Key:
CY = cubic yard

**Table 3.3.2-16 Dredge Requirements at Federal Harbors in Selected Watersheds in the Great Lakes and Possible Suitability for Hydrilla Infestation**

| Harbor | Type of Harbor | Amount of Material Dredged (in CY) | Frequency of Dredging | Last Year Dredged | Water Depth (in feet) | Suitable Habitat for Hydrilla[a] |
|---|---|---|---|---|---|---|
| **Southeastern Lake Ontario Watershed** | | | | | | |
| Rochester Harbor | Deep draft commercial harbor | 220,000 | 2 years | 2014 | 21-24 | Yes |
| Irondequoit Harbor | Shallow draft recreational | Channel - 15,000<br>Harbor – 22,000 | 5-10 years | 2015 | 8-9 | Yes |
| Great Sodus Bay | Deep draft recreational | 42,500 | As needed | 2004 | 10-22 | Yes |
| Little Sodus Bay | Deep draft recreational | 12,000 | As needed | 2005 | 8-15.5 | Yes |
| Oswego | Deep draft commercial | Channel - 72,000<br>Harbor – 175,000 | 3-4 years | 2016 | 21-27 | Yes |
| Port Ontario | Shallow draft recreational | NA | NA | NA | 6-8 | Yes |
| Sackets Harbor | Shallow draft recreational | NA | NA | NA | NA | Yes |
| **Eastern Lake Erie Watershed** | | | | | | |
| Little River/Niagara River Harbor | Shallow draft recreational | 10,000 | As needed | 1988 | 8 | Yes |
| Black Rock Lock/Tonawanda Harbor | Deep draft commercial | 115,000 | As needed | 2009 | 16-21 | Yes |
| Buffalo Harbor | Deep draft commercial | 140,000 | 2 years | 2015 | 22-30 | Yes |
| Sturgeon Point Harbor | Shallow draft commercial/ recreational | NA | As needed | 2005 | 4-8 | Yes |
| Cattaraugus Creek Harbor | Shallow draft recreational | 0 | As needed | 1983 | 6-8 | Yes |
| Dunkirk Harbor | Deep draft commercial/ recreational | 106,000 | 2 years | 2009 | 16-17 (commercial)<br>6-8 (recreational) | Yes |
| Barcelona Harbor | Shallow draft recreational | 71,000 | 5-10 years | 2014 | 8-10 | Yes |
| Erie Harbor | Deep draft commercial | 285,000 | As needed | 2016 | 18-29 | Yes |
| Conneaut Harbor | Deep draft commercial | 120,000 | 2-3 years | 2016 | 22-29 (harbors)<br>8 (access channel) | Yes |
| Ashtabula Harbor | Deep draft commercial | 100,000 | 2-3 years | 2015 | 16-30 | Yes |

**Table 3.3.2-16 Dredge Requirements at Federal Harbors in Selected Watersheds in the Great Lakes and Possible Suitability for Hydrilla Infestation**

| Harbor | Type of Harbor | Amount of Material Dredged (in CY) | Frequency of Dredging | Last Year Dredged | Water Depth (in feet) | Suitable Habitat for Hydrilla[a] |
|---|---|---|---|---|---|---|
| **Southern Lake Erie Watershed** | | | | | | |
| Fairport Harbor | Deep draft commercial | 150,000 | 1-2 years | 2016 | 18-25 | Yes |
| Cleveland Harbor | Deep draft commercial | 225,000 | Every year | 2016 | 18-29 | Yes |
| Rocky River Harbor | Shallow draft recreational | 45,000 | 3-4 years | 2004 | 6-10 | Yes |
| Lorain Harbor | Deep draft commercial | 200,000 | 3 years | 2016 | 17-29 | Yes |
| **Western Lake Erie Watershed** | | | | | | |
| Vermilion Harbor | Shallow draft recreational | 32,000 | 2-3 years | 2004 | 8-12 | Yes |
| Huron Harbor | Deep draft commercial | 190,000 | 1-2 years | 2016 | 21-29 | Yes |
| Sandusky Harbor | Deep draft commercial | 140,000 | Each year | 2016 | 21-26 | Yes |
| West Harbor | Shallow draft recreational | 48,000 | As needed | 2004 | 8-10 | Yes |
| Port Clinton Harbor | Shallow draft recreational | NA | NA | NA | 10 | Yes |
| Toussaint River | Shallow draft recreational | 24,000 | 3-4 years | 2004 | 4 | Yes |
| Cooley Canal Harbor | Shallow draft recreational | 10,000 | 5-10 years | 2004 | 4 | Yes |
| Toledo Harbor | Deep draft commercial | 850,000 | Each year | 2016 | 25-27 | No |
| Bolles Harbor | Shallow draft recreational | 20,000 | 3-5 years | 2010 | 6-8 | Yes |
| Monroe Harbor | Deep draft commercial | 90,000 to 135,000 | 1-2 years | 2016 | 18-21 | Yes |
| **Southwestern Lake Huron Watershed** | | | | | | |
| Lexington Harbor | Shallow draft recreational | 20,000 to 30,000 | 3-5 years | 2014 | 8-10 | Yes |
| Port Sanilac Harbor | Shallow draft recreational | 10,000 | 3-5 years | 2010 | 6-12 | Yes |
| Harbor Beach Harbor | Deep draft commercial | 65,000 to 130,000 | 5-10 years | 2010 | 21-23 | Yes |
| Port Austin Harbor | Shallow draft recreational | 15,000 | 10-15 years | 2010 | 10-12 | Yes |
| Caseville Harbor | Shallow draft recreational | 10,000 to 18,000 | 3-5 years | 2009 | 8-10 | Yes |
| Bay Port Harbor | Shallow draft recreational | NA | 8-12 years | 2011 | 6 | Yes |
| Sebewaing River Harbor | Shallow draft recreational | 9,000 to 15,000 | 3-5 years | 2014 | 8 | Yes |

**Table 3.3.2-16 Dredge Requirements at Federal Harbors in Selected Watersheds in the Great Lakes and Possible Suitability for Hydrilla Infestation**

| Harbor | Type of Harbor | Amount of Material Dredged (in CY) | Frequency of Dredging | Last Year Dredged | Water Depth (in feet) | Suitable Habitat for Hydrilla[a] |
|---|---|---|---|---|---|---|
| Saginaw River | Deep draft commercial | 180,000 | 1 year | 2017 | 20-27 | Yes |
| Point Lookout Harbor | Shallow draft recreational | 20,000 | 5-6 years | 2014 | 6-10 | Yes |
| **Southwestern Lake Michigan** | | | | | | |
| New Buffalo Harbor | Shallow draft recreational | 10,000 | 1-2 years | 2017 | 8-10 | Yes |
| Michigan City Harbor | Shallow draft recreational[1] | 55,000 | 6-8 years | 2013 | 10-15 | Yes |
| Burns Waterway Small Boat Harbor | Shallow draft recreational | NA | NA | 2013 | 6-11 | Yes |
| Burns Waterway Harbor | Deep draft commercial | 86,000 | 1 year | 2017 | 27-30 | No |
| Indiana Harbor | Deep draft commercial | 260,000 | As needed | 2016 | 22-29 | Yes |
| Calumet Harbor | Deep draft commercial | NA | NA | 2016 | 27-29 | No |
| Chicago Harbor | Deep draft commercial | NA | NA | NA | 21-29 | Yes |

Source: USACE, Great Lakes Navigation System 2017.

Note:
[a] Habitat suitability is based on physical geography, likely wave action, and water depth.

Key:
CY = cubic yard
NA = data not available

In a typical year, the USACE ERDC removes approximately 3.3 million CY of dredge material from federally designated harbors throughout the Great Lakes. As illustrated on Table 3.3.2-17 most of the harbors in the representative watersheds have physical characteristics that could support the establishment and spread of Hydrilla if the species were introduced. In an effort to quantify the potential economic ramifications of this occurrence, three scenarios were developed that assumed 25%/50%/75% of all dredge material removed from the Great Lakes were contaminated with Hydrilla. Table 3.3.2-17 provides estimates of the annual costs associated with dredge disposal under each of these scenarios for both minimum and maximum cost differentials.

**Table 3.3.2-17 Estimated Annual Increased Dredge Disposal Costs in the Great Lakes Caused by Potential Hydrilla Infestation by Scenario**

| | Low Scenario (25% Hydrilla Infestation) | | Medium Scenario (50% Hydrilla Infestation) | | High Scenario (75% Hydrilla Infestation) | |
|---|---|---|---|---|---|---|
| Average Annual Volume of Dredge Material Removed | 3,300,000 | | 3,300,000 | | 3,300,000 | |
| Amount of Dredge Material Contaminated with Hydrilla | 825,000 | | 1,650,000 | | 2,475,000 | |
| | **Minimum** | **Maximum** | **Minimum** | **Maximum** | **Minimum** | **Maximum** |
| Cost Differential for Dredge Disposal | $2.76 | $3.95 | $2.76 | $3.95 | $2.76 | $3.95 |
| Estimated Annual Increased Costs | $2,277,000 | $3,258,750 | $4,554,000 | $6,517,500 | $6,831,000 | 9,776,250 |

As shown in the table, estimated annual dredge disposal costs incurred by the USACE ERDC would increase by between $2.2 million under the low scenario minimum cost differential to $9.8 million under the high scenario maximum cost differential. These figures only reflect cost increases incurred by the USACE ERDC. If costs incurred by local and state governments and commercial and private entities were included, the potential annual increase in dredge disposal costs associated with a Hydrilla infestation of the Great Lakes would be substantially greater.

### 3.3.2.6 Water Supply/Electric Power Generation

Surface water from the Great Lakes supplies public water systems, commercial and institutional users, livestock operations, industrial facilities, and thermoelectric and hydroelectric power plants throughout the region. In 2014 a total of 146.0 billion gallons a day were withdrawn from the Great Lakes for various uses in the United States. Table 3.3.2-18 provides a breakdown of Great Lakes' surface water usage by category and by state. As shown on the table, electric power production was the largest single use of water in the Great Lakes. In 2014, approximately 127.2 million gallons of water a day were used for hydroelectric production at the Niagara Power Project in Niagara Falls, New York. No other major hydroelectric facility is located in the Great Lakes system (see Table 3.3.2-18).

Collectively, thermoelectric power production is another large use of surface water in the Great Lakes. In 2014 approximately 13.6 million gallons of water a day were withdrawn from the Great Lakes for thermoelectric production. These withdrawals amount to approximately 72.4 percent of the remainder of U.S. total water usage in the Great Lakes, less the water withdrawn for the Niagara Power Project. Public water supply systems and industrial users are the next largest users of surface water from the Great Lakes. In 2014 approximately 2.7 million gallons of water a day were withdrawn for potable water sources. Industrial applications utilized an additional 2.2 million gallons of water a day (see Table 3.3.2-18).

**Table 3.3.2-18 2014 Great Lakes Surface Water Use Data by Category**

| Use Category | New York | Pennsylvania | Ohio | Michigan | Illinois |
|---|---|---|---|---|---|
| | (expressed in millions of gallons per day) | | | | |
| Public Water Supply | 294 | 28 | 402 | 776 | 873 |
| Commercial and Institutional | 0 | 0 | 0 | 0 | 2 |
| Livestock | 0 | 0 | 0 | 0 | 0 |
| Industrial | 159 | 3 | 51 | 320 | 28 |
| Thermoelectric Power Production | 1,824 | 0 | 932 | 6,866 | 460 |
| Hydroelectric Power Production | 127,204 | 0 | 0 | 0 | 0 |
| Other | 0 | 0 | 1 | 0 | 248 |
| **Total** | **129,481** | **31** | **1,386** | **7,964** | **1,611** |

| Use Category | Minnesota | Wisconsin | Indiana | Total United States |
|---|---|---|---|---|
| | (expressed in millions of gallons per day) | | | |
| Public Water Supply | 29 | 241 | 91 | 2,734 |
| Commercial and Institutional | 1 | 1 | 0 | 4 |
| Livestock | 1 | 0 | 0 | 1 |
| Industrial | 125 | 0 | 1,525 | 2,211 |
| Thermoelectric Power Production | 172 | 3,147 | 224 | 13,625 |
| Hydroelectric Power Production | 0 | 0 | 0 | 127,204 |
| Other | 0 | 5 | 0 | 254 |
| **Total** | **327** | **3,394** | **1,840** | **146,033** |

Source: Great Lakes Commission 2017.

Note: Tables may not sum due to rounding.

In 2010, in the Southeast Lake Ontario watershed, a total of 813,887 residents in Monroe, Wayne, Cayuga, Oswego, and Jefferson counties were served by public water systems and had surface water as their source of potable water (USEPA 2014). The majority of this surface water was directly collected from water intakes on Lake Ontario. Likewise, in 2010 approximately 1.3 million residents in the Eastern Lake Erie watershed, 1.9 million residents in the Southern Lake Erie watershed, and 550,000 residents in the Western Lake Erie watershed were served by public water systems that had surface water as their source of potable water (USEPA 2014). The majority of this surface water was directly collected from water intakes on Lake Erie. No information on surface water usages in the Southwestern Lake Huron watershed or the Southwestern Lake Michigan watersheds were available from this source.

### Impacts of Hydrilla

While introduction and establishment of Hydrilla in the Great Lakes would not affect the quality of the water supply, it would likely affect the operating costs of these water users. Water intakes and water cribs located in less than 25 feet of water in embayments and inlets where Hydrilla is capable of becoming established would be the most directly affected. Hydrilla has been known to grow into thick enough mats to reduce water flow into water intakes and cribs, thereby reducing productivity and increasing operations and maintenance expenses. Costs associated with removal of the plants would be a recurring operations cost borne by water users. No estimates were found for the additional operational and maintenance costs associated with plant removal.

Potential impacts on water intakes and cribs are not restricted to areas that only have environments that are conducive for the establishment of Hydrilla. The presence of Hydrilla mats located upstream have been reported to impact downstream water intakes. In fact there are reported incidences where mats of Hydrilla have forced the closure of water intakes and hydroelectric plants.

In 1989, large mats of Hydrilla broke loose upstream of two hydroelectric turbines at the Guntersville Dam in a Tennessee Valley Authority system after heavy rain and flood discharges. The mats clogged water intakes and forced a shutdown of the turbines. The Hydrilla mats then floated farther downstream and blocked water intakes at the Wheeler Dam. Total economic damages were estimated to be approximately $170,000 ($350,000 expressed in 2017 dollars) in lost power production (NCSU 2017). While this example involves a river, or flowing water, environment, it does indicate the potential for Hydrilla control structures to be deployed and subsequently disturbed by, for example, wave energy, causing additional rounds of installation or the need for addressing the local infestation in a different way. The consequence would be additional costs.

In 1991 the St. Stephen Hydroelectric Power Station, downstream of Lake Moultrie and upstream of Santee River, was similarly impacted by Hydrilla when a mat of Hydrilla floated into the station's water intakes and clogged the turbines. After discharging large quantities of shredded Hydrilla into the Santee River, the turbines became clogged and shut down. The loss of water flow resulted in the largest fish kill in the history of South Carolina (Kirk and Henderson 2006). The powerhouse operations were shut down for seven weeks after the incident. The USACE ERDC estimated the resulting economic damage associated with the loss of electricity production to be approximately $2 million ($3.67 million expressed in 2017 dollars), while repair costs, dredging and fish loss resulted in an additional $2.65 million ($4.86 million expressed in 2017 dollars) in expenses (Balciunas et al. 2002).

As a result of these incidents, several large utility companies actively conduct or contribute to Hydrilla control measures upstream of their facilities. For example, Duke Energy Corporation has been financing various Hydrilla control measures in the Catawba River Basin, including the release of triploid grass carp into Lake Emory and in Lake Wylie as a biological control for Hydrilla (*Charlotte Observer* 2015). Dominion Energy has been supporting similar efforts in Lake Gaston in Virginia and North Carolina. In addition, Duke Energy Corporation, Gastonia Water Supply, and the Charlotte Mecklenburg Utilities Department are partnering with state and local entities to combat Hydrilla in Lake Norman and the Mountain Island Lake on the Catawba River. Management activities include the early detection of Hydrilla, early use of herbicides for plant suppression, and the initial stocking of triploid grass carp, as well as continued maintenance stocking of the triploid grass carp (North Carolina Aquatic Nuisance Species Management Plan Committee 2015).

### Quantity of Water Intakes and Power Plants Potentially Affected

In an effort to provide ROM estimates for the number and type of water intakes that may be affected by the potential establishment of Hydrilla in the Great Lakes, several representative watersheds were analyzed in greater detail.

Based on information collected from U.S. Coast Guard navigation charts, there are 98 potable water intakes located in the nearshore portion of Lake Ontario, Lake Erie, Lake Huron, and Lake Michigan in the six representative watersheds. In addition, there are nine nuclear power plant water intakes, eight steam power/hydroelectric plant water intakes, and 12 large industrial water intakes that serve various manufacturing facilities in these watersheds. The majority of the water intakes located in the Lake Ontario and Lake Michigan are either located in water too deep for Hydrilla or in areas that are not conducive for its establishment in terms of physical geography and/or potential for wave action. In contrast, water intakes in the Lake Erie and Lake Huron watersheds are more likely to be located in shallow waters and in places where there is physical geography conducive for the establishment of Hydrilla (see Table 3.3.2-19).

**Table 3.3.2-19 Water Intakes, Water Depth, and Likelihood of Hydrilla Conducive Environment for Selected Watersheds in the Great Lakes**

| Type of Water Intake | Water Depth in Feet | Suitable Hydrilla Habitat[a] |
|---|---|---|
| **Southeast Lake Ontario Watershed** | | |
| Potable Water Intake – Irondequoit | 41 | No |
| Potable Water Intake – Irondequoit | 46 | No |
| Potable Water Intake – Irondequoit | 29 | No |
| R.E. Ginna Nuclear Power Plant Tunnel/Intake | 29 | No |
| Potable Water Intake – Town of Ontario | 33 | No |
| Potable Water Intake – Town of Ontario | 20 | No |
| Potable Water Intake – Pultneyville | 19 | No |
| Potable Water Intake – Pultneyville | 13 | No |
| Potable Water Intake – Sodus Point | 8 | No |
| Potable Water Intake – Port Bay | 11 | Yes |
| Potable Water Intake – Oswego | 58 | No |
| Oswego Harbor Power Plant – Niagara Mohawk Steam Power Plant Submerged Cribs | 20 | Yes |
| Oswego Harbor Power Plant – Niagara Mohawk Steam Power Plant Submerged Cribs | 18 | Yes |
| Novelis (Aluminum Manufacturer) Water Intakes | 12 | No |
| James Fitzpatrick Nuclear Plant Water Intakes | 18 | No |
| Nine Mile Point Nuclear Plant Water Intakes | 21 | No |
| **Eastern Lake Erie Watershed** | | |
| Water Intake (Industrial) | 7 | No |
| Robert Moses Power Plant – Water Intakes | 30 | No |
| Robert Moses Power Plant – Water Intakes | 19 | No |
| Potable Water Intakes – Niagara Falls Water Board | 14 | No |
| Potable Water Intake – Tonawanda Island | 11 | Yes |
| Potable Water Intake – Tonawanda Island | 15 | Yes |
| Potable Water Intake – Tonawanda Island | 13 | Yes |
| Potable Water Intake – Erie County Water Authority | 11 | Yes |
| Potable Water Intake – Erie County Water Authority: Strawberry Island | 19 | No |
| Potable Water Intake – Buffalo | 13 | Yes |
| Potable Water Intake – Buffalo | 15 | Yes |
| Potable Water Intake – Buffalo | 15 | Yes |
| Potable Water Intake – Grand Island | 13 | No |
| Potable Water Intake – Buffalo | 17 | Yes |
| Potable Water Intake – Lackawanna | 17 | No |
| Potable Water Intake – Lackawanna | 17 | No |
| Potable Water Intake – Wanakah | 2 | No |
| Potable Water Intake – Pinehurst | 2 | No |
| Potable Water Intake – Sturgeon Point | 24 | Yes |
| Potable Water Intake – Dunkirk | 22 | No |
| Potable Water Intake – Presque Isle | 22 | Yes |

**Table 3.3.2-19 Water Intakes, Water Depth, and Likelihood of Hydrilla Conducive Environment for Selected Watersheds in the Great Lakes**

| Type of Water Intake | Water Depth in Feet | Suitable Hydrilla Habitat[a] |
|---|---|---|
| **Southern Lake Erie Watershed** | | |
| Potable Water Intake – Ashtabula | 20 | No |
| Potable Water Intake – Ashtabula | 18 | No |
| Potable Water Intake – Redbird | 15 | No |
| Water Intakes – Perry Nuclear Generating Station | 12 | Yes |
| Water Intakes – Perry Nuclear Generating Station | 12 | Yes |
| Potable Water Intake – Perry | 29 | No |
| Water Intake – Plastic Fabrication Company | 11 | No |
| Potable Water Intake – Fairport Harbor | 16 | Yes |
| Potable Water Intake – Fairport Harbor | 11 | No |
| Potable Water Intake – Mentor-on the- Lake | 14 | No |
| Potable Water Intake – Cleveland Harbor | 29 | No |
| Potable Water Intake – Cleveland Harbor | 28 | No |
| Potable Water Intake – Avon Point | 20 | No |
| Water Intakes – NRG Energy Avon Lake | 5 | Yes |
| Potable Water Intake – Lorain | 12 | Yes |
| Potable Water Intake – Elyria Water Works | 13 | No |
| **Western Lake Erie Watershed** | | |
| Potable Water Intake – Vermillion | 8 | No |
| Potable Water Intake – Huron | 11 | No |
| Potable Water Intake – Fairview Lanes | 16 | No |
| Potable Water Intake – Sandusky | 16 | No |
| Water Intake – US Gypsum | 5 | No |
| Potable Water Intake – Marblehead | 8 | No |
| Potable Water Intake – Lakeside | 8 | No |
| Potable Water Intake – Port Clinton | 6 | Yes |
| Potable Water Intake – Port Clinton | 8 | Yes |
| Potable Water Intake – Kelleys Island | 8 | Yes |
| Potable Water Intake – South Bass Island | 11 | No |
| Potable Water Intake – South Bass Island | 18 | No |
| Potable Water Intake – Camp Perry | 9 | No |
| Water Intake – Davis-Besse Nuclear Power Station | 6 | No |
| Water Intake – Davis-Besse Nuclear Power Station | 6 | No |
| Potable Water Intake – Reno Beach | 8 | No |
| Potable Water Intake – Reno Beach | 17 | No |
| Bay Shore Petroleum Coke Power Plant | 3 | No |
| J. R Whiting Generating Plant | NA | Yes |
| Intake Canal – DTE Energy | NA | Yes |
| Potable Water Intake – Stony Point | 14 | No |
| Water Intakes – Fermi Nuclear Power Plant | 5 | No |

**Table 3.3.2-19 Water Intakes, Water Depth, and Likelihood of Hydrilla Conducive Environment for Selected Watersheds in the Great Lakes**

| Type of Water Intake | Water Depth in Feet | Suitable Hydrilla Habitat[a] |
|---|---|---|
| **Southwestern Lake Huron Watershed** | | |
| Potable Water Intakes – Lambton WTP | 38 | No |
| Potable Water Intakes – Lambton WTP | 38 | No |
| Potable Water Intakes – Lambton WTP | 38 | No |
| Potable Water Intakes – Detroit Water and Sewer | 38 | No |
| Water Intake (non-specified) – Lexington Harbor | 13 | No |
| Potable Water Intake – Harbor Beach | 19 | Yes |
| Potable Water Intake – Harbor Beach | 18 | Yes |
| Potable Water Intake – Port Hope | 3 | Yes |
| Potable Water Intake – Pointe aux Barques | 7 | No |
| Potable Water Intake – Point Austin | 9 | No |
| Potable Water Intake – Caseville | 4 | No |
| Potable Water Intake – Bay City | 11 | Yes |
| Potable Water Intake – Bay City | 3 | Yes |
| Potable Water Intake – Pinconning | 4 | Yes |
| Potable Water Intake – Whitestone Point | 36 | No |
| Potable Water Intake – Alabaster | 10 | No |
| Potable Water Intake – Tawas City | 9 | Yes |
| Potable Water Intake – East Tawas | 20 | No |
| **Southwestern Lake Michigan Watershed** | | |
| Potable Water Intake – Benton Harbor | 23 | No |
| Potable Water Intake – Benton Harbor | 13 | No |
| Potable Water Intake – Benton Harbor | 13 | No |
| Potable Water Intake – Benton Harbor | 13 | No |
| Water Intake – DC Cook Nuclear Power Plant | 11 | No |
| Potable Water Intake – Bridgman | 26 | No |
| Potable Water Intake – New Buffalo | 25 | No |
| Potable Water Intake – Grand Beach | 6 | No |
| Potable Water Intake – Long Beach | 14 | No |
| Potable Water Intake – Michigan City | 25 | No |
| Potable Water Intake – Michigan City | 29 | No |
| Potable Water Intake – Michigan City | 29 | No |
| NIPSO Michigan City Generating Plant Intakes | NA | Yes |
| Water Intakes – Steel Manufacturer | 37 | No |
| Water Intakes – Steel Manufacturer | 33 | No |
| Water Intake – Baily Generating Station[b] | 18 | Yes |
| Water Intake – Steel Manufacturer | 25 | No |
| Potable Water Intake – Burns Harbor | 16 | No |
| Potable Water Intake – Gary | 31 | No |
| Potable Water Intake – Gary | 32 | No |
| Water Intake -Steel Manufacturer | 34 | No |
| Water Intake -Steel Manufacturer | 28 | No |

**Table 3.3.2-19 Water Intakes, Water Depth, and Likelihood of Hydrilla Conducive Environment for Selected Watersheds in the Great Lakes**

| Type of Water Intake | Water Depth in Feet | Suitable Hydrilla Habitat[a] |
|---|---|---|
| Potable Water Intake – East Chicago | 26 | No |
| Potable Water Intake – Indian Harbor | 12 | No |
| Potable Water Intake – Indian Harbor | 14 | No |
| Potable Water Intake – Indian Harbor | 12 | No |
| Potable Water Intake – Hammond | 22 | No |
| Potable Water Intake – Hammond | 16 | No |
| Potable Water Intake – Hammond | 14 | No |
| Water Intakes – Detergent Manufacturer | 13 | No |
| Potable Water Intake – South District | 30 | No |
| Potable Water Intake – Jardine Water Purification Plant | 36 | No |
| Potable Water Intake - Evanston | 20 | No |
| Potable Water Intake - Evanston | 25 | No |
| Potable Water Intake - Evanston | 20 | No |

Sources: NOAA, Office of Coast Survey 2017a-aa.

Notes:
[a] Habitat suitability was determined based on physical geography, likely wave action, and water depth.
[b] Baily Power Station is scheduled to close in 2018.

If Hydrilla were to become established in the Great Lakes, water intakes in Lake Erie and Lake Huron would be more likely to be directly affected by vegetation growing near the intakes. Operations and maintenance costs would likely increase around the affected intakes as plant material would need to be removed periodically to avoid decreases in water flow and the potential clogging of intake machinery. Hydrilla control methods around the potable water intake would be limited to manual, mechanical, or biological control methods. Chemical methods would be avoided due to the fear of contamination of the drinking water. While the exact incremental maintenance and operations costs associated with managing Hydrilla around water intakes are currently unknown, it is anticipated that these costs will be similar to the costs associated with treating Hydrilla-infested waters. See Section 3.3.2.7 for a review of per acre treatment costs for various treatment programs throughout the United States.

While only 32 intakes of the total 127 intakes located in the six representative watersheds would likely be affected by localized Hydrilla growth, all of the water intakes in the watersheds have the potential to be affected by Hydrilla mats located throughout the Great Lakes and its tributaries. Hydrilla mats/rafts grown in other parts of the watershed could migrate to the water intakes via current, wind, or wave action. Without some sort of Hydrilla control measures, all of these facilities could be affected by a potential establishment in the watershed.

No estimates have been made for the economic value associated with potential damage and loss of production caused by Hydrilla mats/rafts in water intakes due to the paucity of case study data and the wide variability of potential impacts. However, while these incidents are rare, when they do occur they could represent significant economic losses.

In order to mitigate the risks associated with this potential loss, water intake operators will likely have to fund some type of Hydrilla eradication/control program. Costs associated with various types of Hydrilla treatment projects are described in more detail in Section 3.3.2.7.

#### 3.3.2.7 Treatment Costs

As described in Sections 3.3.2.2 to 3.3.2.6, the loss of economic value associated with the possible introduction and establishment of Hydrilla in the Great Lakes would be significant. By comparison, the costs of controlling any initial infestation would be far less costly. Table 3.3.2-20 provides a list of treatment costs both annually and per acre for various ongoing Hydrilla abatement programs. As shown on the table, there is substantial variation in treatment costs per acre. The extent of infestation, characteristics of the area affected, and the type of treatment selected all have an impact on the overall cost of the project as well as the cost of treatment per acre. Eradication programs are initially much more expensive than maintenance only programs. However, if effective, the eradication programs are less costly in the long run.

The first five abatement programs shown on Table 3.3.2-20 are projects located within the Great Lakes basin. These projects are all eradication programs that utilize some form of herbicide treatment. As shown on the table, the treatment costs per acre range from a low of $306.94 per acre for Lake Manitou in Fulton County, Indiana, in 2011 to a high of $2,162.00 per acre for treatment of Sonar H4C in Fall Creek, Thompkins County, New York, in 2016. Sonar H4C treatment costs per acre in Fall Creek were greater for the 2015 efforts; however, these figures were skewed by the inclusion of overall project management costs and overstate the costs of treatment (see Table 3.3.2-20).

The five abatement programs shown on Table 3.3.2-20 located in Florida where maintenance, not eradication, is the treatment goal, show a different cost structure than those in the Great Lakes basin. As anticipated, annual per acre treatment costs are significantly less for these maintenance programs than the eradication programs. As shown on the table, annual per acre maintenance costs range from $16.92 in the Suwannee District in 2009 to $1,326.97 in the same district during 2013 (see Table 3.3.2-20).

As illustrated in many of the Florida districts shown on Table 3.3.2-20 when eradication is not achieved, years when the total acres treated and total annual abatement costs decline are typically followed by years when the total acres treated and the total annual abatement costs significantly increase. For example, in the South Florida District in 2014 approximately 6,300 acres were treated at an annual cost of $3.7 million. In 2015 only 4,200 acres were treated for an annual cost of almost $2.0 million. By 2016 more than 8,700 acres had to be treated at an annual cost of $4.5 million (see Table 3.3.2-20). This trend is mirrored throughout the various abatement projects. If funding and treatment areas are reduced before the species is under control, Hydrilla typically becomes more firmly established and spreads farther, thereby increasing future treatment areas and future treatment costs. Therefore, the larger long-term future costs more than offset any short-term cost savings associated with treating less area before Hydrilla is under control.

As shown on the table, per acre costs for biological control tend to be substantially less than chemical treatment costs. While studies have shown that biological control is a very effective management tool, there is an initial lag time of a few years between the introduction of grass carp and the reduction in Hydrilla growth. During this initial lag time Hydrilla can spread and become established in larger areas. Typically triploid grass carp are initially stocked at 20 fish per acre of Hydrilla established surface waters. Annual restocking typically is done at a rate of eight fish per acre of surface water. Prices for sterilized grass carp greater than 10 inches long currently range between $10 and $20 per fish. Therefore, excluding program monitoring, oversight and management costs, in the initial year it typically costs between $200 to $400 an acre to stock tripoloid grass carp in Hydrilla infested areas. Subsequently, costs drop to $80 to $160 per acre for maintenance stocking levels, assuming no contamination of the grass carp population by diploid, or sexually reproducing, individuals.

**Table 3.3.2-20 Treatment Costs for Selected Hydrilla Abatement Programs**

| Type of Treatment | Year | Acres Treated | Cost per Acre | Annual Cost |
|---|---|---|---|---|
| **Tonawanda Creek – Tonawanda, New York** | | | | |
| Herbicide – Full treatment | 2014 | 214.00 | $736.82 | $157,679 |
| Herbicide – Spot treatment | 2014 | 26.00 | $1,102.30 | $28,660 |
| Herbicide – Full and Spot treatment | 2015 | 185.00 (full)<br>0.009 (spot) | $905.38 | $167,504 |
| Herbicide – Full and Spot treatment | 2016 | 129.90 (full)<br>0.10(spot) | $863.55 | $112,262 |
| **Total Costs (2014 to 2016)** | | | | **$466,105** |
| **Cleveland Metro Parks – Cleveland, Ohio** | | | | |
| Herbicide Treatment<br>(Reward and Cutrine Plus) | 2011 | 18.74 | NA | $39.10* |
| Herbicide Treatment<br>(Reward and Cutrine Plus) | 2012 | 18.74 | NA | $2,794* |
| Herbicide Treatment<br>(SonarOne, Galleon, and FasTEST) | 2013 | 28.08 | NA | $12,820* |
| Herbicide Treatment<br>(SonarOne, Galleon, and FasTEST) | 2014 | 30.58 | NA | $14,449* |

**Table 3.3.2-20 Treatment Costs for Selected Hydrilla Abatement Programs**

| Type of Treatment | Year | Acres Treated | Cost per Acre | Annual Cost |
|---|---|---|---|---|
| Herbicide Treatment | 2015 | 30.58 | $1,169.34 | $35,575 |
| Herbicide Treatment | 2016 | 30.58 | $1,094.67 | $33,475 |
| **Total Costs (2011 to 2016)** | | | | **$99,152** |
| **Cayuga Lake Inlet Canal – Thompkins County, New York[a]** | | | | |
| Herbicide Treatment (Sonar Genesis and Sonar One) | 2014 | 92.00 | $1,145.00 | $105,340 |
| Herbicide Treatment (via boat) (Aquathol k) | 2014 | 92.00 | $1,079.00 | $99,268 |
| Herbicide Treatment (Sonar Genesis and Sonar One) | 2015 | 92.00 | $1,435.00 | $132,020 |
| Herbicide Treatment (via boat) (Aquathol k) | 2015 | 92.00 | $1,122.00 | $103,224 |
| Herbicide Treatment (Sonar Genesis and Sonar One) | 2016 | 92.00 | $1,228.00 | $112,976 |
| **Total Costs (2014 to 2016)** | | | | **$552,828** |
| **Fall Creek – Thompkins County, New York[b]** | | | | |
| Herbicide Treatment (via boat) (Aquathol k) | 2014 | 22.00 | $838.00 | $18,436 |
| Herbicide Treatment (Sonar H4C) | 2015 | 4.40 | $3,992.00[2] | $17,564 |
| Herbicide Treatment (via boat and injection) (Aquathol k) | 2015 | 16.00 | $1,063.00 | $17,008 |
| Herbicide Treatment (via boat and injection) (Aquathol k) | 2016 | 24.00 | $1,375.00 | $33,000 |
| Herbicide Treatment (Sonar H4C) | 2016 | 5.50 | $2,162.00 | $11,891 |
| **Total Costs (2014 to 2016)** | | | | **$97,899** |
| **Lake Manitou – Fulton County, Indiana[c]** | | | | |
| Herbicide Treatment (Sonar AS and Sonar Q) | 2007 | 809.00 | $432.53 | $349,920 |
| Herbicide Treatment (Sonar AS and Sonar PR) | 2008 | 809.00 | $392.52 | $317,549 |
| Herbicide Treatment (Sonar AS and Sonar PR) | 2009 | 809.00 | $435.04 | $351,949 |
| Herbicide Treatment (Sonar AS and Sonar PR) | 2010 | 809.00 | $331.37 | $268,076 |
| Herbicide Treatment (Sonar AS and Sonar PR) | 2011 | 809.00 | $306.94 | $248,315 |
| Herbicide Treatment (Sonar AS and Sonar PR) | 2012 | 809.00 | $331.39 | $268,094 |
| Herbicide Treatment (Sonar AS and Sonar PR) | 2013 | 592.00 | $505.44 | $299,219 |

**Table 3.3.2-20 Treatment Costs for Selected Hydrilla Abatement Programs**

| Type of Treatment | Year | Acres Treated | Cost per Acre | Annual Cost |
|---|---|---|---|---|
| Herbicide Treatment (Sonar AS and Sonar PR) | 2014 | 423.00 | $598.24 | $253,054 |
| **Total Costs (2007 to 2014)** | | | | **$2,356,176** |
| **Northwest District – Florida[d]** | | | | |
| Not Specified – Maintenance Only | 2009 | 39.00 | $355.38 | $13,860 |
| Not Specified – Maintenance Only | 2010 | 199.00 | $61.10 | $12,158 |
| Not Specified – Maintenance Only | 2011 | 21.50 | $617.63 | $13,279 |
| Not Specified – Maintenance Only | 2012 | 92.25 | $191.77 | $17,691 |
| Not Specified – Maintenance Only | 2013 | 13.95 | $847.67 | $11,825 |
| Not Specified – Maintenance Only | 2014 | 24.55 | $395.19 | $9,702 |
| Not Specified – Maintenance Only | 2015 | 49.80 | $527.11 | $26,250 |
| Not Specified – Maintenance Only | 2016 | 273.00 | $504.10 | $137,619 |
| **Total Costs (2009-2016)** | | | | **$242,384** |
| **Suwannee District – Florida[d]** | | | | |
| Not Specified – Maintenance Only | 2009 | 85.00 | $16.92 | $1,438 |
| Not Specified – Maintenance Only | 2010 | 0.00 | $0.00 | $0 |
| Not Specified – Maintenance Only | 2011 | 258.10 | $540.33 | $139,458 |
| Not Specified – Maintenance Only | 2012 | 2,866.00 | $86.27 | $247,238 |
| Not Specified – Maintenance Only | 2013 | 9.16 | $1,326.97 | $12,155 |
| Not Specified – Maintenance Only | 2014 | 31.96 | $947.22 | $30,273 |
| Not Specified – Maintenance Only | 2015 | 0.00 | $0.00 | $0 |
| Not Specified – Maintenance Only | 2016 | 11.66 | $1,153.26 | $13,447 |
| **Total Costs (2009-2016)** | | | | **$444,009** |
| **St. Johns District – Florida[d]** | | | | |
| Not Specified – Maintenance Only | 2009 | 1,407.00 | $334.48 | $470,619 |
| Not Specified – Maintenance Only | 2010 | 4,272.00 | $727.80 | $3,109,162 |
| Not Specified – Maintenance Only | 2011 | 3,600.32 | $800.56 | $2,882,286 |
| Not Specified – Maintenance Only | 2012 | 6,065.44 | $657.72 | $3,989,386 |
| Not Specified – Maintenance Only | 2013 | 1,687.11 | $560.09 | $944,931 |
| Not Specified – Maintenance Only | 2014 | 1,057.71 | $535.53 | $566,438 |
| Not Specified – Maintenance Only | 2015 | 2,040.47 | $849.24 | $1,732,840 |
| Not Specified – Maintenance Only | 2016 | 3,027.58 | $716.08 | $2,167,993 |
| **Total Costs (2009-2016)** | | | | **$15,863,655** |
| **Southwest District – Florida[d]** | | | | |
| Not Specified – Maintenance Only | 2009 | 3,310.00 | $553.79 | $1,833,038 |
| Not Specified – Maintenance Only | 2010 | 7,692.00 | $221.78 | $1,705,901 |
| Not Specified – Maintenance Only | 2011 | 3,370.78 | $504.08 | $1,699,156 |
| Not Specified – Maintenance Only | 2012 | 4,725.78 | $428.54 | $2,025,183 |
| Not Specified – Maintenance Only | 2013 | 3,060.18 | $531.13 | $1,625,352 |
| Not Specified – Maintenance Only | 2014 | 1,621.06 | $649.50 | $1,052,871 |
| Not Specified – Maintenance Only | 2015 | 2,703.14 | $639.25 | $1,727,989 |
| Not Specified – Maintenance Only | 2016 | 3,853.57 | $553.79 | $2,237,182 |
| **Total Costs (2009-2016)** | | | | **$13,906,672** |

**Table 3.3.2-20 Treatment Costs for Selected Hydrilla Abatement Programs**

| Type of Treatment | Year | Acres Treated | Cost per Acre | Annual Cost |
|---|---|---|---|---|
| **South Florida District – Florida[d]** | | | | |
| Not Specified – Maintenance Only | 2009 | 22,969.00 | $414.77 | $9,526,826 |
| Not Specified – Maintenance Only | 2010 | 13,448.00 | $519.46 | $6,985,739 |
| Not Specified – Maintenance Only | 2011 | 12,180.75 | $569.14 | $6,932,506 |
| Not Specified – Maintenance Only | 2012 | 16,534.06 | $367.74 | $6,080,185 |
| Not Specified – Maintenance Only | 2013 | 9,381.63 | $515.33 | $4,834,617 |
| Not Specified – Maintenance Only | 2014 | 6,262.91 | $587.32 | $3,678,303 |
| Not Specified – Maintenance Only | 2015 | 4,215.11 | $474.29 | $1,999,177 |
| Not Specified – Maintenance Only | 2016 | 8,733.54 | $516.49 | $4,510,746 |
| **Total Costs (2009-2016)** | | | | **$44,548,099** |
| **Total All Florida Districts (2009-2016)** | | | | **$75,004,819** |
| **Lake Emory – Inman, South Carolina** | | | | |
| Triploid Grass Carp | 2015 | 9.00 | $273.78 | $2,464 |
| Triploid Grass Carp | 2016 | 9.00 | $97.78 | $880 |
| **Total Costs (2015-2016)** | | | | **$3,344** |
| **Lake Waccamaw – Columbus County, North Carolina** | | | | |
| Herbicide Treatment[e] (not specified) | 2013 | 608.00 | $659.54 | $401,000 |
| Herbicide Treatment[e] (not specified) | 2014 | 608.00 | $603.62 | $367,000 |
| Herbicide Treatment[e] (not specified) | 2015 | 608.00 | $822.36 | $500,000 |
| Herbicide Treatment[e] (not specified) | 2016 | 608.00 | $822.36 | $500,000 |
| **Total Costs (2013-2016)** | | | | **$1,768,000** |
| **Lake Gaston –Virginia and North Carolina** | | | | |
| Herbicide Treatment and Triploid Grass Carp | 2006[f] | 3,000.00 | $210.00 | $630,000 |
| Herbicide Treatment and Triploid Grass Carp | 2007 | 3,000.00 | $386.67 | $1,160,000 |
| Herbicide Treatment and Triploid Grass Carp | 2008 | 3,000.00 | $460.00 | $1,380,000 |
| Herbicide Treatment and Triploid Grass Carp | 2009 | 3,000.00 | $333.33 | $1,000,000 |
| Herbicide Treatment and Triploid Grass Carp | 2010 | 3,000.00 | $306.67 | $920,000 |
| Herbicide Treatment and Triploid Grass Carp | 2011 | 3,000.00 | $265.00 | $795,000 |
| Herbicide Treatment and Triploid Grass Carp | 2012 | 3,000.00 | $266.67 | $800,000 |
| Herbicide Treatment and Triploid Grass Carp | 2013 | 3,000.00 | $273.33 | $820,000 |

**Table 3.3.2-20 Treatment Costs for Selected Hydrilla Abatement Programs**

| Type of Treatment | Year | Acres Treated | Cost per Acre | Annual Cost |
|---|---|---|---|---|
| Herbicide Treatment and Triploid Grass Carp | 2014 | 3,000.00 | NA | NA |
| Herbicide Treatment and Triploid Grass Carp | 2015 | 3,000.00 | NA | NA |
| Herbicide Treatment and Triploid Grass Carp | 2016 | 3,000.00 | $286.67 | $860,000 |
| **Total Costs (2006-2016)** | | | | **$8,365,000** |

Sources: Aquatic Control Technology 2014, 2015; Solitude Lake Management 2016; Weldon 2017; Sullivan 2017; Florida Fish and Wildlife Conservation Commission 2017 (a-h); North Carolina Aquatic Nuisance Species Management Committee 2015; Lake Gaston Weed Control Council 2016; SePRO Corporation et al. 2015.

Notes:

* Cost estimates for Cleveland MetroParks from 2011 to 2014 do not include labor costs for application and mobilization.

[a] Costs estimates for the Cayuga Lake Inlet Canal and the Fall Creek project are based on “median” flow rates, which are not necessarily the actual flow or cost of the application.
[b] Costs estimates for 2015 Sonar H4C application at Fall Creek included some overall project support costs. Therefore, unit costs are higher for this component compared to other similar applications.
[c] 2015 and 2016 cost estimates were not available for Lake Manitou.
[d] Cost estimates for Hydrilla control in the state of Florida are for the fiscal year ending June 30 of the stated year.
[e] Costs do not include an additional $15,000 for associated field work including surveys and monitoring activities. 2015 and 2016 costs figures are estimates, not actual expenditures. Management costs are expected to continue to be incurred until at least 2020.
[f] Cost figures for Lake Gaston are for fiscal years. Therefore, the 2006 figure is for the 2005-2006 fiscal year. All figures are approximate. Data for 2014 to 2015 were not readily available.

#### 3.3.2.8 Summary

As described in the previous sections, the introduction and establishment of Hydrilla into the Great Lakes watershed would generate a significant negative economic impact on individuals and local, regional, and national economies. The negative economic impacts would include both additional costs that would be incurred as a result of the establishment of Hydrilla, such as increased dredge disposal costs and costs associated with the removal of Hydrilla from water intakes, and the loss of well-being or loss of utility associated with decreased enjoyment from recreational activities, such as fishing, boating, and beach use on the Great Lakes. As shown in Table 3.3.2-21, the economic loss associated with the impacts on recreational fishing, beach use, recreational boating, and commercial navigation are expected to range between $70 and $500 million annually if Hydrilla were to become established in the Great Lakes. No estimates were made for the increased maintenance costs needed to control Hydrilla around water intakes.

**Table 3.3.2-21 Summary Table: Minimum and Maximum Estimated Annual Economic Loss Associated with the Establishment of Hydrilla in the Great Lakes**

| Resource Affected | Minimum Estimated Annual Economic Loss | Maximum Estimated Annual Economic Loss |
|---|---|---|
| Recreational Fishing/Angling | (29,574,008) | 34,814,477 |
| Beach Use | 10,348,000 | 31,206,000 |
| Recreational Boating | 87,344,800 | 422,887,200 |
| Commercial Navigation/Dredging | 2,277,000 | 9,776,250 |
| Water Supply | not estimated | not estimated |
| **Total** | **70,395,792** | **498,683,927** |

The estimates provided on Table 3.3.2-21 only include the direct loss in economic well-being associated with these narrowly defined uses. The overall macroeconomic impacts on the tourism industry and the recreational fishing and boating industries have not been included. Any loss of sales, employment or earnings associated with the decline in recreational use of the Great Lakes would be an additional economic loss to the local and regional communities.

Given the potentially large economic losses that would occur if Hydrilla were to become established in the Great Lakes, the costs of implementing a prevention and eradication program would be relatively inexpensive. Any costs spent to prevent the spread of Hydrilla to the Great Lakes or to eradicate Hydrilla before it became established in the Great Lakes would be more than offset by the economic losses avoided.

### 3.3.3 Potential Environmental Impacts

This section summarizes a range of potential environmental impacts that could result from the introduction and successful establishment of monecious Hydrilla in the Great Lakes. The discussion of impacts is based in part on a review of scientific journals, aquatic management plans, and interviews with natural resource managers. Collectively, that effort provides a sense of "what" the impacts may be. Additionally, this evaluation attempts to provide information regarding "where" in the Great Lakes environmental impacts may occur and how extensive those impacts may be in the future, specifically in 2025. The latter was accomplished through a desktop analysis using GIS combined with results from the distributional (i.e., habitat-suitability) and dispersal modeling.

Through the literature review process, it became clear that little is known regarding the effects of monoecious Hydrilla on the Great Lakes, or on northern waters in general. An initial literature review conducted in 2015 included a comprehensive review of over 130 articles, technical reports, and management plans. A follow-up literature review conducted in August 2017 identified over 20 additional relevant articles. Much of the literature reviewed did not specify Hydrilla biotype and the majority of scientific research on this topic was conducted outside of the Great Lakes Basin, likely due to the current limited presence of Hydrilla in the

Great Lakes Basin. The lack of specificity and quantitative analysis in this section reflects limitations in available literature, as discussed below.

The GIS desktop analysis was conducted to qualify potential ecological impacts in the Great Lakes Basin by integrating the findings of the habitat suitability and dispersal modeling (see Sections 3.1.3 and 3.1.5). The results of the modeling were overlaid with available spatial data on waterbodies and coastal wetlands, fisheries, and waterfowl and wildlife resources to identify resources potentially at risk within the 18 watersheds that comprise the Great Lakes Basin.

The discussion of potential impacts is organized into five general impact categories: water quality and aquatic plant communities; fisheries and benthic macroinvertebrates; pathogens; waterfowl and wildlife; and hydrology.

#### 3.3.3.1 Water Quality and Aquatic Plant Communities

**Summary of Reviewed Literature**

Researchers studying the effects of Hydrilla on water quality have identified negative impacts related to a waterbody's ability to support other species of aquatic plants and animals. As Hydrilla grows, it creates thick mats of vegetation that can block sunlight, limit water flow, and deplete oxygen levels (Bowes et al. 1979; Barko et al. 1988; Honnel et al. 1992; Foltz and Kirk 1994; Balciunas et al. 2002; Caraco and Cole 2002; Colon-Gaud et al. 2004; Nakamura et al. 2008). Recent phenology experiments suggest that at northern latitudes, monoecious Hydrilla may form mats between July and early December (see Appendix E). Hydrilla forms thick surface canopies that decrease light to bottom waters resulting in the death of vegetation at depth. Subsequently, dead and dying vegetation falls to the bottom of the waterbody, which can increase biological oxygen demand (BOD) and lead to stratification of the water column (Foltz and Kirk 1994). Increased BOD and subsequent reduced DO in the water column may lead to increased stress, suffocation, and death in higher forms of aquatic life (USEPA 2012). Further reduction in DO also results from Hydrilla respiration (Bowes et al. 1979; Barko et al. 1988; Foltz and Kirk 1994; Balciunas et al. 2002; Colon-Gaud et al. 2004). Low DO levels may cause some aquatic organisms to move to other locations, weaken, or die (USEPA 2012).

Other submersed aquatic plants also decrease DO levels through respiration; however, invasive species, such as Hydrilla, have been found to create lower levels of DO compared to native species because the high density of this invasive species reduces light availability, which inhibits the oxygen-producing process of photosynthesis (Honnel et al. 1992; Caraco and Cole 2002). One study found that when ponds with Hydrilla were compared with ponds containing other invasive species (water hyacinth [*Eichornia crassipes*] and Eurasian water-milfoil [*Myriophyllum spicatum*]) and ponds with native plants, the ponds with invasive species all had lower levels of DO; however, the ponds with Hydrilla had the lowest levels of DO (Honnel et al. 1992).

Thick mats of Hydrilla may also reduce water movement and mixing compared to areas of open water, which can affect water quality by increasing water temperatures during summer months, particularly near the surface. The decrease in vertical and horizontal mixing increases temperature stratification in the water column, with temperatures near the surface becoming warmer than deeper water.

Hydrilla can also increase pH levels in water, though this effect may not place a significant amount of stress on other aquatic organisms (Barko et al. 1988; Colon-Guad et al. 2004). One study found that canopies of Hydrilla and native coontail *(Ceratophyllum demersum)* similarly had elevated temperature and pH. However, the study did not find the elevated temperature and pH to be biologically significant to organisms (Colon-Guad et al. 2004). These direct effects of Hydrilla on the physical and chemical characteristics of a waterbody can lead to impacts on fisheries (see Section 3.3.3.2).

A limited amount of Hydrilla may result in some improvement in water quality in waterbodies with no or little existing vegetation or with high nutrient levels, as researchers have found some evidence that Hydrilla can remove excess nutrients from water (Moxley and Langford 1982; Rybicki and Landwehr 2007; Nakamura et al. 2008). Water quality in two experimental vegetated ponds dominated by Hydrilla and two harvested ponds with little vegetation were studied over a three-week period (Nakamura et al. 2008). Researchers found that the ponds vegetated with Hydrilla had lower levels of blue algae and suspended sediments compared with the unvegetated ponds that had higher amounts of turbidity. The same study also found DO levels to decrease near the submerged vegetation (Nakamura et al. 2008). One study found that a hypereutrophic lake with no previous vegetation experienced an improvement in nitrogen and phosphate levels and increase in sport fish population as Hydrilla spread (Moxley and Langford 1982).

Hydrilla may affect existing aquatic plant communities indirectly through impacts on water quality as discussed above, or directly through competition. However, the effects of Hydrilla on the diversity of existing aquatic plant communities appears to be mixed based on the literature. For example, a study of 39 Florida lakes, 17 with Hydrilla and 22 without Hydrilla, indicated no significant difference in total aquatic plant species richness (Hoyer et al. 2008). Total aquatic plant species richness in the first dataset evaluated by Hoyer at al. (2008) averaged 14.4 in lakes with Hydrilla, and 11.8 in lakes without Hydrilla. For the second dataset evaluated by Hoyer et al. (2008), total aquatic plant species richness averaged 2.5 for lakes with Hydrilla, and 2.1 for lakes without Hydrilla. However, two other studies present contrary findings. First, as discussed in Section 3.1.6, growth studies conducted by NCSU indicated that monoecious Hydrilla is able to become established when grown in competition with other cool-climate submerged aquatic plant species under northern latitude climate conditions, and under some conditions monoecious Hydrilla significantly inhibited the growth of native eelgrass (*Vallisneria americana).* Additionally, a four-year study of a Hydrilla-infested lake in New Zealand looked at changes in the flora and fauna in the lake following introduction of grass carp (*Ctenopharyngodon idella*) and removal of

Hydrilla beds. Prior to the introduction of grass carp, Hydrilla was the dominant aquatic plant and was also present in all 15 sites sampled with the highest cover. Following the removal of Hydrilla beds, there was a general increase in the distribution of the native aquatic vegetation (Hofstra and Clayton 2014).

In general, Hydrilla out-competes other aquatic plants as a consequence of its high growth rate and also appears to have allelopathic qualities against certain plants (Gross 2003; Paresh and Freedman 2006; Zhang et al. 2012). *Ceratophyllum*, also known as coontail, may be sensitive to Hydrilla, while Hydrilla extract has been found to inhibit the growth of some freshwater algae, including *Anabaena flos-aquae, Chlorella pyrenoidosa, Scenedesmus obliquus* (Gross 2003; Zhang et al. 2012). The Hydrilla extract apparently damaged the cell membrane of the algae, which resulted in a termination of algal blooms (Zhang et al. 2012).

### Results of Desktop Analysis: Waterbodies and Coastal Wetland Resources in the Great Lakes Basin Potentially Subject to Hydrilla Infestation

Hydrilla has the potential to be introduced to a variety of waterbodies and wetlands in the Great Lakes Basin, as indicated by the dispersal modeling results discussed in Section 3.1.5. Dispersal modeling conducted for this project provided predictions for the total area of waterbodies per watershed infested with Hydrilla in 2025 for the 18 watersheds in the Great Lakes Basin (see Section 3.1.4). The modeling predict that Hydrilla will be present in 236,000 acres of waterbodies in the basin by 2025, ranging from over 72,000 acres in the Southeastern Lake Ontario watershed (approximately 5% of the watershed's waterbodies) to 30 acres or less for the two watersheds comprising Lake Superior (see Table 3.3.3-1). The low value for the Lake Superior watersheds is largely due to their distance from existing Hydrilla infestations and the cooler temperature of those watersheds compared with watersheds in the lower Great Lakes. Regarding temperature, problematic Hydrilla infestation are not expected to occur unless water temperature reaches 68°F or above for at least two months during the summer (see Section 3.1.4.2); such areas are limited in and around Lake Superior.

It is anticipated that impacts on water quality, such as increased thermal stratification, decreased DO, or increased pH, could occur within Hydrilla infested areas in the Great Lakes Basin. The presence of Hydrilla could also influence aquatic vegetation communities directly through competition or indirectly through changes in water quality, which could, in turn, limit or exclude other submerged aquatic plant species spatially or temporally. Biological experiments conducted for this project (see Appendix E) indicated that monoecious Hydrilla was able to become established when grown in competition with cool-climate submerged aquatic plant species under northern latitude climate conditions, and under some conditions significantly inhibited the growth of native species, such as eelgrass (*Vallisneria americana).*

**Table 3.3.3-1 Acreage of Waterbodies per Watershed Predicted to be Infested by Hydrilla in 2025 Based on Dispersal Modeling**

| Hydrilla Introduction Potential and Rank | | Watershed Name | 2025 Waterbody Area Infested[a] (acres) | 2025 Proportion Infested[b] (acres) |
|---|---|---|---|---|
| High | 1 | Southeastern Lake Ontario | 72,733 | 0.0514 |
| | 2 | St. Clair-Detroit | 6,808 | 0.0392 |
| | 3 | Western Lake Erie | 36,663 | 0.0365 |
| | 4 | Southern Lake Erie | 51,593 | 0.0338 |
| Medium | 5 | Southwestern Lake Ontario | 10,796 | 0.0134 |
| | 6 | Eastern Lake Erie | 16,541 | 0.0128 |
| | 7 | Southwestern Lake Michigan 2 | 13,722 | 0.0099 |
| | 8 | Southeastern Lake Michigan | 21,632 | 0.0088 |
| | 9 | Southwestern Lake Huron-Lake Huron | 2,083 | 0.0069 |
| Low | 10 | Northeastern Lake Ontario- Lake Ontario-St. Lawrence | 1,255 | 0.0015 |
| | 11 | Northeastern Lake Michigan-Lake Michigan 2 | 773 | 0.0014 |
| | 12 | Southwestern Lake Michigan 1 | 469 | 0.0009 |
| | 13 | Northwestern Lake Huron 2 | 897 | 0.0004 |
| | 14 | Northeastern Lake Michigan-Lake Michigan 1 | 366 | 0.0002 |
| | 15 | Northwestern Lake Huron 1 | 179 | 0.0001 |
| | 16 | Northwestern Lake Michigan | 43 | 0.0001 |
| | 17 | Southern Lake Superior-Lake Superior | 31 | 0.0001 |
| | 18 | Western Lake Superior | 0 | 0.0000 |
| | | **Total** | **236,585** | |

Sources: Sections 3.1.5 and 3.2, and Appendix D.

Notes:
[a] 2025 Acreage is predicted area of infestation based on gravity model results per watershed.
[b] 2025 Proportion is the proportion of the predicted area of infestation to the total area of water within that watershed.

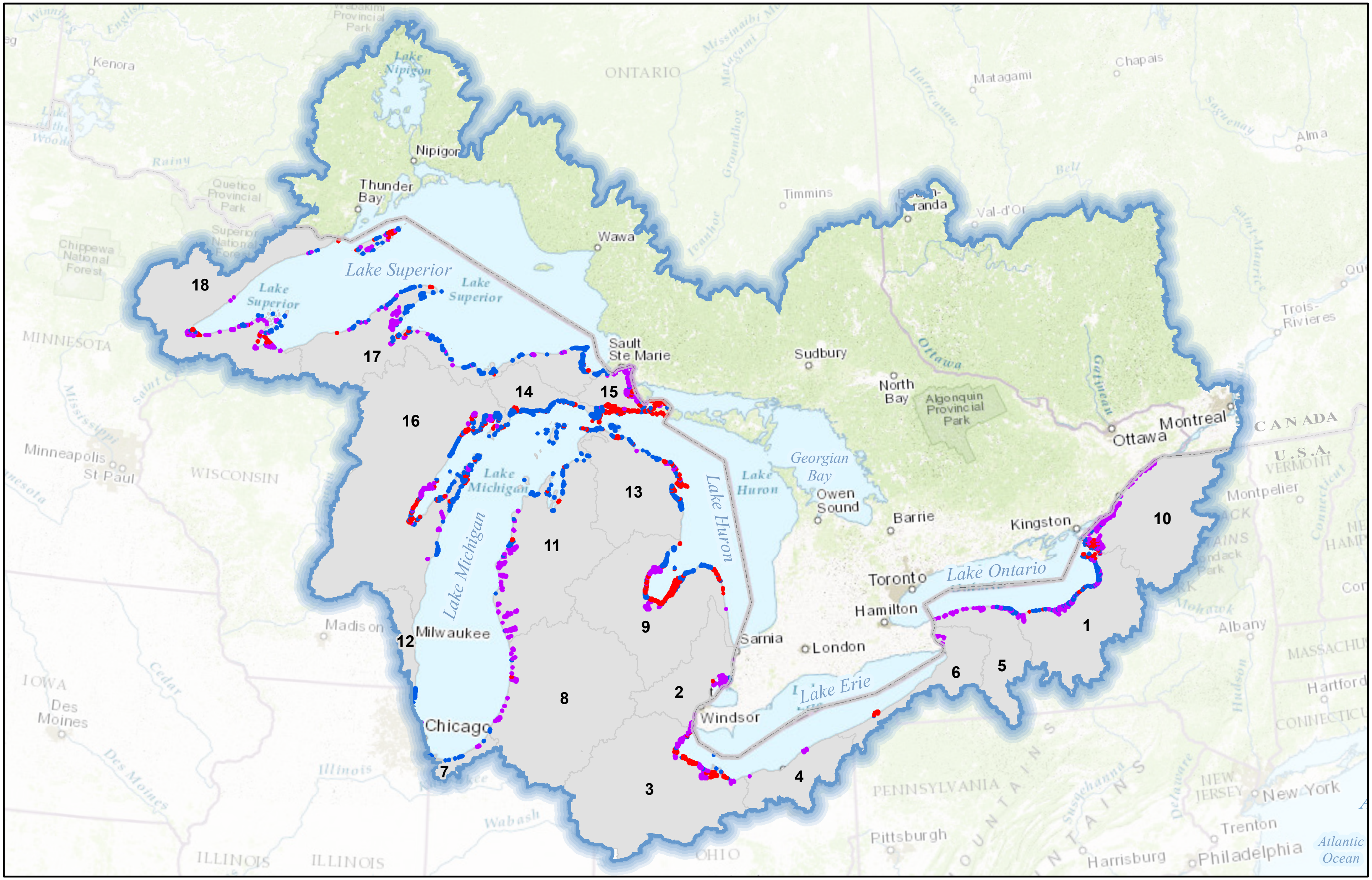
As noted in other sections, this risk assessment primarily focuses on risks and potential impacts on the Great Lakes proper and their shoreline habitats. Coastal wetland habitat is located along many areas of the Great Lakes shoreline; wetlands frequently contain vegetation communities that include native and introduced submerged aquatic plant species. Hydrilla is able to colonize wetland habitats that provide suitable environmental conditions, such as the shallow wetland fringe of a pond or lake. As described above, dense Hydrilla growth can degrade water quality, which in turn affects habitat quality for the plant and animal communities within the coastal wetlands of the Great Lakes. Therefore, as described below, the GIS desktop analysis included an identification of coastal wetlands in the Great Lakes Basin that maybe susceptible to Hydrilla infestation and potential degradation of water quality.

According to the Great Lakes Coastal Wetland Inventory, the shorelines of the Great Lakes contain 1,739 sites classified as coastal wetlands, encompassing 381,000 acres (see Table 3.3.3-2). The Great Lakes Coastal Wetland Inventory was developed through the Great Lakes Coastal Wetland Consortium as an initiative to create a single, hydrogeomorphically classified inventory of all coastal wetlands across the Great Lakes Basin (USGS, WRD et al. 2004). The inventory was built using the most comprehensive data available for coastal wetlands in the United States and Canada along the Great Lakes and connecting waterways. Approximately 42% of coastal wetlands are classified as barrier-protected wetlands, 40% as riverine wetlands, and 17% as lacustrine wetlands (see Table 3.3.3-2).

The majority of United States coastal wetlands in the Great Lakes Coastal Wetland Inventory are less than 1 mile from the Great Lakes shoreline; many are situated less than 0.5 mile from the shoreline. However, in some coastal wetlands in certain bays and river systems, the wetland feature extends inland for more than 1 mile and the maximum distance is approximately 8 miles. To incorporate these features, the desktop analysis established a buffer to identify wetlands up to 8 miles inland for inclusion in the tabulation of acreage potentially subject to Hydrilla infestation.

Application of the predicted 2025 proportions from the dispersal model (see Table 3.3.3-1, last column) to the total acreage of coastal wetlands in the Great Lakes Basin indicates that nearly 3,200 acres of coastal wetland habitat could potentially be colonized by Hydrilla across the Great Lakes Basin in 2025 (see Table 3.3.3-2 [last column] and Figure 3.3.3-1) assuming all future Hydrilla infestations occur only in coastal wetlands. However, as implied by the 2025 predictions, Hydrilla introduction potential varies by watershed. In general, coastal-wetland sites in more northern watersheds present less suitable habitat for Hydrilla establishment based on distributional modeling (see Sections 3.1.3) For the purpose of the impact analysis, this has been interpreted to mean that these sites are less likely to develop problematic Hydrilla infestations if Hydrilla were to be introduced there.

In addition, it should be noted that the estimates of coastal wetland acreages per watershed in Table 3.3.3-2 are likely overestimated to some extent. Some areas mapped as wetland may no longer be functional wetland habitat. Approximately 43.5% of the total coastal wetlands in the Great Lakes Coastal Wetland Inventory were designated as having some level of fill. These wetlands were included in this analysis because the inventory data did not specify the extent of fill activity. Separate from the effects of fill, not all coastal wetlands may provide suitable habitat for Hydrilla, as some wetlands may have highly variable water levels that could result in dry conditions during the summer growing conditions, or water that is too deep for Hydrilla (< 25 feet). There are also likely conditions where wetlands are predominantly shallow emergent systems predominated by cattail (*Typha* spp.), where Hydrilla would be unlikely to colonize. However, data are insufficient and this analysis too general to make predictions beyond applying the dispersal modeling results in the simple manner performed here.




KEY:

Great Lakes Basin

Introduction Potential Watershed

Coastal Wetland

- Barrier Protected Wetland
- Lacustrine Wetland
- Riverine Wetland
- Unknown Wetland

0 50 100 200 Miles

N

Figure 3.3.3-1

**Great Lakes Basin Coastal Wetlands by Watershed and Hydrogeomorphic Classification**

Great Lakes Basin

Data Source: Ecology and Environment, Inc. 2017; Institute for Fisheries Research, Environment Canada, USGS 2011; USGS 2015.

**Table 3.3.3-2 Acreages of Great Lakes Basin Coastal Wetlands by Watershed, Hydrogeomorphic Classification, and Predicted Acreage Potentially Colonized by Hydrilla in 2025[a]**

| Hydrilla Introduction Potential and Rank[b] | | Watershed Name | Number of Coastal Wetland Sites within Watershed[b] | Acreage of Barrier-protected Wetlands[b] | Acreage of Riverine Wetlands[b] | Acreage of Lacustrine Wetlands[b] | Total Acreage of Coastal Wetland Sites within Watershed[b] | Predicted 2025 Acreage of Infested Coastal Wetlands[c] |
|---|---|---|---|---|---|---|---|---|
| High | 1 | Southeastern Lake Ontario | 115 | 9,624 | 10,926 | 32 | 20,585 | 1,058 |
| | 2 | St. Clair-Detroit | 28 | 1,141 | 14,409 | 18 | 15,568 | 610 |
| | 3 | Western Lake Erie | 70 | 188 | 14,240 | 9,466 | 23,904 | 872 |
| | 4 | Southern Lake Erie | 3 | 0 | 805 | 0 | 805 | 27 |
| Medium | 5 | Southwestern Lake Ontario | 39 | 2,321 | 2,016 | 0 | 4,337 | 58 |
| | 6 | Eastern Lake Erie | 27 | 22 | 391 | 1,092 | 1,505 | 19 |
| | 7 | Southwestern Lake Michigan 2 | 42 | 1,565 | 472 | 0 | 2,037 | 20 |
| | 8 | Southeastern Lake Michigan | 20 | 149 | 4,400 | 27 | 4,576 | 40 |
| | 9 | Southwestern Lake Huron-Lake Huron | 75 | 13,007 | 18,550 | 25,393 | 56,960 | 393 |
| Low | 10 | Northeastern Lake Ontario-Lake Ontario-St. Lawrence | 224 | 998 | 7,839 | 483 | 9,499 | 14 |
| | 11 | Northeastern Lake Michigan-Lake Michigan 2 | 135 | 6,690 | 16,322 | 843 | 23,855 | 33 |
| | 12 | Southwestern Lake Michigan 1 | 10 | 2,635 | 13 | 0 | 2,648 | 2 |
| | 13 | Northwestern Lake Huron 2 | 98 | 17,394 | 1,404 | 6,502 | 25,544 | 10 |
| | 14 | Northeastern Lake Michigan-Lake Michigan 1 | 95 | 15,505 | 190 | 2,428 | 18,134 | 4 |
| | 15 | Northwestern Lake Huron 1 | 257 | 17,482 | 14,585 | 11,753 | 43,821 | 4 |
| | 16 | Northwestern Lake Michigan | 228 | 37,404 | 20,051 | 6,752 | 64,207 | 6 |
| | 17 | Southern Lake Superior-Lake Superior | 176 | 31,945 | 14,960 | 772 | 47,759 | 5 |
| | 18 | Western Lake Superior | 97 | 2,576 | 11,542 | 1,222 | 15,343 | 0 |
| | | **Total** | **1,739** | **160,646** | **153,115** | **66,783** | **381,087** | **3,175** |

Notes:

[a] All coastal wetlands in the Great Lakes Coastal Wetland Inventory were included in this analysis. Most coastal wetlands were less than a mile from the shoreline, yet some wetlands extended farther inland; the maximum distance was approximately 8 miles.

[b] USGS, WRD et al. 2004. Total acreage of wetland sites is the summation of acreage of barrier-protected, riverine, and lacustrine coastal wetlands.

[c] Values were calculated by applying predicted proportions of infested waterbodies in 2025 (Sections 3.1.5 and 3.2) to total coastal wetland acreage.

Because environmental systems are variable and dynamic, it would be impractical to identify specific coastal wetlands within each watershed likely to be impacted by Hydrilla or evaluate the extent of the impacts.

The analysis in this section includes all coastal wetlands within the 18 watersheds of the Great Lakes Basin, even those at northern latitudes, because habitat conditions may exist in small protected wetlands that would be suitable for Hydrilla establishment even though conditions in general are less suitable for Hydrilla in the more northerly Great Lakes (see Section 3.1.3). As a result, this desktop analysis did not consider habitat suitability differences with latitude.

#### 3.3.3.2 Fisheries and Benthic Macroinvertebrates

**Summary of Reviewed Literature**

Left unchecked, Hydrilla is widely considered to be detrimental to fish habitats (USACE 2015; State of Washington Department of Ecology 2015; Aquatic Ecosystem Restoration Foundation 2005; U.S. Department of Agriculture 2006; Indiana Department of Natural Resources (DNR) 2009; Cornell Cooperative Extension 2015; Florida Fish and Wildlife Conservation Commission 2015). This is largely due to Hydrilla's ability to quickly spread and form dense canopies that degrade water quality resulting in declines in fish populations (State of Washington Department of Ecology 2015; Foltz and Kirk 1994; Kirk and Henderson 2006; Nakamura et al. 2008; Cornell Cooperative Extension 2015). As submersed aquatic vegetation, Hydrilla may provide food and habitat for certain fish species and benthic macroinvertebrates, which in some cases may result in increased diversity and abundance (Barnett and Schneider 1974; Moxley and Lanford 1982; Watkins et al. 1983; Posey et al. 1993; Maceina 1996; Langeland 1996; Dibble et al. 1997; Kirk and Henderson 2006; Nakamura et al. 2008; Kraus and Jones 2012). However, Hydrilla's worth as food and habitat may be minimal where existing native aquatic vegetation exists and if large mats of Hydrilla are allowed to dominate the waterbody and modify water quality.

Negative impacts on fish and macroinvertebrates have been noted where Hydrilla degrades water quality (e.g., lower levels of DO, increase in temperatures and pH) to the point where it limits the growth and reproduction of species or leads to death of fish (State of Washington Department of Ecology 2015; Foltz and Kirk 1994; Kirk and Henderson 2006; Nakamura et al. 2008; Cornell Cooperative Extension 2015). Excessive aquatic vegetation coverage may also confine nest builders to limited areas resulting in increased competition and decreased success in spawning (Dibble et al. 1997).

Limited coverage of Hydrilla provides food for fish and benthic macroinvertebrates as well as habitat to protect these species from predators, which may result in larger populations and greater species diversity (Barnett and Schneider 1974; Moxley and Lanford 1982; Watkins et al. 1983; Posey et al. 1993; Maceina 1996; Langeland 1996; Dibble et al. 1997; Kirk and Henderson 2006; Nakamura et al.

2008; Kraus and Jones 2012). The presence of Hydrilla at lower densities may have a beneficial effect by providing structure within the water column, thereby increasing habitat functions and values for a variety of aquatic organisms compared with waterbodies that have no SAV. While prey fish prefer vegetated habitat to unvegetated habitat, they do not demonstrate a preference or difference in survival between using Hydrilla versus native plants for refuge (Figueiredo et al. 2015; Thomaz et al. 2015). One study found that fish populations fluctuated between 91 to 437 fish per hectare prior to Hydrilla encroachment and after Hydrilla covered approximately 9% of the lake, the number of fish had increased to 3,947 per hectare (Moxley and Langford 1982). It is likely however that unabated Hydrilla growth would eventually have an adverse effect on fish populations.

Hydrilla's seemingly beneficial effects may be greater in lakes with limited or no vegetation prior to Hydrilla colonization and where Hydrilla has not completely dominated the waterbody. One study concluded that Hydrilla coverage of 10 to 15% in lakes with poor water quality and limited vegetation could have beneficial impacts on fisheries, while another study suggested coverage up to 40% could have beneficial impacts (Moxley and Langford 1982; Langeland 1996; Dibble et al. 1997). However, the cost of managing Hydrilla can be expensive and it would be difficult to maintain a specific density of Hydrilla.

While several studies have looked specifically at Hydrilla's ability to provide benefits through food and habitat for fish (Moxley and Lanford 1982; Posey et al. 1993; Langeland 1996; Dibble et al. 1997; Kirk and Henderson 2006; Nakamura et al. 2008; Kraus and Jones 2012), several studies have shown that other aquatic vegetation can provide these same benefits and suggest that Hydrilla is not a substitute for native or less invasive, non-native species (Barnett and Schneider 1974; Watkins et al. 1983; Maceina 1996).

Studies showing beneficial impacts of Hydrilla on fisheries are supported by the general opinion of some anglers that the presence of Hydrilla improves fishing opportunities (Henderson et al. 2003; Vertuno 2003; Kirk and Henderson 2006). Hydrilla became the dominant aquatic plant species in Lake Moultrie, South Carolina, in the 1980s; triploid grass carp had eliminated nearly all aquatic vegetation in the lake by 1997. Angler surveys found that most anglers at Lake Moultrie preferred aquatic vegetation for fishing and had the opinion that the removal of aquatic vegetation (Hydrilla and native species) had adversely affected fishing success (Henderson et al. 2003; Kirk and Henderson 2006). Several authors have suggested this opposition to eradication of Hydrilla by anglers and the observed benefits of submersed aquatic vegetation should be considered prior to efforts to control or eradicate Hydrilla (Henderson et al. 2003; Kirk and Henderson 2006; Rybicki and Landwehr 2007).

In general, the literature on the impacts of Hydrilla on aquatic organisms reflects a mixed review regarding relative benefits or harm. Several studies found no significant beneficial or negative impacts of Hydrilla on fish populations (Hoyer and Canfield 1996; Hoyer et al. 2008). It appears the type of impact that Hydrilla has on fish populations is dependent on a number of factors, such as presence of existing vegetation, size of the waterbody, and scale and density of the Hydrilla infestation; however, excessive and dense Hydrilla coverage would ultimately have negative effects on fish and macroinvertebrate species from reduced water quality, such as decreased DO.

**Results of Desktop Analysis: Fishery Resources in the Great Lakes Basin Subject to Hydrilla Infestation**

The Great Lakes provide habitat for a variety of fish species at different stages of their life cycles. The habitat quality of fish spawning and nursery sites are important for population recruitment of commercial and recreational fish species. The *Atlas of the Spawning and Nursery Areas of Great Lakes Fishes* (Atlas), developed in 1982, identifies the locations of spawning and nursery sites throughout the Great Lakes. The Atlas was updated in 2011 at the Institute for Fisheries Research, a cooperative unit of the University of Michigan and Michigan DNR, in order to support coastal and offshore planning and research in the Great Lakes (Hoover et al. 2011). The updated Atlas includes 12 fish species of interest: alewife (*Alosa pseudoharengus*), bloater (*Coregonus hoyi*), burbot (*Lota lota*), emerald shiner (*Notropis atherinoides*), lake herring (*Coreqonus artedii*), lake trout (*Salvelinus namaycush*), lake whitefish (*Coregonus clupeaformis*), rainbow smelt (*Osmerus mordax*), slimy sculpin (*Cottus cognatus*), smallmouth bass (*Micropterus dolomieui*), walleye (*Stizostedion vitreum vitreum*), and yellow perch (*Perca flavescens*). The Atlas contains 1,522 locations along the United States side of the Great Lakes Basin.

For each of the 18 watersheds in the Great Lakes Basin, point locations were identified from the updated Atlas that met one of the following criteria:

- Inland (from Great Lakes shoreline) spawning sites within the 18 watersheds;
- Areas within the zone of suitable depth/temperature requirements for Hydrilla establishment within each of the Great Lakes (as defined in Section 3.1.4); or
- Island locations, with the exception of islands in western Lake Superior (coldest watershed, so Hydrilla infestations are less likely).

Inland spawning locations in each of the 18 watersheds were included in the analysis because habitat conditions may exist in small waterbodies that would be suitable for Hydrilla even if conditions are not suitable within the Great Lakes themselves (e.g., Lake Superior) even at more northern latitudes. This is due to the fact the small inland waterbodies typically warm up earlier and to higher temperatures than the Great Lakes proper.

The selection process identified 804 fish spawning and nursery locations that could potentially be impacted by Hydrilla, accounting for approximately 53% of the 1,522 United States' Great Lakes sites (see Table 3.3.3-3 and Figure 3.3.3-2). Watersheds with the highest proportion of the 804 sites are western Lake Erie (ranked 3 for Hydrilla introduction potential with 120 spawning sites or 15% of the 804 total sites) and northwestern Lake Michigan (ranked 16 for Hydrilla introduction potential with 102 spawning sites or 13% of the 804 total sites). It is important to note that the spawning sites identified as potentially impacted locations are not all equally at risk. In general, sites in watersheds with high introduction potential and high habitat suitability are more likely to be infested and impacted by Hydrilla, while spawning sites in watersheds at far northern latitudes where introduction potential and habitat suitability are lower are less likely to experience impacts (see Section 3.2). The values in Table 3.3.3-3 summarize existing resources and present a worst-case scenario in which all spawning sites that meet the above-listed criteria are considered equally susceptible to Hydrilla introduction and establishment. However, in reality, the potential for Hydrilla introduction and establishment is not constant across the Great Lakes Basin, but varies with latitude and distance from known Hydrilla infestations.

**Table 3.3.3-3 Great Lakes Basin Fish Spawning and Nursery Sites Identified as Potentially Susceptible to Hydrilla Introduction and Establishment**

| Hydrilla Introduction Potential and Rank | | Watershed Name | Number of Spawning or Nursery Sites | Percentage of Total Sites[a] |
|---|---|---|---|---|
| High | 1 | Southeastern Lake Ontario | 38 | 4.7 |
| | 2 | St. Clair-Detroit | 32 | 4.0 |
| | 3 | Western Lake Erie | 120 | 14.9 |
| | 4 | Southern Lake Erie | 19 | 2.4 |
| Medium | 5 | Southwestern Lake Ontario | 11 | 1.4 |
| | 6 | Eastern Lake Erie | 50 | 6.2 |
| | 7 | Southwestern Lake Michigan 2 | 34 | 4.2 |
| | 8 | Southeastern Lake Michigan | 28 | 3.5 |
| | 9 | Southwestern Lake Huron-Lake Huron | 62 | 7.7 |
| Low | 10 | Northeastern Lake Ontario- Lake Ontario-St. Lawrence | 58 | 7.2 |
| | 11 | Northeastern Lake Michigan-Lake Michigan 2 | 68 | 8.5 |
| | 12 | Southwestern Lake Michigan 1 | 35 | 4.4 |
| | 13[b] | Northwestern Lake Huron 2 | 22 | 2.7 |
| | 14[b] | Northeastern Lake Michigan-Lake Michigan 1 | 13 | 1.6 |
| | 15[b] | Northwestern Lake Huron 1 | 20 | 2.5 |
| | 16[b] | Northwestern Lake Michigan | 102 | 12.7 |
| | 17[b] | Southern Lake Superior-Lake Superior | 46 | 5.7 |
| | 18[b] | Western Lake Superior | 46 | 5.7 |
| | | **Total** | **804** | **100.0** |

Source: Hoover et al. 2011.

Notes:

[a] Number of identified spawning or nursery sites in each watershed divided by total spawning sites (804).

[b] Watersheds 13, 14, 15, and most of 16, 17, and 18 include inland sites but very few within Great Lakes proper because few areas with suitable water temperatures that can support Hydrilla.

The vast majority of selected spawning or nursey locations were less than 1 mile from the shoreline (either inland or within the lakes proper), with the majority situated less than 0.5 mile from the shoreline. There are 13 sites that are more than 4 miles inland – nine in the northeastern Lake Michigan-Lake Michigan watershed and four in the northwestern Lake Huron watershed. The spatial layout of these spawning sites and their relative prevalence near the shorelines indicate the importance of shoreline habitats, which is relevant because the risk assessment is focused on the Great Lakes proper and their shorelines, with less specific emphasis on inland areas.

As suitable water depths and temperature conditions for Hydrilla establishment do not extend far away from the shoreline in most areas of the Great Lakes (see Figure 3.1.4-1), only a small number of potentially susceptible spawning sites occur within the lakes themselves. Such sites occur mostly in western Lake Erie and Saginaw Bay in Lake Huron, where shallow, warmer water extents far from shore. The maximum distance from shore into the lake was approximately 9 miles in western Lake Erie. Watersheds at more northern latitudes (with introduction potential ranks 13 through 18 included inland sites, but very few within the Great Lakes proper because there are few nearshore areas with suitable water temperatures for Hydrilla establishment.

All inland spawning and nursery locations were included for all 18 watersheds because habitat conditions may exist in small sheltered waterbodies that would be suitable for Hydrilla even if conditions are not suitable within the Great Lakes proper at more northern latitudes. The dispersal modeling results (2025 predictions) could not be used quantitatively in this desktop analysis of fish spawning sites because acreages could not be calculated from the point-based fish spawning atlas data. Additionally, the desktop analysis did not attempt to predict whether there is a northern latitude at which Hydrilla could not survive in any waterbody. It is possible that such a threshold does exist where Hydrilla does not grow well enough to produce impacts on fish habitats; thus, some values in Table 3.3.3-3 are likely to be overestimates for watersheds ranked 14 through 18; in particular watersheds ranked 17 and 18.

#### 3.3.3.3 Pathogens

##### Summary of Reviewed Literature

Hydrilla by itself does not appear to be toxic to animals and can be a source of food and habitat for fish and benthic macroinvertebrates (Barnett and Schneider 1974; Moxley and Lanford 1982; Watkins et al. 1983; Posey et al. 1993; Maceina 1996; Langeland 1996; Dibble et al. 1997; Kirk and Henderson 2006; Nakamura et al. 2008; Kraus and Jones 2012). However, Hydrilla is known to be a host for a pathogen that has led to the death of bald eagles (*Haliaeetus leucocephalus*) and other bird species (Fischer et al. 2002; Birrenkott et al. 2004; Rocke et al. 2005; Kirk and Henderson 2006; Williams et al. 2007; Wilde et al. 2014). In addition, some evidence shows that Hydrilla may have some inhibitory effects on the growth of other aquatic vegetation, as described below.

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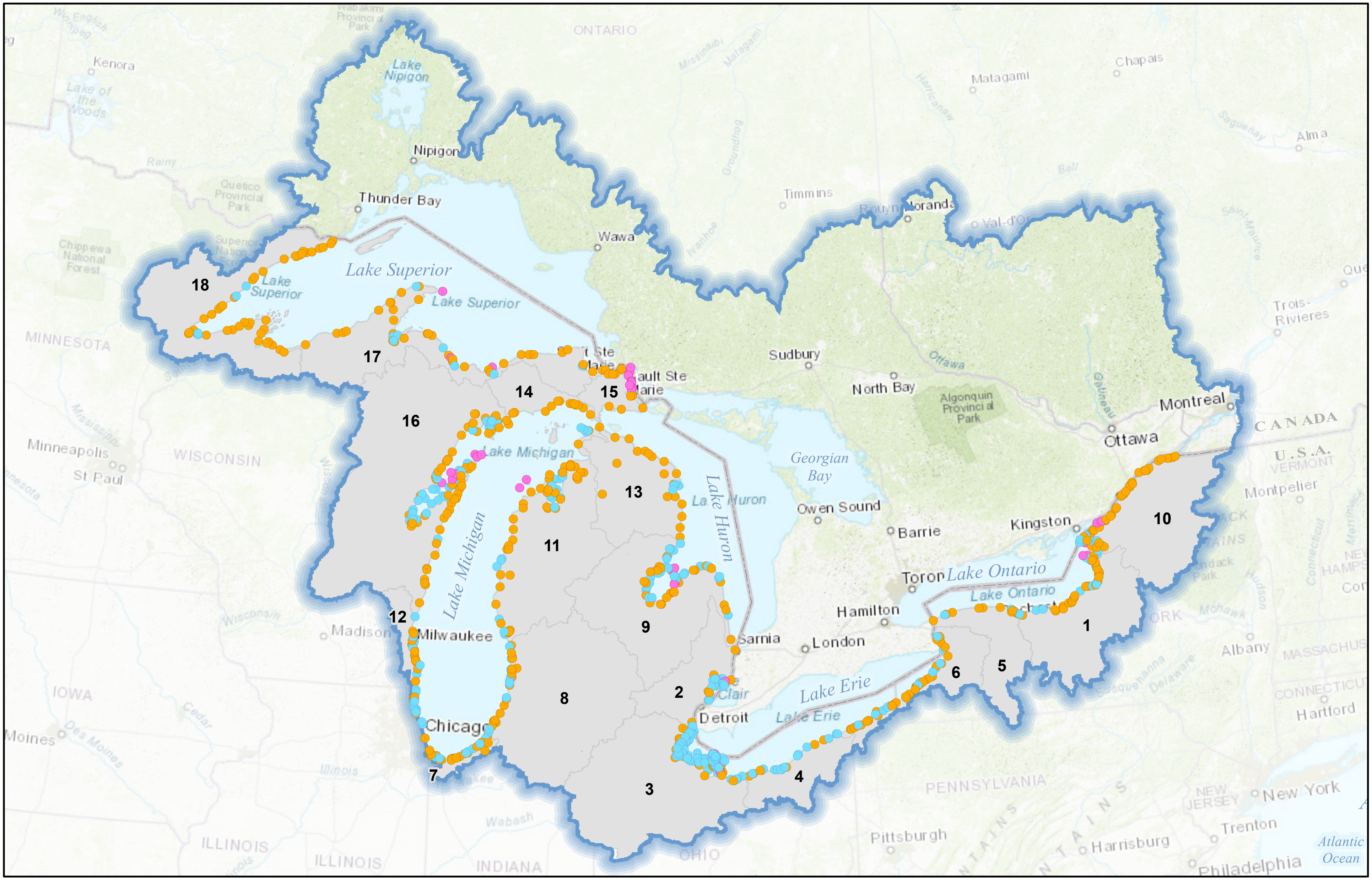


KEY:

Fish Spawning and Nursery Site*
- Coastal
- Inland
- Island

Great Lakes Basin

Introduction Potential Watershed

*Note: Due to the scale of the figure, coastal, inland, and island sites may be difficult to differentiate.

0 50 100 200 Miles

N

Data Source: Ecology and Environment, Inc. 2017; Institute for Fisheries Research 2015; USGS 2015.

Figure 3.3.3-2

**Great Lakes Basin Fish Spawning and Nursery Sites Identified as Potentially Impacted by Hydrilla**

Great Lakes Basin

Avian vacuolar myelinopathy (AVM) is a fatal disease that was first documented in DeGray Lake, Arkansas, in 1994, but may have been present as early as 1990 (Fischer et al. 2002). AVM has been implicated in the deaths of over 170 bald eagles and thousands of American coots (Dodd et al. 2016). AVM affects the nervous system and results in incoordination in birds, including, difficulty flying, walking, and swimming. Brain lesions were also found on birds with AVM. The disease typically manifests within five to seven days of exposure during the months of November and December, and although the cyanobacteria that cause AVM may be present in lakes year round, it does not appear to exist in levels to induce the disease year round (Rocke et al. 2005).

The first observation of AVM occurred during the winter of 1994 to 1995, when 29 eagle deaths were documented at DeGray Lake, followed by a single eagle death in the winter of 1995 to 1996 at nearby Lake Ouchiata. A total of 26 deaths were recorded at both lakes during the winter of 1996 to 1997 (Thomas et al. 1998; Fischer et al. 2002; Rocke et al. 2005). Neurologic signs were observed in 5% of the coot population at DeGray Lake in November and December of 1996; coots migrated farther south by early December and few dead coots (*Fulica americana*) were observed near the lake (Thomas et al. 1998). At the time, the cause of AVM was unknown. The disease was first linked to the migration of coots, but later it was confirmed that the birds did not arrive at the lakes with the disease (Rocke et al. 2005). Later it was determined that waterfowl contact AVM by ingesting Hydrilla or ingesting other waterfowl with AVM (Birrenkott et al. 2004).

Further study revealed that a cyanobacterium present on the leaves of Hydrilla was the cause of AVM (Williams et al. 2007), which was later identified as a new genus named *Aetokthonos hydrillicola*, and most closely related to *Fischerella reptans* (Wilde et al. 2014).

Since 1994, AVM has been observed at approximately 19 sites in Arkansas, Florida, Georgia, North Carolina, South Carolina, and Texas; Hydrilla is currently present in 30 states and Washington D.C., and, therefore, AVM does not appear to be widespread. Sites with AVM were all man-made reservoirs containing invasive aquatic plants, primarily Hydrilla (Wilde et al. 2014). In addition to bald eagles and coots, AVM has been observed in mallards (*Anas platyrhynchos*), ring-necked ducks (*Aythya collaris*), buffelheads (*Bucephala albeola*), Canada geese (*Branta canadensis*), killdeer (*Charadrius vociferus*), and great horned owls (*Bubo virginianus*) (Fischer et al. 2002; Rocke et al. 2005).

When fed Hydrilla treated with the cyanobacterium, grass carp developed similar brain lesions as those found in waterfowl with AVM, but did not appear to develop symptoms or show noticeable mortality (Haynie et al. 2013). Painted turtles fed a diet of Hydrilla containing the cyanobacterium and chickens fed either coot tissue or Hydrilla containing the cyanobacterium displayed neurological dysfunction and developed brain lesions (Mercurio et al. 2014; Lewis-Weis et al. 2004). AVM is also capable of transmission through waterfowl and other prey to predatory species, as demonstrated by the infection of eagles and owls. When fed apple snails that fed on cyanobacterium-containing Hydrilla, chickens developed AVM symptoms and brain lesions (Dodd et al. 2016). However, chickens fed grass carp tissue exposed to the cyanobacterium did not develop AVM, possibly due to how the toxin is metabolized in the grass carp gut (Haynie et al. 2013). Pigs and mice fed infected coot tissue did not develop symptoms or brain lesions (Lewis-Weis et al. 2004; Rocke et al. 2005).

Most studies do not distinguish between the presence of monoecious and dioecious Hydrilla where AVM was observed. However, one study did collect samples of both Hydrilla biotypes from J. Strom Thurmond Lake, on the border of South Carolina and Georgia, and appeared to find the then unknown cyanobacterium on both biotypes (Birrenkott et al. 2004). Although a small area of dioecious Hydrilla was found based on a 2015 survey conducted by the USACE Savannah District, the vast majority of Hydrilla is the monoecious biotype (USACE Savannah District 2016). Dense aquatic macrophyte beds provide ideal substrate for attachment of cyanobacteria and other aquatic plants may also be a host; although Hydrilla appears to be the most common host for the cyanobaterium, and at J. Strom Thurmond Lake, Hydrilla is the predominant submerged aquatic plant (Wilde et al. 2014; Mercurio et al. 2014; USACE Savannah District 2016). Additional study may be needed to determine if there is any difference in the host conditions that monoecious and dioecious Hydrilla provide for *Aetokthonos hydrillicola*. Additional research may also be needed to determine the impact of cooler climates on *Aetokthonos hydrillicola*.

#### Results of Desktop Analysis: Pathogens in the Great Lakes Basin

A desktop analysis was not conducted that examined the relationship between pathogens and Hydrilla. Datasets for the distribution of the pathogens described above were not available for the Great Lakes Basin. In addition, AVM does not appear to be widespread even within areas currently infested with Hydrilla, thus location and extent of outbreaks in the Great Lakes Basin would not be expected to be readily predictable.

### 3.3.3.4 Waterfowl and Wildlife

#### Summary of Reviewed Literature

Hydrilla can serve as a source of food for some waterfowl and wildlife, either when Hydrilla is introduced to a waterbody without existing vegetation or when Hydrilla displaces native vegetation (Kirk and Henderson 2006; Rybicki and Landwehr 2007). Hydrilla by itself appears to be safe for consumption by fish and wildlife, though more research may be needed on the nutritional value of Hydrilla over native plants consumed by birds and wildlife. The negative impacts of Hydrilla associated with consumption appear to be largely related to AVM, which animals may contract from cyanobacteria on the leaves of Hydrilla (Kirk and Henderson 2006; Williams et al. 2007; Wilde et al. 2014) (see Section 3.3.3.3). Hydrilla is currently present in 30 states, while AVM has only been identified at 19 sites within six states (Wilde et al. 2014).

Hydrilla can either be eaten directly by some waterfowl or provide habitat for macroinvertebrates that some birds may feed on (Kirk and Henderson 2006; Rybicki and Landwehr 2007; Hoyer et al. 2008; Balkcom and Morgan 2011). The benefits of Hydrilla as a food source may be highest where no native vegetation is present. Poor water quality in the Potomac River contributed to a decrease in native submerged vegetation and an increase in algae blooms; the number of waterfowl observed along the Potomac River increased significantly after the introduction of Hydrilla in the 1980s (Rybicki and Landwehr 2007). Some hunters and waterfowl groups recognize that waterfowl and wildlife are attracted to Hydrilla and oppose management efforts (Kirk and Henderson 2006). In waterbodies where other aquatic vegetation does exist, there appears to be no significant differences in the number of aquatic plant species or bird densities between lakes with and without Hydrilla (Hoyer et al. 2008). Some evidence suggests waterfowl may prefer Hydrilla to native species. One study looked at the number and distribution of ducks at a lake treated with a low dose of herbicide to target Hydrilla. The study found that the number of ducks at the lake did not change before and after the herbicide treatment, but following treatment, ducks moved away from areas previously covered by Hydrilla and concentrated in areas of the lake where Hydrilla was still present (Balkcom and Morgan 2011).

**Results of Desktop Analysis: Waterfowl and Wildlife Resources in the Great Lakes Basin Potentially Subject to Hydrilla Infestation**

The Great Lakes Basin provides habitat for avian and other wildlife species, including sites of particular habitat value that have one or more official designations, such as National Wildlife Refuges (NWRs) and Important Bird Areas (IBAs). NWRs are a network of terrestrial and aquatic sites managed by the USFWS for the purpose of conservation, management, and in places, restoration of the fish, wildlife, and plant resources. IBAs include public and private lands identified by the National Audubon Society (NAS) at the global, continental, and state levels. Many NWRs and IBAs often contain prominent aquatic components, and the introduction of Hydrilla to these sites could impact habitat quality positively (by providing a food source at low densities) or negatively (by excluding native vegetation communities and degrading water quality at high densities). It is important to note that NWRs and IBAs do not represent the full extent of habitat used by waterfowl and wildlife or habitats available to Hydrilla infestation. While many potential infestation sites such as state parks, state game areas, and state wildlife areas are designated as IBAs and thus included in this analysis, other potential infestation sites are not IBAs. The analysis was limited by the availability of aggregate data at the appropriate scale.

Although the USFWS manages other types of sites, such as waterfowl protection areas and wildlife research stations, this analysis was limited to NWRs as the most likely sites to contain aquatic components that might provide habitat for Hydrilla. The NWR dataset used in the desktop analysis were all located on either the mainland or islands, with no sites located within the Great Lakes proper. Thus, for each of the 18 watersheds in the Great Lakes Basin, NWR sites were identified from the dataset that met one of the following criteria:

- Terrestrial inland sites; or
- Island locations, with the exception of islands in western Lake Superior (coldest watershed, so Hydrilla infestations less likely).

According to aggregated 2017 GIS data of lands and waters administered by the USFWS, the Great Lakes Basin contains 20 NWRs, encompassing approximately 158,000 acres (USFWS 2017; see Table 3.3.3-4 and Figure 3.3.3-3). In considering that the risk assessment primarily focuses on the Great Lakes proper and shoreline habitats, approximately 40,800 acres, or 26%, of the Great Lakes Basin NWRs were fully or partially located within the 8-mile buffer of the Great Lakes shorelines (see Table 3.3.3-4). For consistency with the coastal wetlands analysis, the same 8-mile buffer was applied for the analysis of NWRs, as that was the approximate maximum distance of Great Lakes coastal wetlands extending inland. The watersheds with the highest acreage of NWRs either fully or partially within 8 miles of the Great Lakes shoreline were southeastern Lake Ontario (approximately 22,000 acres for Montezuma NWR in New York State; which includes areas of the refuge within and outside the 8-mile buffer) and western Lake Erie (four NWRs totaling approximately 12,600 acres); both of these watersheds have a relatively high potential for Hydrilla introduction (see Table 3.3.3-4). Overall, the northeastern Lake Michigan-Lake Michigan watershed contained the most acreage of NWRs (approximately 95,000 acres for the Seney NWR in Michigan's Upper Peninsula). However, given the location of the Seney NWR farther inland, coupled with its higher latitude, this site has a lower potential for Hydrilla introduction and establishment than NWRs located farther south, based on dispersal and habitat suitability modeling (see Section 3.2).

Applying the predicted 2025 proportions from the dispersal modeling to total NWR acreage indicates that up to approximately 1,900 acres of NWR habitat may potentially be colonized by Hydrilla across the Great Lakes Basin in 2025, with roughly 1,700 acres, or 88%, within 8 miles of the Great Lakes shoreline. This analysis assumes no difference in Hydrilla introduction potential between sites closer to the shoreline and sites farther inland (see Table 3.3.3-4).

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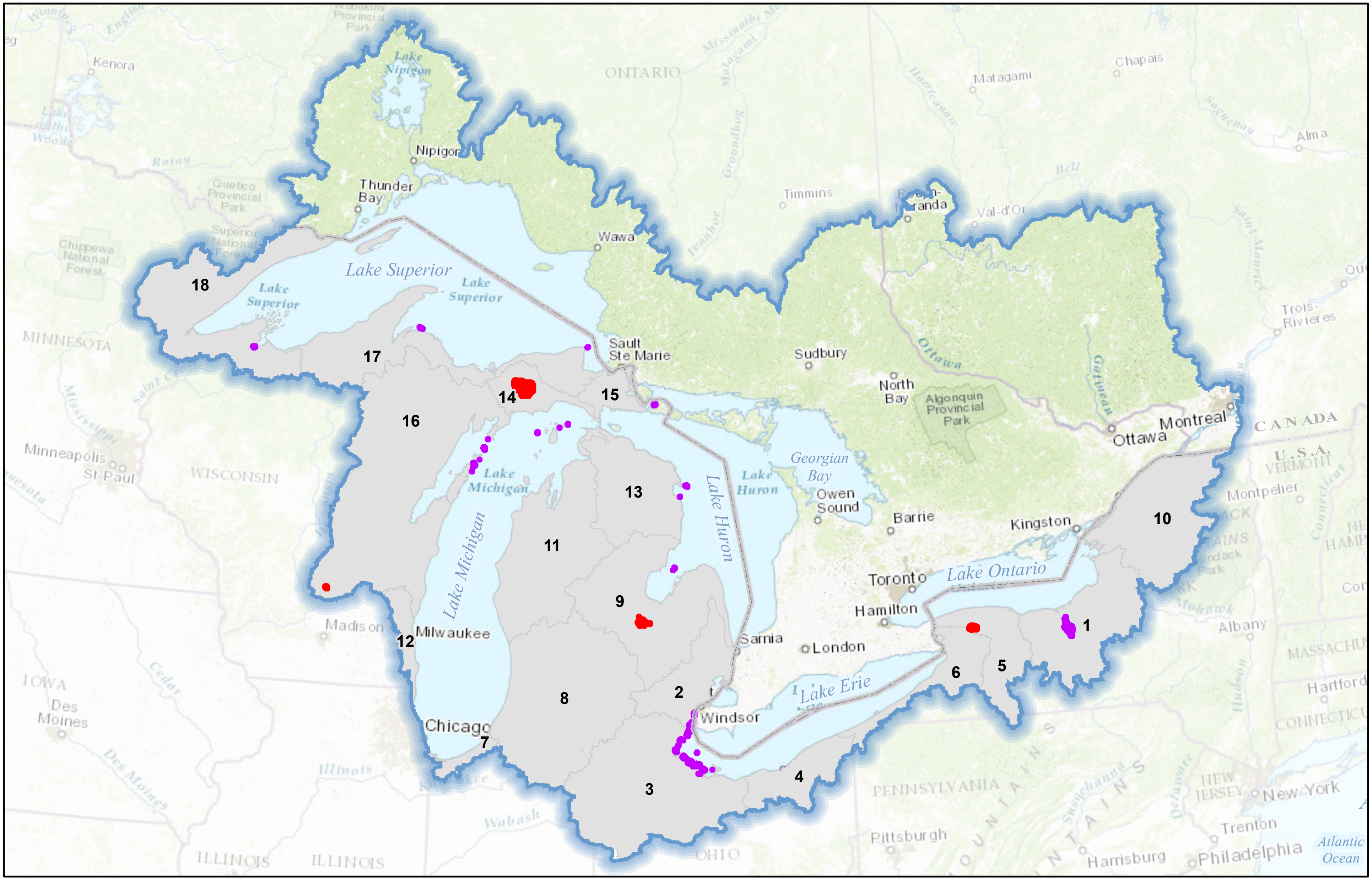


KEY:

Great Lakes Basin

Introduction Potential Watershed

National Wildlife Refuge

Within 8-Mile Shoreline Buffer

Not Within 8-mile Shoreline Buffer

Figure 3.3.3-3

**Great Lakes Basin**

**National Wildlife Refuges (NWR)**

Great Lakes Basin

Data Source: Ecology and Environment, Inc. 2017; USFWS 2017; USGS 2015.

**Table 3.3.3-4 Acreages of Great Lakes Basin National Wildlife Refuges (NWR) by Watershed and Distance to Shoreline and Predicted Acreage Potentially Colonized by Hydrilla in 2025**

| Hydrilla Introduction Potential and Rank[a] | | Watershed Name | Total Number of NWR Sites within Watershed[b] | Total Acreage of NWR Sites within Watershed[b] | Acreage of NWR Sites fully or partially within 8 miles of Great Lakes Shoreline[b] | Predicted 2025 Acreage of Potentially-Infested NWR within Watershed[a] | Predicted 2025 Acreage of Potentially-Infested NWR within 8 miles of Shoreline[a] |
|---|---|---|---|---|---|---|---|
| High | 1 | Southeastern Lake Ontario | 1 | 22,236 | 22,236 | 1,143 | 1,143 |
| | 2 | St. Clair-Detroit | 1 | 2,072 | 2,072 | 81 | 81 |
| | 3 | Western Lake Erie | 4 | 12,627 | 12,627 | 461 | 461 |
| | 4 | Southern Lake Erie | 0 | 0 | 0 | 0 | 0 |
| Medium | 5 | Southwestern Lake Ontario | 1 | 10,297 | 0 | 138 | 0 |
| | 6 | Eastern Lake Erie | 1 | 660 | 0 | 8 | 0 |
| | 7 | Southwestern Lake Michigan 2 | 0 | 0 | 0 | 0 | 0 |
| | 8 | Southeastern Lake Michigan | 0 | 0 | 0 | 0 | 0 |
| | 9 | Southwestern Lake Huron-Lake Huron | 2 | 10,398 | 249 | 72 | 2 |
| Low | 10 | Northeastern Lake Ontario- Lake Ontario-St. Lawrence | 0 | 0 | 0 | 0 | 0 |
| | 11 | Northeastern Lake Michigan-Lake Michigan 2 | 1 | 263 | 263 | 0 | 0 |
| | 12 | Southwestern Lake Michigan 1 | 0 | 0 | 0 | 0 | 0 |
| | 13 | Northwestern Lake Huron 2 | 1 | 394 | 394 | 0 | 0 |
| | 14 | Northeastern Lake Michigan-Lake Michigan 1 | 1 | 95,251 | 0 | 19 | 0 |
| | 15 | Northwestern Lake Huron 1 | 1 | 711 | 711 | 0 | 0 |
| | 16 | Northwestern Lake Michigan | 3 | 2,668 | 1,672 | 0 | 0 |
| | 17 | Southern Lake Superior-Lake Superior | 2 | 206 | 206 | 0 | 0 |
| | 18 | Western Lake Superior | 1 | 358 | 358 | 0 | 0 |
| | | **Totals** | **20** | **158,143** | **40,790** | **1,923** | **1,688** |

Notes:
[a] Sections 3.1.5 and 3.2.
[b] USFWS 2017.

Several habitat suitability considerations applicable for NWRs or fish spawning sites also applied to the NAS's United States IBA dataset (NAS 2015). For each of the 18 watersheds in the Great Lakes Basin, IBA sites were identified from the national IBA dataset that met one of the following criteria:

- Terrestrial inland sites with notable aquatic habitat;
- In the Great Lakes within the zone of suitable depth/temperature requirements for Hydrilla growth; or
- Island locations.

The IBAs in the original dataset were not limited only to sites with aquatic habitat; for example, there are sites designated as IBAs for containing forested, grassland, and alpine habitat. While these terrestrial habitats may potentially contain ponds or other features where Hydrilla could become established, sites designated as IBAs for their terrestrial habitat features and respective avian communities seemed less likely for potential Hydrilla infestations and impacts on birds and wildlife and, therefore, were excluded from consideration.

Figure 3.3.3-4 shows Great Lakes Basin IBAs within 8 miles of Great Lakes Shoreline (purple) and greater than 8 miles (red) from the shoreline. Part of the selection process involved identifying which IBAs within the Great Lakes Basin contained key words within the site names that indicated aquatic habitat (e.g., river, lake, lakeshore, marsh, island, and waterbird). IBAs unlikely to have substantial aquatic habitat (e.g., forest and plains) were excluded from the analysis. For sites that had entirely ambiguous names (e.g., Baker Sanctuary and Barry State Game Area), the site description and bird species of interest on the NAS's IBA website (http://www.audubon.org/important-bird-areas) were used to determine whether the site should be included in the analysis.

The selection process identified a total 205 IBAs in the Great Lakes Basin with prominent aquatic habitat. The selected IBAs encompass approximately 8,073,000 acres (NAS 2018; see Table 3.3.3-5 and Figure 3.3.3-4). Approximately 3,637,000 acres, or 45%, of the Great Lakes Basin IBA land area was located within the 8-mile buffer of the Great Lakes shoreline (see Table 3.3.3-5). The watershed with the highest acreage of IBAs within 8 miles of the Great Lakes shoreline were southwestern Lake Huron-Lake Huron (seven sites totaling approximately 747,000 acres), followed by western Lake Superior (nine sites totaling approximately 736,000 acres) and western Lake Erie (eight sites totaling approximately 535,000 acres). These three watersheds are classified as having medium, low, and high potential, respectively, for Hydrilla introduction (see Table 3.3.3-5). Including inland areas as well, these three watersheds, along with northeastern Lake Michigan-Lake Michigan, contain the most acreage of IBAs with prominent aquatic habitat suitable for supporting Hydrilla (see Table 3.3.3-5).

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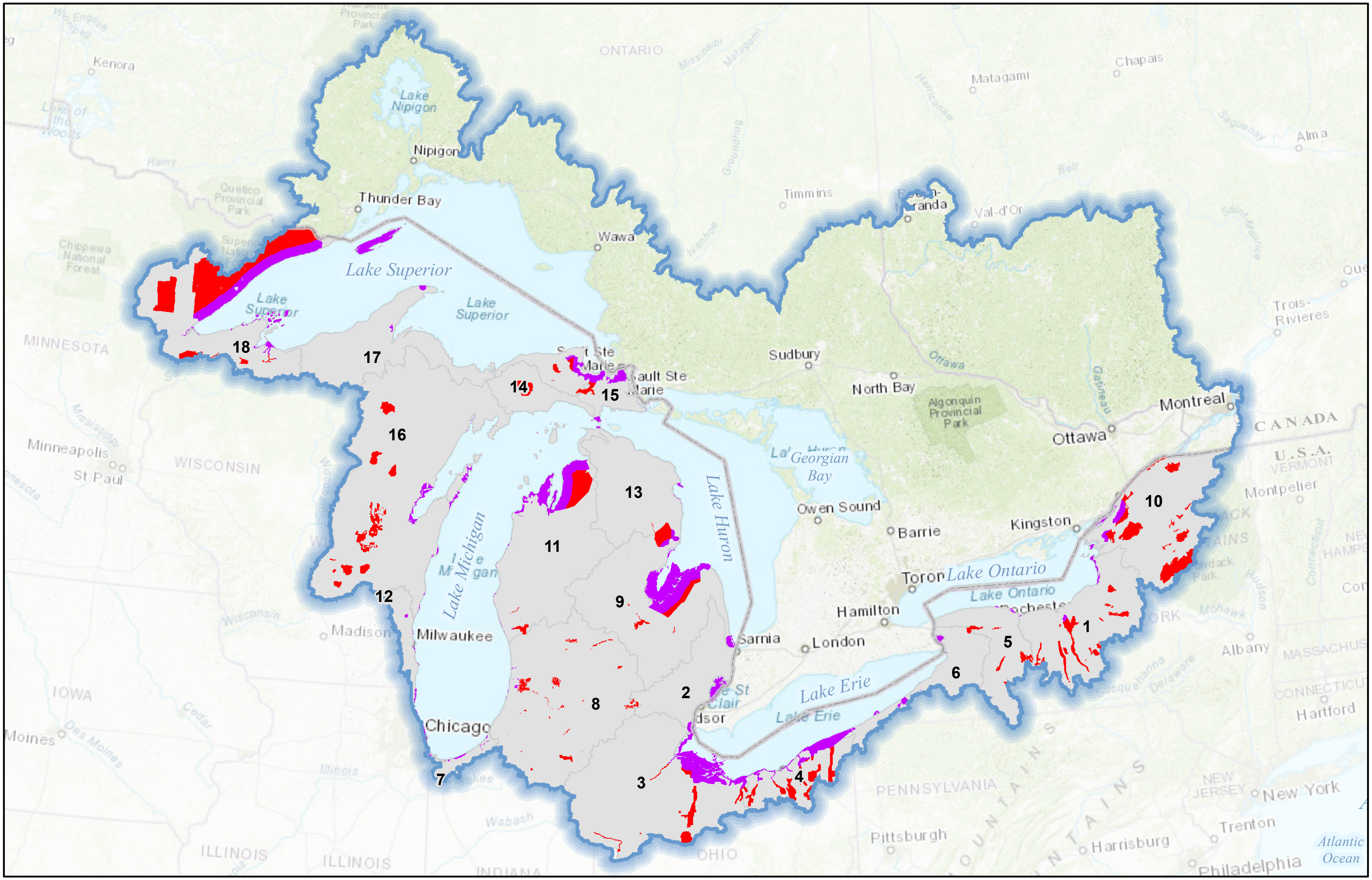


KEY:

Important Bird Area (IBA)

- Within 8-mile Shoreline Buffer
- Not Within 8-mile Shoreline Buffer

- Great Lakes Basin
- Introduction Potential Watershed

Figure 3.3.3-4

**Great Lakes Basin Important Bird Areas (IBA) with Prominent Aquatic Habitat**

Great Lakes Basin

0 50 100 200 Miles

N

Data Source: Ecology and Environment, Inc. 2019; National Audubon Society 2018; USGS 2015.

**Table 3.3.3-5 Acreages of Great Lakes Basin Important Bird Areas (IBA) with Prominent Aquatic Habitat by Watershed and Distance to Shoreline and Predicted Acreage Potentially Colonized by Hydrilla in 2025**

| Hydrilla Introduction Potential and Rank[a] | | Watershed Name | Total Number of IBA Sites within Watershed[b] | Total Acreage of IBA Sites within Watershed[b] | Acreage of IBA Sites within 8 miles of Great Lakes Shoreline[a] | Predicted 2025 Acreage of Potentially-Infested IBA within Watershed[a] | Predicted 2025 Acreage of Potentially-Infested IBA within 8 miles of Great Lakes Shoreline[a] |
|---|---|---|---|---|---|---|---|
| High | 1 | Southeastern Lake Ontario | 21 | 312,713 | 32,734 | 16,073 | 1,683 |
| | 2 | St. Clair-Detroit | 7 | 113,750 | 109,729 | 4,459 | 4,301 |
| | 3 | Western Lake Erie | 17 | 770,305 | 535,115 | 28,116 | 19,532 |
| | 4 | Southern Lake Erie | 19 | 538,427 | 218,524 | 18,199 | 7,386 |
| Medium | 5 | Southwestern Lake Ontario | 9 | 81,169 | 6,824 | 1,088 | 91 |
| | 6 | Eastern Lake Erie | 13 | 92,893 | 83,557 | 1,189 | 1,070 |
| | 7 | Southwestern Lake Michigan 2 | 11 | 37,964 | 37,964 | 376 | 376 |
| | 8 | Southeastern Lake Michigan | 21 | 153,279 | 8,860 | 1,349 | 78 |
| | 9 | Southwestern Lake Huron-Lake Huron | 13 | 940,644 | 746,896 | 6,490 | 5,154 |
| Low | 10 | Northeastern Lake Ontario- Lake Ontario-St. Lawrence | 17 | 730,697 | 113,404 | 1,096 | 170 |
| | 11 | Northeastern Lake Michigan-Lake Michigan 2 | 22 | 771,512 | 473,787 | 1,080 | 663 |
| | 12 | Southwestern Lake Michigan 1 | 9 | 24,831 | 24,246 | 22 | 22 |
| | 13 | Northwestern Lake Huron 2 | 8 | 86,881 | 24,947 | 35 | 10 |
| | 14 | Northeastern Lake Michigan-Lake Michigan 1 | 7 | 102,729 | 7,687 | 21 | 2 |
| | 15 | Northwestern Lake Huron 1 | 9 | 136,480 | 103,648 | 14 | 10 |
| | 16 | Northwestern Lake Michigan | 26 | 512,163 | 112,267 | 51 | 11 |
| | 17 | Southern Lake Superior-Lake Superior | 10 | 313,416 | 260,386 | 31 | 26 |
| | 18 | Western Lake Superior | 16 | 2,352,814 | 736,513 | 0 | 0 |
| | | **Totals** | **205[c]** | **8,072,667** | **3,637,089** | **79,689** | **40,584** |

Notes:
a. Sections 3.1.5 and 3.2.
b NAS 2018.
c The values in the field sum to 255 rather than 205 because the boundaries of 50 IBAs extend into multiple watersheds.

Applying the predicted 2025 proportions from the dispersal modeling to total IBA acreage indicates that up to approximately 80,000 acres of IBA habitat may potentially be impacted by Hydrilla across the Great Lakes Basin in 2025, with roughly 41,000 acres, or 51%, within 8 miles of the Great Lakes shoreline. The analysis assumes no difference in Hydrilla introduction potential between sites closer to the shoreline and sites farther inland (see Table 3.3.3-5).

Similar to coastal wetlands described in Section 1.1, the NWR and IBA acreages presented in Tables 3.3.3-4 and 3.3.3-5 primarily summarize these preeminent ecological resources potentially subject to Hydrilla infestation. As implied by the 2025 predictions, not all locations are equally subject to introduction. In general, sites in more northern watersheds are less likely to be colonized because they are farther from known Hydrilla infestations and offer less suitable habitat. In addition, the estimates of NWR and IBA acreages for each watershed are overestimated to some extent, as portions of these sites do not provide suitable Hydrilla habitat. For example, refuges and preserves are often a mix of aquatic and terrestrial habitat types. Screening IBA sites by site name helped limit the analysis to prominently aquatic sites. Nonetheless, even aquatic habitats may be unsuitable for Hydrilla to become established by having highly variable water levels, water too deep for Hydrilla (> 25 feet), or dense vegetation. However, data are insufficient and this analysis is too general to make predictions beyond applying the results of the dispersal model in the simple manner done here. Environmental systems are sufficiently variable and dynamic that it would be impractical to identify specific NWRs or IBAs within a watershed likely to be impacted by Hydrilla or evaluate the extent of the impacts.

Similar to the coastal wetland analysis, the analyses for NWRs and IBAs included sites within all 18 watersheds, even at northern latitudes, because habitat conditions may exist in small protected waterbodies that would be suitable for Hydrilla even if conditions are not suitable in the Great Lakes proper.

This analysis likely underestimates total wildlife habitat at risk of Hydrilla impact as it does not include areas such as state parks or game areas outside NWRs and IBAs. Use of IBAs was likely sufficiently representative for states that have extensive shoreline IBAs, including Minnesota, Wisconsin, Illinois, Ohio, western Michigan, and the Lake St. Clair region. However, the risk to states or regions with relatively few shoreline IBAs may be underrepresented, including New York, Indiana, Pennsylvania, and Michigan’s Upper Peninsula. Quantifying acreages of all natural areas was beyond the scope of this analysis, so the focus was on preeminent wildlife sites.

### 3.3.3.5 Hydrology

#### Summary of Reviewed Literature

Hydrilla can reduce the flow of water in rivers, irrigation canals, and drainage canals, which can lead to flooding (Thunberg et al. 1992; Searcy 1994; Langeland

1996; Bell and Bonn 2004; Indiana DNR 2009; Florida Fish and Wildlife Conservation Commission 2015; Brewer et al. 2016). As the biomass of aquatic plants in a waterway increases, the efficiency of water movement decreases, resulting in reduced flow rates and rising water levels that spill out into the floodplain (Thunberg et al. 1992; Bal and Meire 2009). Rising tides are also slower to enter a stand of Hydrilla compared to a neighboring water channel and falling tides are slower to leave the stand (Rybicki et al. 1997). Aquatic plants have the potential to reduce the capacity of drainage canals by as much as 95% (University of Florida 2011). This can significantly affect the ability of drainage canals and pumps to dissipate storm surges in low-lying areas.

Florida experienced a crisis in the 1960s when waterways were clogged by hyacinth and water lettuce, but the state of Florida has since taken a proactive approach to reduce the threat of flooding caused by aquatic plants (Weed Science Society of America 2009). One study found that for every dollar spent on aquatic plant control in the city of Old Plantation, Florida, between $57 and $237 in expected annual flood damages were avoided (Thunberg et al. 1992). Another report referenced a model prepared for Lake Istokpoga, Florida, in 1994 (Bell and Bonn 2004). The model compared the lake’s lowest (7%) and highest (46%) levels of Hydrilla coverage since initial infestation in 1970, and estimated the difference in water levels during hypothetical storm events. The results estimated the difference in water levels would range between a 0.5 foot for a five-year storm event and 5.1 feet for a storm more severe than a 100-year storm (Searcy 1994). Few other recent examples were identified where Hydrilla caused flooding, but Hydrilla was partly blamed for flooding in the Kissimmee chain of lakes in Florida in 1994, contributed to the Rio Grande River in Texas ceasing to flow to the Gulf in 2001, and flooding in Lake Austin, Texas, in 2002 during a heavy rainstorm (Bouma 1994; Vertuno 2003; Brewer et al. 2016).

Impacts of Hydrilla on hydropower generation are discussed in Section 3.3.2; however, one example of the impacts of Hydrilla on the St. Stephen Hydroelectric Power Station is included here due to severe negative impacts of reduced flow on fisheries. Specifically, in 1991, a raft of Hydrilla floated into the intake screens at the power station, resulting in the shutdown of the turbines. This resulted in the largest fish kill in the history of South Carolina, including the loss of 20 federally endangered shortnose sturgeon (*Acipenser brevirostrum*) (Kirk and Henderson 2006).

### Results of Desktop Analysis: Hydrology in the Great Lakes Basin

A desktop analysis was not conducted that examined the relationship between hydrology and Hydrilla, as the available datasets did not have waterbody-specific data, such as water depth, flow rate, and temperature to draw meaningful conclusions concerning vulnerability to flooding for the large number of waterbodies in the Great Lakes Basin.

Data for hydrological features are available, most notably the National Hydrography Dataset, which is a database that interconnects and identifies the stream segments that make up the surface water drainage system in the Unites States, and provides an indication of flow direction for many waterbodies. In principle, certain stream features within this layer could be identified as being susceptible to experiencing reduced flow from Hydrilla infestation, both rivers and streams that directly flow into the Great Lakes and those features found farther inland. However, the scale of the effort and limited data for water depth, flow rate, and water temperature greatly limits one's ability to differentiate which stream and channel features that may be more or less vulnerable to Hydrilla establishment and, thus, have resulting impacts on hydrology. Flowing water in streams and rivers often is not optimal Hydrilla habitat in the early stages of invasion compared with quieter lakes and ponds, and stream depth, flow rate, and water temperatures are all example variables that could affect the likelihood of Hydrilla establishment and growth as well as the waterway's vulnerability to clogging or flooding. In addition, the National Hydrography Dataset contains thousands of surface water features within a single watershed. For example, the southeastern Lake Ontario watershed contains over 5,000 surface water features, with over 100 of them connected directly to Lake Ontario. With the data available, it would be beyond the scope of this impact-assessment effort to meaningfully predict how many of these features are potentially at risk of experiencing reduced water flow or flooding in the event of Hydrilla infestation, given the spatial and temporal variability anticipated along each waterbody.

#### 3.3.3.6 Conclusions

The literature review provides an indication of the types and magnitude of environmental impacts that occur when Hydrilla is introduced into an aquatic system with suitable habitat and develops over time into an infestation. These impacts are largely due to the ability of Hydrilla to grow and reproduce rapidly once introduced, thereby clogging waterways, restricting water flow, modifying sunlight and temperature within the water column, lowering DO levels, and generally disrupting submerged aquatic habitats by domination (Netherland and Greer 2014; Shearer 2014; Dayan and Netherland 2005). In contrast, positive impacts on fish and waterfowl have been reported in situations where Hydrilla density was low, but such benefits are expected to be short-lived and limited to the early stages of Hydrilla invasion. It should be noted that there are few examples of Hydrilla invading a system without some form of management activity implemented in response. In many places where Hydrilla has become established, control and management plans have been implemented to curb the spread of Hydrilla, although often with only limited success. Without control or management actions, the types of impacts discussed in this section would be expected to be more severe and/or develop more rapidly.

Combining the literature review of potential environmental impacts with the desktop analysis, which integrated the findings of the habitat suitability and dispersal modeling, provides a means to estimate which areas in the Great Lakes Basin are most susceptible to Hydrilla introduction and establishment and possible extent of future infestations. Overall, this environmental impact analysis provides a high-level estimate of the types of ecological resources—waterbodies, coastal wetlands, fish spawning and nursery sites, NWRs, and IBAs—that are potentially susceptible to Hydrilla introduction and establishment, the types of environmental impacts that may occur, and worst-case extent of those potential impacts in 2025.

### 3.3.4 Potential Tribal Impacts

The spread of Hydrilla in the Great Lakes basin may result in indirect socio-cultural impacts on communities by altering the natural resources that certain communities use for subsistence or for economic purposes. Considering the continued use of Great Lakes ecosystems by Native Americans for subsistence hunting/gathering, cultural and spiritual practices, and economic purposes, and their spiritual/religious connections to the earth and its resources, this assessment focuses on the potential impacts of Hydrilla on those resources identified as being of economic or cultural importance to various federally recognized Indian tribes surrounding the Great Lakes.

A desktop analysis was completed to begin identifying the potential impacts that Hydrilla colonization and infestations may have on federally recognized Indian tribes. In order to initiate this effort, tribes located within the Great Lakes basin and those tribes that are now located outside the Great Lakes basin but have a historical or cultural interest in areas within the basin were identified. The desktop analysis was also conducted to obtain publicly available information on tribes' species of interest and species of concern as they relate to economic and cultural issues, and management (e.g., hunting, trapping, nuisance control).

The literature review indicates that federally recognized Indian tribes are known as having an active interest in the management of the Great Lakes watershed (USACE 2012). The active interest of tribes in the management of the Great Lakes watershed can be recognized as a reflection of tribes' cultural connections to their environment in its entirety. These cultural connections, which are distinct to each tribe, recognize the interrelated spiritual, practical, and ecological aspects of these connections (Greeley 2019).

Information made publicly available by many of the tribes with a potential interest in areas within the Great Lakes Basin documents their cultural relationship to water, as depicted in individual traditions, histories, and myths, legends, and stories. However, on the topic of invasive species, while many federally recognized Indian tribes actively manage for invasive species within waterbodies of tribal lands, including AIS such as European milfoil or zebra mussels (see Appendix G), the effects of AIS such as Hydrilla on resources of interest or concern has not been substantively studied.

#### Desktop Analysis: Federally Recognized Indian Tribes that could be Potentially Affected as a Result of Hydrilla Infestation

The desktop analysis conducted to identify federally recognized Indian tribes located in the states bordering the Great Lakes, or with an interest in lands included in the Great Lakes Basin, provides a sense of the level of outreach and consultation that would be necessary to engage these tribes in the management of Hydrilla. This section summarizes the collective results of the desktop analysis. The analysis conducted to identify these tribes and assess information for species of interest or concern to these tribes is discussed in greater detail in Appendix G.

A total of 61 federally recognized Indian tribes were identified as part of the desktop analysis (see Table 3.3.4-1). These tribes could form the foundation for consultation efforts to clarify tribal concerns regarding potential impacts from Hydrilla infestation.

**Table 3.3.4-1 Federally Recognized Tribes Located in, or with a Potential Interest in Lands included in, the Great Lakes Basin**

| Description |
|---|
| Absentee-Shawnee Tribe of Indians of Oklahoma |
| Bad River Band of the Lake Superior Tribe of Chippewa Indians of the Bad River Reservation, Wisconsin |
| Bay Mills Indian Community, Michigan |
| Bois Forte Band (Nett Lake), component reservation of the Minnesota Chippewa Tribe, Minnesota |
| Cayuga Nation |
| Chippewa-Cree Tribe of the Rocky Boy's Reservation, Montana |
| Citizen Potawatomi Nation, Oklahoma |
| Delaware Nation, Oklahoma |
| Delaware Tribe of Indians |
| Eastern Shawnee Tribe of Oklahoma |
| Flandreau Santee Sioux Tribe of South Dakota |
| Fond du Lac Band, component reservation of the Minnesota Chippewa Tribe, Minnesota |
| Forest County Potawatomi Community, Wisconsin |
| Grand Portage Band, component reservation of the Minnesota Chippewa Tribe, Minnesota |
| Grand Traverse Band of Ottawa and Chippewa Indians, Michigan |
| Hannahville Indian Community, Michigan |
| Keweenaw Bay Indian Community, Michigan |
| Lac Courte Oreilles Band of Lake Superior Chippewa Indians of Wisconsin |
| Lac du Flambeau Band of Lake Superior Chippewa Indians of the Lac du Flambeau Reservation of Wisconsin |
| Lac Vieux Desert Band of Lake Superior Chippewa Indians of Michigan |
| Leech Lake Band, component reservation of the Minnesota Chippewa Tribe, Minnesota |
| Little River Band of Ottawa Indians, Michigan |
| Little Traverse Bay Bands of Odawa Indians, Michigan |
| Lower Sioux Indian Community in the State of Minnesota |
| Match-e-be-nash-she-wish Band of Pottawatomi Indians of Michigan |
| Menominee Indian Tribe of Wisconsin |

**Table 3.3.4-1 Federally Recognized Tribes Located in, or with a Potential Interest in Lands included in, the Great Lakes Basin**

| Description |
|---|
| Miami Tribe of Oklahoma |
| Mille Lacs Band, component reservation of the Minnesota Chippewa Tribe, Minnesota |
| Minnesota Chippewa Tribe, Minnesota |
| Nottawaseppi Huron Band of the Potawatomi, Michigan |
| Oneida Nation of New York |
| Oneida Nation |
| Onondaga Nation |
| Ottawa Tribe of Oklahoma |
| Peoria Tribe of Indians of Oklahoma |
| Pokagon Band of Potawatomi Indians, Michigan and Indiana |
| Prairie Band Potawatomi Nation |
| Prairie Island Indian Community in the State of Minnesota |
| Red Cliff Band of Lake Superior Chippewa Indians of Wisconsin |
| Red Lake Band of Chippewa Indians, Minnesota |
| Sac & Fox Nation of Missouri in Kansas and Nebraska |
| Sac & Fox Nation, Oklahoma |
| Sac & Fox Tribe of the Mississippi in Iowa |
| Saginaw Chippewa Indian Tribe of Michigan |
| Saint Regis Mohawk Tribe |
| Santee Sioux Nation, Nebraska |
| Sault Ste. Marie Tribe of Chippewa Indians, Michigan |
| Seneca-Cayuga Nation |
| Seneca Nation of Indians |
| Shawnee Tribe |
| Sisseton-Wahpeton Oyate of the Lake Traverse Reservation, South Dakota |
| Sokaogon Chippewa Community, Wisconsin |
| Spirit Lake Tribe, North Dakota |
| St. Croix Chippewa Indians of Wisconsin |
| Stockbridge Munsee Community, Wisconsin |
| Tonawanda Band of Seneca |
| Turtle Mountain Band of Chippewa Indians of North Dakota |
| Tuscarora Nation |
| Upper Sioux Community, Minnesota |
| White Earth Band, component reservation of the Minnesota Chippewa Tribe, Minnesota |
| Wyandotte Nation |

Sources: USACE 2012; U.S. National Park Service 2015, 2017; Butler 2015.

Native American peoples have always been drawn to water. Evidence for this can be found in the archaeological remains associated with lakes and rivers and/or the many place names that reflect water features of particular relevance to a tribe or its territory (Leech Lake Division of Resource Management 2018; Little Traverse Bay Bands of Odawa Indians 2005; Miami Tribe of Oklahoma 2019; Nottawaseppti Huron Band of the Potawatomi 2019; Alligood 2019; Sautl Ste Marie Tribe of Chippewa Indians, Michigan 2019). In some cases, a tribe's name specifically reflects its relationship to water, such as the Miami Tribe of Oklahoma's name for itself, Myaamia, which means "the Downstream People" (Miami Tribe of Oklahoma 2019) or the Prairie Island Indian Community's name for itself, Mdewatakanton, which means "those who were born of the waters" (Prairie Island Indian Community 2019) or the Mohican Nation's name, Muh-he-con-ne-ok, which means "the People of the Waters that Are Never Still" (Davids 2004). Furthermore, tribes take their stewardship responsibilities seriously, as in the case of the Onondaga Nation, which states that 'the health and well-being of the [Onondaga] Nation is interconnected with the health and well-being of the land, air and water" and the "living sum of everything" that is important to the wellbeing of the tribe (Onondaga Nation 2019a, 2019c).

The cultural and spiritual relationships of many of the tribes with a potential interest in areas included in the Great Lakes basin to water is also clearly evident in their beliefs, stories, legends, and practices. For example, many tribes have a migration tradition that explains their presence in the Upper Great Lakes, telling of their ancestors that made the long journey west from the Atlantic coast in what is now eastern Canada along the St. Lawrence River and throughout the Great Lakes basin (Jackson 2019, Bois Forte Band of Chippewa 2019, Fond du Lac Band of Lake Superior Chippewa 2018, Forest County Potawatomi 2019, Grand Traverse Band of Ottawa and Chippewa Indians 2019, LCO-NSN 2018, Little Traverse Bay Bands of Odawa Indians 2005, Mille Lacs Band of Ojibwe 2019, Pokégnek Bodéwadmik 2019b, Sokaogon Chippewa Community 2019, White Earth Nation 2019, Connelley 1900).

The stories presenting this migration tradition tell of their ancestors listening to prophets who advised them to seek a place to rest where the food grows on water, many of these migration stories tell of their ancestors that made the long journey west from the Atlantic coast in what is now eastern Canada along the St. Lawrence River and throughout the Great Lakes basin, settling in places where wild rice was found. As such, these tribes maintain a deep cultural and spiritual connection to the waters of the Great Lakes, as well as to wild rice – the food that grow on water (Jackson 2019, Bois Forte Band of Chippewa 2019, Fond du Lac Band of Lake Superior Chippewa 2018, Forest County Potawatomi 2019, Grand Traverse Band of Ottawa and Chippewa Indians 2019, Mille Lacs Band of Ojibwe 2019, Sokaogon Chippewa Community 2019).

Creation stories also portray the important role that water holds in creating various tribes. They tell of water that surrounded land and the tribe's survival was the result of a turtle that carried them until the water receded (Alligood 2019) or that land was created from water when water animals brought earth from beneath the water to rest on the back of a great turtle for people to live on (Oneida Nation 2016a, Oneida Tribe of Indians of Wisconsin 2019a, Jourdan 2013, Connelley

1928). Other stories name a specific place where a tribe originated and/or where their clans were created (Menominee Indian Tribe of Wisconsin 2019a, 2019b; Miami Tribe of Oklahoma 2019). Other stories identify waterbodies as specific barriers or pathways to other worlds, such as the need to cross rivers to reach the Land of the Dead after death (Little Traverse Bay Bands of Odawa Indians 2005) or locations where specific actions have or will occur, such as the St. Lawrence seaway, where Hurons first encountered Europeans, or the bay of Green Bay, where dreams indicated light-skinned men (the French) would come and change their lives forever (Little Traverse Bay Bands of Odawa Indians 2005; Menominee Indian Tribe of Wisconsin 2019b, 2019c), or how the tribe arrived in North America from the north when the water was frozen (Alligood 2019) or in their particular territory after following specific paths of rivers (Oneida Nation 2016c), or how a specific waterbody has become a sacred place, that must be cared for and respected (Onondaga Nation 2019b).

Tribes organized into clans note that some of various animals and birds representing the clans represent elements, many of which are water or water-related (Cayuga Nation 2019, Pokégnek Bodéwadmik 2019a). In some cases, a river is the location whereby specific animals were selected to represent the clans (Oneida Nation 2016c, Brown 2013). Tribes also note the origination of sacred plants from water, such as wild rice, as noted above, but also the appearance of tobacco from otherworldly beings (Oneida Nation 2016b); or note the importance of specific aquatic resources such as quahog shells that comprise wampum, used to commemorate specific binding stories, treaties, or agreements or laws of a people (Oneida Tribe of Indians of Wisconsin 2019b, Jourdan 2013b, Onondaga Nation 2019d); or generally acknowledge water as the source of life for their tribe, not just in the past but through to the current day (Cornelius and Metoxen 2013; Onondaga Nation 2019a-d).

To specify what potential impacts could be on tribes via potential identified species of concern and interest, information on official tribal websites provided a listing of aquatic and terrestrial animal and plant species of interest or concern. Most tribal websites identify specific species of interest or concern, and often reasons for their significance (e.g., for economic purposes or for conservation or wildlife management purposes; see Appendix G). A total of 144 different species or families of species were identified from tribal websites, including: 37 aquatic/fish species; 86 wildlife species, including mammals, birds, waterfowl, furbearers, and game species; and 21 plant species. These species are identified in Tables 3.3.4-2, -3, and -4, respectively.

**Table 3.3.4-2 Fish Species of Interest or Concern to Federally Recognized Indian Tribes in the Study Area**

| Common Name | Scientific Name |
|---|---|
| Alewife | *Alosa pseudoharengus* |
| Bluegill | *Lepomis macrochirus* |
| Brook trout | *Salvelinus fontinalis* |
| Brown trout | *Salmo trutta* |
| Bullhead | *Ameiurus nebulosus* |
| Burbot | *Lota lota* |
| Catfish | *Ictalurus punctatus* |
| Chinook salmon | *Oncorhynchus tshawytscha* |
| Chub | *Couesius plumbeus* |
| Cisco | *Coregonus artedi* |
| Coho salmon | *Oncorhynchus kisutch* |
| Crappie | *Pomoxis annularis/nigromaculatus* (white/black) |
| Grayling | *Thymallus thymallus* |
| Hellbender | *Cryptobranchus alleganiensis* |
| Herring | *Clupea harengus* |
| Lake trout | *Salvelinus namaycush* |
| Largemouth bass | *Micropterus salmoides* |
| Menominee | *Prosopium cylindraceum* |
| Muskellunge | *Esox masquinongy* |
| Northern pike | *Esox lucius* |
| Paddlefish | *Polyodon spathula* |
| Pink salmon | *Oncorhynchus gorbuscha* |
| Pumpkinseed | *Lepomis gibbosus* |
| Rainbow trout | *Ambloplites rupestris* |
| Rock bass | *Ambloplites rupestris* |
| Sauger | *Sander canadensis* |
| Sheepshead | *Archosargus probatocephalus* |
| Smallmouth bass | *Micropterus dolomieu* |
| Smelt | *Osmeridae* (family) |
| Sturgeon | *Acipenser fulvescens* |
| Sucker | *Catostomidae* (family) |
| Sunfish[a] | *Centrarchidae* (family) |
| Tiger muskellunge | *Esox masquinongy X Esox lucius* |
| Walleye | *Sander vitreus* |
| White bass | *Morone chrysops* |
| White perch | *Morone americana* |
| Yellow perch | *Perca flavescens* |

Source: see Appendix G.

Note:
[a] This is a broad range of fish including some already mentioned in this table.

**Table 3.3.4-3 Wildlife Species of Interest or Concern to Federally Recognized Indian Tribes in the Study Area**

| Common Name | Scientific Name |
|---|---|
| Antelope | *Antilocapra americana* |
| Badger | *Taxidea taxus* |
| Bald eagle | *Haliaeetus leucocephalus* |
| Beaver | *Castor canadensis* |
| Bison | *Bison bison* |
| Bittern | *Botaurus lentiginosus* |
| Black bear | *Ursus americanus* |
| Black duck | *Anas rubripes* |
| Black squirrel | *Sciurus carolinensis* |
| Blue-winged teal | *Anas discors* |
| Bluebird | *Sialia* (genus) |
| Bobcat | *Lynx rufus rufus, Lynx rufus superiorensis* |
| Brant | *Branta bernicla* |
| Mud hens (American coot) | *Fulica americana* |
| Bufflehead | *Bucephala albeola* |
| Canada goose | *Branta canadensis* |
| Canvasback | *Aythya valisineria* |
| Caribou | *Rangifer tarandus caribou* |
| Coots | *Fulica* (genus) |
| Cougar | *Puma concolor* |
| Coyote | *Canis latrans* |
| Crow | *Corvus* |
| Diver ducks | *Aythyinae* (family) |
| Doves | *Columbidae* (family) |
| Elk | *Cervus canadensis* |
| Falcons | *Falco* (genus) |
| Feral swine | *Sus scrofa* |
| Fisher | *Martes pennanti* |
| Fox squirrel | *Sciurus niger* |
| Gadwall | *Anas strepera* |
| Gallinule | *Gallinula galeata* |
| Golden eagle | *Aquila chrysaetos* |
| Gray fox | *Urocyon cinereoargenteus* |
| Gray squirrel | *Sciurus carolinensis* |
| Green-winged teal | *Anas carolinensis* |
| Hawks | *Accipitrinae* (subfamily) |
| Heron | *Ardeidae* (family) |
| Lesser scaup | *Aythya affinis* |
| Loon | *Gavia* (genus) |
| Lynx | *Lynx Canadensis* |

**Table 3.3.4-3 Wildlife Species of Interest or Concern to Federally Recognized Indian Tribes in the Study Area**

| Common Name | Scientific Name |
|---|---|
| Mallard | *Anas platyrhynchos* |
| Mergansers | *Mergus merganser* |
| Mink | *Neovison vison* |
| Moose | *Alces alces* |
| Mourning dove | *Zenaida macroura* |
| Mule deer | *Odocoileus hemionus* |
| Muskrat | *Ondatra zibethicus* |
| Opossum | *Didelphis virginiana* |
| Otter | *Lontra canadensis* |
| Owls | *Strigiformes* (order) |
| Partridge (Hungarian) | *Perdix perdix* |
| Pheasant (ring-necked) | *Phasianus colchicus* |
| Pine marten | *Martes americana* |
| Pintail | *Anas acuta* |
| Porcupine | *Erethizon dorsatum* |
| Prairie chicken | *Tympanuchus cupido* |
| Puddle/dabbler ducks[a] | *Anatidae* (family) |
| Quail (bobwhite) | *Colinus virginianus* |
| Rabbit (cottontail) | *Sylvilagus floridanus* |
| Raccoon | *Procyon lotor* |
| Red fox | *Vulpes vulpes* |
| Red squirrel | *Tamiasciurus hudsonicus* |
| Redhead duck | *Aythya americana* |
| Ruffed grouse | *Bonasa umbellus* |
| Sandhill crane | *Grus canadensis* |
| Sea ducks | *Merginae* (subfamily) |
| Sharp-tailed grouse | *Tympanuchus phasianellus* |
| Striped skunk | *Mephitis mephitis* |
| Wilson's snipe | *Gallinago delicata* |
| Snow goose | *Chen caerulescens* |
| Snowshoe hare | *Lepus americanus* |
| Sora rail | *Porzana carolina* |
| Spotted skunk | *Spilogale putorius* |
| Spruce grouse | *Falcipennis canadensis* |
| Swan | *Cygnus* (genus) |
| Tree ducks | *Dendrocygnidae* (family) |
| Turkey | *Meleagris gallopavo* |
| Turtle | *Testudines* (order) |
| Virginia rail | *Rallus limicola* |
| Weasel (short-tailed, long-tailed, least) | *Mustela ermine, Mustela frenata, Mustela nivalis* |

**Table 3.3.4-3 Wildlife Species of Interest or Concern to Federally Recognized Indian Tribes in the Study Area**

| Common Name | Scientific Name |
|---|---|
| White-fronted goose | *Anser albifrons* |
| White-tailed deer | *Odocoileus virginianus* |
| Wolf | *Canis lupus* |
| Wood duck | *Aix sponsa* |
| Woodchuck | *Marmota monax* |
| Woodcock | *Scolopax minor* |

Source: see Appendix G.

Note:
[a] This is a broad range of duck including some already mentioned in this table.

**Table 3.3.4-4 Vegetative Species of Interest or Concern to Federally Recognized Indian Tribes in the Study Area**

| Common Name | Scientific Name |
|---|---|
| Basswood | *Tilia* (genus) |
| Beans | *Phaseolus acutifolius, Phaseolus vulgaris* |
| Black ash | *Fraxinus nigra* |
| Cedar | *Thuja, juniperus* (genus) |
| Christmas trees[a] | Multiple species |
| Ginseng | *Panax quinquefolius* |
| Green corn | *Zea mays* |
| Ironwood[b] | *Carpinus caroliniana* |
| Jack pine | *Pinus banksiana* |
| Princess pine | *Lycopodium obscurum* |
| Red pine | *Pinus resinosa* |
| Sheet moss | *Hypnum curvifolium* |
| Squash | *Cucurbita* (genus) |
| Strawberry | *Fragaria vesca* |
| Sugar maple | *Acer saccharum* |
| Sweetgrass | *Hierochloe odorata* |
| Tamarack | *Larix laricina* |
| White birch | *Betula papyrifera* |
| White pine | *Pinus strobus* |
| White spruce | *Picea glauca* |
| Wild rice | *Zizania palustris* |

Source: see Appendix G.

Notes:
[a] Multiple species.
[b] Many different species referred to as ironwood.

Many of these species may also be of traditional cultural significance. However, information regarding the traditional cultural significance of a given species is generally not specifically provided on official tribal websites. Therefore, it is likely that the results of the desktop analysis underestimates the number of species of cultural significance to current and former resident tribes within the Great Lakes Basin.

Information obtained from the websites of federally recognized Indian tribes in the study area confirms the importance of aquatic and terrestrial animal and plant species for tribal economic and cultural activities (see Appendix G). Fishing continues to be essential to many tribes for both subsistence and economic reasons. Although not as essential to survival as in the past, subsistence hunting is also still an important aspect of tribal life. Present members of the majority of tribes in the Great Lakes basin hunt traditional waterfowl and game species as their ancestors did generations ago.

Various plant species also remain economically, culturally, and spiritually important to tribal life. In particular, wild rice remains an essential component of many tribes' economic and cultural practices. The potential for Hydrilla to affect aquatic habitats where harvesting of wild rice is conducted presently in the Great Lakes basin is possible if Hydrilla were to be introduced into those habitats.

As such, the establishment of Hydrilla in the Great Lakes Basin has the potential to disrupt traditional tribal ways of life and affect customary tribal nourishment practices, as well as spiritual beliefs. Such impacts would be likely if dense Hydrilla infestations were to develop in aquatic habitats traditionally used by one or more to the tribes identified in this section.

# 4 Risk Characterization

This section discusses the potential risk that Hydrilla poses to different areas of the Great Lakes Basin based on differences in habitat suitability, introduction potential, and potential for socio-cultural, economic, environmental, and tribal impacts. The Great Lakes nearshore environment and inland waterbodies are both discussed. This section also identifies and presents important sources of uncertainty in the overall assessment and whether those uncertainties are likely to over- or underestimate the potential risk that Hydrilla poses to the Great Lakes Basin. Lastly, the results of other Hydrilla risk assessment and invasiveness studies are discussed and compared with the results of this assessment.

## 4.1 Relative Risks for Watersheds in the Great Lakes Basin

The principal objective of this assessment was to identify areas in the Great Lakes Basin most vulnerable to Hydrilla invasion based on likelihood of introduction and environmental suitability (see Section 1.2). This objective was addressed by combining the distributional modeling results, dispersal modeling results, and water-depth and water-temperature requirements for Hydrilla, as described in Section 3.2 and shown in Figure 3.2-2. Combining this information shows that watersheds bordering Lakes Erie and Ontario in New York, Pennsylvania, and Ohio, and Lake St. Clair in southeast Michigan, have the greatest Hydrilla introduction potential and most suitable habitat for Hydrilla. Conversely, watersheds bordering Lake Superior have the lowest Hydrilla introduction potential and lowest habitat suitability. Watersheds around Lakes Michigan and Huron have intermediate values for Hydrilla introduction potential and habitat suitability. The impact assessments suggest that all watersheds in the Great Lakes Basin include abundant socio-cultural, economic, environmental, and tribal resources that may be adversely affected by Hydrilla (see Sections 3.3.1 to 3.3.4), regardless of introduction potential or habitat suitability, as would be expected.

Based on the totality of analyses presented in Section 3, it was concluded that the watershed ranks presented in Figure 3.2-2 and Table 3.2-1 based on introduction potential (i.e., proportion of waterbody area per watershed infested with Hydrilla in 2025) are the best predictor of the potential risk that Hydrilla poses to watersheds in the Great Lakes Basin. Using introduction potential to assign relative risks is logical and appropriate because habitat suitability varies directly with introduction potential (see Figure 3.2-2) and because the types of resources that may be impacted by Hydrilla are plentiful throughout the Great Lakes Basin and generally evenly distributed. Hence, the relative risks from Hydrilla to the 18 watersheds in the Great Lakes Basin are:

**High Risk Group:**

1. Southeastern Lake Ontario
2. St. Clair-Detroit
3. Western Lake Erie
4. Southern Lake Erie

**Medium Risk Group:**

5. Southwestern Lake Ontario
6. Eastern Lake Erie
7. Southwestern Lake Michigan 2 (actually, southern Lake Michigan)
8. Southeastern Lake Michigan
9. Southwestern Lake Huron

**Low Risk Group:**

10. Northeastern Lake Ontario (Lake Ontario – St. Lawrence)
11. Northeastern Lake Michigan 2
12. Southwest Lake Michigan
13. Northwestern Lake Huron
14. Northeastern Lake Michigan 1 (actually, northern Lake Michigan)
15. Northwestern Lake Huron
16. Northwestern Lake Michigan
17. Southern Lake Superior
18. Western Lake Superior

Watershed locations and risk ranks are shown on Figure 4-1.

L:\Buffalo\Hydrilla\Maps\MXDs\Hydrilla_Suitability\2019_Jan\4-1_Hydrilla_Suitability_Great_Lakes_1_MAXENT_with_Watersheds.mxd 1/29/2019

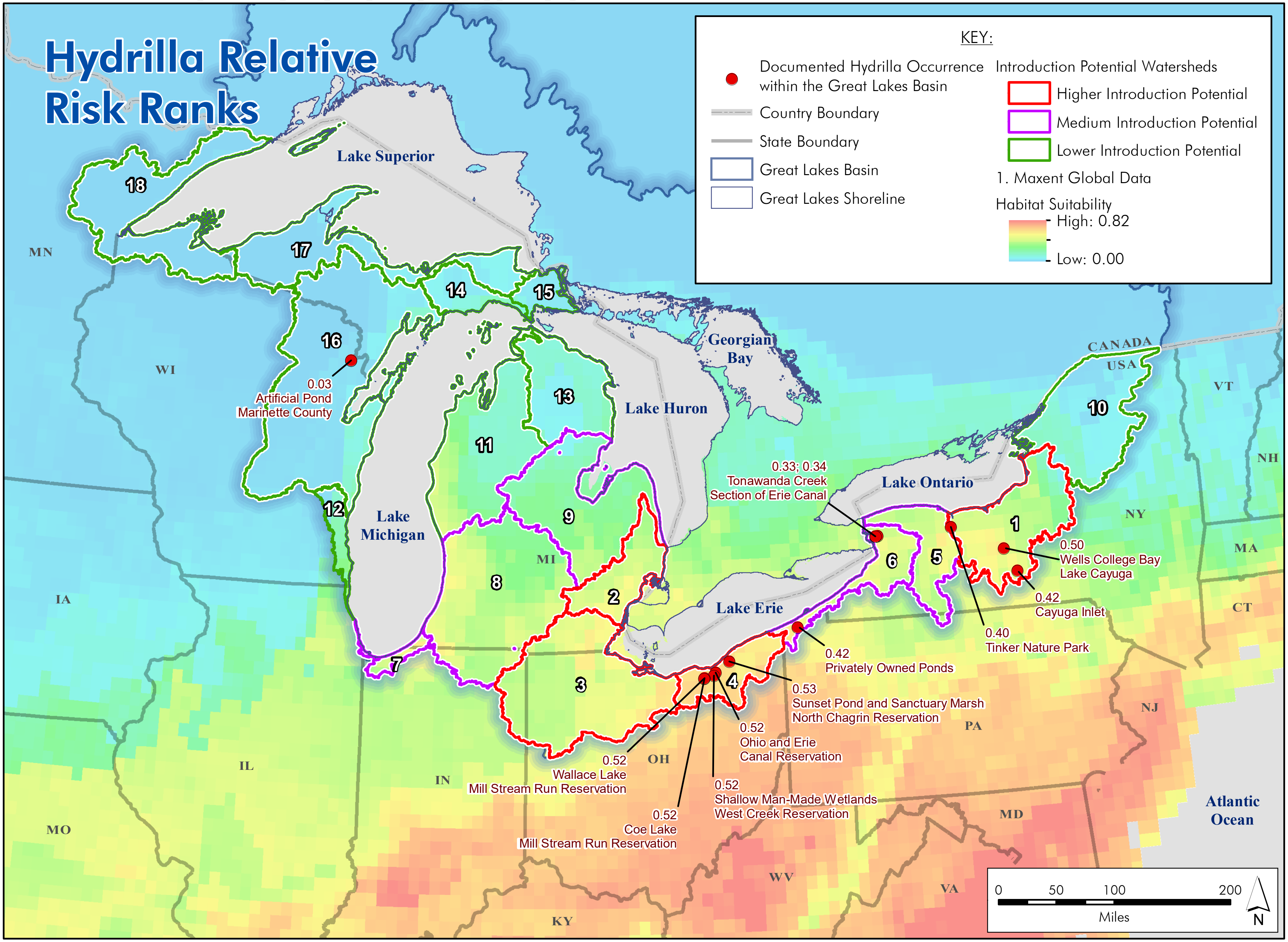


**Figure 4-1 Hydrilla Relative Risk Ranks for Watersheds in the Great Lakes Basin**

**Occurrences as of 2/26/2016**

## 4.2 Vulnerable Great Lakes Areas

As noted in the previous section, the potential risk that Hydrilla poses to the Great Lakes varies across the Basin, with Lakes Erie, Ontario, and St. Clair at greatest risk, and Lake Superior at least risk. Within the Great Lakes proper, potential habitat for Hydrilla generally is limited to areas where water depth is less than 25 feet (due to hydrostatic pressure) and summer water temperature is at least 68°F for two consecutive months (see Section 3.1.4). Also, if light penetration is less than 25 feet, then the effective depth to which Hydrilla can grow will be correspondingly less. These limitations mean that the habitats most vulnerable to Hydrilla invasion in the Great Lakes are near-shore, littoral-zone habitats. However, not all littoral zone habitats are equally at risk. In general, shallow, near-shore areas that are sheltered from wave action, including embayments, coves, coastal wetlands, natural and constructed harbors, and creek and river mouths, provide more suitable habitat for Hydrilla than open, wave-swept shorelines. Hence, shallow, sheltered areas along the south shores of Lakes Erie and Ontario and along the shoreline of Lake St. Clair are the areas considered to be most at risk from Hydrilla and, therefore, where resource managers should be most vigilant for the appearance of this AIS.

## 4.3 Vulnerable Inland Areas

The relative risk ranks listed in Section 4.1 also apply to inland waterbodies in the 18 Great Lakes watersheds. Hence, inland waterbodies in watersheds bordering Lakes Erie and Ontario in New York, Pennsylvania, and Ohio, and Lake St. Clair in southeast Michigan, are at greatest risk from Hydrilla, whereas those in watersheds bordering Lake Superior are at lowest risk (see Figure 4-1). In general, inland waterbodies are expected to be more vulnerable to a Hydrilla infestation than the Great Lakes proper because they are less turbulent, shallower, and warmer than the Great Lakes. Indeed, within the Great Lakes Basin currently, all known Hydrilla infestations exist in inland waterbodies, as shown in Figure 4-1, not in the Great Lakes proper. Inland infestations may act as sources of propagules to other nearby inland waterbodies or to the Great Lakes and, therefore, resource managers should be especially watchful for the appearance of new Hydrilla infestations near existing ones.

Although introduction potential and habitat suitability are low for Hydrilla in the northern portion of the Great Lakes Basin, it is worth noting that at least one Hydrilla infestation has been reported from this region, in an artificial pond in northeast Wisconsin (see Figure 4-1). The occurrence of this infestation indicates that potential risks from Hydrilla to this portion of the Great Lakes Basin still are present despite the very low modeled habitat suitability and introduction potential for Hydrilla in this area. Hence, resource managers in the northern portion of the Great Lakes Basin still should be watchful for Hydrilla, especially given the large number of small inland lakes and ponds in this region.

## 4.4 Uncertainties and Limitations

This section describes uncertainties associated with the Hydrilla occurrence database, distributional and dispersal modeling results, coverage of GIS layers for the

Great Lakes, and available information regarding monoecious Hydrilla growth and impacts in northern waters.

### 4.4.1 Hydrilla Occurrence Database

The development of the Hydrilla occurrence database for this project was based on a thorough review of all recent sources of Hydrilla occurrence data for the Great Lakes Basin, United States, North America, and world (see Section 3.1.2). Since the completion of this task in early 2016, additional observations of Hydrilla occurrences in the Great Lakes Basin and elsewhere have been reported. However, the new occurrences are a very small percentage of the total Hydrilla occurrences in the project database and their omission is not expected to have a measurable effect on the output of the dispersal or distributional models for which the occurrence database was used. However, a large number of new or undetected occurrences would be a different matter, as noted in the following section.

### 4.4.2 Distributional (Habitat-Suitability) Modeling

#### 4.4.2.1 General Uncertainties and Limitations of Maxent and Maxlike

Despite the emergence of SDMs as a powerful tool for biodiversity conservation and management, several general criticisms have noted assumptions or limitations during SDM development, which may contribute to uncertainty in their interpretation. For example, SDMs typically assume that populations exist in an "equilibrium" distribution with respect to their surrounding and potential habitat (Svenning and Sandel 2013), and this assumption may be particularly violated in the case of invasive species whose populations are actively spreading (Broennimann and Guisan 2008). Furthermore, SDMs have been criticized for their emphasis on abiotic drivers of species survival while failing to account for biotic interactions or historical dispersal constraints (Araujo and Luoto 2007; Pagel and Schurr 2012). SDMs in general have also been accused of ignoring heterogeneity in population and genetic structure across geographical ranges (Hampe and Petit 2005), though our present analysis has sought to address this potential source of uncertainty by combining separate modeling efforts focused on monoecious and dioecious biotypes of Hydrilla. Nevertheless, all of the above criticisms represent potential sources of uncertainty in our implementation of Maxent and Maxlike models.

One specific criticism of presence-only models such as Maxent and Maxlike is their implicit assumption that occurrence data represent the outcome of a random sampling of space. This assumption is undoubtedly violated by most studies, including the current effort in which Hydrilla records were collected from the scientific literature, agency and museum records, and other sources with a likely positive searching bias (i.e., people tend to look for invasive species and other targets of ecological study where they expect to find them). Among the strongest recent criticisms, Gotelli and Standon-Geddes (2015) charged that a reliance on presence-only data made Maxent, Maxlike (and, indeed, all presence-only species distribution models) "statistically fragile." Nevertheless, in a comparison of model performance, Merow and Silander (2014) concluded that "both models [Maxent and Maxlike] can reliably predict relative differences in occurrence probability" while emphasizing the need for studies to be aware of such sampling assumptions.

In a review of SDM literature, Yackulic et al. (2012) noted general uncertainty about what Maxent output represents. They observed that while the Maxent output is often referred to as some metric of likelihood of occurrence, the developers of Maxent (Phillips and Dudík 2008) warned explicitly that this is not what the output represents. Indeed, the underlying Maxent philosophy is that occurrence probability cannot be estimated from presence-only data and that the model instead outputs an index, which most recent modeling efforts have interpreted as habitat suitability (e.g., Barnes et al. 2014). Royle et al. (2012) developed Maxlike and suggested their new method as a way to estimate occurrence probability. In a comparison between a presence-absence logistic model and presence-only Maxent and Maxlike models of Carolina wren (*Thryothorus ludovicianus*) distribution based on North American Breeding Bird Survey data, Royle et al. (2012) found that Maxent underpredicted habitat in the center of the known wren range and overpredicted habitat outside of it, and they further observed that Maxent performed poorly relative to both logistic regression and Maxlike models.

Fitzpatrick et al. (2013) also compared Maxent and Maxlike while modeling distributions of six species of ants in New England. Like Royle et al. (2012), Fitzpatrick et al. (2013) found that, in general, Maxlike models were better supported by the data than Maxent models, but Fitzpatrick et al. (2013) also offered a more nuanced comparison between the two modeling methods. They observed that Maxlike models assigned higher probability of occurrence to known sites than Maxent, which assumes 0.5 by default, and a higher average probability of occurrence overall. In other words, while Maxlike models made stronger predictions within known species ranges, they also generally predicted larger areas of probable occurrence than Maxent, potentially representing an overall over-prediction. Furthermore, Maxlike tended to exhibit larger standard deviations and greater uncertainty across large areas of the study region than Maxent. Critically, their analysis led Fitzpatrick et al. (2013) to conclude that while Maxent performs relatively poorly when predicting distributions within highly sampled areas, Maxlike may perform relatively poorly when projecting to unsampled areas.

Fitzpatrick (2013) also found that the suitability indices output by Maxent and Maxlike were poorly correlated with one another overall, suggesting that they may in fact estimate different parameters. In a critique of the Maxlike approach, Hastie and Fithian (2013) accused Royle et al. (2012) of "manufacturing information" to make the underlying mathematical framework of Maxlike work, including invalid or arbitrary statistical assumptions. In particular, Hastie and Fithian (2013) argued that the assumption of a linear logistic framework within the Maxlike procedure for estimating occurrence probability doesn't match the real world in which "functional forms are almost never linear." In their assessment of the state of SDMs in general, Hastie and Fithian (2013) concluded that all presence-only methods model relative occurrence rate consistently better than absolute occurrence rate.

#### 4.4.2.2 Uncertainties and Limitations Specific to this Assessment

Three points should be made regarding potential uncertainties in the distributional models developed for this project (see Section 3.1.3). First, it should be understood that the modeled extent of suitable habitat for Hydrilla in the Great Lakes Basin, or elsewhere, is strongly influenced by the current distribution of Hydrilla in its native and introduced ranges. Because the Hydrilla invasion in North America is not yet complete, the current models may underestimate the possible extent of suitable habitat for Hydrilla in the Great Lakes Basin and elsewhere in North America. This is due to the fact that the models were trained using current, known Hydrilla occurrences; many new occurrences, especially from more northerly locations, would alter model predictions.

Second, to identify geographic areas where model predictions are most uncertain, models were replicated (run) 100 times each. From the 100 runs for each model, a standard deviation was calculated and mapped to identify areas where the uncertainty in the model prediction was greatest. The standard deviation map for the global Maxent model (the distributional model most integral to this risk assessment) shows that the overall greatest uncertainty occurs along the Appalachian Mountains in West Virginia and Virginia (see red areas in Figure 4-2). Within the Great Lakes Basin, uncertainty is greatest along the edges of the Hydrilla invasion front, including eastern Lake Erie, south of Lake Ontario, and east of Lake Michigan (see yellow and orange areas in Figure 4-2). Because the Great Lakes lies along the northern edge of the Hydrilla invasion front in North America, the habitat suitability forecasts for the Great Lakes Basin have a fair amount of uncertainty associated with them. This is to be expected based on the first point. If the invasion is still expanding northward, then we would expect the invasion front to represent the area with highest uncertainty. Standard deviation maps for other Maxent and Maxlike models are provided in Appendix B.

Third, as described in Section 3.1.3, the distributional modeling relied on global atmospheric temperature patterns and variation to infer habitat suitability for Hydrilla. Although atmospheric temperature has been shown to be an acceptable surrogate for water temperature, the use of atmospheric instead of water temperature is a compromise and introduces an unknown degree of uncertainty into the model results. For example, the Sahara may represent suitable Hydrilla habitat in terms of air temperature (see Figure 3.1.3-3) even though water, a critical habitat element, is not abundant. Continuous environment layers are not available at global scales for the aquatic environment. The availability of such data would be a significant advancement to researchers' ability to implement SDMs for aquatic species.

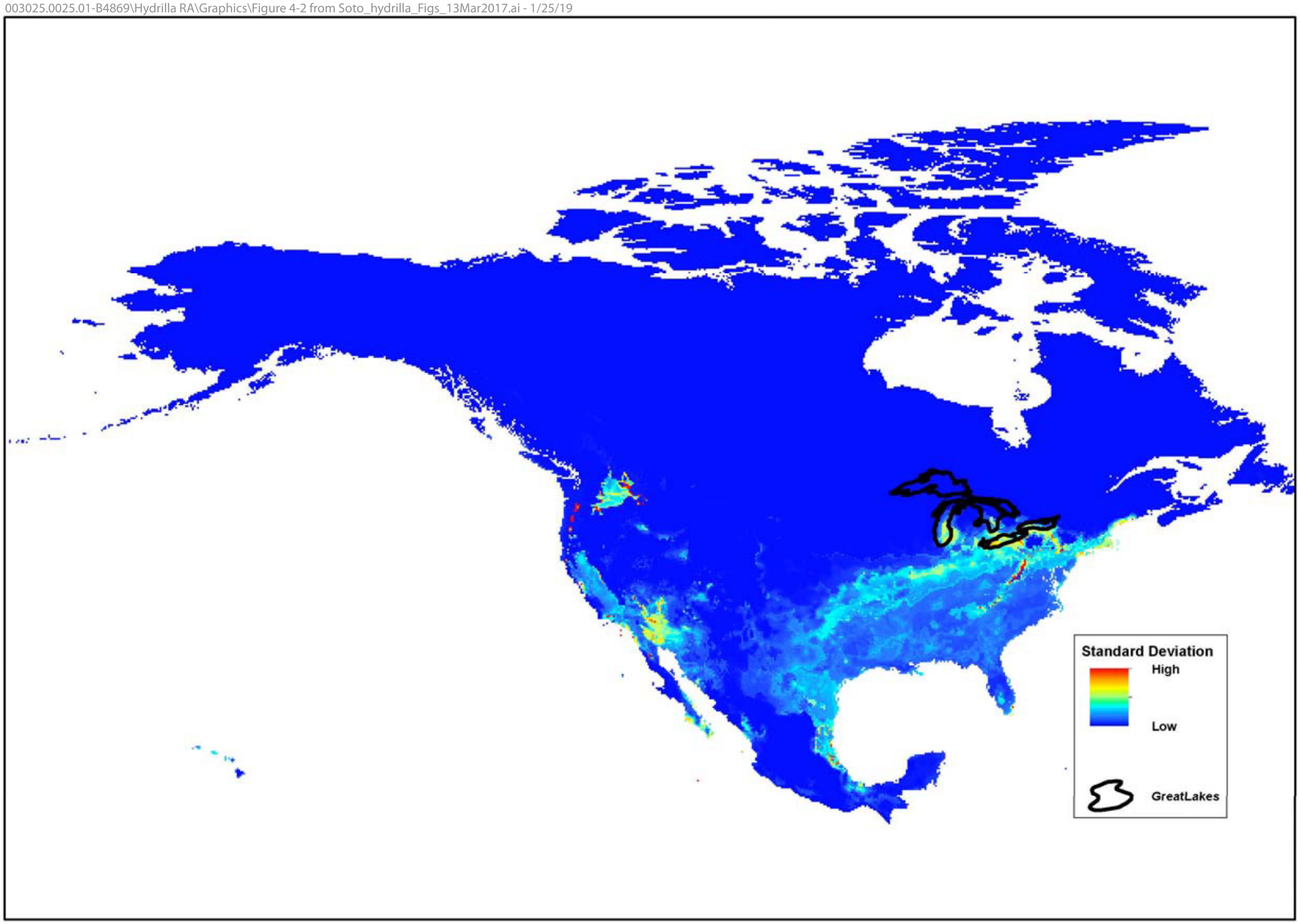


**Figure 4-2 Maxent All-Data (Global) Standard Deviation for *Hydrilla verticillata***

### 4.4.3 GIS Habitat Layers

As noted in Section 3.1.4, GIS layers for a wide range of parameters potentially useful for inferring habitat suitability for Hydrilla in the Great Lakes were evaluated, including water depth, water temperature, sediment composition, nutrient levels, photoperiod, and, coverage by other submerged aquatic plants, including Eurasian watermilfoil. Of these parameters, only water depth and temperature were available as GIS layers that could be applied across the Great Lakes Basin. Better coverage for a greater number of parameters would have allowed for a more thorough evaluation of habitat suitability for Hydrilla in the Great Lakes and thus a more refined understanding of at-risk habitats within the lakes.

### 4.4.4 Dispersal Modeling

The current area of Hydrilla infestation in the continental United States is 1,553,643 ha based on the Hydrilla occurrence data from 1953 to 2015. On average, the model resulted in an over estimation, estimating that 1,859,367 ha would be infested by 2015. However, the observed value of 1,553,643 ha was well within the first and third quartiles (1,409,404 and 2,258,049, respectively) of the distribution of dispersal model results. The overall range of infested area over 1,000 model trials was 544,301 to 3,935,747 ha for the continental United States (standard deviation of 594,965).

When modeling at the scale of the continental United States, there are logistical and data limitations that constrain the accuracy or specificity of the model results. As noted in Section 3.1.5, the dispersal model developed for this project considered only recreational boats and trailers as vectors for Hydrilla. As expected, the dispersal model showed that watersheds with high boater registration, and surrounding watersheds with high boater registration, have a higher risk of infestation. However, the model did not distinguish between different types of boats. Resident boats for instance that stay in one body of water are not likely to transport Hydrilla to other waterbodies. Hydrilla dispersal would be more driven by transient boats; therefore, if a watershed has a high number of resident boats then the results may overestimate the risk of that watershed or surrounding watersheds.

In addition, other potential vectors exist, including water flow, disposal of dredge spoils containing Hydrilla tubers, waterfowl migration, and disposal of aquarium plants (see Section 2.3). Consequently, it is possible that the dispersal model may somewhat underestimated the future spread of Hydrilla into the Great Lakes Basin, but the degree to which Hydrilla dispersal may be underestimated is unknown.

The waterbody data used as an input for the dispersal model was appropriate for this scale, but does not include minor waterways. As a result, not all infestations will be reflected in the dispersal model. For example, the current Tonawanda Creek infestation in western New York is not reflected in the model.

The probability of a destination watershed becoming infested was also influenced by the habitat suitability of the watershed as per the results of the distributional modeling (see Section 3.1.3). As noted in Section 4.4.2, the distributional model results were strongly influenced by the current distribution of Hydrilla, and the models may underestimate the potential extent of Hydrilla in North America because the invasion is not yet complete. As a result, the gravity models predicting potential for Hydrilla introduction may also be underestimates. The distributional model results were at a finer resolution than the HUC 4 watersheds used for the dispersal model. The average habitat suitability probability was calculated for each watershed from the distributional model results. A scalar was estimated to adjust the distributional model values to be taken into consideration in the dispersal model while ensuring that the distributional model results were not outweighing the dispersal model results. The product of the scalar adjustment and average habitat suitability produced a fitted habitat suitability probability for each watershed.

Despite these limitations, the dispersal model results can give regional guidance as to where to monitor and prioritize additional modeling or analyses to provide further refinement of the model predictions.

### 4.4.5 Monoecious Hydrilla Growth in Northern Waters

Recent growth and competition experiments with monoecious Hydrilla provided valuable information regarding the ability of this invasive species to grow in cool-water habitats and compete with selected cool-water plant species (see Section 3.1.6). Nonetheless, the monoecious Hydrilla biotype has received relatively little study compared with the dioecious biotype that is prevalent in the southeastern United States. Hence, many things still are poorly understood regarding the ability of monoecious Hydrilla to successfully invade habitats in the Great Lakes Basin and other northern waters, including effects of sediment composition, nutrient levels, ice scour, and wave action.

### 4.4.6 Monoecious Hydrilla Impacts in Northern Waters

Little published information is available regarding the potential environmental impacts that may be caused by monoecious Hydrilla in northern waters. Most published information regarding environmental impacts from Hydrilla have focused on the dioecious biotype in warm-water habitats in the southeastern United States. Although potential environmental impacts are estimated in Section 3.3.3, that assessment is at a very high level, indicating only the main types and possible extent (future acreage) of impacted habitats, not the specific nature or degree of impacts and how they may vary with latitude across the Great Lakes Basin. Hence, potential impacts from Hydrilla in northern water are not fully understood, but are generally expected to be adverse and long-lasting.

## 4.5 Other Hydrilla Risk Assessments and Invasiveness Studies

Other entities have conducted risk assessments or similar evaluations for Hydrilla including the NYSDEC and Ontario Ministry of Natural Resources and Forestry

(OMNRF). NYSDEC (2008) completed their *Invasiveness Ranking Form* for Hydrilla and concluded that Hydrilla was likely to be very highly invasive in New York State. The OMNRF (2016) prepared a risk assessment for Hydrilla using methodology they developed and concluded that the overall risk for invasion and impacts in Ontario is very high. The general reasons that both assessments concluded that Hydrilla was likely to be highly invasive and have negative impacts are:

- Probability of arrival in new areas is high because Hydrilla has a high dispersal potential. Turions, tubers, and stem fragments are transported by water currents, boats, and waterfowl.
- Probability of survival is high because Hydrilla grows in lakes, ponds, rivers and streams and is able to survive in a variety of nutrient regimes, salinities, pH values, and temperatures.
- Probability of establishment is high because Hydrilla has readily become established in a variety of ecosystems across the United States. It reproduces asexually from vegetative fragments and by producing tubers and turions and does so in lakes, ponds, rivers, and streams under a variety of nutrient regimes, salinities, pH values, and temperatures.
- The expected ecological impacts from Hydrilla are likely to be high. Hydrilla alters water flow, light and nutrient availability, and forms dense mats on the water surface that suppress other aquatic vegetation, thereby altering ecosystem processes, community structure, and community composition. Negative impacts on native species are expected and have been observed in locations where dense Hydrilla infestations have developed in the United States.
- Managing Hydrilla is difficult, costly, and a long-term endeavor.

Recent publications from the peer-reviewed literature also suggest that the invasion potential for Hydrilla is likely to be high. Zhu et al. (2017) reached this conclusion generally for North and South America and presented Maxent heat maps showing habitat-suitability for Hydrilla that are similar to those generated for this project (e.g., Figure 3.1.3). Wittmann et al. (2017) focused their work on the Great Lakes and concluded that climatic and habitat conditions in the Great Lakes were suitable for Hydrilla in several of the lakes, including Lakes Erie, Michigan, and Huron. Overall, the findings of the above-mentioned assessments and publications are consistent with this assessment and support the general conclusion that Hydrilla poses a serious potential risk to the Great Lakes region, especially the southerly Great Lakes region.

# 5 Risk Management

## 5.1 Recommendations for Prevention, Detection, and Response

The recommendations presented in this section are based on review of existing information pertaining to early detection and rapid response programs and numerous Hydrilla control projects, as well as active engagement with stakeholders involved in the prevention, detection, and management of Hydrilla across the country. The recommendations also take into account the results of the distributional and dispersal modeling (see Sections 3.1.3 and 3.1.5) as well as the findings of the Hydrilla growth studies undertaken as part of this risk assessment (see Section 3.1.6).

### 5.1.1 Prevention

The first step to prevent the spread of Hydrilla is public education directed toward water users, including passive recreation users, boaters, and fishermen. It is important to share information about the potential impacts of Hydrilla, and what can be done to reduce the risks associated with transport. The following recommendations should be implemented first in the watersheds with the greatest Hydrilla introduction potential and most suitable habitat for Hydrilla: Southeastern Lake Ontario, St. Clair-Detroit, Western Lake Erie, and Southern Lake Erie.

**Prevention Recommendation #1:** ***Develop a public information campaign to educate the public, specifically water recreational users, on what Hydrilla is, how to identify it, and the threat it poses to the Great Lakes.***

This recommendation focuses on public education by developing Hydrilla-specific targeted outreach and education materials, drawing upon existing regional and national program materials, and using existing venues to distribute the materials. Examples include distributing materials at public and private marinas and botanical gardens, organizing lake management and angler association membership mailings and events, developing state AIS programs, and conducting workshops implemented by Partnerships for Regional Invasive Species Management (PRISMs).

For example, the Illinois Hydrilla Task Force increased statewide public awareness and the capacity to detect, report, and respond to populations of Hydrilla through species-targeted outreach and education materials derived from existing examples and using existing venues for dissemination of these materials. Their educational campaign used waterproof *Hydrilla Hunt!* 3-inch by 5-inch cards, posters, and plant identification sheets. These were distributed widely, and recipients included homeowner and lake management associations, fishing tournaments, the Chicago Botanic Garden, and water gardening trade shows (Illinois Hydrilla Task Force 2015).

Outreach and educational materials should include the following content to be most effective:

- Information on how to identify the plant and how to distinguish it from native plants. The Hydrilla Hunt! ID sheet and ID card (available at https://niipp.net/hydrilla/additional-resources/) are examples of identification materials.
- An overview of Hydrilla's potential impacts if it successfully establishes in the Great Lakes and the importance of diligence with respect to early detection efforts.

**Prevention Recommendation #2:** ***Post signage at all access points and implement watercraft inspections at areas of high traffic or at highest use boat ramps within priority public watercourses.***
Recreational boating has been identified as a key pathway in the spread of AIS across the Great Lakes Basin including inland waterbodies (Rothlisberger et al. 2010; Hebebrand and Bossenbroek 2017). Provision of signage, watercraft inspections, wash stations, and nuisance species disposal stations should be done with priority given to already infested waters, waters with high boater activity, and proximity to existing infestations. These activities are the most critical in the four high risk watersheds (Southeastern Lake Ontario, St. Clair-Detroit, Western Lake Erie, and Southern Lake Erie).

Watercraft inspection consists of visually inspecting all areas of boating and recreational equipment – boats, trailers, motors, livewells, anchors, snorkeling and scuba gear, paddles – that come into contact with or hold water, removing visible plants, animals and mud, and draining water from all compartments/containers. As indicated in the *New York Watercraft Inspection Steward Program Handbook* (New York Sea Grant 2014), watercraft inspection lead by stewards is an effective way:

- To inform boaters about AIS issues and teach them how to intercept the potential introduction and establishment of AIS;
- To help reduce the spread of AIS between waters; and
- To empower boaters to protect the natural resources they love.

Boat launch stewards can serve in an educational capacity and facilitate proper boat cleaning. Such programs have been implemented in many locations, including the efforts undertaken by the Maryland DNR at several state-managed waterbodies, and the Clean Boats Crew, a volunteer outreach program in Illinois and Indiana, focused on promoting water resource stewardship by actively involving individuals in preventing the spread of harmful AIS (Illinois-Indiana Sea Grant et al. 2015). The Maryland DNR hired three seasonal employees to serve as launch stewards to work at state parks and private marinas to educate the public and facilitate proper boat cleaning. Through the Clean Boats Crew program, volunteers are trained to organize and conduct an AIS education program in their community, using resources that have been developed for this purpose. Their 2015 manual entitled, *Clean Boats Crew: Guidelines for the Illinois and Indiana Aquatic Invasive Species Volunteer Outreach Program*, provides information on how volunteers can organize an AIS watercraft education program, including how to conduct an inspection, a sample script for approaching recreational users, and other useful information (Illinois-Indiana Sea Grant et al. 2015). The *New York State Watercraft Inspection Steward Program Handbook* can also be a reference on how to conduct inspections (New York Sea Grant 2014).

**Prevention Recommendation #3:** ***For coastal wetland restoration projects within the littoral zones of the Great Lakes, include specific requirements for post-construction monitoring of invasive species, including Hydrilla, in project plans and specifications.***
Some Great Lakes states, like Ohio, are focusing on coastal wetland restoration to improve water quality by reducing nutrient and sediment loading to Lake Erie, and to incorporate beneficial use of dredge material to enhance coastal wetland and fisheries habitat. Projects incorporating fill material should confirm the absence of Hydrilla and other AIS from source areas prior to selecting and using fill for aquatic habitat restoration. Plans/specifications should clearly specify the pre-project presence/absence screening of fill material in a detailed monitoring program. Specifics would include methods, timing, frequency, and overall duration for the monitoring effort. Additionally, plans/specifications should include requirements for similar post-construction monitoring.

### 5.1.2 Detection

On-the-ground plant monitoring is still the primary means of early detection, as there is no substitute for it. This includes visual monitoring for plants, tuber presence and density monitoring, and rake-tosses to provide an indication of Hydrilla abundance, as described in more detail in Section 5.2.

Environmental DNA (eDNA), a nuclear or mitochondrial DNA that is released from aquatic and semiaquatic organisms into the environment, has not gained widespread use in early detection of aquatic invasive plant species (Barnes and Turner 2016). Most eDNA research and monitoring has focused on detection of vertebrates and invertebrates (Newton et al. 2016). eDNA monitoring allows for the identification of organisms from DNA present in collected water samples. Research conducted by Newton et al. 2016 suggests that eDNA techniques have the potential to be useful for the early detection of Eurasian watermilfoil (*Myriophyllum spicatum*). Additionally, the State University of New York at Oneonta is conducting extensive surveys of all of the AIS that have made their way into the reservoirs and tributary streams that make up the water supply in New York City using eDNA sampling on a variety of AIS, including Eurasian watermilfoil (New York City Department of Environmental Protection 2018). However, in light of the limited use of eDNA for other AIS including Eurasian watermilfoil, no published data has been found on the use of eDNA for early detection of Hydrilla.

One challenge to the perceived utility of eDNA for aquatic invasive plants is that the plants tend to be invasive because they form such dense population and large canopies; by that point the eDNA tool would be irrelevant. The greatest potential benefit of using eDNA would be if it could allow early detection of Hydrilla in sediment or water samples before disruptive population sizes have been reached, and when eradication efforts may still be effective. An additional challenge is that eDNA testing indicates that the DNA is there; however, it is not an positive indicator that the plant is present. For example, if a duck consumes Hydrilla in one location and defecates in another location, that second location could lead to a positive detection of Hydrilla DNA, even though the plant itself is not present.

### New Populations

Early detection of new populations is critical in controlling the spread of Hydrilla as is monitoring of existing infested sites. Active and passive detection networks are necessary to survey and monitor high priority waterbodies, as defined as those within the watersheds identified as having higher introduction potential (see Section 4.1). The following recommendations should be implemented first in the highest priority watersheds.

<u>**Detection Recommendation #1:**</u> ***Visual monitoring should prioritize boat ramps/launches and inlets in waterbodies without existing infestations, and popular recreational waterbodies and embayments with marinas, and waters with depths less than 25 feet.***
As discussed in Sections 4.2 and 4.3, inland waterbodies are expected to be more vulnerable to a Hydrilla infestation than the Great Lakes proper because they are less turbulent, shallower, and warmer. However, early detection efforts should include nearshore, littoral zone habitats of the Great Lakes within the highest risk watersheds (Southeastern Lake Ontario, St. Clair-Detroit, Western Lake Erie, and Southern Lake Erie).

<u>**Detection Recommendation #2:**</u> ***Develop a specific process for people to report sightings/presence of Hydrilla which includes agency verification.***
For example, the *Hydrilla Hunt!* program encourages the public to take and send close-up photos of aquatic plants that they suspect may be Hydrilla, along with a description of where it was found, to an email address where it can be verified by one of their experts (Northeast Illinois Invasive Plant Partnership 2018). As an additional example, EDDMapS provides real-time tracking of invasive species locations and an online tool for reporting sightings (https://www.eddmaps.org/).

#### Areas with Current Infestations

**Detection Recommendation #3:** ***Focus monitoring efforts near existing infestations, using a bathymetric map or transects prioritized by likely invasion points or potentially threatened resources.***
Use of a bathymetric map of the site can help to hone in on areas where water depths are suitable for Hydrilla (i.e., 25 feet or less), and transects can be established in those areas at regular intervals. If resources are limited, transects should be prioritized based on likely invasion points (access points) or potentially threatened resources (e.g., intakes, swimming areas, and key habitat). Refer to Section 5.2 for BMPs for monitoring.

### 5.1.3 Response
For the purposes of the risk assessment, the term "response" has been subdivided into rapid response and long-term sustained control. Recommendations for both rapid response and long-term sustained control are provided below.

#### 5.1.3.1 Rapid Response
To truly achieve "rapid response," upon detection, treatment should be accelerated as much as is feasible. Two key recommendations are as follows.

**Rapid Response Recommendation #1:** ***Focus response efforts on use of a contact herbicide.***
Contact herbicides control Hydrilla relatively quickly by damaging the parts of the plant that they directly contact.

**Rapid Response Recommendation #2:** ***Advocate that state agencies develop a streamlined process that facilitates rapid response upon detection.***
Successful rapid response will require close up front coordination with regulatory agencies and a willingness of regulators to streamline permitting processes, where feasible. Laws and permitting – specifically with respect to application of herbicides -- need to provide a path to rapid treatment of new infestations. Existing permitting processes in many states have review and public notification timeframes that hamper the ability to treat Hydrilla quickly. Thus, there is a need for a streamlined permitting process. Such a "rapid response" permit should be considered by state agencies for treatments under 3 acres to provide leeway for managers to quickly address new infestations.

#### 5.1.3.2 Long-term Sustained Control
Based on eradication and management programs in other parts of the country (e.g., Maine, California, North Carolina, and Washington), eradication is a multi-year effort and requires a long-term commitment; it requires five or more years of successful treatment (Nawrocki et al. 2016, Netherland 2019). This is largely due to the fact that tubers can remain dormant in the sediment for many years. Because of the length of duration of a successful eradication program, it requires buy-in and support from agencies and project proponents, as well as a sustained funding source.

The first year or two of treatment in an eradication program is the most critical in decreasing overall Hydrilla biomass and reducing the number of Hydrilla fragments by orders of magnitude, which reduces the chance for further spread. Typically, years three through eight of a treatment program are designed to control the last 1 to 5 percent of the tuber bank. In later years, it becomes increasingly difficult to eliminate the final 1 to 2 percent of the tuber bank, as detection becomes difficult.

With advancements in treatment methodology honed from in-field observations, the current long-term treatment approach at multiple Great Lakes and Northeast sites employs contact herbicides in addition to or in lieu of fluridone. This marks a shift from previous approaches which employed fluridone over the course of about 90 days at a low dose, initiated at the first sign of active plant growth (Bellaud and Sullivan 2018). Treatment can now be more targeted with respect to herbicide application.

Based on observations of ongoing treatment at multiple sites, herbicide application appears to be the most effective means of Hydrilla management in the Great Lakes and states with similar climates (i.e., the Northeast). Biological controls have been implemented on a much lower frequency and have been used in concert with herbicides, and to manage lower level infestations. For example, early finds of Hydrilla were treated effectively with an initial herbicide application followed by grass carp in Medford, New Jersey and Orange County, New York (Bellaud and Sullivan 2018). The USACE ERDC is currently researching possible biocontrol agents for monoecious Hydrilla, but no such agents are currently available. Mechanical controls are not a preferred management option unless the infestation is limited to a small patch of Hydrilla that can be isolated with a curtain. Mechanical controls can be cost- and labor-intensive and result in extensive spread of plant fragments. Hand removal and benthic barriers were used to successfully treat two large rooted patches in the southeastern corner of Cayuga Lake in 2013, with no reoccurrence (Racine-Johnson Aquatic Ecologists 2016; 2017).

Hydrilla can be found in a variety of systems, from lakes and reservoirs to flowing streams. Identifying the most effective treatment plan for each site is a case-by-case exercise. For high flow systems, in general, injection has been the most successful treatment (Harris 2017; Bellaud and Sullivan 2017). In Florida, injections of herbicides at a continuous steady drip, applied at a slow rate over a sustained period of time (i.e., 30 to 60 days), has been effective (Harris 2017). Injection has also been used on Tonawanda Creek in Western New York where contact herbicide has been applied over a two-day treatment period. Injection of endothall, coupled with the use of turbidity barriers to aid management efforts by limiting access to the adjacent pond and lagoon and to potentially slow the rate of dilution of herbicide treatments, were used on Fall Creek, a flowing system and tributary to Cayuga Lake (Hinicke 2018; Racine-Johnson Aquatic Ecologists 2016).

In systems with high exchange rates, fluridone pellets have been used – sometimes successfully and sometimes unsuccessfully. Efforts are underway within an embayment of Cayuga Lake that will provide information on how to manage Hydrilla in high water exchange systems.

### Control of Isolated Hydrilla Patches

With effective long-term sustained control, over time, Hydrilla will transition to isolated patches/satellite populations that survive treatment or re-sprout from the bank of subsurface tubers. For these isolated patches, several approaches have been documented to be effective and are recommended:

**Control Recommendation #1:** ***Apply contact herbicides at the maximum label rates, along with limited public access in those areas*** (Harris 2017);

**Control Recommendation #2:** ***Use benthic mats (i.e., burlap barriers) on very small patches of Hydrilla in shallow, low-velocity water*** (Evans and Ruby 2017). Due to their cost and labor requirements with respect to installation, benthic mats are not feasible for use in larger areas (Harris 2017; Kratville and Heintz 2018).

**Control Recommendation #3:** ***Use limnocorrals (impermeable dividers) to isolate Hydrilla beds for direct application of herbicide.***
These have proved to be effective as applied on Tonawanda Creek but are labor intensive (Evans and Ruby 2017).

Suction dredging has also been employed on a limited basis. In California, the cost of dredging made that treatment option infeasible due to costs to contain the spoils for Hydrilla tubers as well as contaminants (Kratville and Heintz 2018).

## 5.2 BMPs for Hydrilla Prevention, Detection, Management, and Monitoring

BMPs for Hydrilla prevention, detection, management, and monitoring are provided below.

### Prevention

- Develop a public information campaign to educate the public, specifically water recreational users, on what Hydrilla is, how to identify it, and the threat it poses to the Great Lakes.
- Develop a targeted educational campaign for angler groups to explain that a Hydrilla infestation is beneficial for sportfishing only under limited conditions and from a larger ecological perspective, prevention of Hydrilla infestation is best. The campaign should educate anglers with respect to the impacts of Hydrilla on sport fishing – from creating physical impediments during fishing and limiting shoreline access, to reducing the size and weight of sport fish. The campaign should include messaging that emphasizes the need to be proactive in prevention (i.e., reporting Hydrilla sightings) to prevent the establishment of a dense monoculture of Hydrilla, which would result in areas that

would be less suitable habitat for young fish and would result in a decline in sport fishing in the Great Lakes.

- Post signage at all access points and implement watercraft inspections at areas of high traffic or at highest use boat ramps within priority public watercourses.
- For coastal wetland restoration projects within the littoral zones of the Great Lakes, include specific requirements for post-construction monitoring of invasive species, including Hydrilla, in project plans and specifications.

## Early Detection

- Train professionals to detect Hydrilla early, especially in areas where there is heightened concern. Provide these individuals with information on who to contact if they find Hydrilla or a plant suspected to be Hydrilla.
- Develop a specific process for people to report sightings/presence of Hydrilla which includes agency verification.
- Visual monitoring should prioritize boat ramps/launches and inlets in waterbodies without existing infestations, and popular recreational waterbodies and embayments with marinas, and waters with depths less than 25 feet.
- Focus monitoring efforts near existing infestations, using a bathymetric map or transects prioritized by likely invasion points or potentially threatened resources.
- Include signage at boat ramps to help aid early detection and provide outreach to lake associations, lake user groups, and marina owners focused on how to report the presence of Hydrilla or a plant suspected to be Hydrilla.

## Management

### *Timing of Herbicide Treatment*

- To maximize use of available management resources, conduct surveys for Hydrilla when water temperatures reach 62.6 °F (17°C) for at least two weeks. This is based on the findings of the plant growth studies which highlighted the importance of monitoring environmental conditions (Henry 2017). Low temperatures were found to reduce sprouting and vegetative growth.
- Conduct pre-treatment plant surveys beginning in mid-July to inform the annual treatment plan, as surveys will determine plant locations and will provide input to determine duration and dosage of treatment.
- Employ chemical treatment after tubers have sprouted (late June to July) but prior to the formation of new tubers (late August to November). Tuber sprouting has been documented to be synchronous in the Great Lakes and Northeast, and therefore, should allow for consistent annual treatment timing. In the Great Lakes Basin, time systemic chemical treatments, such as fluridone, which targets vegetative tissues (leaves, stems, or roots) to occur no earlier

than mid-June, as systemic herbicides should be applied when tubers are sprouting. This window is based on the plant growth studies conducted as part of this risk assessment, which found that female floral initiation did not occur until July 14, coupled with the findings of the Tonawanda Creek project and observations in the Northeast that early Hydrilla growth occurs in early to mid-July (Henry 2017; Bellaud and Sullivan 2018).

### *Treatment – General*

- Use bathymetric data to facilitate an accurate determination of water volume (SePRO Corporation et al. 2012). Using this data will help generate treatment plans that will achieve more consistent and evenly distributed herbicide concentrations, which is more efficient and cost-effective effective.

- Provide herbicide applicators with GIS shapefiles of the areas to be treated that can be downloaded into their GPS systems. Doing so will help to keep herbicide applications in the target area of interest.

### *Treatment – Rapid Response*

- Focus response efforts on use of a contact herbicide.

- Advocate that state agencies develop a streamlined process that facilitates rapid response upon detection.

### *Treatment – Long-term Control of Patches*

- Apply contact herbicides at the maximum label rates, along with limited public access in those areas.

- Use benthic mats (i.e., burlap barriers) on very small patches of Hydrilla in shallow, low-velocity water.

- Use limnocorrals (impermeable dividers) to isolate Hydrilla beds for direct application of herbicide.

### Monitoring

For all Hydrilla control projects, monitoring is critical to assessing the rate of plant expansion, informing the components of a treatment plan, and evaluating the efficacy of a treatment plan. Monitoring is critical to obtain an estimate of remaining Hydrilla populations after each year of treatment, and monitoring data are also used to inform the development of annual treatment plans, as they are used to determine locations, and durations and dosages of herbicide treatments. Based on a review of several Hydrilla eradication projects (Racine-Johnson Aquatic Ecologists 2016; SePRO Corporation et al. 2016; Evans and Ruby 2017), annual monitoring should occur and it should include the following:

- **Assessment of tuber presence and density:** Conduct annual fall tuber sampling at established locations via taking sediment cores, which provides an indication of tuber presence and density. [Note: Methods for tuber sampling are described in Nawrocki et al. 2016; SePRO et al. 2008; Madsen et al. 2007.] Conduct this intensive monitoring for the first couple of years of a treatment plan because, as multi-year management projects progress, tuber numbers get so low that the sampling effort outweighs the benefits of collecting the data to demonstrate significantly reduced tuber values. During the later years of a project, perform assessments of plant species diversity and abundance as described below.
- **Assessment of plant species diversity and abundance:** Annual rake-toss data provide an indication of Hydrilla abundance (estimated biomass) as well as overall plant species diversity. Conduct surveys pre- and post-treatment each year using grids established using the point intercept method. Pre-treatment surveys should be done mid-to-late July and post-treatment surveys should be done in late September/early November. Increase grid size if new locations of Hydrilla are found, for example, on a lake or reservoir, to facilitate a larger search area for detection. Assess the rate of plant expansion to inform the control strategy. Record the following metrics: native and rare plant species presence and abundance; and Hydrilla plant status, including whether plants are injured, and whether there is regrowth or formation of tubers or turions. [Note: Methods for conducting and evaluating data from plant species diversity surveys are described in Madsen 1999 and SePRO et al. 2008.]

In addition to plant monitoring, water quality monitoring during and immediately following treatment should be conducted to determine herbicide concentrations throughout the treatment area to ensure that effective herbicide concentrations were achieved and maintained. Water quality sampling can also facilitate an understanding of how an herbicide may disperse within a system – both vertically and laterally. Lastly, water quality sampling to determine the degradation of the herbicide over time is recommended.

## 5.3 Stakeholder Outreach

As indicated in Figure 1-2, the conclusion of the risk management stage of the risk assessment, and the final step in the risk assessment process, is to share the results and contribute to the management of the identified risks by promoting the implementation of recommendations and BMPs by stakeholders such as resource managers, educators, and policy-makers, and other interested parties. Specifically, this entails dissemination of the final risk assessment report and targeted outreach activities to communicate the findings of the assessment with respect to the colonization potential of monoecious Hydrilla in specific geographic areas, and to promote the steps and activities described in Sections 5.1 and 5.2.

As noted in Sections 3.1 and 5.1, effective coordination and outreach are critical for communicating the potential for the introduction and spread of Hydrilla throughout the Great Lakes Basin. Potential stakeholder outreach activities following the finalization of the risk assessment could include the following:

- Preparation and distribution of one or more fact sheets to communicate the findings of the risk assessment as well as the recommendations and BMPs discussed in Sections 5.1 and 5.2. Fact sheets will be distributed by email to stakeholders identified through the course of preparing the risk assessment and via emails from USACE ERDC personnel to their respective networks, and at relevant events (e.g., conferences) attended by USACE ERDC and/or other Project Team staff. Additionally, USACE ERDC and E & E have initiated the Great Lakes Hydrilla Collaborative with input from the Great Lakes Commission. The stakeholder list for the Great Lakes Hydrilla Collaborative includes over 200 interested parties, and are a representative network with which the risk assessment fact sheets will be shared.
- Dissemination of the Great Lakes Hydrilla Risk Assessment. The report will be made available to previously contacted stakeholders for downloading from a publicly accessible website. The risk assessment can be made available to a larger group of stakeholders by way of creating links on other websites, leading users to the report. Limited print copies may also be produced and made available. The availability of the report will be communicated in the fact sheets noted above and in the meetings and webinar recording noted below.
- Presentation of the findings of the risk assessment at one or more meetings with stakeholders within each of the four watersheds found to be at higher relative risk (Southeastern Lake Ontario, St. Clair-Detroit, Western Lake Erie, and Southern Lake Erie). The USACE ERDC and E & E project staff could coordinate with known stakeholders within these areas to increase participation in these meetings by additional local stakeholders, such as:
    - Resource managers;
    - State and federal agency representatives;
    - Tribal representatives;
    - Elected officials and their staffs, including officials from the respective local, state and federal governments;
    - Boating and angling association representatives;
    - Marina operators;
    - Lake association leaders;
    - Volunteer monitoring group representatives; and
    - Non-governmental organizations.
- Presentation of the findings of the risk assessment during one or more webinars intended for stakeholders whose roles and responsibilities focus on any of the watersheds within the Great Lakes Basin.

- Production of a digital recording of a webinar presentation or live presentation of the risk assessment findings, and announcement of the availability of the digital recording to stakeholders. The presentation file and associated digital recording could be made available on the Great Lakes Hydrilla Collaborative and other websites.

Future Great Lakes Basin discussions should involve stakeholder consideration regarding the possibilities of additional, ongoing outreach activities and programs focused on implementing the recommendations and BMPs presented above, with the stated goal of reducing the likelihood of the introduction and further spread of monoecious Hydrilla within the Great Lakes Basin.

# 6 References


Alligood, Nekole. 2019. Delaware Nation: History. Available online at http://delawarenation.com/history/. Accessed January 4, 2019.

American Sportfishing Association. 2013. "Sportfishing in America: An Economic Force for Conservation." Available at http://asafishing.org/uploads/2011_ASASportfishing_in_America_Report_January_2013.pdf Accessed on May 15, 2015.

Aquatic Control Technology. 2014. "Contract Documents for the Tonawanda Creek Hydrilla Abatement Program for 2014."

Aquatic Control Technology. 2015. "Contract Documents for the Tonawanda Creek Hydrilla Abatement Program for 2015."

Aquatic Ecosystem Restoration Foundation. 2005. *Aquatic Plant Management, Best Management Practices in Support of Fish and Wildlife Habitat*. Accessed online at: https://www.extension.org/mediawiki/files/4/4b/Aquatic_Plant_Management,_BMPs_in_Support_of_Fish_and_Wildli.pdf. Accessed on May 3, 2015.

Aquatic Weed Control. 2007. *2006 Lake Manitou Vegetation Management Plan Update, Fulton County, Indiana*. Accessed online at: http://in.gov/dnr/fishwild/files/Lake_Manitou_AVMP_2006_Update_Fulton_Feb_2007.pdf

Araujo, M.B. and M. Luoto. 2007. The importance of biotic interactions for modelling species distributions under climate change. *Global Ecology and Biogeography* 16: 743–753.

Arguez A., I. Durre, S. Applequist, M. Squires, R. Vose, X. Yin, and R. Bilotta. 2010. NOAA's U.S. Climate Normals (1981-2010). NOAA National Centers for Environmental Information.

Bal, K. and Patrick Meire. 2009. The influence of macrophyte cutting on the hydraulic resistance of lowland rivers. *Journal of Aquatic Plant Management*, 47: 65-68.

Balciunas, J.K., M.J. Grodowitz, A.F. Cofrancesco, and J.F. Shearer. 2002. "Hydrilla" in Biological Control of Invasive Plants in the Eastern United States by Roy Van Driesche, Bernd Blossey, Mark Hoddle, Suzanne Lyon, and Richard Reardon, U.S Department of Agriculture, Forest Service. Forest Health Technology Team. USDA Forest Service Publication FHTET-2002-04, 413 p. Available online at http://wiki.bugwood.org/Archive:BCIPEUS/Hydrilla_verticillata. Accessed on July 13, 2017

Balkcom, Gregory D., and Donald M. Morgan. 2011. Effects of Hydrilla Control on Wintering Waterfowl at Lake Seminole, Georgia. *Georgia Journal of Science* 69, (2): 102-113, Accessed online at: http://search.proquest.com/docview/1017545453?accountid=27106 (accessed May 8, 2015).

Barko, John W., Gordon L. Godshalk, Virginia Carter, and Nancy B. Rybicki. 1988. *Effects of Submersed Aquatic Macrophytes on Physical and Chemical Properties of Surrounding Water*, Technical Report A-88-11, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Barnes, M.A., C.L. Jerde, M.E. Wittmann, W.L. Chadderton, J. Ding, J. Zhang, M. Purcell, M. Budhathoki, and D.M. Lodge. 2014. Geographic selection bias of occurrence data influences transferability of invasive Hydrilla verticillata distribution models. *Ecology and Evolution* 4(12):2584-2593.

Barnes, M.A., and C.R. Turner. 2016. The ecology of environmental DNA and implications for conservation genetics. *Conservation Genetics* 17:1-17.

Barnett, B.S., and R.W. Schneider. 1974. Fish populations in dense submersed plant communities. *Hyacinth Control Journal*. 12:12-14

Bell, F.W., and M.A. Bonn. 2004. Economic sectors at risk from invasive aquatic weeds at Lake Istokpoga, Florida. Prepared for the Bureau of Invasive Plant Management, Florida Department of Environmental Protection, Tallahassee, Florida.

Bellaud, Marc and Glenn Sullivan. 2018. SOLitude Lake Management. Phone call with K. Evans, Ecology and Environment, Inc. on January 8, 2018.

Birrenkott, A., S.B. Wilde, J.J. Hains, J.R. Fischer, T.M. Murphy, C.P. Hope, P.G. Parnell, W.W. Bowerman. 2004. Establishing a food-chain link between aquatic plant material and avian vacuolar myelinopathy in mallards (*Anas platyrhynchos*). *J. Wildlife Dis.* 40 (3), 485–492.

Bobeldyk, A.M, J.M. Bossenbroek, M.A. Evan-White, D.M. Lodge and G.A. Lamberti. 2005. Secondary Spread of Zebra Mussels (*Dreissena polymorpha*) in Lake-Stream Systems. *Ecoscience* 12:414-421.

Bois Forte Band of Chippewa. 2019. A Brief Summary of Bois Forte History. Available online at http://www.boisforte.com/history.htm. Accessed on January 4, 2019.

Bossenbroek, J. M., Kraft, C.E., and Nekola, J.C. 2001. Prediction of long-distance dispersal using gravity models: zebra mussel invasion of inland lakes. *Ecological Applications* 11(6), 1778-1788.

Bouma, K. 1994. Blame Hydrilla for flooding. *Orlando Sentinel.* Accessed online at: http://articles.orlandosentinel.com/19941130/news/9411300241_1_hydrillafloodingwater. Accessed on July 7, 2015.

Bowes, George A., Scott Holaday, and William T. Haller. 1979. Seasonal Variation in the Biomass, Tuber Density, and Photosynthetic Metabolism of hydrilla in Three Florida Lakes. *Journal of Aquatic Plant Management* 17:61-65

Brewer, Shannon K., Ryan A. Mcmanamay, Andrew D. Miller, Robert Mollenhauer, Thomas A. Worthington, and Tom Arsuffi. 2016. Advancing environmental flow science: Developing frameworks for altered landscapes and integrating efforts across disciplines. *Environmental management* 58, (2) (08): 175-192, Accessed online at: https://search.proquest.com/docview/1800917884?accountid=27106 (accessed August 30, 2017).

Broennimann, O. and A. Guisan. 2008. Predicting current and future biological invasions: both native and invasive ranges matter. *Biology Letters* 4: 585–589.

Brown, Bob. 2013. Iroquois Clan System: Clans of the Oneida People. Oneida Cultural Heritage Department. September 2013. Available online at https://oneida-nsn.gov/dl-file.php?file=2016/04/IROQUOIS-CLAN-SYSTEM-CLANS-OF-THE-ONEIDA-PEOPLE-9.13.pdf. Accessed January 18, 2019.

Buehler, Denis. 2017. Personal communication. Regional Director, Ohio State Parks with K. Rabeler, Ecology and Environment, Inc., on November 16, 2017.

Butler, William. 2015. Agency Technical Review Comment Sheet for GLFER Hydrilla Risk Assessment (Cultural Impacts Draft (E&E, 10/7/15). 10 December 2015.

Caraco, N.F. and J.J. Cole. 2002. Contrasting impacts of a native and alien macrophyte on dissolved oxygen in a large river. *Ecological Applications.* 12: 1496-1509.

Cayuga Nation. 2019. Culture. Available online at http://cayuganation-nsn.gov/culture.html. Accessed on January 4, 2019.

*Charlotte Observer*. April 22, 2015. "Groups Unite to Kill Hydrilla on Lake Wylie." Available online at http://www.charlotteobserver.com/news/local/community/south-charlotte/article19228191.html. Accessed on July 14, 2017.

Ciruna, K.A., L.A. Meyerson, and A. Gutierrez. 2004. The ecological and socio-economic impacts on invasive alien species in inland water ecosystems. Report to the Convention on Biodiversity on behalf of the Global Invasive Species Program. Available online at https://www.cbd.int/doc/ref/alien/ias-inland-waters-en.pdf. Website accessed May 3, 2017.

Colon-Gaud, J. C., W. E. Kelso, and D. A. Rutherford. 2004. Spatial distribution of macroinvertebrates inhabiting hydrilla and coontail beds in the Atchafalaya Basin, Louisiana. *Journal of Aquatic Plant Management*, 42, 85-91.

Connecticut Envirothon. 2017. The Economic Impact of Invasive Species on Provision Services, Ecosystem Services, Cultural Services. . Available online at http://ctenvirothon.org/wp-content/uploads/2014/08/The-Impact-of-Invasive-Species-v8.pdf. Website accessed on May 3, 2017.

Connelley, William Elsey. 1900. Wyandot Folk-Lore. Available online at https://www.wyandotte-nation.org/culture/folk-lore-and-myths/wyandot-folk-lore/. Accessed January 21, 2019.

Connelley, William Elsey. 1928. Indian Myths. Available online at https://www.wyandotte-nation.org/culture/folk-lore-and-myths/indian-myths/. Accessed January 21, 2019.

Cornelius, Carol, Dr., and Loretta V. Metoxen. Duck Creek: A Way of Life! Oneida Cultural Heritage Department. September 2013. Available online at https://oneida-nsn.gov/dl-file.php?file=2016/04/DUCK-CREEK-A-WAY-OF-LIFE-9.13.pdf. Accessed January 18, 2019.

Cornell Cooperative Extension. 2012. "Mechanical Controls: Dredging in the Cayuga Inlet and Eradication of Hydrilla Verticilata." Accessed online at: http://staff.ccetompkins.org/environment/invasive-species/mechanical-controls-dredging. Accessed on March 25, 2015.

Cornell Cooperative Extension. 2015. "Ecological Impacts of Hydrilla." Accessed online at: http://erie.cce.cornell.edu/invasive-species/ecological-impacts-of-hydrilla. Accessed on May 3, 2015.

Davids, Dorothy. 2004. *A Brief History of the Mohican Nation: Stockbridge Munsee Band*. . Published by the Stockbridge Munsee Historical Committee, Arvid E. Miller Memorial Library Museum, Bowler, Wisconsin. Spring 2001 (Revised 2004). Available online at https://www.mohican.com/mt-content/uploads/2015/10/a-brief-history-of-the-mohican-nation-stockbridge-munsee-band-2004.pdf. Accessed January 4, 2019.

Dayan, F.E. and M.D. Netherland. 2005. Hydrilla, the Perfect Aquatic Weed, Becomes More Noxious than Ever, *Outlooks on Pest Management*, Dec. 2005:277-282.

Dibble, E., K. Kilgore, and S. Harrell. 1997. Assessment of Fish Plan Interactions. United States Army Corps of Engineers, Miscellaneous Paper A-97-6.

Dodd, Shelley R., Rebecca S. Haynie, Susan M. Williams, and Susan B. Wilde. 2016. Alternate Food-Chain Transfer of The Toxin Linked to Avian Vacuolar Myelinopathy and Implications for the Endangered Florida Snail Kite (*Rostrhamus Sociabilis*). Journal of Wildlife Diseases: April 2016, Vol. 52, No. 2, pp. 335-344.

Ecology and Environment, Inc. (E & E). 2015. *Risk Assessment Methodology for the Great Lakes Hydrilla Risk Assessment*, prepared for USACE–Buffalo District, Buffalo, New York by E & E, Lancaster, New York.

Evans, Katie and Rich Ruby. 2017. Tonawanda Creek Hydrilla Eradication Demonstration Project, as presented on October 18, 2017, at the Healing Our Waters Great Lakes Restoration Conference, Buffalo, New York.

Ewing, Bob. 2009. Digital Journal "What is the Real Impact of Invasive Species?" Available online at http://www.digitaljournal.com/article/267940 . Website accessed on May 3, 2017.

Figueiredo, Bruno R., S., Roger P. Mormul, and Sidinei M. Thomaz. 2015. Swimming and hiding regardless of the habitat: Prey fish do not choose between a native and a non-native macrophyte species as a refuge. *Hydrobiologia* 746, (1) (03): 285-290. Accessed online at: https://search.proquest.com/docview/1646554024?accountid=27106 (accessed August 30, 2017).

Fischer, J.R., L.A. Lewis, T. Augspurger, and T.E. Rocke. 2002. Avian vacuolar myelinopathy: A newly recognized fatal neurological disease of eagles, waterfowl, and other birds. *Transactions of the North American Wildlife and Natural Resources Conference* 67: 51–61

Fitzgerald, Gerald, and Roger Wilkinson. 2009. Assessing the social impact of invasive animals in Australia: A report produced for the Invasive Animals Cooperative Research Centre. Available online at http://www.pestsmart.org.au/wp-content/uploads/2010/03/Social-impacts-FINAL-report.pdf. Website accessed May 3, 2017.

Fitzpatrick, M.C., N.J. Gotelli, and A.M. Ellison. 2013. MaxEnt versus MaxLike: empirical comparisons with ant species distributions. *Ecosphere* 4:55.

Florida Fish and Wildlife Conservation Commission. 2017a. "Annual Report of Activities Conducted under the Cooperative Aquatic Plant Control Program in Florida Public Waters for Fiscal Year 2015-2016." Available online at http://myfwc.com/media/4137470/annualreport15-16.pdf. Accessed on June 19, 2017.

Florida Fish and Wildlife Conservation Commission. 2017b. "Annual Report of Activities Conducted under the Cooperative Aquatic Plant Control Program in Florida Public Waters for Fiscal Year 2014-2015." Available online at https://plants.ifas.ufl.edu/wp-content/uploads/files/aquaticplant-management-FY14-15.pdf Accessed on June 19, 2017.

Florida Fish and Wildlife Conservation Commission. 2017c. "Annual Report of Activities Conducted under the Cooperative Aquatic Plant Control Program in Florida Public Waters for Fiscal Year 2013-2014." Available online at https://plants.ifas.ufl.edu/wp-content/uploads/files/AquaticPlant-Management-2013-2014.pdf Accessed on June 19, 2017.

Florida Fish and Wildlife Conservation Commission. 2017d. "Annual Report of Activities Conducted under the Cooperative Aquatic Plant Control Program in Florida Public Waters for Fiscal Year 2012-2013." Available online at https://plants.ifas.ufl.edu/wp-content/uploads/files/AquaticPlant-Manage_12-13.pdf Accessed on June 19, 2017.

Florida Fish and Wildlife Conservation Commission. 2017e. "Annual Report of Activities Conducted under the Cooperative Aquatic Plant Control Program in Florida Public Waters for Fiscal Year 2011-2012." Available online at http://myfwc.com/media/2473130/aquaticplantmanage-fy2011-12.pdf Accessed on June 19, 2017.

Florida Fish and Wildlife Conservation Commission. 2017f. "Annual Report of Activities Conducted under the Cooperative Aquatic Plant Control Program in Florida Public Waters for Fiscal Year 2010-2011." Available online at http://myfwc.com/media/2072922/AquaticPlantManage_10-11.pdf Accessed on June 19, 2017.

Florida Fish and Wildlife Conservation Commission. 2017g. "Annual Report of Activities Conducted under the Cooperative Aquatic Plant Control Program in Florida Public Waters for Fiscal Year 2009-2010." Available online at http://myfwc.com/media/2072919/AquaticPlantManage_09-10.pdf Accessed on June 19, 2017.

Florida Fish and Wildlife Conservation Commission. 2017h. "Annual Report of Activities Conducted under the Cooperative Aquatic Plant Control Program in Florida Public Waters for Fiscal Year 2008-2009." Available online at http://myfwc.com/media/2072916/AquaticPlantManage_08-09.pdf Accessed on June 19, 2017.

Florida Fish and Wildlife Conservation Commission. 2015. Wildlife & Habitats, Invasive Plants, Weed Alerts, Hydrilla. Accessed online at: http://myfwc.com/wildlifehabitats/invasive-plants/weed-alerts/hydrilla/. Accessed on May 3, 2015.

Foltz, J.W., and J.P. Kirk. 1994. Aquatic vegetation and water quality in Lake Marion, South Carolina. In W. T. Haller (Ed.), Proceedings of the Grass Carp symposium (pp. 93-107). Vicksburg, Mississippi: US Army Corps of Engineers, Waterways Experiment Station.

Fond du Lac Band of Lake Superior Chippewa. 2018. The Presence at the End of the Lake: Migration Tradition. Available online at http://www.duluth-stories.net/migrationtradition.html. Accessed January 4, 2019.

Forest County Potawatomi. 2019. Timeline of Potawatomi History. Available online at https://www.fcpotawatomi.com/culture-and-history/timeline-of-potawatomi-history/. Accessed January 4, 2019.

Fox, Nick J. 1999. "Postmodern reflections on 'risk', hazards' and life choices." *Risk and sociocultural theory: new directions and perspectives*. Edited by Deborah Lupton. Cambridge University Press: pp. 12-33. Available online at http://catdir.loc.gov/catdir/samples/cam032/99024201.pdf. Website accessed January 4, 2018.

Gotelli, N.J. and J. Stanton-Geddes. 2015. Climate change, genetic markers and species distribution modelling. *Journal of Biogeography* 42: 1577–1585.

Grand Traverse Band of Ottawa and Chippewa Indians. 2019. We are the Anishinaabek. Available online at http://www.gtbindians.org/history.asp. Accessed January 7, 2019.

Great Lakes Commission. 2017. *Annual Report of the Great Lakes Regional Water Use Database- Representing 2014 Water Use Data.* Available at https://waterusedata.glc.org/pdf/wateruserpt2014.pdf Accessed on July 7, 2017.

Greeley, June-Ann. 2017. Water in native American Spirituality: Liquid Life – blood of the Earth and Life of the Community. Green Humanities, vol. 2 (2017), pp. 156-179. Available online at http://greenhumanities.org/archive/vol02/vol2article07jagreeley.pdf. Accessed January 4, 2019.

Gross, Elisabeth M. 2003. Allelopathy of aquatic autotrophs. *Critical Reviews in Plant Sciences* 22, (3): 313-339, Accessed online at: http://search.proquest.com/docview/199549423?accountid=27106. Accessed June 18, 2015.

Hampe, A. and R.J. Petit. 2005. Conserving biodiversity under climate change: the rear edge matters. *Ecology Letters* 8: 461–467

Harris, Ed. 2017. Invasive Plant Management Section, Florida Fish and Wildlife Conservation Commission. Phone call with K. Evans on December 18, 2017.

Hass, Nicole. 2017. Recreation Program Manager, City of Avon Lake, Ohio. Personal communication with K. Rabeler, Ecology and Environment, Inc. on November 15, 2017.

Hastie, T. and W. Fithian. 2013. Inference from presence-only data; the ongoing controversy. *Ecography* 36: 864-867.

Haynie, R.S, W.W. Bowerman, S.K. Williams, J.R. Morrison, and J.M. Grizzle. 2013. Triploid grass carp susceptibility and potential for disease transfer when used to control aquatic vegetation in reservoirs with avian vacuolar myelinopathy. *J Aquat Anim Health* 25: 252.

Hazel, Chris. 2017. Park Supervisor, North Perry Village, Ohio. Personal communication with K. Rabeler, Ecology and Environment, Inc., on November 15, 2017.

Hebebrand, K., and J. Bossenbroek. 2017. *Potential Spread of* Hydrilla verticillata *in the Great Lakes Basin, University of Toledo – Hydrilla Risk Assessment, Final Report*. Prepared for Ecology and Environment, Inc.

Henderson, J.E., J.P. Kirk, S.D. Lamprecht, and W.E. Hayes. 2003. Economic impacts of aquatic vegetation to angling in two South Carolina reservoirs. *Journal of Aquatic Plant Management*, 41, 53-52.

Henry, A. 2017. *Monoecious Hydrilla (Hydrilla verticillata (L.f) Royle) Growth and Phenology in Two Dissimilar Climates*, Master of Science Thesis, Crop Science Department, North Carolina State University, Raleigh, NC.

Hentschl, Neil. 2017. Personal communication. Secretary-Manager, Huron County Road Commission telephone conversation with K. Rabeler, Ecology and Environment, Inc., on November 13, 2017.

Hijmans, Robert J., et al. Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology* 25.15 (2005): 1965-1978.

Hinicke, Angel. 2018. Resource Conservationist, Tompkins County Soil and Water Conservation District. Telephone conversation with K. Evans, Ecology and Environment, Inc., on January 31, 2018.

Hofstra, D. and J. Clayton. 2014. Native flora and fauna response to removal of the weed Hydrilla verticillata (L.f.) Royle in Lake Tutira. *Hydrobiologia*, 737: 297-308.

Honnell, D., J.D. Madsen, R.M. Smart. 1992. Effects of aquatic plants on water quality in pond ecosystems. In: Proceedings, 26 Annual Meeting, Aquatic Plant Control Research Program, Report A-92-2. US Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS.

Hoover, A., N.R. Cosmo, and E. Rutherford. 2011. Spawning_sites_gsa_ah_2011 [GIS data]. Accessed online at: http://glahf.org/data/. Accessed June 2017.

Hoyer, M.V., and D.E. Canfield, Jr. 1996. Largemouth bass abundance and aquatic vegetation in Florida lakes: an empirical analysis. *Journal of Aquatic Plant Management*, 34, 23-32.

Hoyer, M.V., M. Woods Jackson, M.S. Allen, and D.E. Canfield, Jr. 2008. Lack of exotic hydrilla infestation effects on plant, fish and aquatic bird community measures. *Lake Reserv. Manage.* 24:331-338

Illinois Hydrilla Task Force. 2015. *Early Detection Rapid Response Plan for Hydrilla verticillata in Illinois*. Updated January 2015.

Illinois-Indiana Sea Grant, Illinois Natural History Survey, Illinois Department of Natural Resources, and Northeast Illinois Invasive Plant Partnership. 2015. *Clean Boats Crew Guidelines for the Illinois and Indiana Aquatic Invasive Species Volunteer Outreach Program. 2015 Edition*. Accessed online at: http://iiseagrant.org/ais/CBC%20Manual%20Complete_2015.pdf

Indiana Department of Natural Resources (DNR). 2009. Aquatic Invasive Species, Hydrilla. Accessed online at: http://www.in.gov/dnr/6347.htm. Accessed on May 3, 2015.

Jackson, D.J. 2019. A Brief Bad River History/Description. Available online at http://www.badriver-nsn.gov/history. Accessed on January 4, 2019.

James G. Zupka, CPA, Inc. 2017. Lake Metroparks Lake County, Ohio Audit Report for the Year Ended December 31, 2016. Available online at https://ohioauditor.gov/auditsearch/Reports/2017/Lake_MetroParks_District_16-Lake.pdf Accessed on November 2, 2017.

Jourdan, Judith L. 2013a. Oneida Nation Cultural Symbols: In and Around the Oneida Reservation. Oneida Cultural Heritage Department. September 2013. Available online at https://oneida-nsn.gov/dl-file.php?file=2016/04/ONEIDA-NATION-CULTURAL-SYMBOLS-IN-AND-AROUND-ONEIDA-RESERVATION-9.13.pdf. Accessed January 18, 2019.

Jourdan, Judith L. 2013b. Wampum: Our Historical Record. Oneida Cultural Heritage Department. September 2013. Available online at https://oneida-nsn.gov/dl-file.php?file=2016/04/WAMPUM-OUR-HISTORICAL-RECORD-9.13.pdf. Accessed January 18, 2019.

Keller, R. P. 2009. *Bioeconomics of Invasive Species: Integrating Ecology, Economics, Policy, and Management*. Oxford University Press.

Kirk, J.P. and J.E. Henderson. 2006. "Management of hydrilla in the Santee Cooper reservoirs, South Carolina: experiences from 1982 to 2004," *Journal of Aquatic Plant Management* 44:98-103. Available online at http://www.apms.org/japm/vol44/v44p98.pdf.

Kraus, Richard T., and R.C. Jones. 2012. Fish abundances in shoreline habitats and submerged aquatic vegetation in a tidal freshwater embayment of the Potomac River. *Environmental monitoring and assessment* 184, (5) (05): 3341-57. Accessed online at: http://search.proquest.com/docview/1013444714?accountid=27106. Accessed May 8, 2015.

Kratville, David and Jonathan Heintz. 2018. California Department of Food and Agriculture. Phone call with K. Evans, Ecology and Environment, Inc. on January 10, 2018.

Lake Gaston Weed Control Council. 2016. "Lake Gaston Weed Control Council FY 2015-2016 Financial Statements." Available online at http://www.lgwcc.org/pdfFiles/financials/LGWCCFinancialStatement2015-16.pdf. Accessed on July 14, 2017.

Langeland, K.A. 1996. *Hydrilla verticillata* (L.F.) Royle (*Hydrocharitaceae*), "The Perfect Aquatic Weed." *Castanea* 61: 293-304.

LCO-NSN.gov. 2018. History of Lac Corte Oreilles. Available online at https://lcotribe.wixsite.com/lcotribe/our-historyhttps://lco-tribe.wixsite.com/lcotribe/our-history. Accessed January 7, 2019.

Leech Lake Division of Resource Management. 2018. Heritage Sites. Available online at http://www.llojibwe.org/drm/cultural/heritage.html. Accessed January 17, 2019.

Lewis-Weis L.A., R.W. Gerhold, J.R. Fischer. 2004. Attempts to reproduce vacuolar myelinopathy in domestic swine and chickens. *Journal of Wildlife Diseases* 40: 476–484.

Little Traverse Bay Bands of Odawa Indians. 2005. A 200 Year History of Our Land Use. Available online at http://www.ltbbodawa-nsn.gov/Arch/Our%20Land%20and%20Culture%20for%20web.pdf. Accessed January 17, 2019.

Loomis, John. 2005. "Updated Outdoor Recreation Use Value on National Forests and Other Public Lands." U.S. Forest Service. General Technical Report PNW-GTR-658. October 2005.

Lorain County Metro Parks. 2017. *2016 Annual Report to the Citizens of Lorain County*. Available online at http://metroparks.cc/annualreports/annual-report-2016.pdf. Accessed on November 2, 2017.

Maceina, M.J. 1996. Largemouth bass abundance and aquatic vegetation in Florida Lakes: an alternative interpretation. *Journal of Aquatic. Plant Management*. 34:43-47.

Madsen, John. 1999. Point Intercept and Line Intercept Methods for Aquatic Plant Management. Aquatic Plant Control Technical Note MI-02 February 1999. Available at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.595.4659&rep=rep1&type=pdf. Accessed on January 11, 2019.

Madsen, J.D. and C.S. Owens. 2000. *Factors Contributing to the Spread of Hydrilla in Lakes and Reservoirs*, Aquatic Plant Control Research Program (APCRP) Technical Notes Collection, ERDC/TN APCRP-EA-01, US Army Engineer Research and Development Center, Vicksburg, MS.

Madsen, John D., Ryan M. Wersal, and Thomas E. Woolf. 2007. A New Core Sampler for Estimating Biomass of Submersed Aquatic Macrophytes. *Journal of Aquatic Plant Management. 45: 31-34.*

Martin Associates. 2018. "The Economic Impacts of Maritime Shipping in the Great Lakes – St. Lawrence Region." Available at http://www.greatlakes-seaway.com/en/pdf/eco_impact_full.pdf Accessed on January 9, 2019.

Maryland Department of Natural Resources. 2014. *Strategy for Control of Hydrilla in Deep Creek Lake*. Presented at the Deep Creek Lake Policy Review Board Meeting on March 20, 2014. Accessed online at: http://www.deepcreeklakepoa.com/resources/dcl-poa/pdf/Hydrilla-strategy-final20Mar14.pdf.

McDowell, W.G., A.J. Benson, and J.E. Byers. 2014. Climate controls the distribution of widespread invasive species: implications for future range expansion. *Freshwater Biology*. 59:847-857.

McGonigal, Kathy. 2017. Deputy Director, Department of Aging and Youth, Wayne County New York. Personal communication with K. Rabeler, Ecology and Environment, Inc., on November 13, 2017.

McLaughlin, Jackie. 2017. Cleveland Metroparks *2015 Enhanced Visitation Evaluation.* Available online at https://clevelandmetroparks.com/getmedia/5e697117-3186-45f3-9394-281d9dff8b08/Cleveland-Metroparks-2015-Visitation-Report-Mar-2016.pdf.ashx. Accessed on November 2, 2017.

Menominee Indian Tribe of WI. 2019a. Posoh Mawanew Weyak (Hello Everyone). Available online at http://www.menominee-nsn.gov/. Accessed January 7, 2019.

Menominee Indian Tribe of WI. 2019b. Who We Are. Available online at http://www.menominee-nsn.gov/CulturePages/AboutUs.aspx. Accessed January 7, 2019.

Menominee Indian Tribe of WI. 2019c. Menominee Indian Tribe Cultural Museum. Available online at http://www.menominee-nsn.gov/CulturePages/CulturalMuseum.aspx. Accessed January 17, 2019.

Mercurio A.D., S.M. Hernandez, J.C. Maerz, M.J. Yabsley, A.E. Ellis, et al. 2014. Experimental Feeding of *Hydrilla verticillata* Colonized by Stigonematales Cyanobacteria Induces Vacuolar Myelinopathy in Painted Turtles (*Chrysemys picta*). PLoS ONE 9(4): e93295. doi: 10.1371/journal.pone.0093295

Merow, C., and J.A. Silander. 2014. A comparison of Maxlike and Maxent for modelling species distributions. *Methods in Ecology and Evolution* 5:215–225. Oxford, New York.

Meybeck, M. 1995. Global Distribution of Lakes. In: Lerman, A., Imboden, D., and Gat, J. (eds). *Physics and Chemistry of Lakes*. *New York*.

Miami Tribe of Oklahoma. 2019. History. Available online at http://www.mi-amination.com/node/11. Accessed January 7, 2019.

Michigan Department of Natural Resources and Environment, Recreation Division. 2010. *General Management Plan: Grand Mere State Park.* Available online at http://www.michigan.gov/documents/dnr/grand-mere-general-mgmt-plan_347890_7.pdf. Accessed on November 3, 2017.

Mille Lacs Band of Ojibwe. 2019. Our History. Available online at https://millelacsband.com/about/our-history. Accessed January 7, 2019.

Monterroso, Iliana. 2005. Comparison of two socio-economic assessment methods for the analysis of the invasion process of *Hydrilla verticillata* in Lake Izabal, Guatemala. Master Dissertation for the Degree of Environmental Science, Ecological Economics, and Environmental Management, Institut de Ciencia i Teconologia Ambiantals, Universitat Autonomo de Barcelona, October 27, 2005. Available online at http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.133.6702&rep=rep1&type=pdf. Website accessed May 3, 2017.

Moxley, D.J., and F.H. Langford. 1982. Beneficial effects of hydrilla on two eutrophic lakes in central Florida. In *Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies* (Vol. 36, pp. 280-286).

Nakamura, Keigo, Yuichi Kayaba, Jun Nishihiro, and Noriko Takamura. 2008. Effects of submerged plants on water quality and biota in large-scale experimental ponds. Landscape and *Ecological Engineering 4*, (1) (05): 1-9, Accessed online at: http://search.proquest.com/docview/213910878?accountid=27106. Accessed May 8, 2015.

National Audubon Society (NAS). 2018. Important Bird Areas Database, Boundary Digital Data Set [GIS data]. Willow Grove, Pennsylvania. January 2018. Contact: Joanna Wu, iba@audubon.org. Accessed January 2019.

National Marine Manufacturers Association. 2015. *2012 Recreational Boating Economic Study*. Available at http://www.nmma.org/assets/cabinets/cabinet432/nmma_ecoimpact_booklet_optimized.pdf. Accessed on May 1, 2015.

National Oceanic and Atmospheric Administration (NOAA). 2017. "Economics: National Ocean Watch." Available online at https://coast.noaa.gov/quickreport/#/index.html Accessed on August 31, 2017.

NOAA. Office of Coast Survey. 2017a. "Coastal Survey: Port Bay to Long Point – Lake Ontario: #14804." Available online at http://www.charts.noaa.gov/PDFs/14804.pdf Accessed on May 26, 2017.

NOAA. Office of Coast Survey. 2017b. "Coastal Survey: Sodus Bay – Lake Ontario: #14814." Available online at http://www.charts.noaa.gov/PDFs/14814.pdf Accessed on May 26, 2017.

NOAA. Office of Coast Survey. 2017c. "Coastal Survey: Six Miles South of Stony Point to Port Bay – Lake Ontario: #14803." Available online at http://www.charts.noaa.gov/PDFs/14803.pdf Accessed on May 30, 2017.

NOAA. Office of Coast Survey. 2017d. "Coastal Survey: Clayton to False Duck Island – Lake Ontario: #14802." Available online at http://www.charts.noaa.gov/PDFs/14802.pdf Accessed on May 30, 2017.

NOAA. Office of Coast Survey. 2017e. "Lower Niagara River: #14816." Available online at http://www.charts.noaa.gov/PDFs/14816.pdf Accessed on September 19, 2017.

NOAA. Office of Coast Survey. 2017f. "Upper Niagara River: #14832." Available online at http://www.charts.noaa.gov/PDFs/14832.pdf Accessed on September 19, 2017.

NOAA. Office of Coast Survey. 2017g. "Coastal Survey: Buffalo Harbor: #14833." Available online at http://www.charts.noaa.gov/PDFs/14833.pdf Accessed on September 19, 2017.

NOAA. Office of Coast Survey. 2017h. "Coastal Survey: Approaches to Niagara River and Welland Canal: #14822." Available online at http://www.charts.noaa.gov/PDFs/14822.pdf Accessed on September 19, 2017.

NOAA. Office of Coast Survey. 2017i. "Coastal Survey: Buffalo to Erie: #14838." Available online at http://www.charts.noaa.gov/PDFs/14838.pdf Accessed on September 19, 2017.

NOAA. Office of Coast Survey. 2017j. "Coastal Survey: Sturgeon Point to Twenty Mile Creek: #14823." Available online at http://www.charts.noaa.gov/PDFs/14823.pdf Accessed on September 19, 2017.

NOAA. Office of Coast Survey. 2017k. "Coastal Survey: Sixteen Mile Creek to Conneaut: #14824." Available online at http://www.charts.noaa.gov/PDFs/14824.pdf Accessed on September 19, 2017.

NOAA. Office of Coast Survey. 2017l. “Coastal Survey: Ashtabula to Chagrin River #14825.” Available online at http://www.charts.noaa.gov/PDFs/14825.pdf Accessed on September 19, 2017.

NOAA. Office of Coast Survey. 2017m. “Coastal Survey: Ashtabula Harbor: #14836.” Available online at http://www.charts.noaa.gov/PDFs/14836.pdf Accessed on September 19, 2017.

NOAA. Office of Coast Survey. 2017n. “Coastal Survey: Western Lake Erie: #14830.” Available online at http://www.charts.noaa.gov/PDFs/14830.pdf Accessed on October 2, 2017.

NOAA. Office of Coast Survey. 2017o. “Coastal Survey: Western Lake Erie: #14846.” Available online at http://www.charts.noaa.gov/PDFs/14846.pdf Accessed on October 2, 2017.

NOAA. Office of Coast Survey. 2017p. “Coastal Survey: Moss Point to Vermilion: #14826.” Available online at http://www.charts.noaa.gov/PDFs/14826.pdf Accessed on October 2, 2017.

NOAA. Office of Coast Survey. 2017q. “Coastal Survey: Chicago Lake Front: #14927.” Available online at http://www.charts.noaa.gov/PDFs/14927.pdf Accessed on October 2, 2017.

NOAA. Office of Coast Survey. 2017r. “Coastal Survey: Calumet to Indiana Harbors: #14929.” Available online at http://www.charts.noaa.gov/PDFs/14929.pdf Accessed on October 2, 2017.

NOAA. Office of Coast Survey. 2017s. “Coastal Survey: Huron Harbor: #14843.” Available online at http://www.charts.noaa.gov/PDFs/14843.pdf Accessed on October 9, 2017.

NOAA. Office of Coast Survey. 2017t. “Coastal Survey: Sandusky Harbor: #14845.” Available online at http://www.charts.noaa.gov/PDFs/14845.pdf Accessed on October 9, 2017.

NOAA. Office of Coast Survey. 2017u. “Coastal Survey: South Shore of Lake Erie: #14842.” Available online at http://www.charts.noaa.gov/PDFs/14842.pdf Accessed on October 9, 2017.

NOAA. Office of Coast Survey. 2017v. "Coastal Survey: Islands in Lake Erie – Put in Bay: #14844." Available online at http://www.charts.noaa.gov/PDFs/14844.pdf Accessed on October 13, 2017.

NOAA. Office of Coast Survey. 2017w. "Coastal Survey: Toledo Harbor: #14847." Available online at http://www.charts.noaa.gov/PDFs/14847.pdf Accessed on October 13, 2017.

NOAA. Office of Coast Survey. 2017x. "Coastal Survey: Port Huron to Pte. aux Barques: #14862." Available online at http://www.charts.noaa.gov/PDFs/14862.pdf Accessed on October 20, 2017.

NOAA. Office of Coast Survey. 2017y. "Coastal Survey: South End of Lake Huron: #14865." Available online at http://www.charts.noaa.gov/PDFs/14865.pdf Accessed on October 20, 2017.

NOAA. Office of Coast Survey. 2017z. "Coastal Survey: Saginaw Bay: #14863." Available online at http://www.charts.noaa.gov/PDFs/14863.pdf Accessed on October 20, 2017.

NOAA. Office of Coast Survey. 2017aa. "Saginaw River: #14867." Available online at http://www.charts.noaa.gov/PDFs/14867.pdf Accessed on October 20, 2017.

Nawrocki J.J., R.J. Richardson, S.T. Hoyle. 2016. Monoecious Hydrilla Tuber Dynamics Following Various Management Regimes on Four North Carolina Reservoirs. *J. Aquat. Plant Manage.* 54:12-19. http://www.apms.org/wp/wp-content/uploads/2015/12/japm-54-01-12.pdf.

Netherland, Mike. 2019. The 5th Wave of Hydrilla Invasion in the U.S. Presentation [no date]. Available online at file:///C:/Users/RockwellC/Downloads/5th%20Wave%20Hydrilla%20Netherland.pdf. Accessed on January 14, 2019.

Netherland, M.D. and M. Greer. 2014. *Establishing Research and Management Priorities for Monoecious Hydrilla*, Aquatic Plant Control Research Program (APCRP) Technical Notes Collection, ERDC/TN APCRP-MI-8, US Army Engineer Research and Development Center, Vicksburg, MS.

New York City Department of Environmental Protection. 2018. "Aquatic Invasive Species Prevention and Early Detection". Accessed online at: http://www.nyc.gov/html/dep/html/watershed_protection/invasive_species_aquatic.shtml; accessed February 2, 2018.

New York Sea Grant. 2014. *New York State Watercraft Inspection Steward Program Handbook: A Guide for Starting New Watercraft Inspection Programs.* Prepared for the Cornell University Statewide Invasive Species Outreach Program Publication ID: NYSGI-H-14-001. Accessed online at: http://www.dec.ny.gov/docs/lands_forests_pdf/aiswcimanual2.pdf.

New York State Department of Environmental Conservation (NYSDEC). 2008. New York Non-Native Plant Invasiveness Ranking Form: *Hydrilla verticillata.* Accessed online at: http://www.nyis.info/user_uploads/1bd86_Hydrilla.verticillata.NYS.pdf.

NYSDEC. 2015. *NYS DEC Lake Erie 2014 Annual Report to the Lake Erie Committee and the Great Lakes Fishery Commission.* Available online at http://www.dec.ny.gov/docs/fish_marine_pdf/2014lerpt.pdf Accessed on September 25, 2017.

NYSDEC. 2016a. *NYS DEC Lake Erie 2015 Annual Report to the Lake Erie Committee and the Great Lakes Fishery Commission.* Available online at http://www.dec.ny.gov/docs/fish_marine_pdf/2015lerpt.pdf Accessed on September 25, 2017.

NYSDEC. 2016b. *2015 Annual Report: Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unite to the Great Lakes Fishery Commission's Lake Ontario Committee.* Available online at http://www.dec.ny.gov/docs/fish_marine_pdf/lorpt15.pdf Accessed on June 2, 2017.

NYSDEC. 2017a. "Hydrilla Factsheet." Division of Lands and Forests. Available online at http://www.dec.ny.gov/docs/lands_forests_pdf/hydrillafs.pdf Accessed on July 18, 2017.

NYSDEC. 2017b. *NYS DEC Lake Erie 2016 Annual Report to the Lake Erie Committee and the Great Lakes Fishery Commission.* Available online at http://www.dec.ny.gov/docs/fish_marine_pdf/2016lerpt.pdf Accessed on June 2, 2017.

New York State Office of Parks, Recreation and Historic Preservation. 2017. "Acreage of and Attendance at Facilities Operated by the Office of Parks, Recreation, and Historic Preservation: Fiscal Years 2005-06 to 2012-13."

Newton, Jeremy, Adam Sepulveda, Kevin Slyvester, and Ryan Thum. 2016. Potential utility of environmental DNA for early detection of Eurasian watermilfoil (*Myriophyllum spicatum*). *Journal of Aquatic Plant Management*. 54: 46-49.

North Carolina Aquatic Nuisance Species Management Plan Committee. 2015. *North Carolina Aquatic Nuisance Species Management Plan.* Available online at https://ncdenr.s3.amazonaws.com/s3fs-public/Water%20Resources/files/awc/Aquatic%20Nuisance%20Species%20Management%20Plan%20-%20final.pdf Accessed on July 14, 2017.

North Carolina State University. 2017. "Hydrilla: A Rapidly Spreading Aquatic Weed in North Carolina." Available online at http://www.weedscience.ncsu.edu/aquaticweeds/hydrilla.PDF. Accessed on July 10, 2017.

Northeast Illinois Invasive Plant Partnership. 2018. "How Can I Help?" Accessed online at: https://www.niipp.net/hydrilla/how-can-i-help; accessed February 4, 2018.

Nottawaseppi Huron Band of the Potawatomi, Michigan. 2019. NHBP Culture. Available online at https://www.nhbpi.org/culture/. Accessed January 7, 2019.

Ohio Department of Natural Resources. 2017. *Ohio's Lake Erie Fisheries: 2016.* Lake Erie Fisheries Units. Available online at https://wildlife.ohiodnr.gov/portals/wildlife/pdfs/fishing/LakeErieStatus.pdf Accessed on September 25, 2017.

Oneida Indian Nation. 2016a. The Haudenosaunee Creation Story. Available online at http://www.oneidaindiannation.com/the-haudenosaunee-creation-story/. Accessed January 17, 2019.

Oneida Indian Nation. 2016b. The Legend of the Gift of Tobacco. Available online at http://www.oneidaindiannation.com/the-legend-of-the-gift-of-tobacco/. Accessed January 17, 2019.

Oneida Indian Nation. 2016b. Godasiyo, the Woman Chief. Available online at http://www.oneidaindiannation.com/godasiyo-the-woman-chief/. Accessed January 17, 2019.

Oneida Indian Nation. 2016d. How the Clans were Chosen. Available online at http://www.oneidaindiannation.com/how-the-clans-were-chosen/. Accessed January 17, 2019.

Oneida Tribe of Indians of Wisconsin. 2019a. Creation Story; As told by Amos Christjohn. . Available online at https://oneida-nsn.gov/our-ways/our-story/creation-story/. Accessed January 17, 2019.

Oneida Tribe of Indians of Wisconsin. 2019b. Kayanlaˀ Kówa – Great Law of Peace: The Peace Maker & Hiawatha. Available online at https://oneida-nsn.gov/our-ways/our-story/great-law-of-peace/. Accessed January 18, 2019.

Onondaga Nation. 2018a. Stewards of the Land. Available online at http://www.onondaganation.org/land-rights/stewards-of-the-land/. Accessed January 18, 2019.

Onondaga Nation. 2018b. Onondaga Lake – The Most Polluted Lake In America. Available online at http://www.onondaganation.org/land-rights/onondaga-lake/. Accessed January 18, 2019.

Onondaga Nation. 2018c. Onondaga Nation's Vision for a Clean Onondaga Lake. Available online at http://www.onondaganation.org/land-rights/onondaga-nations-vision-for-a-clean-onondaga-lake/. Accessed January 18, 2019.

Onondaga Nation. 2018d. Onondaga Creek Mudboil Study. Available online at http://www.onondaganation.org/land-rights/onondaga-creek-mud-boils/. Accessed January 18, 2019.

Ontario Ministry of Natural Resources and Forestry (OMNRF). 2016. *A Risk Assessment for Hydrilla (Hydrilla verticillata) in Ontario, Final Draft, August 2016*, Natural Resource Heritage Section, Natural Resources Conservation Policy Branch, OMNRF.

Pagel, J. and F.M. Schurr. 2012. Forecasting species ranges by statistical estimation of ecological niches and spatial population dynamics. *Global Ecology and Biogeography* 21: 293– 304.

Paresh, Lacoul and Bill Freedman. 2006. Environmental influences on aquatic plants in freshwater ecosystems. *Environmental Reviews* 14, (2): 89-110,112-136, Accessed online at: http://search.proquest.com/docview/206766170?accountid=27106 (accessed June 18, 2015).

Pejchar, Liba, and Harold A. Mooney. 2009. Invasive Species, Ecosystem Service and Human Well-being. Available online at http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&cad=rja&uact=8&ved=2ahUKEwjxyrWh5tTfAhXD1VkKHQwKDMQFjABegQICRAC&url=http%3A%2F%2Fciteseerx.ist.psu.edu%2Fviewdoc%2Fdownload%3Fdoi%3D10.1.1.472.8767%26rep%3Drep1%26type%3Dpdf&usg=AOvVaw25rCvznmjAUowd7Zuyhugw. Website accessed January 4, 2019.

Phillips, S. and M. Dudík. 2008. Modeling of species distribution with maxent: new extensions and a comprehensive evaluation. *Ecography* 31: 161–175.

Pokégnek Bodéwadmik. 2019a. Clans. Available online at http://www.pokagon-band-nsn.gov/our-culture/clans. Accessed on January 21, 2019.

Pokégnek Bodéwadmik. 2019b. History. Available online at http://www.pokagonband-nsn.gov/our-culture/history. Accessed January 21, 2019.

Poovey, A.G. and S.H. Kay. 1998. The potential of a summer drawdown to manage monoecious Hydrilla. *Journal of Aquatic Plant Management*, *36*, pp.127-129.

Posey, M. H., C. Wigand, and J.C. Stevenson. 1993. Effects of an introduced aquatic plant, Hydrilla verticillata, on benthic communities in the upper Chesapeake Bay. *Estuarine, Coastal and Shelf Science*, 37(5), 539-555.

Prairie Island Indian Community. 2019. Home: the People of Prairie Island welcome you! Available online at http://prairieisland.org/. Accessed January 7, 2019.

Quinlan, H., M. Dryer, G. Czypinski, J. Pyatskowit, and J. Krajniak. 2007. Strategic approach to problem identification and monitoring of aquatic invasive species within Great Lakes Inventory and Monitoring Network park units. U.S. Fish and Wildlife Service, Ashland Fishery Resources Office, Ashland, Wisconsin, for National Park Service, Great Lakes Inventory and Monitoring Network, Ashland, Wisconsin. GLKN/2007/08. Available online at https://irma.nps.gov/DataStore/DownloadFile/147894. Accessed January 4, 2018.

Racine-Johnson Aquatic Ecologists. 2016. *2015 Monitoring Report of the Cayuga Inlet and Southern Cayuga Lake Monecious Hydrilla Eradication Project.* Accessed online at: https://s3.amazonaws.com/assets.cce.cornell.edu/attachments/14361/2015_Plant_Monitoring_Report_FINAL.pdf?1459189603

Racine-Johnson Aquatic Ecologists. 2017. *2016 Monitoring Report of the Cayuga Inlet and Southern Cayuga Lake Monecious Hydrilla Eradication Project*. January 2017.

Ready, R.C., T.B Lauber, G.L Poe, L.G. Rudstam. R.C. Stedman, and N.A. Connelly. 2016. "Impacts of Aquatic Invasive Species on Sport Fish and Recreational Fishing in the Great Lakes: Possible Future Scenarios." HDRU Publ. No. 16-1, Dept. of Natural Resources, College of Agricultural and Life Science, Cornell University, Ithaca, NY.

Regan, S.M. 2017. Factors Affecting Monoecious Hydrilla (*Hydrilla verticillata*) in Dynamic Systems, Master of Science Thesis, Department of Fisheries, Wildlife, and Conservation Biology, North Carolina State University, Raleigh, NC.

Reshetnikov, A.N. and G.F. Ficetola. 2011. Potential range of the invasive fish rotan (*Perccottus glenii*) in the Holartic. *Biological Invasions* 13:2967-2980.

Rocke, T.E., N.J. Thomas, C.U. Meteyer, C.F. Quist, and J.R. Fischer. 2005. Attempts to identify the source of avian vacuolar myelinopathy for waterbirds. *J Wildl Dis* 41: 163–170.

Rothlisberger, J.D., W.L. Chadderton, J. McNulty, and D.M. Lodge. 2010. Aquatic invasive species transport via trailered boats: what is being moved, who is moving it, and what can be done. *Fisheries,* 35(3), 121-132.

Royle, J.A., R.B. Chandler, C. Yackulic, and J.D. Nichols. 2012. Likelihood analysis of species occurrence probability from presence-only data for modelling species distributions. *Methods in Ecology and Evolution* 3: 545–554.

Rybicki, N.B., and J.M. Landwehr. 2007. Long-term changes in abundance and diversity of macrophyte and waterfowl populations in an estuary with exotic macrophytes and improving water quality. *Limnology and Oceanography*, 52(3), 1195-1207.

Rybicki, N.B., H.L. Jenter, V. Carter, R.A. Baltzer, and M. Turtora. 1997. Observations of tidal flux between a submersed aquatic plant stand and the adjacent channel in the Potomac River near Washington, DC. *Limnology and Oceanography*, 42(2), 307-317.

Sault Ste. Marie Tribe of Chippewa Indians, Michigan. 2019. Available online at https://www.saulttribe.com/history-a-culture/story-of-our-people. Accessed January 7, 2019.

SePRO Corporation, Aquatic Control, Aquatic Weed Control, and ReMetrix. 2008. *Lake Manitou Aquatic Vegetation Management Plan Update, Fulton County, IN.* March 14, 2008. Available online at: https://collab.dnr.in.gov/connect.ti/LARE/view?objectId=8388261https://collab.dnr.in.gov/connect.ti/LARE/view?objectId=8388261. Accessed on January 11, 2019.

SePRO Corporation, Aquatic Control, Aquatic Weed Control, and ReMetrix. 2012. *2011 Lake Manitou Aquatic Vegetation Management Plan Update Fulton County, IN*. January 16, 2012.

SePRO Corporation, Aquatic Control, Aquatic Weed Control, and ReMetrix. 2015. "2014 Lake Manitou Aquatic Vegetation Management Plan Update: Fulton County, IN." Available online at http://www.in.gov/dnr/fish-wild/files/fw-1150_Lake_Manitou_AVMP_2014_Update_Fulton_County_Feb_2015.pdf Accessed on June 16, 2017.

SePRO Corporation, Aquatic Control, Aquatic Weed Control, and ReMetrix. 2016. *2016 Lake Manitou Aquatic Vegetation Management Plan Update Fulton County, IN*. December 19, 2016.

Searcy, Howard L. 1994. Regulation Schedule Modification Study: Lake Istokpoga, Florida, U.S. Army Corps of Engineers. August 1994.

Shearer, J.F. 2014. *Surveys for Pathogens of Monoecious Hydrilla*, APCRP Technical Notes Collection, ERDC/TN APCRP-BC-31, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Sokaogon Chippewa Community. 2019. History: Sokaogon Chippewa Community. Available online at http://sokaogonchippewa.com/about-us/history/. Accessed January 7, 2019.

Solitude Lake Management. 2016. "Contract Documents for the Tonawanda Creek Hydrilla Abatement Program for 2016."

Soto, S. 2017. *Hydrilla verticillata biotype alters spatial distribution model prediction*, Master of Science Thesis, Department of Natural Resources Management, Texas Tech University, Lubbock, TX.

Spencer, D.F., G.G. Ksander, and S.R. Bissell. 1992. Growth of Monoecious Hydrilla on Different Soils Amended with Peat or Barley Straw. *Journal of Aquatic Plant Management* 10, 73-78.

State of Washington Department of Ecology. 2015. "Non-native Invasive Freshwater Plants, Hydrilla [no date]." Accessed online at: http://www.ecy.wa.gov/programs/wq/plants/weeds/aqua001.html. Accessed on April 27, 2015.

Suedel, B.C, T.S. Bridges, J. Kim, B.S. Payne, and A.C. Miller. 2007. Application of Risk Assessment and Decision Analysis to Aquatic Nuisance Species, *Integrated Environmental Assessment and Management* 3:79–89.

Sullivan, Glen. 2017. Personal communication. Solitude Lake Management with K. Evans, Ecology and Environment, Inc. dated June 6, 2017.

Svenning, J.C. and B. Sandel. 2013. Disequilibrium vegetation dynamics under future climate change. *American Journal of Botany* 100: 1266–1286.

Thomas, N.J., C.U. Meteyer, and L. Sileo. 1998. Epizootic vacuolar myelinopathy of the central nervous system of bald eagles *Haliaeetus leucocephalus* and American coots *Fulica americana*. *Veterinary Pathology* 35:479–487.

Thomaz, Sidinei M., Roger P. Mormul, and Thaisa S. Michelan. 2015. Propagule pressure, invasibility of freshwater ecosystems by macrophytes and their ecological impacts: A review of tropical freshwater ecosystems. *Hydrobiologia* 746, (1) (03): 39-59, Accessed online at: https://search.proquest.com/docview/1646554052?accountid=27106 (accessed August 30, 2017).

Thunberg, E.M., C.N. Pearson, and J.W. Milon. 1992. Residential flood control benefits of aquatic plant control. *Journal of Aquatic Plant Management*, 30: 66-70.

Tomczak, Dan. 2017. Senior Park Ranger/Manager, Bay County Pinconning Park, Michigan. Personal communication with K. Rabeler, Ecology and Environment, Inc., on November 14, 2017.

True-Meadows, S., E.J. Haug, R.J. Richardson. 2016. Monoecious Hydrilla – A Review of the Literature. *J. Aquat. Plant Manage*. 54: 1-11.

Turnley, Jessica Glicken, PhD. 2002. Social, Cultural, Economic Impact Assessments: A Literature Review. Prepared for The Office of Emergency and Remedial Response, U.S. Environmental Protection Agency. Submitted October 2002. Galisteo Consulting Group, Inc. Available online at https://www.nist.gov/sites/default/files/documents/2017/05/09/EPA_Social-Cultural-Economic-Impact-Assessments-2002.pdf. Accessed January 4, 2018.

U.S. Army Corps of Engineers (USACE). 2015. "Invasive Species Management, Hydrilla [no date]." Accessed online at: http://www.usace.army.mil/Missions/Environmental/InvasiveSpeciesManagement.aspx. Accessed on May 3, 2015.

USACE. 2008. "Great Lakes Recreational Boating." Available at http://www.lre.usace.army.mil/Portals/69/docs/PPPM/PlanningandStudies/JohnGlenn/boating.pdf Accessed on May 1, 2015.

USACE. 2012. *Treaty Rights and Subsistence Fishing in the U.S. Waters of the Great Lakes, Upper Mississippi River, and Ohio River Basins*. Great Lakes and Mississippi River Interbasin Study. June 2012. Available online at http://glmris.anl.gov/documents/docs/Subsistence_Fishing_Report.pdf. Website accessed December 28, 2017.

USACE. 2016. "Great Lakes Navigation Update: February 9, 2016." Available online at http://www.lre.usace.army.mil/Portals/69/docs/Navigation/STAKEHOLDERMTGS/1%20Strum%20Waterways%209%20Feb%202016.pdf Accessed on July 5, 2017.

USACE, Great Lakes Navigation System. 2017. "Great Lakes Navigation System: Fact Sheets (June 2017)." Available online at http://lre-ops.usace.army.mil/OandM/factsheets/GLNAV.pdf Accessed on July 6, 2017.

USACE, Navigation Data Center. 2016 "Dredging Information System – Dollars, Numbers of Contracts and Cubic Yards by Type of Material Disposal and Fiscal Year." Available online at http://www.navigationdatacenter.us/dredge/drgdisp.htm Accessed on May 31, 2017.

USACE Savannah District. 2016. Avian Vacuolar Myelinopathy (AVM) Plan for USACE, Savannah District J. Strom Thurmond Project. April 2016. http://www.sas.usace.army.mil/Portals/61/docs/lakes/thurmond/Avian_Vacuolar_Myelinopathy_Plan_Final.pdf?ver=2017-02-07-125149-900

U.S. Department of Agriculture. 2006. "Weed of the Week, Hydrilla." Accessed online at: http://www.na.fs.fed.us/fhp/invasive_plants/weeds/hydrilla.pdf. Accessed on May 3, 2015.

U.S. Department of Commerce. 1994. Guidelines and Principles For Social Impact Assessment. May 1994. Prepared by The Interorganizational Committee on Guidelines and Principles for Social Impact Assessment. Available online at http://www.nmfs.noaa.gov/sfa/social_impact_guide.htm. Website accessed January 4, 2018.

U.S. Department of the Interior. 2003. Invasive Exotic Plan Management Plan and Environmental Assessment, Rocky Mountain National Park. Prepared by the U.S. Department of the Interior, National Park Service, Rocky Mountain national Park, Colorado, August 2003. Available online at https://www.nps.gov/romo/learn/management/upload/exotic_plant_ea_final.pdf. Website accessed May 3, 2017.

U.S. Environmental Protection Agency (USEPA). 1997. *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments,* Interim Final, Environmental Response Team, Edison, N.J.

USEPA. 1998. *Guidelines for Ecological Risk Assessment*. Risk Assessment Forum, USEPA, Washington, D.C., EPA/630/R-95/002F.

USEPA. 2012. Water: Monitoring & Assessment, Dissolved Oxygen and Biochemical Oxygen Demand. Accessed online at: http://water.epa.gov/type/rsl/monitoring/vms52.cfm. Accessed on June, 18, 2015.

USEPA. 2014. SDWISFED Drinking Water Data. "Public Water System Inventory Data from SDWIS October 2013." Available at http://water.epa.gov/scitech/datait/databases/drink/sdwisfed/pivottables.cfm#details Accessed on May 11, 2014.

USEPA. 2017. "BEACON – Beach Advisory and Closing On-line Notification." Available at https://ofmpub.epa.gov/apex/beacon2/f?p=BEACON2:12:::NO::P12_YEARS:Current Accessed on August 31, 2017.

U.S. Fish and Wildlife Service (USFWS). 2014a. 2011 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation: United States. Available online at https://www.census.gov/prod/2012pubs/fhw11-nat.pdf Accessed on July 18, 2017.

USFWS. 2014b. *2011 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation: New York State.* Available online at https://www.census.gov/prod/2013pubs/fhw11-ny.pdf Accessed on May 12, 2017.

USFWS. 2014c. *2011 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation: Commonwealth of Pennsylvania.* Available online at https://www.census.gov/prod/2013pubs/fhw11-pa.pdf Accessed on July 17, 2017.

USFWS. 2014d. *2011 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation: State of Ohio.* Available online at https://www.census.gov/prod/2013pubs/fhw11-oh.pdf Accessed on July 18, 2017.

USFWS. 2014e. *2011 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation: State of Michigan.* Available online at https://www.census.gov/prod/2013pubs/fhw11-mi.pdf Accessed on July 17, 2017.

USFWS. 2014f. *2011 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation: State of Illinois.* Available online at https://www.census.gov/prod/2013pubs/fhw11-il.pdf Accessed on July 17, 2017.

USFWS. 2014g. *2011 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation: State of Minnesota.* Available online at https://www.census.gov/prod/2013pubs/fhw11-mn.pdf Accessed on July 17, 2017.

USFWS. 2014h. *2011 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation: State of Wisconsin.* Available online at https://www.census.gov/prod/2013pubs/fhw11-wi.pdf Accessed on July 17, 2017.

USFWS. 2014i. *2011 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation: State of Indiana.* Available online at https://www.census.gov/prod/2013pubs/fhw11-in.pdf Accessed on July 18, 2017.

USFWS. 2017. FWSInterest [GIS data]. April 2017. Accessed online at: https://www.fws.gov/GIS/data/CadastralDB/index_cadastral.html?q=Realty&sort=none&metadata_type=geospatial&organization=fws-gov&ext_location=&ext_bbox=&ext_prev_extent=-142.03125,8.754794702435605,-59.0625,61.77312286453148#sec-tags. Accessed June 2017.

U.S. Geological Survey, Water Resources Discipline (USGS, WRD), Environment Canada Canadian Wildlife Service-Ontario Region (EC,CWS-OR), Michigan Natural Features Inventory (MNFI) and Ontario Ministry of Natural Resources (OMNR). November 2004. Great Lakes Coastal Wetland Inventory [GIS data]. http://gis.glin.net/ogc/services.php#great_lakes_coastal_wetlands. Accessed online from: https://databasin.org/. Accessed June 2017.

United States Geological Survey (USGS). 2016. *Hydrilla verticillata* distribution by drainage and biotype (October 2016), available at: https://nas.er.usgs.gov/taxgroup/plants/.

U.S. National Park Service. 2015. National NAGPRA Online Databases: Native American Consultation Database (New York, Pennsylvania, Ohio, Michigan, Indiana, Illinois, Wisconsin, and Minnesota). Available online at http://grantsdev.cr.nps.gov/Nagpra/NACD/. Website accessed December 2, 2105.

U.S. National Park Service. 2017. National NAGPRA: Indian Land Areas Judicially Established 1978. Available online at https://www.nps.gov/nagpra/DOCUMENTS/ClaimsMAP.htm. Website accessed December 28, 2017.

University of Florida. 2011. "Plant Management in Florida Waters: Flood Control." Accessed online at: http://plants.ifas.ufl.edu/manage/overviewoffloridawaters/usesandfunctions/floodcontrol. Accessed July 7, 2015.

Van, T.K., W.T. Haller, G. Bowes. 1976. Comparison of the Photosynthetic Characteristics of Three Submersed Aquatic Plants. *Plant Physiol*. 58: 761-768.

Vertuno, Jim. 2003. "Hydrilla Creeps up on Lake Austin." *Laredo Morning Times*. Laredo, TX. Accessed online at: http://airwolf.lmtonline.com/news/archive/010603/pagea6.pdf. Accessed March 25, 2015.

Warman, Mark. 2017. Hydrilla Project Coordinator, Cleveland Metroparks. Meeting with K. Evans, Ecology and Environment, Inc., on April 13, 2017.

Watkins, C.E., J.V. Shireman, and W.T. Haller. 1983. The influence of aquatic vegetation upon zooplankton and benthic macroinvertebrates in Orange Lake, Florida. *Journal of Aquatic Plant Management*, 21(2), 78-83.

Wayman, Mike. 2017. Personal communication. Commissioner, Ashtabula Township Park Commission, Ashtabula, Ohio, email to K. Rabeler, Ecology and Environment, Inc. on November 16, 2017.

Weed Science Society of America. 2009. Preventing hurricane havoc [Press release]. Accessed online at: http://wssa.net/2009/09/preventing-hurricane-havoc/. Accessed September 22, 2017.

Weldon, C. 2017. 2017 Cleveland Metroparks Hydrilla Report. Cleveland Metroparks Technical Report 2017/NR-01. Division of Natural Resources, Cleveland Metroparks, Cleveland, Ohio.

White Earth Nation. 2019. History of White Earth. Available online at http://whiteearth.com/history.html. Accessed January 21, 2019.

Wittmann, M.E., G. Annis, A.M. Kramer, L. Mason, C. Riseng, E.S. Rutherford, W.L. Chadderton, D. Beletsky, J.M. Drake, and D.M. Lodge. 2017. Refining Species Distribution Model Outputs Using Landscape-Scale Habitat Data: Forecasting Grass Carp and Hydrilla Establishment in the Great Lakes Region. *J. Great Lakes Res.* 43: 298-307.

Wittmann, M.E., M.A. Barnes, C.L. Jerde, Jones L.A., and Lodge DM. 2016. Confronting species distribution model predictions with species functional traits. *Ecology and Evolution* 6: 873-880.

Wilde, S.B., J.R. Johansen, H.D. Wilde, P. Jiang, B.A. Bartelme, and R.S. Haynie. 2014. *Aetokthonos hydrillicola* gen. et sp. nov.: epiphytic cyanobacteria on invasive aquatic plants implicated in Avian Vacuolar Myelinopathy. *Phytotaxa* 181(5): 243-260, 7 fig., 4 tables.

Williams, S.K., J. Kempton, S.B. Wilde, and A. Lewitus. 2007. A novel epiphytic cyanobacterium associated with reservoirs affected by avian vacuolar myelinopathy. *Harmful Algae* 6: 343–353

Wood, J.D. 2017. Biology and Management of Monoecious Hydrilla, Master of Science Thesis, University of Florida.

WorldClim. 2016. WorldClim - Global Climate Data. Accessed online at: http://www.worldclim.org/.

Wruble, Ron. 2017. City Director, Harbor Beach, Michigan. Personal communication with K. Rabeler, Ecology and Environment, Inc., on November 22, 2017.

Yackulic, C.B., R. Chandler, E.F. Zipkin, J.A. Royle, J.D. Nichols, E.H. C. Grant, and S. Veran. 2012. Presence-only modelling using MAXENT: when can we trust the inferences? *Methods in Ecology and Evolution* 4: 236–243.

Zhang, T. -t, M. He, A. -p Wu, and L. -w Nie. 2012. Inhibitory effects and mechanisms of hydrilla verticillata (linn.f.) royle extracts on freshwater algae. *Bulletin of environmental contamination and toxicology* 88, (3) (03): 477-81, Accessed online at: http://search.proquest.com/docview/921046419?accountid=27106 (accessed June 9, 2015).

Zhu, J., X. Xu, Q. Tao, P. Yi, D. Yu, and X. Xu. 2017. High Invasion Potential of *Hydrilla verticillata* in the Americas Predicted Using Ecological Niche Modeling Combined with Genetic Data. *Ecology and Evolution* 7:4982-4990.