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Great Lakes Hydrilla
Risk Assessment

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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, socio-cultural, 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.

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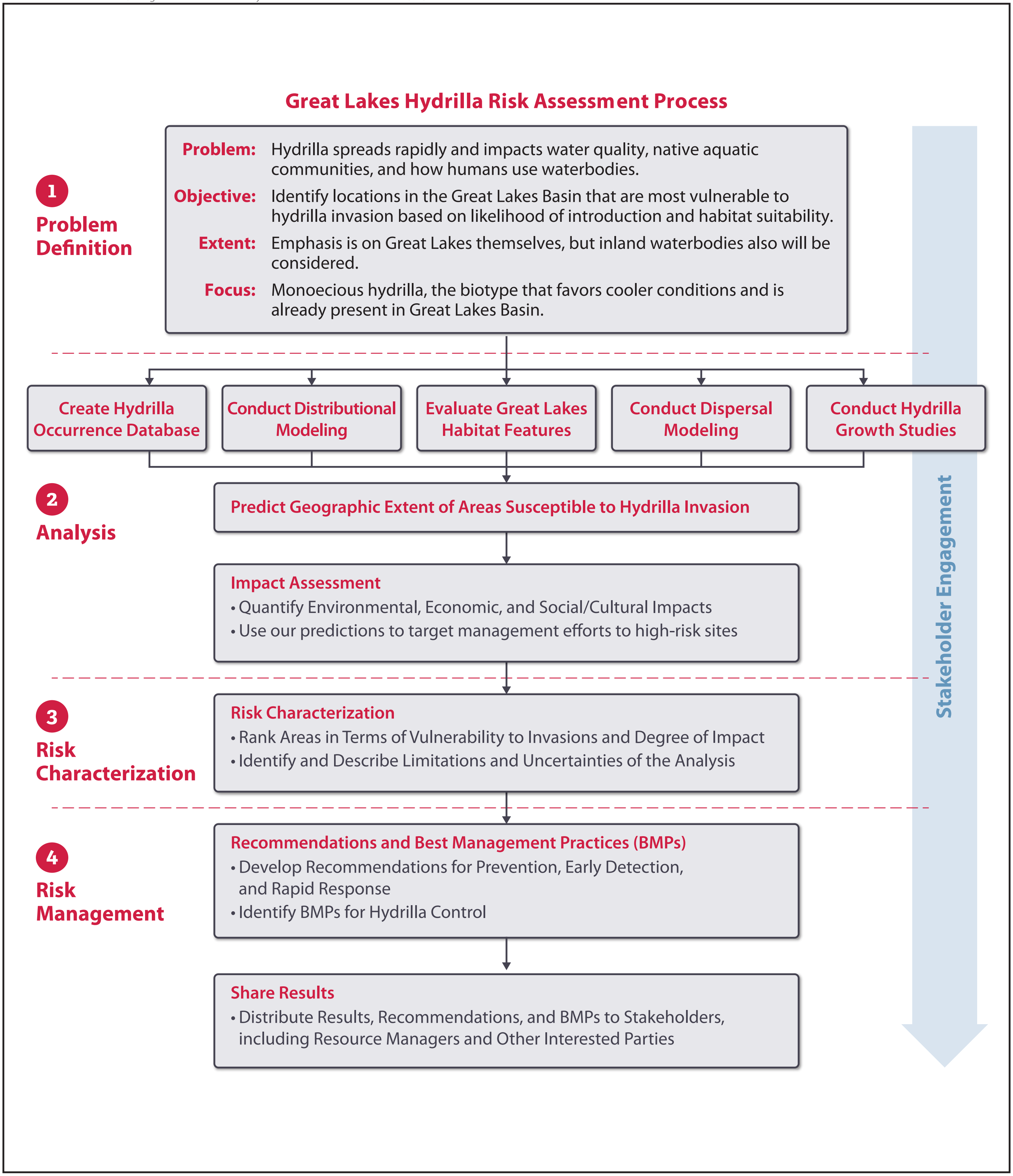

Figure SR-1 Great Lakes Hydrilla Risk Assessment Process

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.

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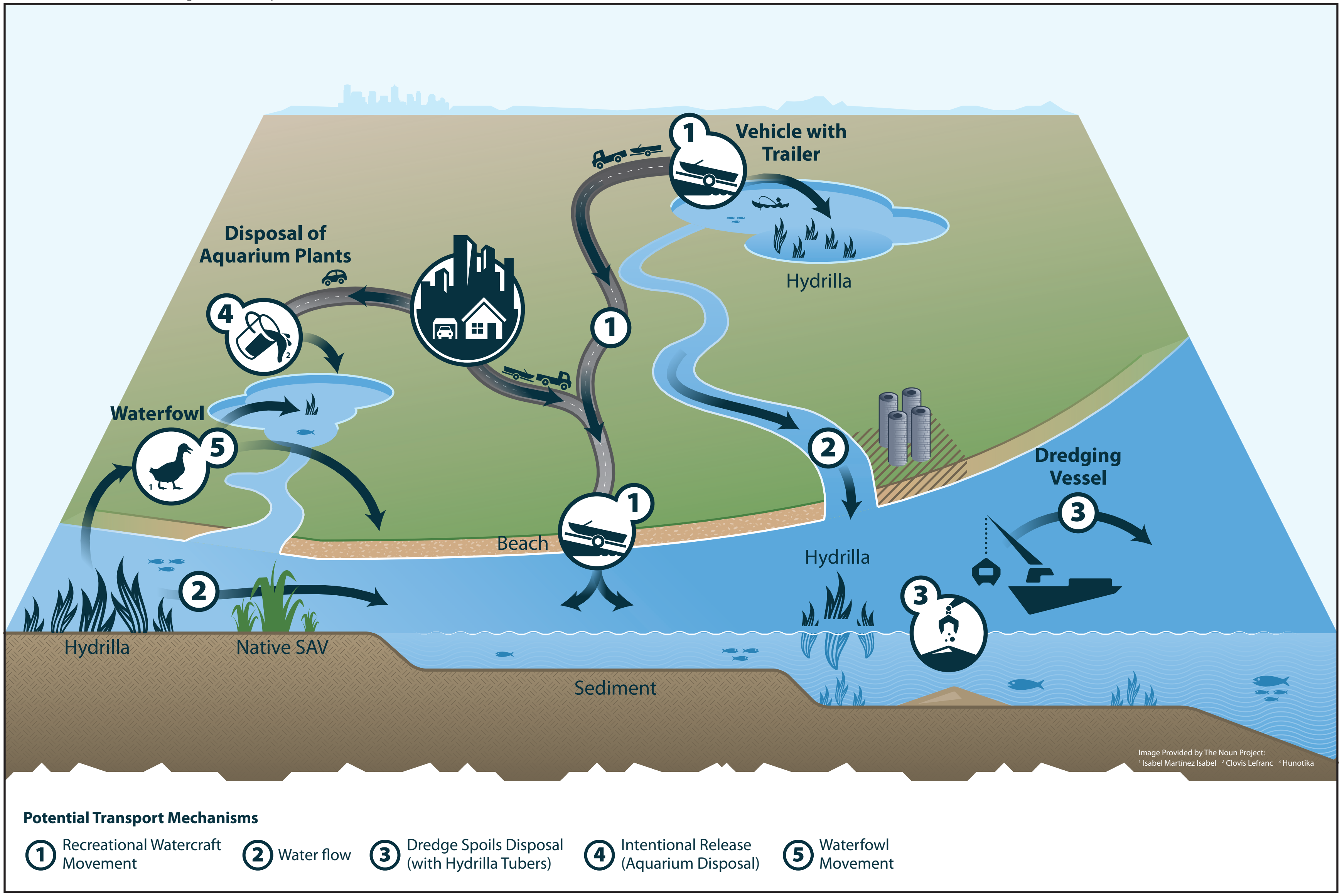

Figure SR-2 Conceptual Model Illustrating Potential Means of Hydrilla Movement in a Typical Great Lakes Environment

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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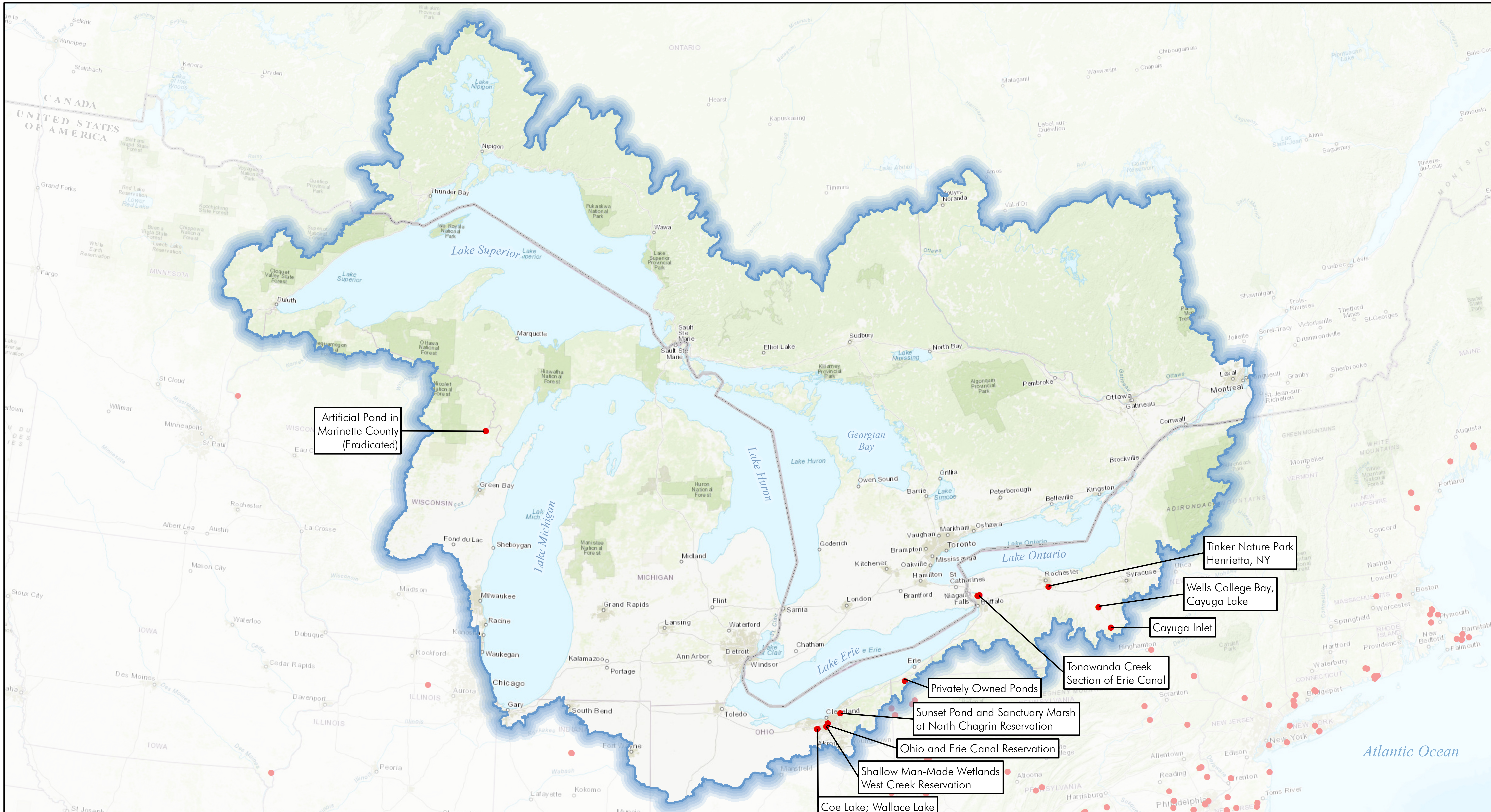

KEY:

- 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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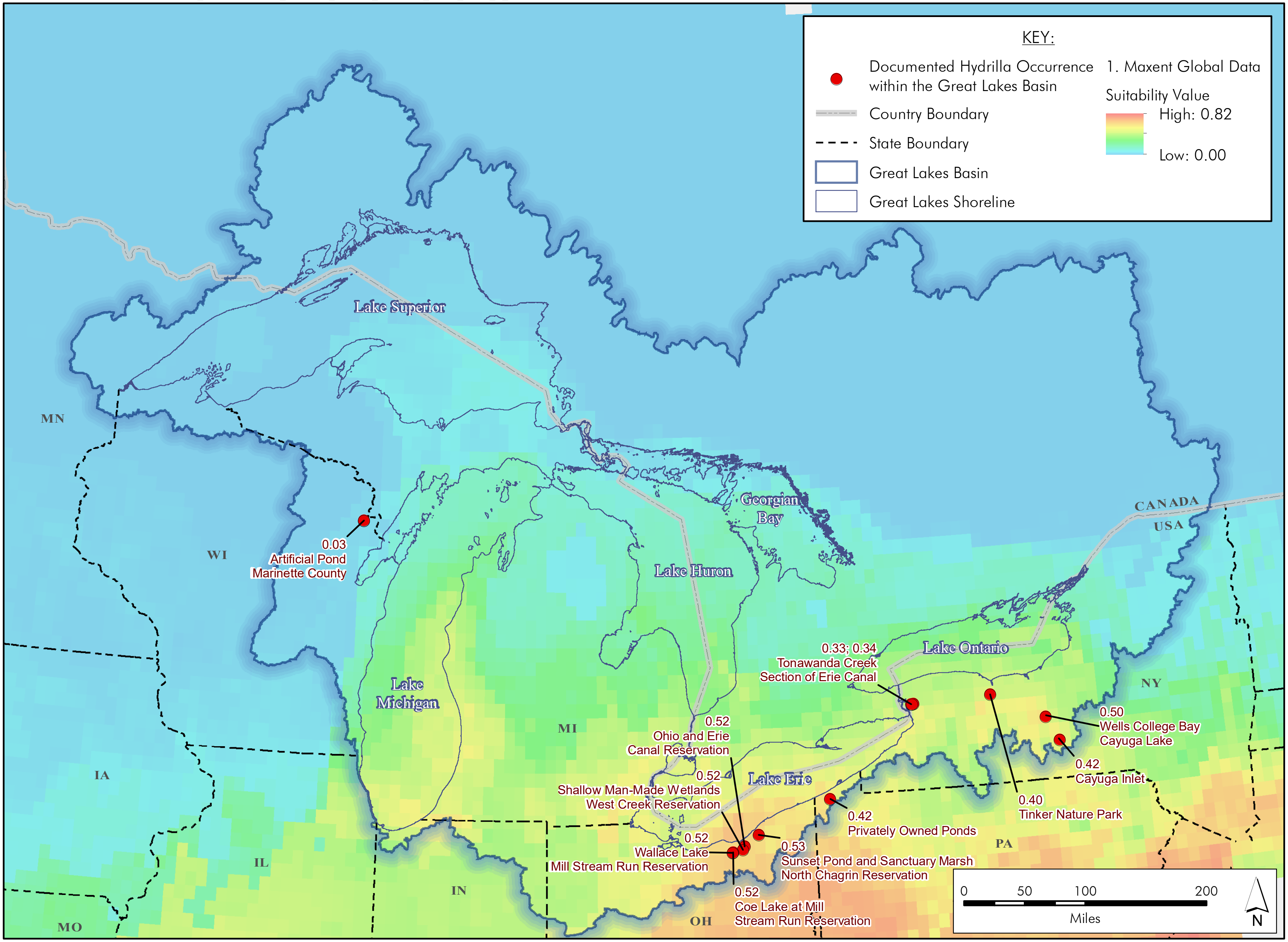
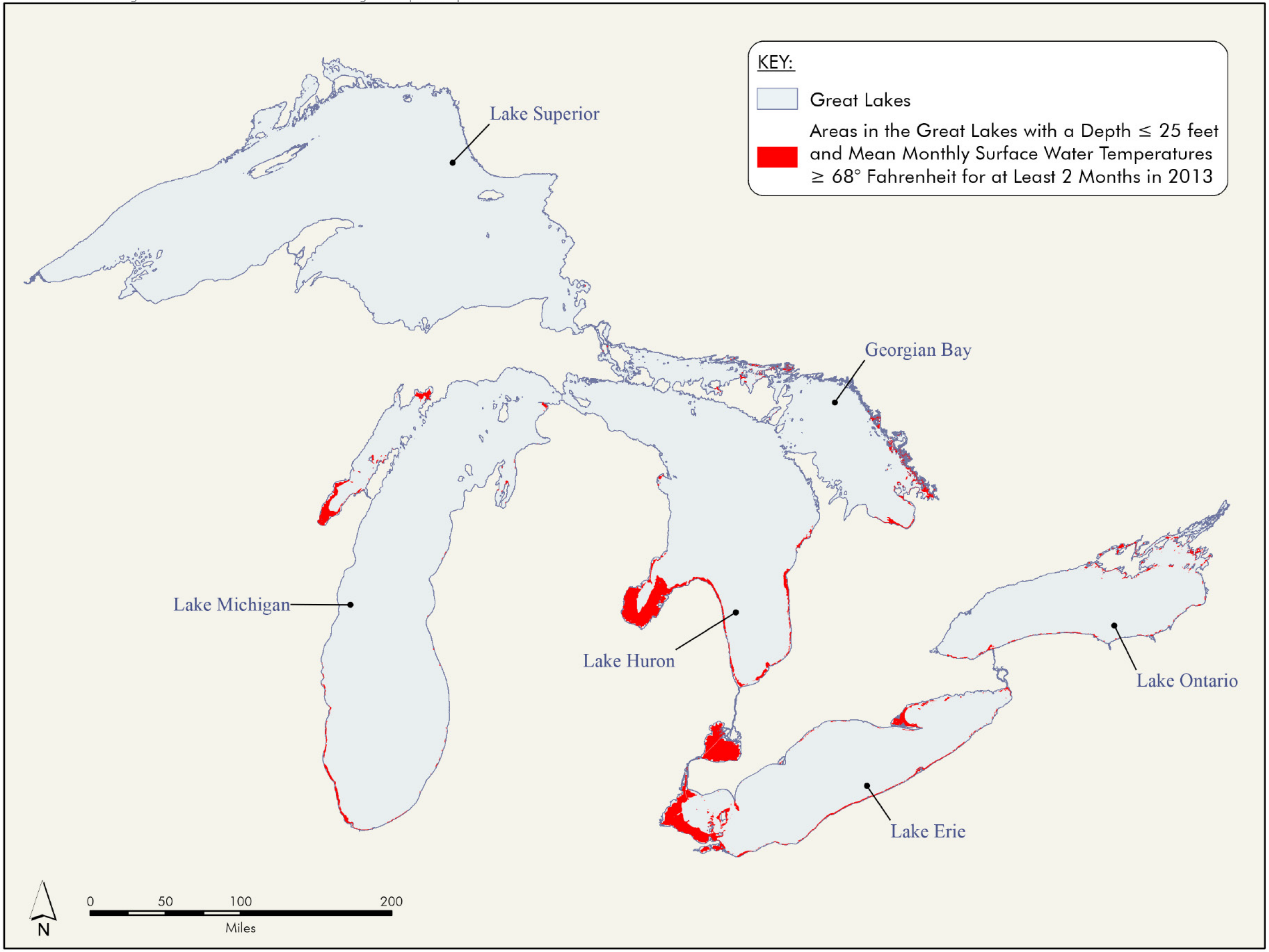


Figure SR-4 Maxent Global Model Output Zoomed to Extent of Great Lakes Basin

Occurrences as of 2/26/2016



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

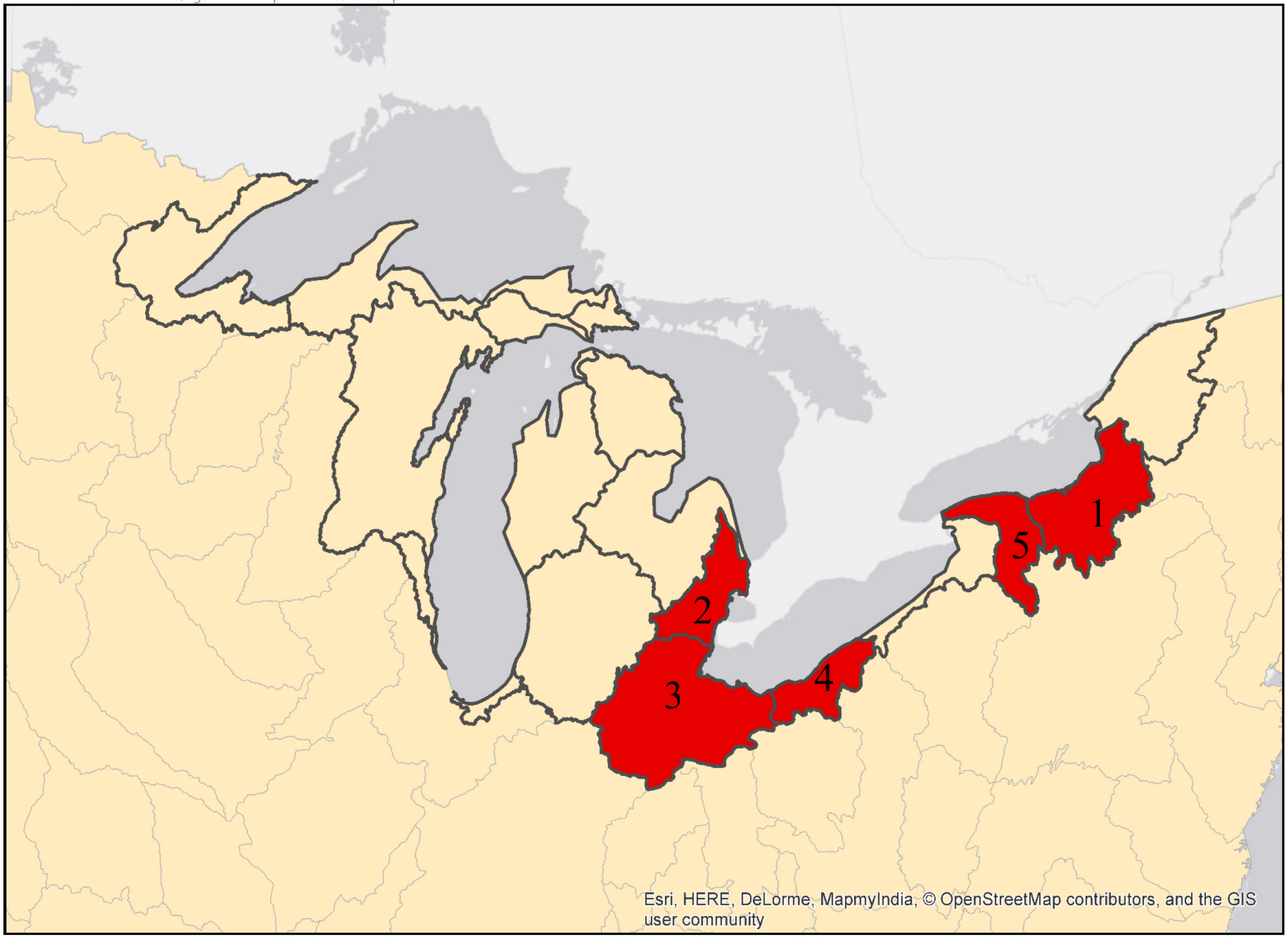


Figure SR-6 Top Five Watersheds in Great Lakes Basin Predicted by Modeling to Have the Greatest Future Proportion of Hydrilla-Infested Waterbody Area: Southeastern Lake Ontario (1), St. Clair-Detroit (2), Western Lake Erie (3), Southern Lake Erie (4), and Southwestern Lake Ontario (5)

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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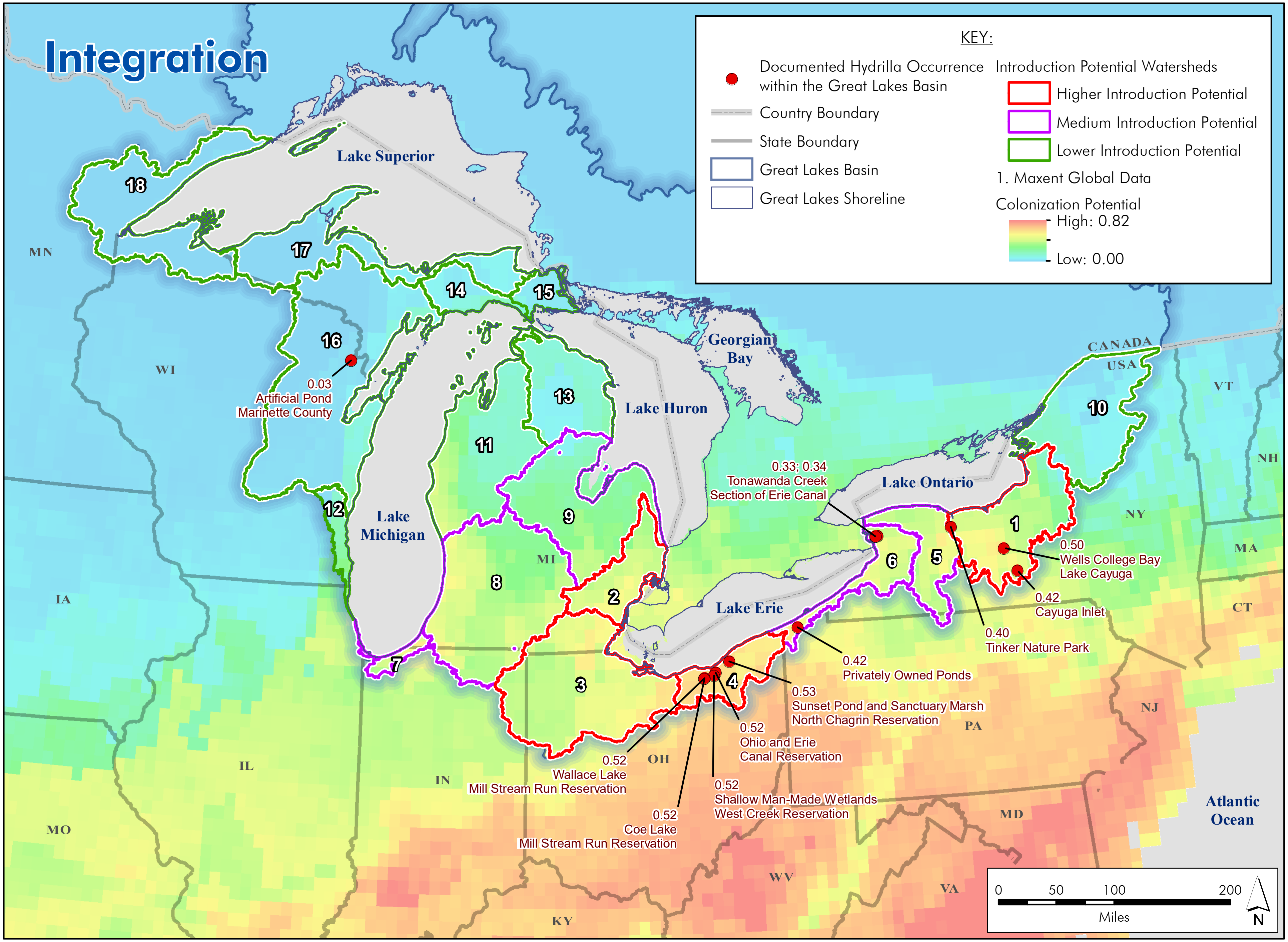

Figure SR-7 Integration of Maxent Model Results, Water-Depth and Water-Temperature Requirements, and Dispersal Model Results for Hydrilla

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).