



Voyageurs National Park Interior Lakes Status and Impact Assessment

Natural Resource Report NPS/VOYA/NRR—2022/2351



ON THE COVER

Shoepack Lake.

NPS photo

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Contents

	Page
Figures.....	v
Tables.....	vii
Appendices.....	vii
Abstract.....	ix
Acknowledgments.....	xi
Introduction.....	1
Methods.....	5
Data Preparation and Lake Scoring.....	5
Scoring Strategies and Generation of Combined Scores.....	5
Water Quality	5
Mercury	5
Fish	6
Generation of Combined Scores and Assignment of Lakes to Impact Categories.....	6
Results.....	7
Overall	7
Water Quality	8
Mercury	10
Fish	12
Summary.....	14
Discussion	17
Water Quality	17
Mercury	18
Fish	19
Lake Trout	19
Smallmouth Bass.....	20
Northern Pike.....	20

Contents (continued)

	Page
General Management Recommendations	20
Literature Cited	23

Figures

	Page
Figure 1. Voyageurs National Park in northern Minnesota (<i>inset map</i>) includes all or part of four large lakes: Rainy, Kabetogama, Namakan, and Sand Point.	1
Figure 2. Overall impact assessments for interior lakes at Voyageurs National Park based on assessments of combined scores for water quality, mercury, and fish.....	7
Figure 3. Level of impact to interior lakes at Voyageurs National Park based on water quality data analysis.	9
Figure 4. Level of impact to interior lakes at Voyageurs National Park based on mercury data analysis.	11
Figure 5. Level of impact to interior lakes at Voyageurs National Park based on analysis of fish data.....	13
Figure A3-1. A screenshot example of the scoring sheet completed by NPS and Minnesota Department of Natural Resources reviewers to assess water quality, mercury, and fish conditions in lakes at Voyageurs National Park.....	38

Tables

	Page
Table 1. Average scores for three factors (water quality, mercury, and fish) assessed for the interior lakes at Voyageurs National Park.....	8
Table 2. Water quality scores for interior lakes at Voyageurs National Park.	9
Table 3. Mercury scores for interior lakes at Voyageurs National Park. Combined average is the average of the NPS scores and MNDNR scores.	11
Table 4. Fish scores for interior lakes at Voyageurs National Park.	13
Table 5. “Most impacted” interior lakes at Voyageurs National Park.	14
Table 6. Average scores for each of three factors assessed for the interior lakes at Voyageurs National Park: water quality, mercury, and fish. Combined average score also shown for each lake.....	15
Table A2-1. Calculated water quality averages and standard errors.	34
Table A3-1. Average concentrations of sulfate and pH in lakes at Voyageurs National Park, and estimated mercury concentrations in standard-size Northern Pike based on Knights et al. (2005) compared to actual concentrations based on fish collected and measured from each lake.....	36

Appendices

	Page
Appendix 1. Interior Lake Assessment Factors, Datasets, and Scoring Strategy	29
Appendix 2. Water Quality Reference Criteria and Standards for Scoring VOYA Interior Lakes	33
Appendix 3. Mercury Standards for Comparison to VOYA Interior Lake Data.	35

Abstract

Voyageurs National Park (VNP) is a water-based park that includes part or all of four large lakes and twenty-six smaller lakes commonly referred to as “interior lakes”. The 26 interior lakes of VNP are important aquatic resources with differing size and depth, water chemistry, trophic status, fish communities, and visitor use. Despite the remote location of these lakes, they have been impacted by multiple stressors, including contaminants and non-native species. This assessment provides key information in support of a science-based management plan for these lakes. The objectives of this assessment were to: 1) assess the status of each of the interior lakes and categorically rank the lakes from least to most impacted; 2) use the results to make specific science-based management and restoration recommendations for the most impacted lakes; and 3) make general recommendations that may be useful in managing all of Voyageurs National Park’s interior lakes.

When all factors considered in this analysis (water quality, fish mercury concentrations, and fish community characteristics) were combined and assessed, thirteen lakes were classified as *most impacted*, nine as *moderately impacted*, and three as *least impacted*. Although nearly half of the lakes were classified as most impacted in this assessment, many of these lakes are in excellent condition compared to other lakes in the region. The factor-by-factor impact status of the lakes was considered to help describe the condition of the lakes and the potential for restoration. No local management options were identified to mitigate the mercury contamination in these lakes as research has shown the sources of the contamination to arrive from regional and global sources. Similarly, no management actions were identified to reduce nutrient concentrations in the lakes ranked most impacted for nutrient conditions as these are remote lakes with minimal or no development within their watersheds, and it was also noted that paleolimnological studies have shown that the nutrient status of the interior lakes was relatively unchanged from pre-European settlement conditions. Finally, for the lakes in which presumed introduced fish species are present, piscicides were considered as a potential management action. Piscicides were not recommended as a strategy to eradicate introduced fish species as it was determined that genetic conservation of the populations of native fish species still present in these lakes was more valuable than eradicating the introduced species.

The following general recommendations were made for management of these lakes to best maintain them in an unimpaired condition.

1. Continue to monitor water quality, fish assemblages, and mercury in the interior lakes of Voyageurs National Park. This monitoring provides baseline information necessary for maintaining resources in an unimpaired condition.
2. Make the current regulations and Best Management Practices (BMPs) for preventing introduction of aquatic invasive species (AIS) and fish diseases into the interior lakes permanent. The current regulations and BMPs protect the interior lakes from multiple invasion vectors and provide additional time for scientists to develop technologies for elimination or control for AIS and fish diseases.

3. Require visitors to watch a training video and to acknowledge having watched and understood the video before being issued a camping permit or boat reservation. The video should focus on Voyageurs National Park's regulations and BMPs for preventing the spread of AIS and fish diseases and on the ecological repercussions of failing to follow the regulations and BMPs.
4. Continue to provide vessels for rent on some interior lakes. The rental system is straightforward and easy to monitor. Maintaining the current vessel rental program and adding additional vessels to that program, as appropriate, is the most reasonable option for preventing the spread of AIS and fish diseases while still allowing visitors to boat on some interior lakes of Voyageurs National Park.

Acknowledgments

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Introduction

Voyageurs National Park (VNP) was established to protect “the outstanding scenery, geological conditions, and waterway system which constituted a part of the historic route of the Voyageurs” (Public Law 91-661). Voyageurs National Park is a water-based park in northern Minnesota, encompassing part or all of four large lakes and twenty-six smaller lakes commonly referred to as “interior lakes” (Figure 1). Voyageurs is one of only two U.S. national parks to protect a series of southern boreal lakes on the Precambrian Shield and its lakes are recognized by the State of Minnesota as “Outstanding Resource Value Waters.” The 26 interior lakes of VNP are important aquatic resources, and they span gradients of size and depth, water chemistry, trophic status, fish communities, and visitor use (Kallemeyn et al. 2003). Voyageurs National Park co-manages the fisheries in these lakes with the Minnesota Department of Natural Resources (MNDNR).

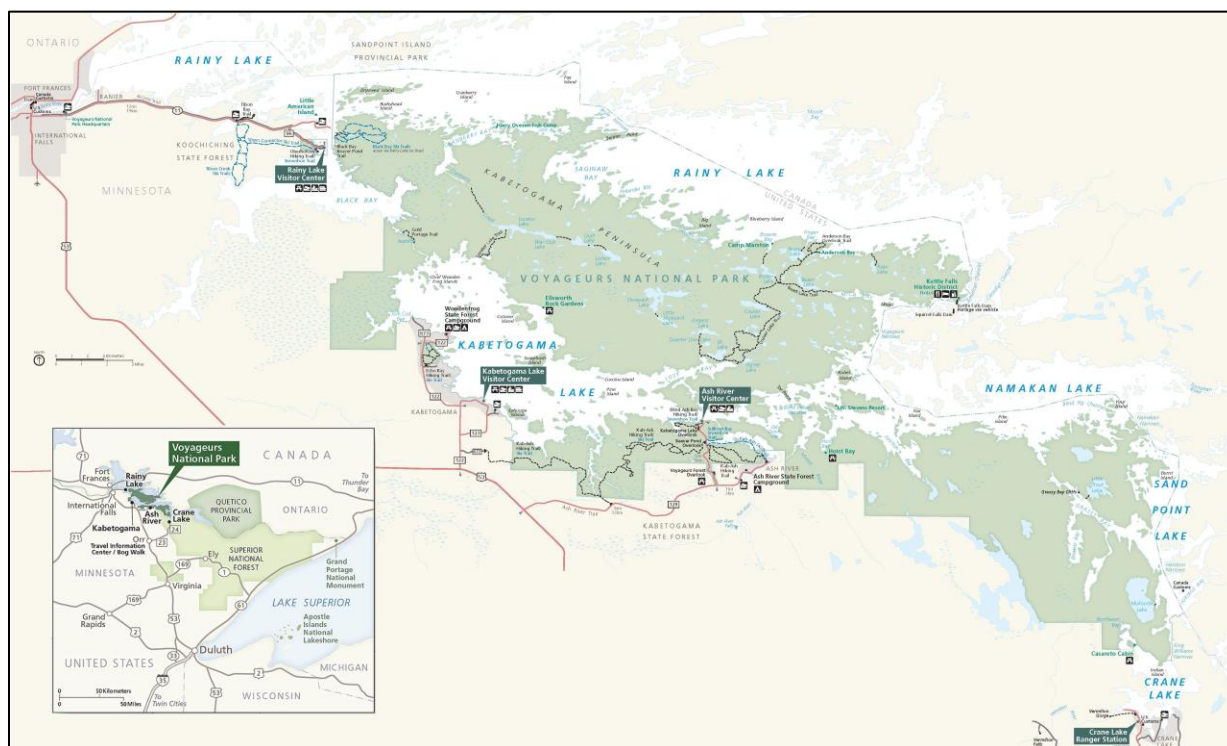


Figure 1. Voyageurs National Park in northern Minnesota (*inset map*) includes all or part of four large lakes: Rainy, Kabetogama, Namakan, and Sand Point. Twenty-six smaller lakes within the park boundaries are referred to as “interior lakes”.

Despite the semi-remote location and seemingly pristine condition of the park, the interior lakes have been impacted in a variety of ways. The mercury concentrations of Northern Pike (*Esox lucius*) in multiple interior lakes exceed the U.S. Environmental Protection Agency criterion established for protecting the health of people who eat fish (Knights et al. 2005), and two of the lakes contain fish with some of the highest concentrations of mercury in the state (Kallemeyn et al. 2003). Survey data indicate that Lake Trout (*Salvelinus namaycush*) populations have decreased in Little Trout and

Mukooda lakes (Minnesota Department of Natural Resources 2020a). Additionally, two lakes were treated with piscicides prior to VNP establishment (Minnesota Department of Natural Resources 2020b), and some lakes are now home to native and non-native fish assemblages inconsistent with historical assemblages (Kallemeyn et al. 2003; Minnesota Department of Natural Resources unpublished fish stocking records, International Falls, Minnesota).

The interior lakes are in need of a science-based management plan to address known stressors and VNP's goal of preserving "... for the inspiration and enjoyment of present and future generations, that outstanding scenery, geological conditions, and water system which constituted a part of that historic route of the Voyageurs who contributed significantly to the opening of the Northwestern United States" (Voyageurs National Park Enabling Legislation, 8 January 1971; NPS 2016). Lake management plans developed by the Minnesota Department of Natural Resources (MNDNR) with input from Voyageurs National Park focus specifically on fisheries. Otherwise, there are only a few park regulations (NPS 2020a) and Best Management Practices (NPS 2020b) in place for the interior lakes that focus on aquatic invasive species. They are as follows:

Regulations to Protect the Interior Lakes from Exotic Species and Fish Diseases:

- Artificial bait only (on all interior lakes, does not include Rainy Lake, Kabetogama Lake, Namakan Lake, or Sand Point Lake)
- No privately-owned watercraft allowed in interior lakes (the park will continue to provide canoes and row boats for rent through the Boats on Interior Lakes Program (BOIL) and Commercial Use Authorizations on Mukooda lake)
- No float plane landings on interior lakes

Best Management Practices for Using Interior Lakes:

- Bring a separate set of gear that is likely to contact lake water (including fishing gear) to use on the interior lakes, or before using any gear on an interior lake, make sure that all gear has been thoroughly dried for at least 5 days or washed with hot water (>140°F) for at least one minute
- When leaving any lake, remove sediment, aquatic plants and animals, and any material that looks gelatinous or like cotton batting from equipment, including fishing line.

To support a comprehensive and science-based management plan, it was necessary to first develop a synthesis and analysis of existing data. To provide the data synthesis, LeDuc and Maki (2020) consolidated interior lake data and developed an annotated bibliography.

This assessment served as the next step toward development of a management plan. The objectives of the assessment were to: 1) assess the status and impact of each interior lake and categorically rank the lakes from least to most impacted; 2) use the results to make specific science-based management and restoration recommendations for the most impacted lakes; and 3) make general recommendations that may be useful in managing all of Voyageurs National Park's interior lakes. This project was

accomplished by National Park Service (NPS) and MNDNR biologists and ecologists who routinely work with the lakes of this region.

Methods

Data Preparation and Lake Scoring

The annotated bibliography (LeDuc and Maki 2020) resulted in identification of three factors with full datasets for 25 study lakes: water quality, mercury contamination of fish, and fish community characteristics. Paleolimnology research results and toxaphene (piscicide) treatment history of the lakes were also considered, but those data were only available for a subset of the study lakes and were, therefore, excluded from the assessment. For the mercury factor, lakes were ranked based on mercury tissue data from top predator fish species. For the fish community characteristics factor, lakes were ranked based on number of introduced species, presence of stocked species, and species or communities of high conservation value, including genetically distinct strains. Data for some variables were not available for Wiyapka Lake, so Wiyapka was excluded from the study. This left 25 study lakes with complete datasets.

The project team who scored the lakes consisted of eight biologists and ecologists from the NPS and MNDNR with a variety of specialties within aquatic science. Each scorer was given datasets and information (Appendix 1) for each factor and asked to use that material in scoring every lake on a scale of 1 to 5, with 1 being the *most impacted* and 5 being the *least impacted*.

Scoring Strategies and Generation of Combined Scores

See Appendix 1 for full strategies.

Water Quality

For the water quality factor, the status of water quality conditions relative to existing water quality criteria was assessed. Lakes were assigned a score from 1 (not consistent with reference criteria or standards) to 5 (consistent with reference criteria or standards). The water quality dataset was prepared based on NPS Great Lakes Inventory and Monitoring Network (GLKN) monitoring data from 2006 through 2012 (many lakes had 2006 data only), except for Lucille, McDevitt, and Weir lakes, the data for which were from 2007 and were collected by other NPS staff. Scorers were given a matrix with calculated water quality means and standard errors where possible (Appendix 2, Table A2-1). The variables included were chlorophyll-*a*, total nitrogen, pH, Secchi depth, and total phosphorus. Scorers were also given water quality standards (Appendix 2), EPA Reference Criteria, and the values provided by Herlihy et al. (2013) to evaluate the dataset and formulate a score for each lake. Since all or nearly all study lakes met both Minnesota Pollution Control Agency eutrophication standards (Minnesota Pollution Control Agency 2008, 2014) and the EPA pH standard for protection of aquatic life (USEPA 1986), these standards were not used in this assessment.

Mercury

For the mercury factor, mercury concentrations in fish were assessed rather than mercury concentrations in water since the United States EPA has established standards for mercury concentrations in fish but not for mercury concentrations in water (Borum et al. 2001). Northern Pike (*Esox lucius*) mercury concentration data from Knights et al. (2005), Wiener et al. (2016), and the Minnesota Department of Health (unpublished data) were compiled for 17 of the interior lakes. Mercury data from other top predator fish were used for five lakes: Muskellunge (*Esox*

masquinongy) data were used for Shoepack and Little Shoepack lakes; Largemouth Bass (*Micropterus salmoides*) data were used for Loiten and Quill lakes; and Lake Trout (*Salvelinus namaycush*) data were used for Cruiser Lake (Voyageurs National Park, unpublished data). For the remaining three lakes, an equation developed by Knights et al. (2005) for estimating Northern Pike mercury concentrations was used incorporating the best available water quality data (the equation predicts mercury concentration in Northern Pike 55 cm in length):

$$\begin{aligned} \text{Northern Pike mercury (mg/g, ww)} \\ = (\text{dissolved sulfate} \times 383.35147) - (757.53686 \times \text{pH}) + 5219.6531 \end{aligned}$$

Sulfate and pH data used in the equation were obtained from the U.S. Geological Survey (USGS National Water Information System 1983), Michigan Technological University (unpublished data, 1984–1985), and GLKN (Elias and Damstra 2011, 2012). For quality assurance, the Knights et al. (2005) equation was used to calculate Northern Pike mercury concentrations for 17 lakes with measured Northern Pike mercury values and the calculated values were compared to measured fish mercury data (Appendix 3). Scorers were asked to use the United States EPA standards for methylmercury in fish for human consumption (Borum et al. 2001) and the thresholds for fish health effects from Sandheinrich and Wiener (2011) to formulate a score for each lake.

Fish

Fish community data were compiled and divided into four sub-categories: 1) assessment of likely introduced species for each lake, 2) stocking history of each lake (including whether non-native stocked species persist), 3) genetic information (Muskellunge in Shoepack and Lake Trout in Mukooda and Little Trout are genetically distinct, native species), and 4) species or communities of high conservation value based on heritage community summary information (Gorman et al. 2014). Gorman et al. (2014) defined heritage communities as communities that contain species that likely colonized inland lakes during the early Holocene and/or have limited distributions. Scorers were instructed to use a combination of all sub-categories to generate a score for each lake.

Generation of Combined Scores and Assignment of Lakes to Impact Categories

Average MNDNR and NPS lake scores were generated separately, then the average of the two was used as the final score. This allowed for equal input from each agency even though the number of scorers differed between the two agencies.

The Jenks optimization method (Jenks 1967) was used in ArcMap to create natural breaks in the scorer data and separate the lakes into different categories—*most impacted*, *moderately impacted*, and *least impacted*—for each factor independently and then for all the factors combined. The Jenks optimization method is a data cluster technique designed to separate the best arrangement of values into different classes by reducing the variance within classes and maximizing the variance between classes (Jenks 1967). Color-coded maps of the lakes in their impact categories were also created in ArcMap. Red depicts the *most impacted*, yellow the *moderately impacted*, and green the *least impacted* lakes.

Results

Overall

Based on the scores generated by combining all three factors, thirteen lakes were classified as most impacted, nine as moderately impacted, and three as least impacted (Figure 2, Table 1).

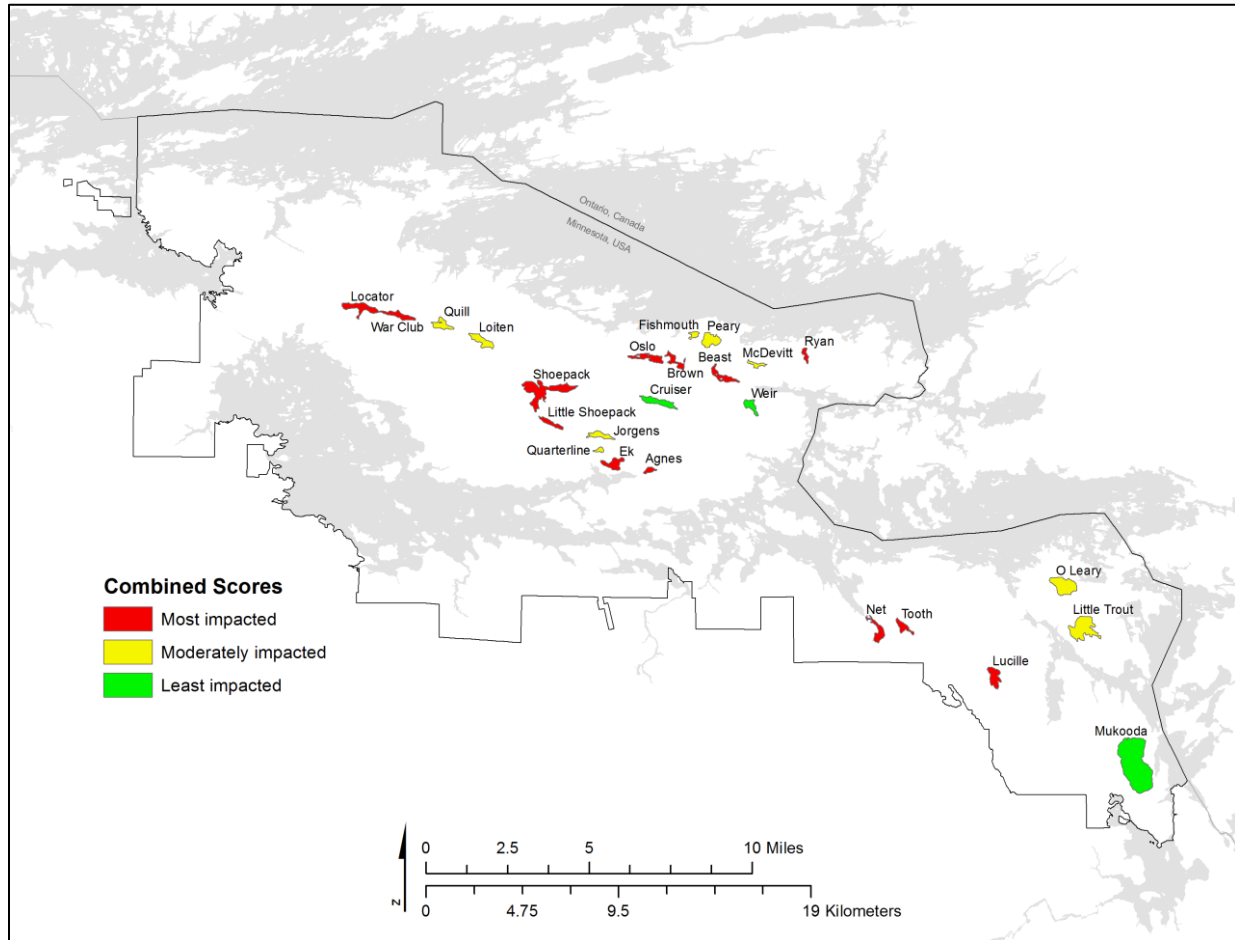


Figure 2. Overall impact assessments for interior lakes at Voyageurs National Park based on assessments of combined scores for water quality, mercury, and fish. Impact categories created using the Jenks optimization method in ArcMap: most impacted lakes (*red*), moderately impacted lakes (*yellow*), and the least impacted lakes (*green*).

Table 1. Average scores for three factors (water quality, mercury, and fish) assessed for the interior lakes at Voyageurs National Park. The combined average is the average of the NPS scores and MNDNR scores for water quality, mercury, and fish. Scores ranged from 1 to 5, with 1 being the least consistent with water quality reference criteria and standards (or most impacted) and 5 being the most consistent with water quality reference criteria and standards (or least impacted). Lakes moderately impacted (*), Lakes most impacted (**).

Lake Name	NPS Average	MNDNR Average	Combined Average
Agnes**	2.1	2.7	2.4
Beast**	2.8	3.2	3.0
Brown**	2.9	3.0	3.0
Cruiser	4.5	5.0	4.8
EK**	2.6	3.3	3.0
Fishmouth*	3.5	3.7	3.6
Jorgens*	2.9	3.5	3.2
Little Shoepack**	2.8	3.0	2.9
Little Trout *	3.5	3.7	3.6
Locator**	2.5	2.8	2.7
Loiten*	3.2	3.5	3.4
Lucille**	2.8	2.5	2.7
McDevitt*	3.5	3.7	3.6
Mukooda	4.1	4.0	4.0
Net**	2.3	2.8	2.6
O'Leary*	3.4	3.5	3.5
Oslo**	3.1	3.2	3.1
Peary*	3.3	3.5	3.4
Quarterline*	3.1	3.3	3.2
Quill *	3.5	4.0	3.8
Ryan**	2.8	3.0	2.9
Shoepack**	2.7	2.8	2.8
Tooth**	3.1	3.2	3.1
War Club**	2.7	3.3	3.0
Weir	3.9	4.5	4.2

Water Quality

In the water quality analysis, six lakes were classified as most impacted (**), twelve as moderately impacted (*), and seven as least impacted (Figure 3, Table 2).

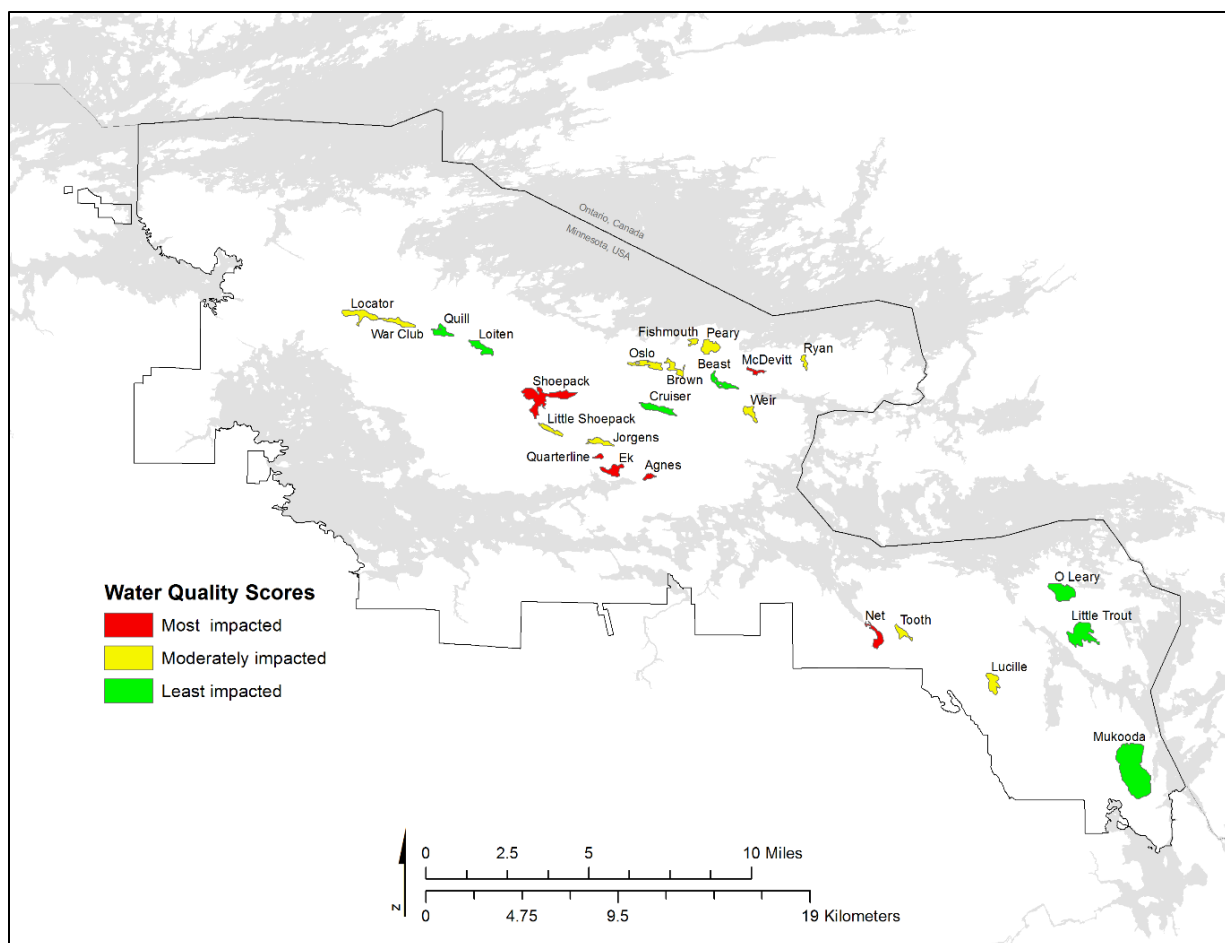


Figure 3. Level of impact to interior lakes at Voyageurs National Park based on water quality data analysis. Most impacted lakes (*red*), moderately impacted lakes (*yellow*), and least impacted lakes (*green*).

Table 2. Water quality scores for interior lakes at Voyageurs National Park. The combined average is the average of the NPS scores and MNDNR scores. Scores ranged from 1 to 5, with 1 being the most impacted and 5 being the least impacted. Lakes moderately impacted (*), Lakes most impacted (**).

Lake Name	NPS Average	MNDNR Average	Combined Average
Agnes**	1.5	2.5	2.0
Beast	4.2	4.5	4.3
Brown*	3.3	4.0	3.7
Cruiser	5.0	5.0	5.0
Ek**	2.3	3.0	2.7
Fishmouth*	3.3	4.0	3.7
Jorgens*	3.2	3.5	3.4
Little Shoepack*	3.1	3.5	3.3

Table 2 (continued). Water quality scores for interior lakes at Voyageurs National Park. The combined average is the average of the NPS scores and MNDNR scores. Scores ranged from 1 to 5, with 1 being the most impacted and 5 being the least impacted. Lakes moderately impacted (*), Lakes most impacted (**).

Lake Name	NPS Average	MNDNR Average	Combined Average
Little Trout	5.0	5.0	5.0
Locator*	3.3	4.0	3.7
Loiten	4.2	4.5	4.3
Lucille*	2.9	3.0	3.0
McDevitt**	2.4	2.5	2.5
Mukooda	4.2	4.5	4.4
Net**	1.9	2.5	2.2
O'Leary	4.2	4.5	4.4
Oslo*	3.2	4.0	3.6
Peary*	3.2	3.5	3.3
Quarterline**	2.1	2.5	2.3
Quill	3.6	4.5	4.1
Ryan*	3.3	4.5	3.9
Shoepack**	1.9	2.5	2.2
Tooth*	3.3	4.0	3.7
War Club*	3.3	4.0	3.6
Weir*	2.5	3.5	3.0

Mercury

Based on mercury data analysis, eleven lakes were classified as most impacted, eight as moderately impacted, and six as least impacted (Figure 4, Table 3). Although it was not optimal to estimate mercury values for three lakes based on water quality data and the equation from Knights et al. (2005), our comparison of estimates generated by the Knights et al. (2005) equation to measured fish mercury values provided evidence that the estimates were reasonable, and this was the best available information (Appendix 2).

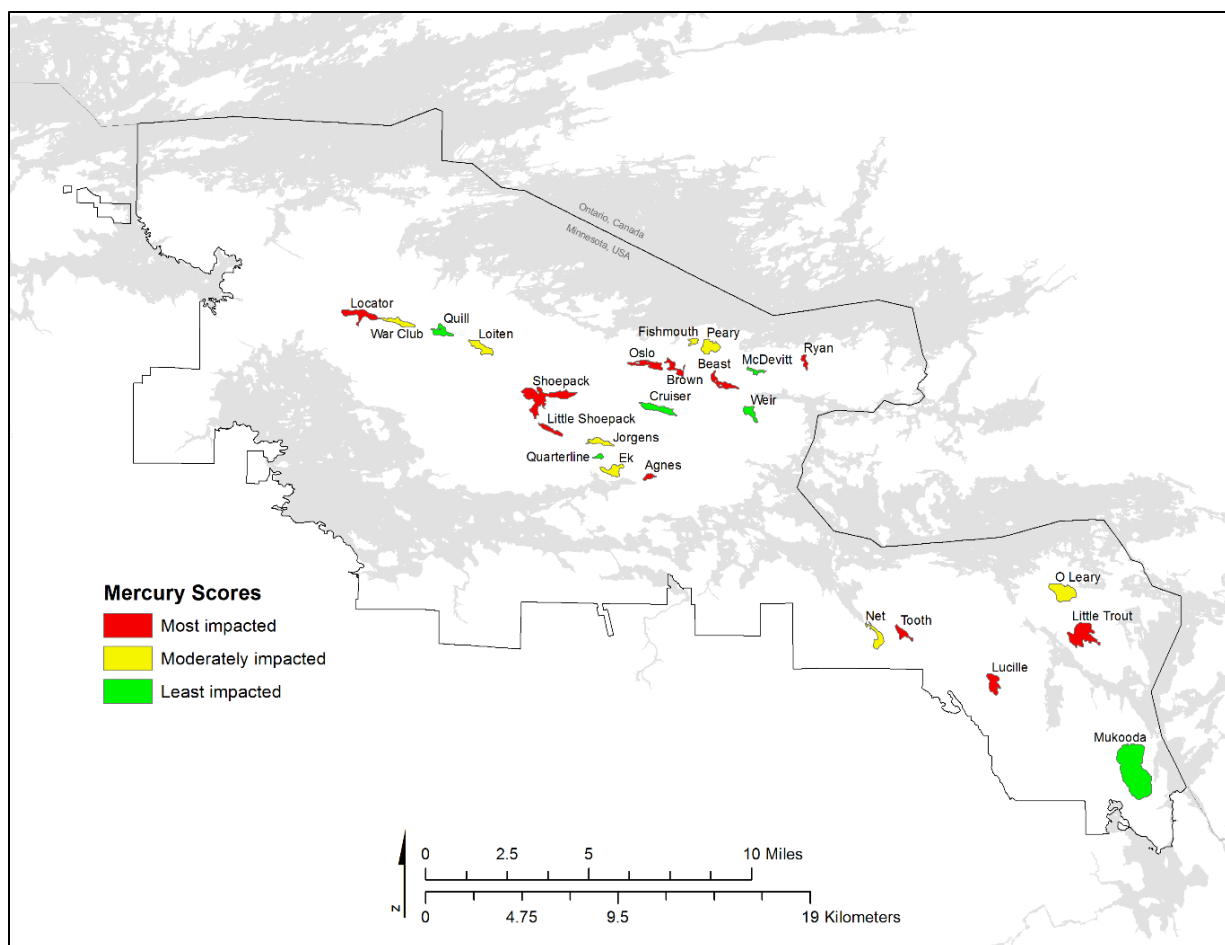


Figure 4. Level of impact to interior lakes at Voyageurs National Park based on mercury data analysis. Most impacted lakes (*red*), moderately impacted lakes (*yellow*), and least impacted lakes (*green*).

Table 3. Mercury scores for interior lakes at Voyageurs National Park. Combined average is the average of the NPS scores and MNDNR scores. Scores ranged from 1 to 5, with 1 being the most impacted and 5 being the least impacted. Lakes moderately impacted (*), Lakes most impacted (**).

Lake Name	NPS Average	MNDNR Average	Combined Average
Agnes**	3.0	2.0	2.1
Beast**	1.0	1.0	1.0
Brown**	2.0	1.0	1.5
Cruiser	4.8	5.0	4.9
Ek*	3.3	4.0	3.6
Fishmouth*	2.5	2.5	2.5
Jorgens*	3.0	3.5	3.3
Little Shoepack**	1.5	1.0	1.3
Little Trout**	2.3	2.0	2.1

Table 3 (continued). Mercury scores for interior lakes at Voyageurs National Park. Combined average is the average of the NPS scores and MNDNR scores. Scores ranged from 1 to 5, with 1 being the most impacted and 5 being the least impacted. Lakes moderately impacted (*), Lakes most impacted (**).

Lake Name	NPS Average	MNDNR Average	Combined Average
Locator**	2.3	1.5	1.9
Loiten*	2.8	3.0	2.9
Lucille**	2.0	1.0	1.5
McDevitt	4.5	3.5	4.5
Mukooda	4.8	5.0	4.9
Net*	2.3	2.5	2.4
O'Leary*	3.3	4.0	3.6
Oslo**	2.5	1.5	2.0
Peary*	2.8	3.0	2.9
Quarterline	3.8	4.0	3.9
Quill	3.8	4.0	3.9
Ryan**	1.5	1.0	1.3
Shoepack**	1.3	1.0	1.1
Tooth**	1.8	1.0	1.4
War Club*	2.8	3.0	2.9
Weir	5.0	5.0	5.0

Fish

Based on assessment of fish community data, eight lakes were classified as most impacted, eleven as moderately impacted, and six as least impacted (Figure 5, Table 4).

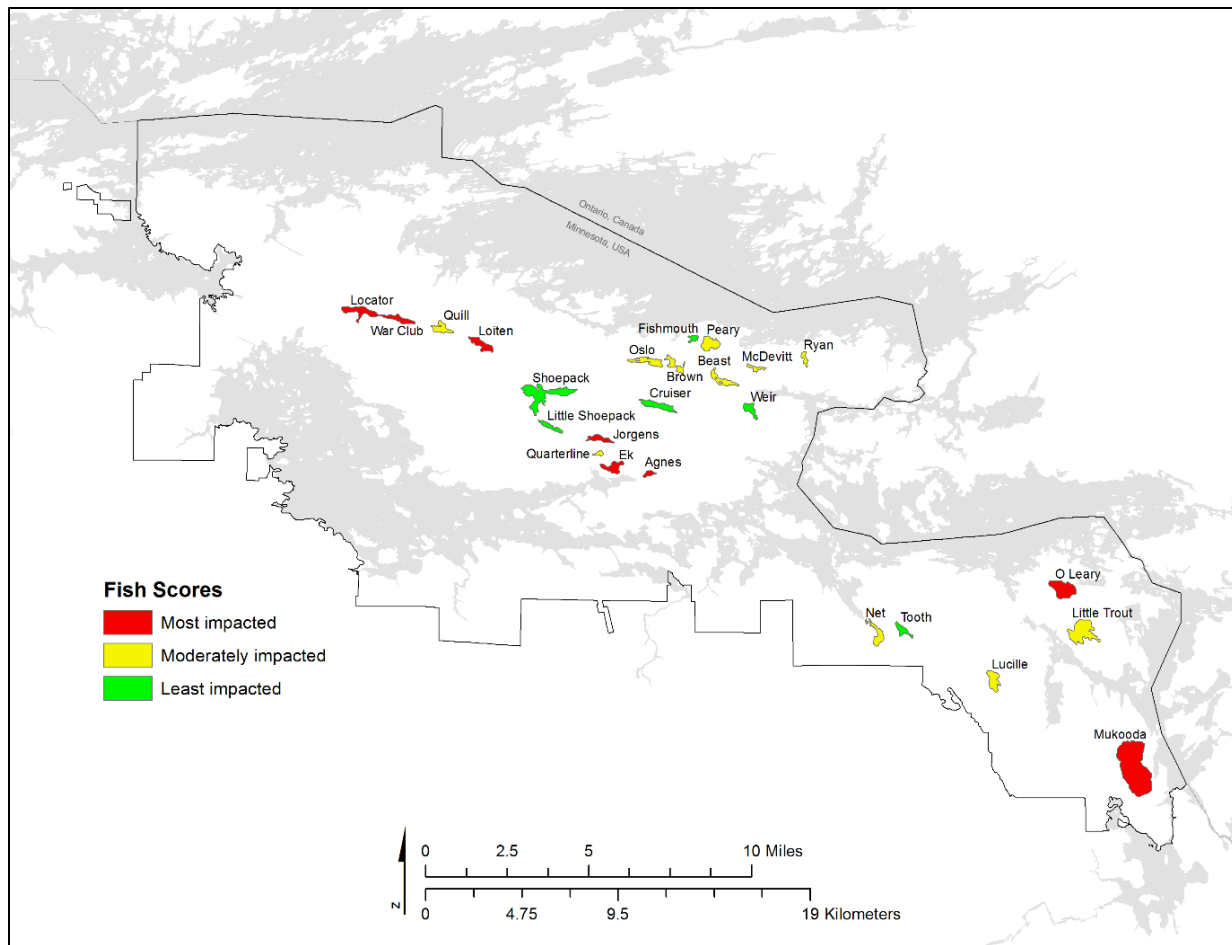


Figure 5. Level of impact to interior lakes at Voyageurs National Park based on analysis of fish data. Most impacted lakes (*red*), moderately impacted lakes (*yellow*), and least impacted lakes (*green*).

Table 4. Fish scores for interior lakes at Voyageurs National Park. The combined average is the average of the NPS scores and MNDNR scores. Scores ranged from 1 to 5, with 1 being the most impacted and 5 being the least impacted. Lakes moderately impacted (*), Lakes most impacted (**).

Lake Name	NPS Average	MNDNR Average	Combined Average
Agnes**	2.6	3.5	3.0
Beast*	3.3	4.0	3.6
Brown*	3.5	4.0	3.8
Cruiser	3.9	5.0	4.4
Ek**	2.3	3.0	2.7
Fishmouth	4.7	4.5	4.6
Jorgens**	2.6	3.5	3.0
Little Shoepack	3.7	4.5	4.1
Little Trout*	3.3	4.0	3.6

Table 4 (continued). Fish scores for interior lakes at Voyageurs National Park. The combined average is the average of the NPS scores and MNDNR scores. Scores ranged from 1 to 5, with 1 being the most impacted and 5 being the least impacted. Lakes moderately impacted (*), Lakes most impacted (**).

Lake Name	NPS Average	MNDNR Average	Combined Average
Locator**	2.0	3.0	2.5
Loiten**	2.8	3.0	2.9
Lucille*	3.5	3.5	3.5
McDevitt*	3.6	4.0	3.8
Mukooda**	3.3	2.5	2.9
Net*	2.9	3.5	3.2
O'Leary**	2.8	2.0	2.4
Oslo*	3.5	4.0	3.8
Peary*	4.0	4.0	4.0
Quarterline*	3.4	3.5	3.5
Quill*	3.2	3.5	3.3
Ryan*	3.7	3.5	3.6
Shoepack	5.0	5.0	5.0
Tooth	4.3	4.5	4.4
War Club**	2.0	3.0	2.5
Weir	4.2	5.0	4.6

Summary

Many of the lakes were heavily impacted by mercury (Tables 5 and 6), which had a large influence on the number of lakes (13) that were assigned to the most impacted category in the analysis of the three categories combined.

Table 5. “Most impacted” interior lakes at Voyageurs National Park. Factors driving the lakes to be in the most impacted category are listed. For lakes with fish as a driving factor, the introduced fish species impacting the lake are listed.

Lakes Most Impacted	Driving Factor(s)	Introduced fish species
Agnes	fish, mercury, water quality	Black Bullhead (<i>Ameiurus melas</i>)
Beast	mercury	–
Brown	mercury	–
Ek	fish, water quality	Smallmouth Bass (<i>Micropterus dolomieu</i>) and Black Crappie (<i>Pomoxis nigromaculatus</i>)
Little Shoepack	mercury	–
Locator	fish, mercury	Sunfish (<i>Lepomis</i> spp.) and Largemouth Bass (<i>Micropterus salmoides</i>)

Table 5 (continued). “Most impacted” interior lakes at Voyageurs National Park. Factors driving the lakes to be in the most impacted category are listed. For lakes with fish as a driving factor, the introduced fish species impacting the lake are listed.

Lakes Most Impacted	Driving Factor(s)	Introduced fish species
Lucille	mercury	–
Net	water quality	–
Oslo	mercury	–
Ryan	mercury	–
Shoepack	mercury, water quality	–
Tooth	mercury	–
War Club	fish	Sunfish (<i>Lepomis</i> spp.) and Largemouth Bass (<i>Micropterus salmoides</i>)

Table 6. Average scores for each of three factors assessed for the interior lakes at Voyageurs National Park: water quality, mercury, and fish. Combined average score also shown for each lake.

Lake Name	Water Quality	Mercury	Fish	Combined Average
Agnes	2.0	2.1	3.0	2.4
Beast	4.3	1.0	3.6	3.0
Brown	3.7	1.5	3.8	3.0
Cruiser	5.0	4.9	4.4	4.8
Ek	2.7	3.6	2.7	3.0
Fishmouth	3.7	2.5	4.6	3.6
Jorgens	3.4	3.3	3.0	3.2
Little Shoepack	3.3	1.3	4.1	2.9
Little Trout	5.0	2.1	3.6	3.6
Locator	3.7	1.9	2.5	2.7
Loiten	4.3	2.9	2.9	3.4
Lucille	3.0	1.5	3.5	2.7
McDevitt	2.5	4.5	3.8	3.6
Mukooda	4.4	4.9	2.9	4.0
Net	2.2	2.4	3.2	2.6
O'Leary	4.4	3.6	2.4	3.5
Oslo	3.6	2.0	3.8	3.1
Peary	3.3	2.9	4.0	3.4
Quarterline	2.3	3.9	3.5	3.2
Quill	4.1	3.9	3.3	3.8

Table 6 (continued). Average scores for each of three factors assessed for the interior lakes at Voyageurs National Park: water quality, mercury, and fish. Combined average score also shown for each lake.

Lake Name	Water Quality	Mercury	Fish	Combined Average
Ryan	3.9	1.3	3.6	2.9
Shoepack	2.2	1.1	5.0	2.8
Tooth	3.7	1.4	4.4	3.1
War Club	3.6	2.9	2.5	3.0
Weir	3.0	5.0	4.6	4.2

Discussion

This project benefitted from the collaborative analysis of experienced biologists and resource managers from the Minnesota DNR and the National Park Service with a variety of expertise in fisheries and aquatic ecology. The methods used in this project are transferable to other National Park Service units with water resources, especially where those water resources are cooperatively managed with other agencies.

The analysis resulted in 13 lakes being classified as *most impacted*, nine as *moderately impacted*, and three as *least impacted* when all factors (water quality, mercury, and fish) were combined. Mercury was a driving factor for 9 of the 13 lakes classified as *most impacted*. Voyageurs National Park is situated within a mercury sensitive landscape, and more than half of the lakes contain fish with mercury concentrations that exceed the U.S. Environment Protection Agency criteria for protection of human health (Knights et al. 2005). Mercury contamination in the interior lakes has been a serious issue for decades (Kallemeyn et al. 2003), and mercury effects are a human health concern throughout Minnesota (Minnesota Department of Health 2011, 2015).

It is important to recognize that the impact status of each lake was based solely on comparison to the other 24 study lakes within Voyageurs National Park. Although nearly half of the lakes were classified as *most impacted* when water quality, mercury, and fish scores were combined, many of these lakes are in excellent condition compared to other lakes outside of Voyageurs National Park (USEPA 2016, VanderMeulen et al. 2016). The factor-by-factor impact status of these lakes is further considered below to help describe the condition of the lakes and the potential for restoration through specific actions or management strategies.

Water Quality

The water quality status of each lakes relative to reference criteria and standards was scored rather than the direct impact on the lake from human disturbances. Although the eutrophication present in some of the lakes may be natural, the conditions still mimic those of lakes that are anthropogenically impacted through eutrophication. In the analysis of water quality status, six lakes were classified as *most impacted*, twelve as *moderately impacted*, and seven as *least impacted*. The interior lakes ranked *least impacted* had lower nutrient levels, higher clarity, neutral pH, and lower productivity based on chlorophyll-*a* concentration. These lakes reflected conditions well within water quality reference criteria and standards. The six lakes categorized as *most impacted* had high nutrient concentrations relative to the other study lakes, were shallower in depth, and had water quality conditions inconsistent with reference criteria and standards. Although VOYA's interior lakes are largely isolated from anthropogenic nutrient runoff, atmospheric deposition of nitrogen has been shown to affect water quality in remote lakes in the upper Midwest (Hobbs et al. 2016). As such, local, regional, or global emissions controls could provide some benefit to the water quality in these lakes. However, atmospheric nutrient deposition affects all the VOYA lakes, not just the six *most impacted* lakes. These six *most impacted* lakes are unique in that they were predominantly shallow lakes. Shallow lakes may respond differently to nutrient inputs than larger, deeper lakes, and there is

a burgeoning literature on water quality restoration techniques in these types of waters, with a focus on macrophyte dynamics (Scheffer and Jeppesen 1998; Janssen et al. 2014; Hilt et al. 2018).

The water quality of the interior lakes is generally good (Kallemeyn et al. 2003), yet many of the lakes fail to meet current EPA nutrient criteria. Recent assessments have shown that EPA water quality criteria may be too stringent for some lakes in this region (Herlihy et al. 2013, VanderMeulen et al. 2016). Paleolimnological assessments show minimal, if any, change in interior lake water quality since pre-European settlement of this area (Ramstack et al. 2004, Edlund et al. 2008). This suggests that the current water quality status of these lakes may be natural regardless of which impact status was assigned in this analysis.

Mercury

In the mercury analysis, eleven of the 25 study lakes were rated *most impacted*, eight as *moderately impacted*, and six as *least impacted*. Mercury concentrations in many of the interior lakes exceed thresholds shown to affect fish reproduction and physiological condition (Sandheinrich and Wiener 2011). Voyageurs National Park is regarded as a mercury sensitive landscape (Knights et al. 2005), meaning that compared to most landscapes, a relatively high proportion of deposited mercury is methylated and incorporated into the food web. Although VOYA's lakes presumably receive approximately the same mercury deposition, the lakes that are more conducive to methylation and bioaccumulation of methylmercury will have fish with higher mercury concentrations and are, thus, more impacted. The six lakes categorized as *least impacted* likely have watershed and water quality characteristics less conducive to mercury methylation.

Currently, the majority of mercury found in fish in these lakes is a result of deposition from anthropogenic sources outside of VOYA (Knights et al. 2005, Engstrom et al. 2007). Disturbances within the watersheds of these lakes such as water level fluctuations related to changing precipitation patterns and construction and failure of beaver dams may also influence the methylmercury concentrations in the biota and water in these lakes (Brigham et al. 2014). The National Park Service generally manages for natural processes, which likely precludes artificially maintaining water levels on these lakes, so we have no recommendations for onsite management of mercury in these lakes. However, local, regional, and global emissions controls could help reduce contamination, as mercury deposition has declined in concert with emission controls in recent decades (Brigham et al. 2021; Brigham et al. 2014, Wiener et al. 2006, Woodruff et al. 2009). Park managers should work to prevent human disturbances and environmental changes such as increased deposition of mercury or sulfate to Voyageurs National Park to prevent an increase in methylmercury production.

Although it is difficult to identify direct actions to manage mercury on a local scale, the human health effects of mercury contamination can be mitigated through sustained communication. The park and the State of Minnesota continue to communicate the health risk of consuming fish with high mercury concentrations to people who consume fish from interior lakes. Fish consumption advisories are in place for all Voyageurs National Park lakes.

Fish

In the assessment of fish data, eight lakes were classified as *most impacted*, eleven as *moderately impacted*, and six as *least impacted*. Scoring the fish factor for this project was a complex task because value judgements were required on four components: introduced species, stocking history, genetics, and heritage community summary information. Locator, War Club, Agnes, and Ek lakes were classified as *most impacted* in the overall (combined) impact analysis, and the fish factor scores for those lakes were a driving factor. Locator and War Club have two stocked species that persist, and both are non-native species. Agnes and Ek each have one stocked, non-native fish species and a low heritage community score. Lakes with a large number of heritage species, such as Mukooda, Little Trout, Beast, Cruiser, and Shoepack received higher scores. The genetically distinct Muskellunge in Shoepack and Little Shoepack lakes likely increased scores for those lakes as well.

Lake Trout

Recent MNDNR lake surveys suggest that Lake Trout populations in Little Trout and Mukooda lakes are declining, and the MNDNR has temporarily closed both lakes to harvest of Lake Trout to protect the remaining individuals. However, because those lakes contain genetically distinct strains of Lake Trout, scorers likely rated these lakes more highly. If the Lake Trout populations in those lakes become extirpated, interpretation of the impact status of those lakes might change. Moored temperature arrays and monthly lake profiles were used to determine the availability of coldwater habitat suitable for Lake Trout in Little Trout and Mukooda lakes. Analysis of those data suggests that suitable Lake Trout habitat (defined by water temperatures below 15.0°C and dissolved oxygen above 4 mg/L) existed throughout all summers during this monitoring effort in Little Trout Lake (2011–2019) and in Mukooda Lake (2013–2019). The declining Lake Trout populations in these lakes seem likely to be due to factors other than oxythermal habitat and may be related to competition/predation from other species, including the non-native species that persist in these lakes.

Manipulating fish assemblages to match the historical fish assemblages present in these lakes would help resource managers meet the NPS mission of maintaining resources in an unimpaired condition. Cisco and Lake Trout populations are on the decline in parts of Minnesota and Wisconsin, so maintaining existing populations of these coldwater fish species is a high priority. Research has identified genetically distinct Lake Trout populations in VOYA interior lakes (unpublished data from Loren Miller, MNDNR).

One management strategy for lakes impacted by non-native fish is to use a piscicide to eliminate all fish and then to restock with native fish, but we do not recommend this for several reasons. Treating lakes with piscicide would potentially eliminate non-target, native, genetically distinct fish populations in these lakes and does not guarantee full removal of non-native fish. Additionally, re-establishing historical assemblages is a challenging task. In order to conserve the native populations, agencies would need to dedicate substantial funds to collecting native fish from the lake prior to treatment and would need to succeed at re-establishing them in the same lake. Past efforts of this sort have shown that re-establishment success is uncertain and risks losing the native populations. Alternatively, fish species from other nearby lakes could be stocked in lakes where piscicides were used, but the strains would not be genetically identical.

Smallmouth Bass

After non-native Smallmouth Bass were detected in Ek Lake, Voyageurs National Park staff began removal efforts using a combination of angling, netting, and nest destruction in 2012 to prevent establishment of the species in the lake. Although Smallmouth Bass appeared to have established a reproducing population in Ek Lake by 2018, no Smallmouth Bass were captured in Ek by NPS staff in 2016 and 2017, and none were captured by the DNR in a 2016 fisheries survey (LeDuc and Maki 2017). This indicates that although these tactics may delay establishment of an introduced population, more aggressive approaches such as piscicide might be necessary to prevent establishment (if warranted by the negative impacts of the introduced species).

Northern Pike

The size structure of Northern Pike populations shows signs consistent with overharvest or limited forage in some interior lakes. The authors considered recommending regulations to restore a more natural size structure to the Northern Pike populations. While the study was underway, the MNDNR changed Northern Pike regulations statewide, establishing a three-zone system. The new regulations for the Northeastern Zone, which includes the lakes of Voyageurs National Park, are designed to restore a more natural size structure to Northern Pike populations. Thus, we do not propose any additional Northern Pike regulations.

General Management Recommendations

Since this project was designed to provide information in support of a management plan for the interior lakes of Voyageurs National Park, the authors also developed the following recommendations for management of these lakes that would best maintain them in an unimpaired condition.

Monitoring of water quality, fish assemblages, and mercury should be continued in the interior lakes of Voyageurs National Park to support future development of thresholds for management action and to provide the baseline information necessary for maintaining these resources in an unimpaired condition. The resulting monitoring data will prepare resource managers from Voyageurs National Park and the Minnesota Department of Natural Resources for continued collaborative management of the fisheries in these lakes. It will also prepare Voyageurs National Park for continued work with external partners and the NPS Air Resources Division to protect water quality in the park.

The current regulations and Best Management Practices (BMPs) for preventing introduction of exotic species and fish diseases into the interior lakes should be made permanent. The regulations and BMPs were designed to protect the interior lakes from all aquatic invasive species (AIS), non-native fish species, and fish diseases. Invasion by spiny water flea (SWF), specifically, is a sensitive indicator of the effectiveness of the regulations and BMPs because visitors must cross SWF-infested water to get to the interior lakes. Results from a 2016 survey and additional sampling in 2017 suggest that SWF have not established populations in any of the interior lakes (LeDuc et al. 2017) indicating that the regulations and the BMPs have been effective at slowing the spread of SWF into the interior lakes for at least 10 years. The current regulations and BMPs protect the interior lakes from multiple invasion vectors and provide additional time for scientists to develop technologies for elimination or control for AIS and fish diseases.

The goal of regulations and BMPs focused on aquatic invasive species should be to minimize the risk of AIS, non-native fish species, and fish-disease spread while still providing public access and fishing opportunities. From a risk-based perspective, the more visitors who use the lakes, the higher the risk of introducing AIS and fish diseases. This is particularly supported by assessments of compliance rates with the State of Minnesota's AIS regulations (Invasive Species Program 2018), which show that more than 10% of the public fail to comply with Minnesota's AIS regulations each year, and by records showing that park visitors do not always follow VNP's regulations and BMPs for the interior lakes (personal communication with VNP Law Enforcement).

- We recommend that visitors be required to watch a VNP-specific training video and to acknowledge having watched and understood the video before being issued a camping permit or boat reservation. The video should focus on Voyageurs National Park's regulations and BMPs for preventing the spread of AIS and fish diseases and on the repercussions of failing to follow the regulations and BMPs.
- We recommend that VNP continues providing vessels for rent on some interior lakes. The rental system is straightforward and easy to explain and monitor. We recommend that visitors not be allowed to portage any type of vessel into the interior lakes. Portaging can be a dispersal vector for invasive species, such as spiny water flea and zebra mussel, from the large lakes. Zooplankton can attach to canoe hulls and are able to establish viable populations even after exposure to portage conditions for 30 minutes (Stasko et al. 2012). Because spiny water flea and zebra mussel are present in Rainy Lake, and because spiny water flea is present in all five lakes of the Namakan Reservoir, allowing visitors to portage vessels creates an unacceptable threat of transferring the AIS to the interior lakes. Maintaining the current vessel rental program and adding additional vessels to that program, as appropriate, is the most reasonable option for preventing the spread of AIS and fish diseases while still allowing visitors to boat on some interior lakes in Voyageurs National Park.

Literature Cited

- Borum, D., M. K. Manibusan, R. Schoeny, and E. L. Winchester. 2001. Water quality criterion for the protection of human health: Methylmercury. EPA-823-R-01-001. Office of Science and Technology Office of Water, U.S. Environmental Protection Agency, Washington, D.C.
- Brigham, M. E., M. B. Sandheinrich, D. A. Gay, R. P. Maki, D. P. Krabbenhoft, and J. G. Wiener. 2014. Lacustrine responses to decreasing wet mercury deposition rates—Results from a case study in northern Minnesota. *Environmental Science and Technology* 48(11):6115–6123.
- Brigham, M. E.; VanderMeulen, D. D.; Eagles-Smith, C. A.; Krabbenhoft, D. P.; Maki, R. P.; DeWild, J. F. 2021. Long-Term Trends in Regional Wet Mercury Deposition and Lacustrine Mercury Concentrations in Four Lakes in Voyageurs National Park. *Applied Sciences* 11: 1879. <https://doi.org/10.3390/app11041879>.
- Edlund, M. B., J. M. Ramstack, and D. R. Engstrom. 2008. Biomonitoring using diatoms and paleolimnology in the western Great Lakes national parks. Annual report (2006–2007) submitted to Great Lakes Inventory and Monitoring Network. St. Croix Watershed Research Station, Science Museum of Minnesota, Marine on St. Croix, Minnesota.
- Elias, J. E., and D. VanderMeulen. 2008. Monitoring water quality of inland lakes, 2007: Annual summary report. National Park Service, Great Lakes Inventory and Monitoring Network Report GLKN/2008/05. National Park Service, Ashland, Wisconsin.
- Elias, J. E., and R. A. Damstra. 2011. Monitoring water quality of inland lakes, Great Lakes Network, 2009 and 2010: Data summary report. Natural Resource Data Series NPS/GLKN/NRDS—2011/163. National Park Service, Fort Collins, Colorado. Available at: <https://irma.nps.gov/DataStore/Reference/Profile/2170874>.
- Elias, J. E., and R. A. Damstra. 2012. Monitoring water quality of inland lakes, Great Lakes Network, 2011: Data summary report. Natural Resource Data Series NPS/GLKN/NRDS—2012/363. National Park Service, Fort Collins, Colorado. Available at: <https://irma.nps.gov/DataStore/Reference/Profile/2189073>.
- Engstrom, D. R., S. J. Balogh, and E. B. Swain. 2007. History of mercury inputs to Minnesota lakes: Influences of watershed disturbance and localized atmospheric deposition. *Limnology and Oceanography* 52(6):2467–2483.
- Goldstein, R. M., M. E. Brigham, L. Steuwe, and M. A. Menheer. 2003. Mercury data from small lakes in Voyageurs National Park, northern Minnesota. U.S. Geological Survey. Open-File Report. 03-480.

- Gorman, O., L. Kallemeyn, and R. Maki. 2014. Biogeographic patterns of inland lake fish communities at Isle Royale, Voyageurs, and Sleeping Bear Dunes national park units. Natural Resource Technical Report NPS/GLKN/NRTR—2014/893. National Park Service, Fort Collins, Colorado. Available at: <https://irma.nps.gov/DataStore/Reference/Profile/2211844>.
- Hansen, G. J., T. D. Ahrenstorff, B. J. Bethke, J. D. Dumke, J. Hirsch, K. E. Kovalenko, J. F. LeDuc, R. P. Maki, H. M. Rantala, and T. Wagner. 2020. Walleye growth declines following zebra mussel and *Bythotrephes* invasion. *Biological Invasions* 22(4):1481–1495.
- Herlihy, A. T., N. C. Kamman, J. C. Sifneos, D. Charles, M. D. Enache, and R. J. Stevenson. 2013. Using multiple approaches to develop nutrient criteria for lakes in the conterminous USA. *Freshwater Science* 32(2):367–384.
- Hilt, S., M. M. Alirangues Nuñez, E. S. Bakker, I. Blindow, T. A. Davidson, M. Gillefalk, L-A. Hansson, J. H. Janse, A. B. G. Janssen, E. Jeppesen, T. Kabus, A. Kelly, J. Köhler, T. L. Lauridsen, W. M. Mooij, R. Noordhuis, G. Phillips, J. Rücker, H-H. Schuster, M. Søndergaard, S. Teurlincx, K. van de Weyer, E. van Donk, A. Waterstraat, N. Willby, and C. D. Sayer. 2018. Response of Submerged Macrophyte Communities to External and Internal Restoration Measures in North Temperate Shallow Lakes. *Frontiers in Plant Science*. 9:194. doi:10.3389/fpls.2018.00194
- Hobbs, W. O., B. M. Lafrancois, R. Stottlemeyer, D. Toczydlowski, D. R. Engstrom, M. B. Edlund, J. E. Almendinger, K. E. Strock, D. VanderMeulen, J. E. Elias, and J. E. Saros. 2016. Nitrogen deposition to lakes in national parks of the western Great Lakes region: Isotopic signatures, watershed retention, and algal shifts. *Global Biogeochemical Cycles* 30. Available at: [doi:10.1002/2015GB005228](https://doi.org/10.1002/2015GB005228).
- Invasive Species Program. 2018. Invasive species of aquatic plants and wild animals in Minnesota: Annual report for 2018. Minnesota Department of Natural Resources, St. Paul, Minnesota.
- Janssen, A. B. G., S. Teurlincx, A. Shuqing, J. H. Janse, H. W. Paerl, and W. M. Mooij. 2014. Alternative stable states in large shallow lakes? *Journal of Great Lakes Research*. 40(4): 813-826. <https://doi.org/10.1016/j.jglr.2014.09.019>
- Jenks, G. F. 1967. The data model concept of statistical mapping. *International Yearbook of Cartography* 7:186–190.
- Kallemeyn, L. W., K. L. Holmberg, J. A. Perry, and B. Y. Odde. 2003. Aquatic synthesis for Voyageurs National Park. U.S. Geological Survey, Information and Technology Report 2003-0001.
- Knights, B. C., J. G. Wiener, M. B. Sandheinrich, J. D. Jeremiason, L. W. Kallemeyn, K. R. Rolffhus, and M. E. Brigham. 2005. Ecosystem factors influencing bioaccumulation of mercury from atmospheric deposition in interior lakes of the Voyageurs National Park, Minnesota. Project Final Report to the National Park Service, Midwest Region under NRPP Project Number: 02-01.

- LeDuc, J. F., and R. P. Maki. 2020. Annotated bibliography of Voyageurs National Park interior lakes documents and datasets. Natural Resource Report NPS/VOYA/NRR—2020/2209. National Park Service, Fort Collins, Colorado. Available at: <https://doi.org/10.36967/nrr-2282255>.
- LeDuc, J. F., and R. P. Maki. 2017. Efforts to prevent the establishment of an introduced population of Smallmouth Bass in Ek Lake. Voyageurs National Park internal report. National Park Service, International Falls, Minnesota.
- LeDuc, J. F., C. Kissane, and R. P. Maki. 2017. Twenty-six lake survey for presence or absence of spiny water flea. Voyageurs National Park Resource Management Report—2017. National Park Service, International Falls, Minnesota.
- Minnesota Department of Health. 2011. Mercury levels in blood from newborns in the Lake Superior Basin (GLNPO ID 2007-942). Available at: www.health.state.mn.us/divs/eh/hazardous/topics/studies/glnpo.pdf.
- Minnesota Department of Health. 2015. The economic burden of the environment on children's disease: The cost of prenatal mercury exposure in Minnesota. Environmental Public Health Tracking Report. Available at: www.health.state.mn.us/divs/healthimprovement/content/documents-tracking/MercuryBurdenReport.pdf.
- Minnesota Department of Natural Resources. 2020a. Lake survey reports. Available at: <https://www.dnr.state.mn.us/lakefind/surveys.html> (accessed 20 November 2020).
- Minnesota Department of Natural Resources. 2020b. Lake management plans. Available by request at International Falls Area Fisheries Office, International Falls, Minnesota.
- Minnesota Department of Natural Resources. *Various years*. Unpublished fish stocking records. St. Paul, Minnesota.
- Minnesota Pollution Control Agency. 2008. Eutrophication standards for lakes/reservoirs and rivers. Minnesota State Register 32:1699–1728.
- Minnesota Pollution Control Agency. 2014. Eutrophication standards for lakes/reservoirs and rivers. Minnesota State Register 39:154–156.
- NPS (National Park Service) 2016. Voyageurs National Park foundation document. Voyageurs National Park, U.S. National Park Service, U.S. Department of the Interior, Washington, D.C. Available at: https://www.nps.gov/voya/getinvolved/upload/VOYA_FD_2016_508Comp.pdf.
- NPS (National Park Service). 2020a. Voyageurs National Park superintendent's compendium. Available at: www.nps.gov/voya/learn/management/superintendents-compendium.htm#:~:text=SUPERINTENDENT%E2%80%99S%20COMPENDIUM%20CONTENTS%20%20%20Common%20Name%20,%20Rubus%20spp.%20%205%20more%20rows%20
[0](http://www.nps.gov/voya/learn/management/superintendents-compendium.htm#:~:text=SUPERINTENDENT%E2%80%99S%20COMPENDIUM%20CONTENTS%20%20%20Common%20Name%20,%20Rubus%20spp.%20%205%20more%20rows%20)

- NPS (National Park Service). 2020b. Voyageurs National Park aims to protect interior lakes from exotic species and fish diseases (website). Available at: www.nps.gov/voya/learn/nature/aquatic-invasive-species.htm.
- Ramstack, J. M., F. C. Fritz, and D. R. Engstrom. 2004. Twentieth century water quality trends in Minnesota lakes compared with presettlement variability. *Canadian Journal of Fisheries and Aquatic Sciences* 61(4):561–576.
- Sandheinrich, M. B., and J. G. Wiener. 2011. Methylmercury in freshwater fish: Recent advances in assessing toxicity of environmentally relevant exposures. In W. N. Beyer and J. P. Meador, editors. *Environmental Contaminants in Biota: Interpreting Tissue Concentrations*, 2nd edition, Boca Raton, Florida, U.S.A., Taylor and Francis Publishers.
- Scheffer, M. and E. Jeppesen. 1998. Alternative Stable States. In: Jeppesen, E., M. Søndergaard, M. Søndergaard, and K. Christoffersen (eds). *The Structuring Role of Submerged Macrophytes in Lakes*. Ecological Studies (Analysis and Synthesis), 131. Springer, New York, NY.
https://doi.org/10.1007/978-1-4612-0695-8_31
- Stasko, A. D., T. Patenaude, A. L. Strecker, and S. E. Arnott. 2012. Portage connectivity does not predict establishment success of canoe-mediated dispersal for crustacean zooplankton. *Aquatic Ecology* 46(1):9–24.
- USEPA (U.S. Environmental Protection Agency). 1986. National recommended water quality criteria—Aquatic life criteria table. Available at: www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table.
- USEPA (U.S. Environmental Protection Agency). 2016. National lakes assessment 2012: A collaborative survey of lakes in the United States. EPA 841-R-16-113. U.S. Environmental Protection Agency, Washington, D.C. Available at: <https://nationallakesassessment.epa.gov/>.
- USGS (United States Geological Survey) National Water Information System. 1983. Lucille Lake data from National Water Information System.
- USGS (United States Geological Survey) National Water Information System. 2014. National Water Information System: Web interface. Available at: <https://waterdata.usgs.gov/nwis> (accessed February 2014).
- VanderMeulen, D. D., B. M. Lafrancois, M. B. Edlund, J. M. Ramstack Hobbs, and R. Damstra. 2016. Pairing modern and paleolimnological approaches to evaluate the nutrient status of lakes in upper Midwest national parks. *JAWRA Journal of the American Water Resources Association* 52(6):1401–1419.
- Wiener, J. G., B. C. Knights, M. B. Sandheinrich, J. D. Jeremiason, M. E. Brigham, D. R. Engstrom, L. G. Woodruff, W. F. Cannon, and S. J. Balogh. 2006. Mercury in soils, lakes, and fish in Voyageurs National Park (Minnesota): Importance of atmospheric deposition and ecosystem factors. *Environmental Science and Technology* 40:6261–6268.

- Wiener, J. G., R. J. Haro, K. R. Rolfhus, M. B. Sandheinrich, S. W. Bailey, R. M. Northwick, and T. J. Gostomski. 2016. Bioaccumulative contaminants in aquatic food webs in six national park units of the western Great Lakes region: 2008–2012. Natural Resource Report NPS/GLKN/NRR— 2016/1302. National Park Service, Fort Collins, Colorado. Available at: <https://irma.nps.gov/DataStore/Reference/Profile/2233537>.
- Woodruff, L. G., M. B. Sandheinrich, M. E. Brigham, and W. F. Cannon. 2009. Impact of wildfire on levels of mercury in forested watershed systems—Voyageurs National Park, Minnesota. U.S. Geological Survey, Scientific Investigations Report 2009–5151. Available at: <http://pubs.usgs.gov/sir/2009/5151/>.

Appendix 1. Interior Lake Assessment Factors, Datasets, and Scoring Strategy

After an assessment of available data, we chose to rank the impact status of the 25 study lakes based on three factors. The factors, datasets, and scoring strategy are described in this appendix.

Factors

Water Quality

Dataset: GLKN data from 2006–2012 and NPS data from 2007 to fill gaps for three lakes. Because we were assessing current conditions as much as possible, we only used the 2007 data to backfill where GLKN data were lacking.

Analysis: Compared data against EPA reference criteria and Herlihy et al. (2013) criteria; made reference in report text to the fact that all (or nearly all) of these lakes meet Minnesota Pollution Control Agency eutrophication standards (Minnesota Pollution Control Agency 2008, 2014) and EPA pH standard for protection of aquatic life.

Fish Community

Dataset: Interior lake fish species presence/absence matrix prepared for Gorman et al. (2014); stocking history; genetic information for Shoepack Muskellunge and Lake Trout from Cruiser, Little Trout, and Mukooda; “heritage community” information from Gorman et al. (2014).

Analysis: Assess number of likely introduced species per lake; assess stocking history; incorporate genetic information where available; incorporate “heritage community” information from Gorman et al. (2014).

Mercury Contamination

Dataset: Knights et al. (2005) for mercury concentrations in fish; Sandheinrich’s Northern Pike mercury data for three lakes (2010–2012); Minnesota DNR and Department of Health data to fill gaps.

Analysis: Compare against EPA standards for methylmercury in fish for human consumption; compare against the standard for fish health effects (Sandheinrich and Wiener 2011); discuss results in final report in the context of wildlife health, fish health, and human health.

Scoring Strategy

Lakes were scored on a scale of 1–5 for each factor, where 1 was severely impacted and 5 was most natural. Additional information regarding criteria and datasets used for each factor are below. The factors were weighted equally. The Jenks optimization method (Jenks 1967) was used in ArcMap to create natural breaks in the scorer data and separate the lakes into three categories: *most impacted*, *moderately impacted*, and *least impacted*, for each factor independently and then for all factors combined.

Water Quality:

Scorers were sent a data matrix with data for each variable, and a file listing the standards to which they compared the values for each variable. Scorers were asked to use both the EPA Reference Criteria provided and the values provided by Herlihy et al. (2013). In each case, the lake met the standard if the value for the parameter in question within that lake was less than the reference criterion value. The EPA Reference Criteria are widely thought to be overly restrictive for some types of lakes, and the Herlihy et al. (2013) standards were designed as an attempt to set more realistic standards. Scorers were asked to consider each set of standards to formulate a score for each lake between 1 and 5, with 1 being *most impacted* and 5 being *most natural*. The data used were from NPS Great Lakes Inventory and Monitoring Network sampling completed between 2006 and 2012 (for many lakes, only data from 2006 exist), with the exception of data for Lucille, McDevitt, and Weir lakes which were from one-time collections made in 2007 by other NPS staff.

Fish:

Scorers were sent information for each sub-factor. Scorers were asked to use a combination of the following to generate a score for each lake:

- assessment of likely introduced species for each lake,
- stocking history of each lake,
- genetic information (basically just that the Shoepack Muskellunge and the Lake Trout in Mukooda and Little Trout are genetically distinct native species), and
- heritage community summary information from Gorman et al. (2014).

Species-by-lake matrix: “Likely introduced” species

Scorers were provided with a fish species-by-lake matrix and were asked to note that the species listed in red are “likely introduced”. It is very difficult if not impossible to determine with absolute certainty which species are introduced to each of these lakes, but based on analysis of past connectivity of watersheds, filters affecting what species persist in what types of lakes through time, sampling results, and expertise and experience of our MNDNR colleagues collaborating on this project, we have established certain species as likely introduced to the interior lakes of VNP.

Stocking history

Scorers were provided with files summarizing the fish stocking history for each of these lakes. Many of these lakes were stocked prior to establishment of VNP, and some have been stocked with Lake Trout very recently (through 2021 on Little Trout Lake and through 2010 on Mukooda Lake). Scorers were also provided with information as to when the fish in the lake were last sampled (assessed) and whether or not the stocked species persist in the lake (see additional notes about this in separate paragraph below). This information was included because some of the stocked species have failed to persist in certain lakes and likely had minimal impact on those lakes. Scorers were asked to estimate how important the stocking was to the lakes by considering which species were stocked, the number of fish stocked, the years during which the lakes were stocked, and whether the species persisted in the lake.

Additional information for the column indicated whether stocked fish persist in the lakes:

- For Beast Lake: Rainbow Trout did not persist, but Northern Pike stocked by VNP to re-establish a native species did persist (there is a “no” in the column indicating whether stocked species persist).
- For Jorgens Lake: there is also a “no” in that column for Jorgens. Largemouth Bass are present and were stocked, but they didn’t show up in assessments for many years after stocking and were likely not introduced or established due to DNR stocking. The source is unknown, and the population became established well after stocking ceased.

Genetic information

Scorers were provided with a poster that includes evidence that the Lake Trout in Mukooda and Little Trout lakes are genetically distinct native strains. Based on a combination of the evidence presented in that poster and information found in the Gorman et al. (2014) report described in the next paragraph, it may also be that the Lake Trout found in Cruiser Lake are a genetically distinct native strain. It has also been established that the Muskellunge found in Shoepack and Little Shoepack lakes are genetically distinct native fish.

Heritage community information (Gorman et al. 2014)

Scorers were asked to consider the heritage community scores that Gorman et al. (2014) provided in Table 17 of their report. They were also asked to read the descriptive text on pages 40–42 of the report and use the information in Table 17 to formulate this portion of their scores. Here are two excerpts from that section:

The heritage communities of each region are those communities that contain heritage species, those species that likely colonized inland lakes during the early Holocene and/or and have limited distributions (Tables 16–18). Populations in some of these lakes have been isolated for 2,000–10,000 years and represent unique natural resources.

A fish community is considered to have high heritage value when dominated by heritage species (Tables 16–18). Early Holocene colonizers with widespread distribution across [Isle Royale, Voyageurs, and Sleeping Bear dunes] (e.g., Northern Pike, Yellow Perch, and Blacknose Shiner) are omitted from our exercise.

Scorers were provided with the following caveats:

1. Although it is likely that the minnow species listed for Beast Lake, which give it a high heritage value score in the report, survived the toxaphene treatment by being located on the fringes of the lake or repopulating it from connected wetlands. This is not known.
2. It is also possible that the MNDNR staff stocked minnow species after the toxaphene treatment in order to help provide forage species in the lake. These fish would have likely come from Namakan Lake.
3. Also, some species have been stocked illegally in certain lakes in VNP. We do not have perfect knowledge of which species and which lakes. We do, however, question whether Walleye and Sauger were present in Little Trout Lake and whether Walleye were present in Mukooda Lake, or whether these species were introduced into these lakes by people trying to

increase fishing opportunity (these species were not caught in the earliest fisheries assessments carried out on Mukooda and Little Trout lakes).

There are enough other heritage species found in Mukooda and Little Trout that it is likely the heritage community value would remain high even if Walleye and Sauger were excluded.

Although there are uncertainties affecting the scoring of this factor, scorers used the best available information to score the lakes. Including this scoring strategy as an appendix means the scores can be updated through time as new information emerges.

Mercury:

The mercury scores were generated by assessing fish mercury concentrations in the context of EPA mercury standards and the standard for mercury in axial tissue of Northern Pike from Sandheinrich and Wiener (2011). There were sufficient Northern Pike mercury data for scoring 17 lakes. We used data from other top predators to fill in data for five additional lakes. We used muskellunge mercury data for Shoepack and Little Shoepack lakes. We used Largemouth Bass mercury data for Loiten and Quill lakes, and we used Lake Trout mercury data for Cruiser Lake. Although these species do not all accumulate mercury identically, we feel this approach adds better information than using nothing for lakes with no Northern Pike mercury data or using an average value from all other lakes to fill in gaps. For the remaining three lakes, we used an equation developed by Knights et al. (2005) for VOYA interior lakes to estimate Northern Pike mercury (see the Methods section of this report). The inputs to the equation are pH and dissolved sulfate. We have pH data for these lakes from 2007, and we have dissolved sulfate data from the early 1980s. Although not perfect, we think this offers more benefit than the alternatives and allows us to estimate mercury values for these lakes based on past research at VOYA and on the characteristics of the lakes rather than applying dummy values or an average value.

Also, we used the most recent three years of mercury data for each lake (or data from fewer years if data from less than three years were available). We felt this was the best strategy based on data showing that fish (and water column) mercury concentrations change through time in these lakes and that the trends are not always in the same direction among lakes.

Combined Factor Scores

The resulting dataset allowed us to generate a combined factor score for the 25 lakes without any missing data and without using “dummy” values or averages to fill in data gaps. We used the Jenks optimization method (Jenks 1967) in ArcGIS to create natural breaks in the data and split the lakes into three groups for the combined factor score.

Appendix 2. Water Quality Reference Criteria and Standards for Scoring VOYA Interior Lakes

The scorers were asked to score each lake in comparison to both the EPA reference criteria and to nutrient reference criteria proposed by Herlihy et al. (2003). The reference criteria and the water quality dataset for the study lakes are below (Table A2-1). Because all or nearly all study lakes met both the Minnesota Pollution Control Agency's Eutrophication Standard (2008, 2014) and the USEPA pH standard for protection of aquatic life (USEPA 1986), the scorers did not consider those standards in their assessment. However, the standards are listed below for reference.

EPA reference criteria for our sub ecoregion:

Total N: 400 (µg/L)

Total P: 9.69 (µg/L)

Secchi: 4.2 (m)

Chl *a*: 1.38 (µg/L)

Herlihy et al. (2003):

Total N: 529 (µg/L)

Total P: 18.3 (µg/L)

We have included the standards below for your reference only. We will briefly cover in the report text that the interior lakes of VOYA meet the MPCA eutrophication standards and the EPA pH standard for protection of aquatic life (values shown below).

Eutrophication standards for Class 2A lakes and reservoirs:

Designated lake trout lakes in all ecoregions (lake trout lakes support natural populations of lake trout, *Salvelinus namaycush*)

Total P: 12 (µg/L)

Chl *a*: 3 (µg/L)

Secchi: 4.8 (m)

(Applies to Little Trout, Cruiser, and Mukooda lakes)

Eutrophication standards for Class 2Bd lakes, shallow lakes, and reservoirs:

Lakes, Shallow Lakes, and Reservoirs in Northern Lakes and Forest Ecoregion

Total P: 30 (µg/L)

Chl *a*: 9 µg/L

Secchi: 2.0 (m)

(Applies to all other inland lakes at VOYA)

EPA pH standard for protection of aquatic life: 6.5–9.0

Table A2-1. Calculated water quality averages and standard errors. Data from the NPS Great Lakes Inventory and Monitoring Network collected from 2006 through 2012 (for many lakes, only data from 2006 exist), except for Lucille, McDevitt, and Weir, which were sampled once in 2007 by other NPS staff. Asterisk indicates values from VOYA/Midwest Region survey completed in 2007 with assistance from GLKN (unpublished data). “nd” = no data. Wiyapka Lake not included due to lack of data.

Lake	Chl-a		Total Nitrogen		pH		Secchi		Total Phosphorus	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Agnes	10.0	2.6	642	80	6.37	0.17	1.2	0.2	23.3	6.3
Beast	3.3	0.8	412	34	6.85	0.16	4.5	0.3	5.0	nd
Brown	2.9	0.4	459	16	7.01	0.05	3.0	0.1	8.4	0.9
Cruiser	0.8	0.2	207	7	7.45	0.04	8.4	0.2	3.4	0.4
Ek	6.2	1.0	673	28	7.30	0.05	2.0	0.1	19.1	1.1
Fishmouth	4.0	2.0	511	7	7.40	0.22	3.4	0.2	5.0	nd
Jorgens	5.8	1.5	422	21	7.19	0.11	3.0	0.3	9.7	2.4
Little Shoepack	8.8	1.9	528	7	7.12	0.21	2.3	0.1	12.7	0.9
Little Trout	1.2	0.1	272	7	7.54	0.20	6.2	0.2	3.6	0.4
Locator	3.0	0.3	453	10	7.12	0.06	2.8	0.1	9.3	0.9
Loiten	2.1	0.4	363	14	7.12	0.18	3.7	0.2	5.0	nd
Lucille	nd	nd	*570	nd	7.72	nd	2.0	nd	*9	nd
McDevitt	nd	nd	*532	nd	6.94	nd	1.2	nd	*29	nd
Mukooda	4.2	1.1	374	19	7.96	0.11	5.2	0.3	5.0	nd
Net	12.9	5.5	686	48	7.09	0.17	1.4	0.1	27.0	3.0
O'Leary	3.8	0.7	398	16	8.00	0.19	5.2	0.4	7.0	2.0
Oslo	6.3	1.9	449	27	7.02	0.13	2.4	0.2	5.0	nd
Peary	5.1	1.0	528	22	7.30	0.06	2.5	0.1	17.0	1.2
Quarterline	10.4	1.1	583	20	6.52	0.08	1.4	0.2	14.3	4.7
Quill	2.5	0.7	414	35	7.06	0.19	4.0	0.4	3.3	0.8
Ryan	2.8	0.3	477	8	6.92	0.06	3.0	0.1	8.2	0.7
Shoepack	6.4	1.0	688	13	6.54	0.06	1.4	0.0	20.3	1.3
Tooth	3.8	1.4	450	18	7.07	0.19	3.1	0.2	7.0	2.0
Warclub	2.1	0.4	410	14	7.01	0.11	2.6	0.1	5.0	nd
Weir	nd	nd	*119	nd	7.26	nd	1.0	nd	*38	nd

Appendix 3. Mercury Standards for Comparison to VOYA Interior Lake Data.

EPA Methylmercury Standard

The EPA water quality criterion for methylmercury (MeHg) is based on the MeHg concentration in fish, not water (Borum et al. 2001).

The criterion is as follows:

The resulting Tissue Residue Criterion is **0.3 mg methylmercury/kg fish**. This is the concentration in fish tissue that should not be exceeded based on a total fish and shellfish consumption-weighted rate of 0.0175 kg fish/day.

The fish mercury values are given in total mercury on the spreadsheet for scoring, while the above standard is expressed as a methylmercury concentration (Table A3-1 and Figure A3-1). The standard can be used directly, however, since it has been demonstrated that nearly all mercury present in fish is methylmercury, as covered in the Sandheinrich and Wiener (2011) and the work they cite.

Specifically see Page 171, second paragraph:

Nearly all of the mercury in fish is methylmercury (Grieb et al. 1990, Bloom 1992, Hammerschmidt et al. 1999). ... Fish accumulate very little inorganic mercury (Oliveira Ribeiro et al. 1999), even in surface waters and ecosystems containing unusually high concentrations of inorganic mercury. ... Mercury in fish muscle is typically quantified by determination of total mercury, which requires less effort and cost than determination of methylmercury. Unless specifically indicated, the fish-mercury concentrations reported herein were from determination of total mercury.

Standard for mercury in axial tissue of Northern Pike from Sandheinrich and Wiener (2011):

0.5 to 1.2 mg Hg/kg fish as wet weight in axial muscle

Scorers were also asked to compare the mercury values found on the spreadsheet to this standard, which is discussed in depth in Sandheinrich and Wiener (2011; referenced above) and summarized as:

Recent laboratory experiments and field studies demonstrate that freshwater fish are adversely affected at tissue concentrations of methylmercury well below 1.0 mg Hg/kg wet weight We conclude that changes in biochemical processes, damage to cells and tissues, and reduced reproduction in fish occur at methylmercury concentrations of about ... 0.5 to 1.2 mg Hg/kg wet weight in axial muscle.

Note: The units in the above quote have been converted to match units on data used for this study (Table A3-1).

Table A3-1. Average concentrations of sulfate and pH in lakes at Voyageurs National Park, and estimated mercury concentrations in standard-size Northern Pike based on Knights et al. (2005) compared to actual concentrations based on fish collected and measured from each lake. Unless otherwise indicated, sulfate and pH data are from Goldstein et al. (2003) and Actual Fish Mercury Concentration data are averages of Northern Pike mercury concentrations from Knights et al. (2005). “nd” = no data.

Lake Name	Sulfate	pH	Actual Fish Mercury Concentration (average) Wet Weight (mg/kg)	Estimated Mercury Concentration for Standard 55 cm Northern Pike	
				Wet Weight (mg/g)	Wet Weight (mg/kg)
Agnes	0.86	6.38	0.796	716.25	0.716
Beast	nd	nd	1.106 ^d	nd	nd
Brown	1.57 ^a	7.10 ^a	0.921 ^e	444.81	0.445
Cruiser	nd	nd	0.220 ^h	nd	nd
Ek	1.27	6.95	0.459	441.63	0.442
Fishmouth	1.4	6.72	0.640	665.70	0.666
Jorgens	1.91	6.86	0.500	755.15	0.755
Little Shoepack	nd	nd	1.120 ^g	nd	nd
Little Trout	2.91	7.33	0.763	782.46	0.782
Locator	2.68	6.83	0.845	1073.06	1.073
Loiten	nd	nd	0.560 ^f	nd	nd
Lucille	4.00 ^b	7.64 ^a	nd	965.48	0.965
McDevitt	1.63	7.36 ^a	nd	269.04	0.269

^a Elias and VanderMeulen (2008)

^b USGS National Water Information System (2014).

^c Michigan Technological University, unpublished data.

^d Minnesota Department of Health, unpublished data.

^e Wiener et al. (2016)

^f Voyageurs National Park, unpublished data (Largemouth Bass)

^g Voyageurs National Park, unpublished data (Muskellunge)

^h Voyageurs National Park, unpublished data (Lake Trout)

Table A3-1 (continued). Average concentrations of sulfate and pH in lakes at Voyageurs National Park, and estimated mercury concentrations in standard-size Northern Pike based on Knights et al. (2005) compared to actual concentrations based on fish collected and measured from each lake. Unless otherwise indicated, sulfate and pH data are from Goldstein et al. (2003) and Actual Fish Mercury Concentration data are averages of Northern Pike mercury concentrations from Knights et al. (2005). “nd” = no data.

Lake Name	Sulfate	pH	Actual Fish Mercury Concentration (average) Wet Weight (mg/kg)	Estimated Mercury Concentration for Standard 55 cm Northern Pike	
				Wet Weight (mg/g)	Wet Weight (mg/kg)
Mukooda	1.81	7.35	0.206	345.62	0.346
Net	2.26	6.66	0.742	1040.83	1.041
O'Leary	2.13	7.59	0.470	286.49	0.286
Oslo	1.59	6.87	0.891	624.90	0.625
Peary	2.56 ^a	7.24 ^a	0.544 ^e	718.74	0.719
Quarter Line	1.96	6.58	0.368	986.43	0.986
Quill	nd	nd	0.387 ^f	nd	nd
Ryan	3.4 ^a	7.00 ^a	1.076 ^e	1222.82	1.223
Shoepack	nd	nd	2.172 ^g	nd	nd
Tooth	3.14	6.78	0.968	1287.28	1.287
War Club	nd	nd	0.593 ^d	nd	nd
Weir	1.22 ^c	7.45 ^a	nd	43.69	0.044

^a Elias and VanderMeulen (2008)

^b USGS National Water Information System (2014).

^c Michigan Technological University, unpublished data.

^d Minnesota Department of Health, unpublished data.

^e Wiener et al. (2016)

^f Voyageurs National Park, unpublished data (Largemouth Bass)

^g Voyageurs National Park, unpublished data (Muskellunge)

^h Voyageurs National Park, unpublished data (Lake Trout)

Interior Lakes Assessment Project Scoring Spreadsheet			
Lake Name	Water Quality	Mercury	Fish
Agnes			
Beast			
Brown			
Cruiser			
Ek			
Fishmouth			
Jorgens			
Little Shoepack			
Little Trout			
Locator			
Loiten			
Lucille			
McDevitt			
Mukooda			
Net			
O'Leary			
Oslo			
Peary			
Quarterline			
Quill			
Ryan			
Shoepack			
Tooth			
War Club			
Weir			

Scorer:

Figure A3-1. A screenshot example of the scoring sheet completed by NPS and Minnesota Department of Natural Resources reviewers to assess water quality, mercury, and fish conditions in lakes at Voyageurs National Park.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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National Park Service
U.S. Department of the Interior



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