Comprehensive Management Plan for Eleven Lakes in the Penokee Hills of Ashland and Iron Co., Wisconsin

Wisconsin Department of Natural Resources
Surface Water Grants Program

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Mary Griggs Burke Center for Freshwater Innovation
Northland College
1411 Ellis Ave
Ashland, WI 54806

Primary Author: Matt Hudson, Associate Director – Great Lakes

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A lake management planning effort involving eleven lakes over six years can't be completed without the hard work, support, input, and guidance from many people and organizations.

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Matt Hudson, Burke Center Associate Director – Great Lakes, June 2022

Table of Contents

List of Tables

List of Figures

1. Executive Summary

This document describes a plan for the long-term management of eleven lakes near the Penokee Iron Range of Ashland and Iron Co., Wisconsin, hereafter referred to as the Penokee Lakes. The eleven lakes and their associated waterbody identification codes (WBIC) covered by this management plan include: East Twin (2935800; also known as "Twin Lakes East"), West Twin (2935700, also known as "Twin Lakes"), Eureka (2935600), Galilee (2935500), Meder (2935300), Long (2934800), Maki (2931300), McCarthy (2931100), Upson (2908500), O'Brien (2928400), and Caroline (2938000) Lakes. This plan was developed with funding support from the Wisconsin Department of Natural Resources (WDNR) Surface Water Grants program (Grant numbers: LPL155615, LPL155715, LPL159016, LPL159118, LPL163317, LPL163417, LPL166818, and LPL166918) and was prompted by a recent proposal to mine iron ore from the Penokee Iron Range and a lack of baseline data on the condition of these lakes. The eleven lakes are being considered as one "system" for the purposes of this management plan. Reasons for this approach include geographical proximity, similar geologic setting, similar low levels of shoreline and watershed development, and the hydrological connection among the lakes. Considering these lakes together in one management plan also simplifies the data summary and management plan review process, as well as creating opportunities and synergies to work on multiple lakes during the management plan implementation process.

To enhance communication to the broadest range of audiences, this plan is structured such that the level of technical detail increases throughout the document. The Executive Summary is intended as a non-technical summary for all audiences. Sections 2 through 4 provide increased detail and background information to help the reader better understand the social and ecological components of the Penokee Lakes ecosystem and rationale for different management recommendations. The appendices are intended for more technical audiences and focus on in-depth details of the existing data sets for different elements of the Penokee Lakes ecosystem.

Successful management of the Penokee Lakes is dependent on an understanding of the relationship between the desired "use" of the lakes and the physical, chemical, biological, and social processes that shape the ecosystem of each lake. To this end, the plan is comprised of an assessment of 1) the uses and values of the Penokee Lakes and 2) their current condition and the potential problems affecting them.

To describe how the Penokee Lakes are used and valued by different groups, this plan was developed with input from Penokee Lake landowners, the Galilee Lake Association, the Wisconsin Department of Natural Resources (WDNR), the Mashkiiziibii Natural Resources Department, the Red Cliff Environmental Department, the Great Lakes Indian Fish and Wildlife Commission (GLIFWC), the Ashland and Iron County Land and Water Conservation Departments, The Nature Conservancy, the Superior Rivers Watershed Association, and the Northland College Center for Rural Communities. Based on this process, it is clear that the Penokee Lakes are an important ecological, social, and cultural resource that are used and valued by different groups for different reasons. Across multiple questions in a landowner survey and through conversations with other lake users and stakeholders, the majority of respondents highlighted the value of the Penokee Lakes as sites for recreational activity and important ecological and cultural resources that should be protected for the benefit of the natural world and use by future generations.

To describe ecosystem conditions in each of the eleven Penokee Lakes, a six-year study was conducted between 2015-2020 to collect and summarize data describing the current condition of each lake by assessing each of the following elements: physical and chemical conditions, shoreline habitat conditions, watershed characteristics, and biological community assessments. In addition, future lake conditions were simulated utilizing data on current conditions and a development scenario possible with existing policies that govern shoreline development. From these studies, a number of important findings emerged:

1. The Penokee Lakes are healthy lake systems with water chemistry and native fish and plant communities consistent with what we expect for northern Wisconsin lakes with high percentages of forest and wetland land cover in their watersheds and shoreland areas. These conditions are sustained primarily due to little to no human development along shoreland areas or within the watersheds draining to each lake.
2. Despite overall healthy conditions in these lakes, there are a number of factors that make them vulnerable to future water quality and biological community declines from a wide range of human development:
    a. Most of the lakes are shallow and small with very low acid neutralizing capacity and water budgets likely dominated by surface runoff and shallow groundwater contributions. In addition, some of the lakes have long water residence times. All of these factors make them susceptible to things like shoreland and watershed development pressure, acid mine drainage, and acid rain.
    b. Potential changes in land use, particularly in shoreland development, could alter the availability and quality of nearshore habitat, as well as the aesthetics of the shoreland area. Lakes with high percentages of shoreland protected through public or land trust ownership including Caroline, Upson, and West Twin are less vulnerable to future water quality declines due to shoreland development than lakes with high percentages of private ownership including O'Brien, McCarthy, Maki, Eureka, Galilee, Meder, and Long. East Twin Lake has a large percentage of land trust ownership but is still seen as vulnerable to development because of its small size, small watershed to lake surface area ratio, and long water residence time.
    c. The proximity of the lakes to the Penokee Iron Range and the potential for future iron ore mining has the potential to dramatically alter the condition of these lakes. A greater understanding of the groundwater contributing areas and surface water/groundwater interactions is needed so any future mining plans can adequately maintain the health of the lakes.
    d. Although there was no evidence of non-native or invasive aquatic plant species in any of the Penokee Lakes, purple loosestrife has previously been treated along shoreline areas of Lake Galilee (GLIFWC). Non-native and invasive animal species were not evaluated, but Chinese mystery snail is known to be present in Lake Galilee and O'Brien Lake. This serves as a reminder of the vulnerability of these lakes, particularly those with public boat launches, to introductions of non-native and invasive species.
    e. Future climate predictions for the Penokee Lakes region suggest warmer temperatures and more extremes, including drought and heavy precipitation events. While climate change could lead to a range of unpredictable effects on hydrology and water quality, maintaining healthy watersheds and shoreland areas provide the best opportunity for promoting resilience to the worst effects of a changing climate.
    f. Whether related to climate change or not, two cyanobacterial (blue green algae) blooms were observed in O'Brien Lake during the study period. The genus present in at least one of the blooms (*Dolichospermum sp.*) can produce harmful toxins, although it is unknown whether toxins were present in either of the observed

blooms. While the presence of cyanobacterial blooms in this lake is most likely due to natural conditions, these blooms could be a signal related to climate change and are important to monitor as regional climate is predicted to warm.

g. Total mercury concentrations from Eureka Lake dragonfly larvae were among the highest measured as part of the nationwide Dragonfly Mercury Program. Investigating the cause of this and collecting fish tissue mercury data from Eureka and other Penokee Lakes is important to understand potential risk of human and wildlife exposure to mercury from eating fish from these lakes.

Considering these and other findings from the use and value and ecosystem condition assessments, along with feedback from Penokee Lake stakeholders, a series of goals and implementation strategies to achieve those goals were developed to guide management of the Penokee Lakes into the future.

Management Plan Goals and Implementation Strategies:

1. Maintain ecosystem health in the lakes and surrounding watersheds in a manner that meets subsistence, economic, cultural, medicinal, and spiritual needs for Ojibwe tribes with treaty-reserved rights in the 1842 ceded territory. Because healthy ecosystems are needed to support Ojibwe tribal lifeways, this goal is seen as an overarching approach that the remaining goals and implementation strategies are working to achieve.
2. Maintain and enhance existing water quality conditions.
    a. Ensure compliance with existing county private onsite wastewater treatment systems (POWTS) pumping and maintenance requirements and Chapter SPS 383 of State of Wisconsin Administrative Code.
    b. Ensure that timber harvests in the watersheds of these lakes follow best management practices (BMPs) for forest health, water quality, and climate resiliency (https://dnr.wisconsin.gov/topic/forestmanagement/bmp) and broader forest management considers climate change strategies outlined by the Climate Change Response Network (https://forestadaptation.org/field-guide-northern-wisconsin).
    c. Continue long-term monitoring of trophic status (nutrients, chlorophyll-a, and Secchi depth) in each lake if feasible or a subset of lakes representing a gradient of development conditions. O'Brien Lake should be a priority because of observed cyanobacterial blooms. The Wisconsin Citizen Lake Monitoring Network is a great program for individuals and lake associations to collect these data for their lakes: https://dnr.wisconsin.gov/topic/lakes/clmn.
    d. Comprehensively evaluate the ability of local land use and zoning policies to effectively manage water quality and aesthetics in the Penokee Lakes into the future, with particular attention towards anticipated future climate conditions and renewed interest in developing iron ore deposits in the Penokee Iron Range.
    e. Collect fish tissue mercury concentrations with a focus on lakes in the "moderate" and "high" hazard categories from the dragonfly larvae total mercury analyses to investigate any relationship between fish tissue and dragonfly larval mercury concentrations. Re-survey lakes for dragonfly larvae total mercury concentrations every 5-10 years.
    f. Seek opportunities for technical assistance and protection funding through Wisconsin's Healthy Watersheds, High-Quality Waters program (https://dnr.wisconsin.gov/topic/SurfaceWater/HQW.html).

3. Protect shoreland habitat.
    a. Implement a shoreland habitat protection program for private landowners focusing on areas with the lowest restoration potential (i.e. greatest protection potential) highlighted in the shoreland habitat surveys and areas of high aquatic plant diversity identified in the aquatic plant surveys. A particular focus of the program could include connecting land trusts with private landowners that have large parcels of undeveloped shoreland around any of these lakes to discuss conservation easements, enrolling in carbon markets, and other tools that limit future development while providing financial benefits to landowners. Another potential focus for the program could be to seek Critical Habitat Area designations through WDNR to protect these areas.
    b. Consider implementation of a shoreland buffer tax incentive program to incentivize shoreland protection for property owners (at the county or township level). Use the work in Burnett County as a potential starting point (https://www.burnettcounty.com/1123/Shoreline-Incentive-Program-SIP).
    c. Consider slow-no-wake or non-motorized ordinances for lakes where appropriate. Utilize "*A Guideline for Creating Local Boating Ordinances and Placing Waterway Markers in Wisconsin Waters* (https://dnr.wi.gov/files/PDF/pubs/le/LE0317.pdf) for guidance.
4. Restore shoreland habitat where appropriate.
    a. Implement a shoreland habitat restoration and stormwater management program focusing on areas with the greatest restoration potential highlighted in the shoreland habitat surveys. The program could take place in conjunction with the shoreland buffer tax incentive program in 3.b. to provide technical and financial project implementation support for property owners. Outreach and education for this program will be needed so property owners understand best practices for maintaining healthy shoreland areas on their property. Also see: https://healthylakeswi.com/
    b. Implement coarse woody habitat (CWH) additions to shoreline areas with low amounts of CWH to promote habitat for fish and other aquatic life.
5. Maintain resilient hydrologic processes.
    a. Conduct a groundwater study of each lake to understand groundwater contributing areas and surface water/groundwater interactions. Groundwater contributing areas for each lake can be used to further focus priority protection areas.
    b. Conduct an education and outreach campaign about beaver ecology and beaver management, including resources available to landowners to manage beaver on their property.
    c. Continue long-term monitoring of water levels on a subset of lakes to help understand potential climate change effects on hydrology.
6. Maintain diverse native plant communities.
    a. Protect any and all populations of manoomin (wild rice), including those reported in Upson and O'Brien lakes. Similar to Goal 3.a., consider establishing Critical Habitat Area designations to protect these areas.
    b. Seek opportunities to establish wild rice where appropriate.
    c. Protect areas of high aquatic plant diversity identified in the aquatic plant surveys. Similar to Goal 3.a., consider establishing Critical Habitat Area designations for these areas.

   d. Conduct periodic invasive species/non-local beings early detection monitoring such as snorkel surveys at boat launch areas.
   e. Conduct point-intercept surveys of the entire aquatic plant community every 5 years to assist in identifying non-local and invasive beings, as well as characterizing any changes that may be resulting from related stressors like climate change and/or shoreline development.
7. Maintain diverse native fish communities.
   a. Goals 3 and 4 and the implementation strategies related to maintaining and improving shoreland habitat areas are key to maintaining diverse native fish communities.
   b. Maintain harvestable walleye populations in Lake Galilee and Meder Lake by:
      i. Documenting consistent natural reproduction at or above regional recruitment benchmarks utilized by WDNR and GLIFWC.
      ii. Promote favorable walleye habitats, protect limited spawning habitats, promote a conducive fish community for walleye dominance, and maintain a native biotic community.
      iii. Continued monitoring of adult/juvenile walleyes, as well as overall fish community structure to support adaptive walleye management strategies.
8. Maintain scenic beauty
   a. Several other implementation strategies address this goal including 2.b., 3.a., 3.b., and 4.a.

These management plan goals and implementation strategies are seen by managers and stakeholders as the best approaches to protect and enhance the Penokee Lakes and their uses into the future. As with any management plan, implementation of its contents will rely on the continued dedication and support from the many people who use and value these lakes as an ecological, social, and cultural resource.

2. Introduction

This document describes a plan for the long-term management of eleven lakes near the Penokee Iron Range of Ashland and Iron Co., Wisconsin, hereafter referred to as the Penokee Lakes. The eleven lakes and their associated waterbody identification codes (WBIC) covered by this management plan include: East Twin (2935800; also known as "Twin Lakes East"), West Twin (2935700, also known as "Twin Lakes"), Eureka (2935600), Galilee (2935500), Meder (2935300), Long (2934800), Maki (2931300), McCarthy (2931100), Upson (2908500), O'Brien (2928400), and Caroline (2938000) Lakes.

The Penokee Lakes lie south and east of the City of Mellen, Wisconsin, within the headwaters of the Bad River watershed (Figures 2.1 and 2.2).

Six of the eleven lakes are connected via Minnow Creek, a Bad River tributary. The rest flow into other tributaries, with the exception of Caroline Lake, which is the headwaters for the Bad River (Figure 2.1). Water from all eleven lakes eventually drains into the Bad River and empties into the Bad River/Kakagon Sloughs at Lake Superior, which is a globally recognized Ramsar Wetland of International Importance located on the Mashkiiziibii (Bad River) Indian Reservation (Figure 2.2).

The Penokee Lakes area is part of the ancestral, traditional, and contemporary lands of the Ojibwe people, ceded by the 1842 Treaty of La Pointe. The Ojibwe migration story tells that groups of Ojibwe people followed the sacred Megis shell to this area from the East Coast (GLIFWC, 2005; MHS, 2021). Eventually it led them to Mooningwanekaaning, now known as Madeline Island, the place where food grows on water. This food was manoomin, or wild rice, which continues to be a sacred food for the Ojibwe people who live in this area. European contact occurred sometime in the 1600's and the area then became a center for the fur trade.

After the land was colonized by Europeans, it was heavily deforested during the late 1800s and early 1900s. Logging activity peaked between 1890 and 1910 in what is referred to as the "cutover" (Durand, Loyal and Bertrand, 1935). Logging was not the only industry that found its way to the region. The first mining operations occurred in 1884, and within four years, annual shipments of iron ore exceeded one million tons (Cannon et al., 2008). It is estimated that there are still more than three billion metric tons of taconite iron reserves within the Gogebic Range (known as the Penokee Iron Range in Wisconsin) that runs through Wisconsin (Marsden, 1978).

The lake research and management planning work in the Penokee Lakes evolved from a recent proposal by Gogebic Taconite, LLC (GTAC) to develop an open-pit iron ore mine in a portion of the Penokee Iron Range (https://dnr.wisconsin.gov/topic/Mines/Gogebic.html) and a corresponding lack of baseline data on potentially affected lakes in the area. Northland College's Sigurd Olson Environmental Institute (SOEI), proposed to study these lakes as a "system" by applying for a series of 2-year Comprehensive Management Planning (Lake Planning) grants, which are part of Wisconsin Department of Natural Resources (WDNR) Surface Water Grants program (https://dnr.wisconsin.gov/aid/SurfaceWater.html). Lakes were chosen based on proximity to the Penokee Iron Range in the vicinity of the GTAC proposal and also having some sort of public access point. Beginning in 2015, work on the lakes occurred in 2-year phases due to the nature of the WDNR Lake Planning grants. Grant numbers that covered the project work include: LPL155615, LPL155715, LPL159016, LPL159118, LPL163317, LPL163417, LPL166818, and LPL166918. Also in 2015, the Mary Griggs Burke Center for Freshwater Innovation (Burke Center) was created at Northland College and work on the Penokee Lakes transitioned from SOEI to the Burke Center for the remainder of the project. SOEI remained the named grant applicant. Budget savings in 2019 allowed the Burke Center to sample and collect detailed water quality data on all 11 lakes in the same year, allowing for the most comparable data on water quality conditions in these lakes during the study period. All 11 lakes were sampled again during 2020, although with a much smaller parameter list and less frequency than in 2019 due to staffing reductions caused by the COVID-19 pandemic.

Successful management of the Penokee Lakes is dependent on an understanding of the relationship between the desired "use" of the lakes and the physical, chemical, biological and social processes that shape the lake ecosystems. Throughout this document the word "use" will be used to describe all of the potential ways in which people directly use (e.g., fishing and boating), interact with (e.g., wildlife observation) and value (e.g., a site for the conservation of species and native ecosystems, cultural value) the Penokee Lakes.

Thus, to effectively manage the Penokee Lakes, it is necessary to:

1. Develop a series of goals that protect and/or restore the most highly valued uses for the lakes by different user groups
2. Describe the conditions of the physical, chemical, biological and social processes that enable and sustain these different uses
3. Identify management options to protect and/or restore the desired use of the lakes and reconcile any potential conflicts among user groups

The following WDNR Surface Water grants funded the majority of project activities: LPL159016, LPL159116, LPL163317, LPL163417, LPL-1556-15, and LPL-1557-15. Additional funding and in-kind contributions were provided by the Burke Center at Northland College and the plan was developed collaboratively through volunteer contributions from Penokee Lakes property owners, the Galilee Lake Association, and technical contributions from the WDNR, the Mashkiiziibii Natural Resources Department, the Red Cliff Environmental Department, the Great Lakes Indian Fish and Wildlife Commission, the Ashland and Iron County Land and Water Conservation Departments, The Nature Conservancy, the Superior Rivers Watershed Association, and the Northland College Center for Rural Communities.

2.1. Structure of the Plan

This plan is comprised of a series of sections that link the use, current conditions and potential management options for the lakes:

1) **Lake Uses and Users -** summarizes who primarily uses the Penokee Lakes and how they are used and valued by different groups

2) **Lake Condition Assessment -** summarizes the historical and newly collected data that describe the conditions of the physical, chemical and biological processes that shape the Penokee Lakes ecosystem

3) **Management Goals and Implementation Strategies -** describes specific goals and actions to protect and/or restore the ecological and social conditions necessary to sustain desired uses and values for the Penokee Lakes

4) **Appendices** - provide further detail on the use and value survey and from the lake condition assessment related to hydrology, shoreland habitat, and biological communities

Figure 2.1. Penokee Lakes Study Area. The eleven Penokee Lakes are shown as well as the connecting tributaries. All the tributaries run into the Bad River. The location of the Penokee Iron Range is marked, and extends along the arrows past the extent of this map. The inset map shows the location of the lakes within the state of Wisconsin.

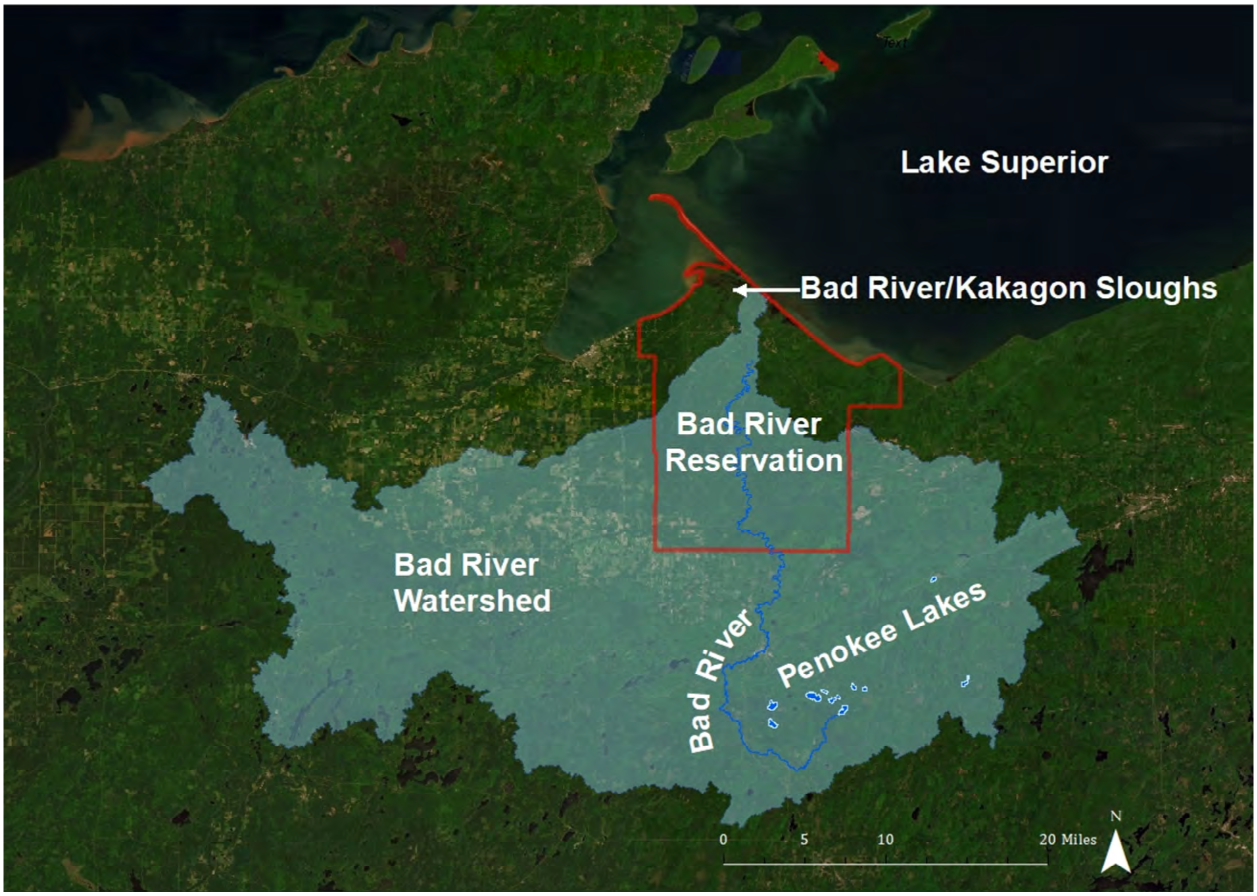


Figure 2.2. The eleven Penokee Lakes are shown in relation to the Bad River Watershed, the Bad River Reservation, Bad River/Kakagon Sloughs and Lake Superior.

3. Lake Uses and Users

To describe how the Penokee Lakes are used and valued by different groups of people, a series of stakeholder meetings were held throughout the project period and a property owner survey was conducted. This information was used to shape the management plan goals and implementation strategies described in section 5. Active participants in the stakeholder engagement process included private lakeshore landowners and representatives from the following groups, agencies, and organizations: the Wisconsin Department of Natural Resources, the Mashkiiziibii Natural Resources Department, the Red Cliff Environmental Department, the Great Lakes Indian Fish and Wildlife Commission, the Ashland and Iron County Land and Water Conservation Departments, The Nature Conservancy, the Galilee Lake Association, the Superior Rivers Watershed Association, and the Northland College Center for Rural Communities. The following sections describe results and key outcomes from the stakeholder involvement process.

3.1 Cultural Use and Values

The text in section 3.1 was contributed by Dawn White and John Coleman from the Great Lakes Indian Fish and Wildlife Commission (GLIFWC), with input from Edith Leoso, Bad River Tribal Historic Preservation Officer on April 1st, 2021.

The eleven Penokee Lakes in Ashland and Iron Counties Wisconsin identified within this plan are within the 1842 Ceded Territory Treaty Boundary. Signatory Ojibwe tribes to this treaty with the United States have reserved hunting, fishing, and gathering rights in this territory, to maintain a "lifeway" in a manner that meets their subsistence, economic, cultural, medicinal, and spiritual needs. These tribes advocate for the conservation of natural resources and the protection of habitats and ecosystems that support those resources. Conservation is dependent on effective and progressive management.

Not all uses or activities by tribal members are known or documented. Most recently documented is the use of several lakes for ceremony and walleye harvest purposes. Reports from the Great Lakes Indian Fish and Wildlife Commission (GLIFWC) indicate Lake Galilee and Meder Lake have been identified by Ojibwe tribes as having harvestable walleye. The intent to harvest walleye from Meder Lake was declared in 1989, but no harvest by Ojibwe tribal members was reported. Lake Galilee has been identified for harvest every year since 2012 and was harvested in 2013, 2014, and 2015 (https://www.glifwc.org/Mazinaigan/Summer2015/files/inc/6328d4976f.pdf). The tribes continue to have an interest in the lakes maintaining viable walleye populations that can be harvested. Tribal non-use should not be construed as not having an interest in the lake.

Manoomin, wild rice, is culturally important to local tribes. Recommendations to protect any and all populations of manoomin (wild rice) such as those reported in Upson and O'Brien lakes are encouraged. These relatively undeveloped lakes provide protection from human activities that often have adverse impacts to manoomin.

Although the Bad River Tribes Water Quality Standards only apply within reservation boundaries, the Penokee Lakes form the headwaters of the tribe's Outstanding Tribal Resource Water(s)* namely the Bad and Potato Rivers. The quality of upstream waters need to be maintained to enable compliance with water quality standards within reservation boundaries, providing for the designated uses within the reservation and lifeways throughout the Ceded Territory.

Since these lakes are south of the Bad River Reservation, it would be helpful to communities on the reservation to incorporate a long-term monitoring component to track changes in plant and animal communities due to climate change. Advanced knowledge of changes of plant phenology as well as animal and bird populations and behaviors would help Bad River communities better prepare for impacts to traditional uses and practices on reservation. Long-term monitoring and documentation of these changes are encouraged.

*"Outstanding Tribal Resource Water" (Chi minosingbii or "best waters") is a classification for those waters so designated in the antidegradation policy that are considered largely pristine and constitute a significantly important cultural and ecological resource. These waters are important for the cultivation of wild rice or the spawning of lake sturgeon, or have other special resource values. This classification is roughly equivalent to EPA's Tier 3 classification under its antidegradation policy, though this classification may be more protective than the Agency's policy. Source: https://www.epa.gov/wqs-tech/water-quality-standards-regulations-bad-river-band-lake-superior-chippewa-tribe

3.2 Property Owner Surveys

To further assess the usage patterns and users of the Penokee Lakes from people most regularly engaged with the lakes, a stakeholder survey of Penokee Lakes property owners was conducted in 2015 by the Center for Rural Communities at Northland College. Survey results are summarized here and the full survey report is included in Appendix A.

The survey was focused on property owners within one-mile of the shoreline of the eleven lakes as one of the primary mechanisms to capture information about values, attitudes, uses and behaviors of this stakeholder group. The final survey was divided into six parts covering a variety of topics including:

(1) participant demographic information,
(2) property information,
(3) participant uses of the lake,
(4) importance of these uses,
(5) participant attitudes toward the lake and its uses, and
(6) general values of the participants.

A census sample (i.e., the entire population) of households within one mile of the lakeshore of at least one of 15 Penokee Lakes was drawn from the Ashland and Iron County records. At the time the survey was conducted there were plans to study 15 lakes, but the present study includes the 11 in Figure 2.1. The only lake represented in this survey that is not one of the 11 Penokee Lakes is Beaver Lake (Table 3.1). After removing undeliverable surveys, duplicate landowners, or vacant properties, the final sampling size was 111 households. Surveys were delivered via mail using a modified Dillman method, where respondents were contacted prior to receiving their survey, sent the survey, and then sent a reminder if they did not return the survey within approximately two weeks. Surveys were sent out and received between September and November of 2015 with a 35.6 percent response rate (47 surveys returned). Average age of survey respondents was 63.4 years (ranging from 42 to 82), with the most commonly identified income range being below $100,000. Of the respondents, approximately 86.7 percent were waterfront owners and 56.8 percent were year-round residents (Table 3.2).

Given that the response rate was below 60%, response statistics should not be viewed as a representation of the entire population living within a mile of one of the Penokee Lakes. Furthermore, given the spatial limitations of the survey, these views should not be viewed as a representation of all those who may depend on the Penokee Lakes to meet their physical, emotional, and spiritual needs or well-being.

Several trends emerged from the survey responses that highlight how different individuals and groups use and value the lakes (Figures 3.1 and 3.2). Survey responses are summarized below with respect to the primary survey questions. The full survey report and survey form are located in Appendix A.

Main Survey Questions and Response Summaries:

1) How are the Penokee Lakes used?

The Penokee Lakes were most heavily used as a recreational resource by survey respondents. Among these uses, enjoying nature, gathering with friends, boating and fishing were the most common activities, with the majority of respondents participating in them at least once a month or more (Figure 3.1). Fisherpersons most typically fish crappie, bluegill and sunfish, although many indicate an interest in more opportunity to catch walleye.

2) Which potential uses are most important and/or highly valued by different user groups?

Among the different potential uses of the lakes, those that are most highly valued were the following: enjoyment of scenic beauty, maintaining a sense of peace and relaxation, gathering with family and friends, and fishing/ice fishing. Enjoying nature, snow sports, and the Penokee Lakes community were relatively highly valued by many individuals as well (Figure 3.2). Overall, survey results suggest that outside of the most highly valued, non-utilitarian uses, there exists a wide diversity of both recreational and utilitarian uses of the lakes among the different user groups.

3) What are the general attitudes among lake users relative to different ecological elements and potential stressors to the lake system?

The majority of respondents enjoyed the peace and quiet wilderness setting of the Penokee Lakes. Accordingly, many indicated that the lakes should be managed for conservation of its natural ecosystem. The majority of respondents asserted they care for the water quality of the lakes, a similar majority noted that if the health of the lake were to decline their property value would decline as well. Based on responses from fisherpersons, it seems that protection and maintenance of the ecosystem would be most supportive of their highest valued elements of fishing. Outside of general care for ecosystem health, there were no specific ecological elements or stressors that seemed to be of overwhelming concern to respondents. Even still, many respondents suggested that human intervention may be necessary in order to maintain the overall health of the Penokee Lakes ecosystem.

It should be noted that about two-thirds of the property owner survey respondents agreed or were undecided that having a grass lawn down to the lake's shore is better than natural vegetation and approximately two thirds also disagreed or were undecided that aquatic plants improve the appearance of the lake nearest their property. Thus, there appears to be a gap between the way some people perceive shoreland property management and the best shoreland management practices to promote healthy lakes (discussed in section 4.6). Any effort to work with shoreland property owners on habitat improvement projects may also need to include a thoughtful education and outreach strategy in order to reach their target audience.

4) How important are the Penokee Lakes in the lives of different user groups?

The Penokee Lakes are clearly an important part of the lives of those who use and interact with them; the majority of survey respondents indicated that declines in the lakes' health would adversely affect their well-being. Answers from respondents indicate significant potential for landowner involved protection efforts, but as noted in #3, education and outreach related to current perceptions about shoreland property management and best practices for helping the lakes may be needed. Many respondents would attend events, volunteer, limit current use or modify their own property management, of the lakes —in many cases, even if they were not likely to have opportunities to routinely use the lakes. Respondents would be less likely to financially support protection efforts.

5) What are the general value sets and/or beliefs that lake users likely base their actions on?

In general, survey respondents see the Penokee Lakes as a place to live and recreate. The majority of respondents are not only closely tied to the ecosystem, but the community surrounding the lakes. The majority of respondents indicated that lakes should, generally, be managed for conservation, but there was neutrality around the management responsibility and timeline (management for current or future needs).

Table 3.1. Survey respondent property location by lake.

On which lake is your property located?	
Lake Galilee	42.6%
Meder Lake	21.3%
Long Lake	12.8%
Eureka Lake	10.6%
East and West Twin Lake	4.3%
Beaver Lake	2.1%
Caroline Lake	2.1%
Maki Lake	2.1%
O'Brien Lake	2.1%

Table 3.2. Survey respondent residency.

How would you best describe your residency?	
Year-round	56.8%
Full time in the summer and more throughout the year	13.6%
Weekends throughout the year	9.1%
Weekends and/or part-time throughout the year	9.1%
Summer weekends and/or part-time in the summer	6.8%
Irregular	4.5%

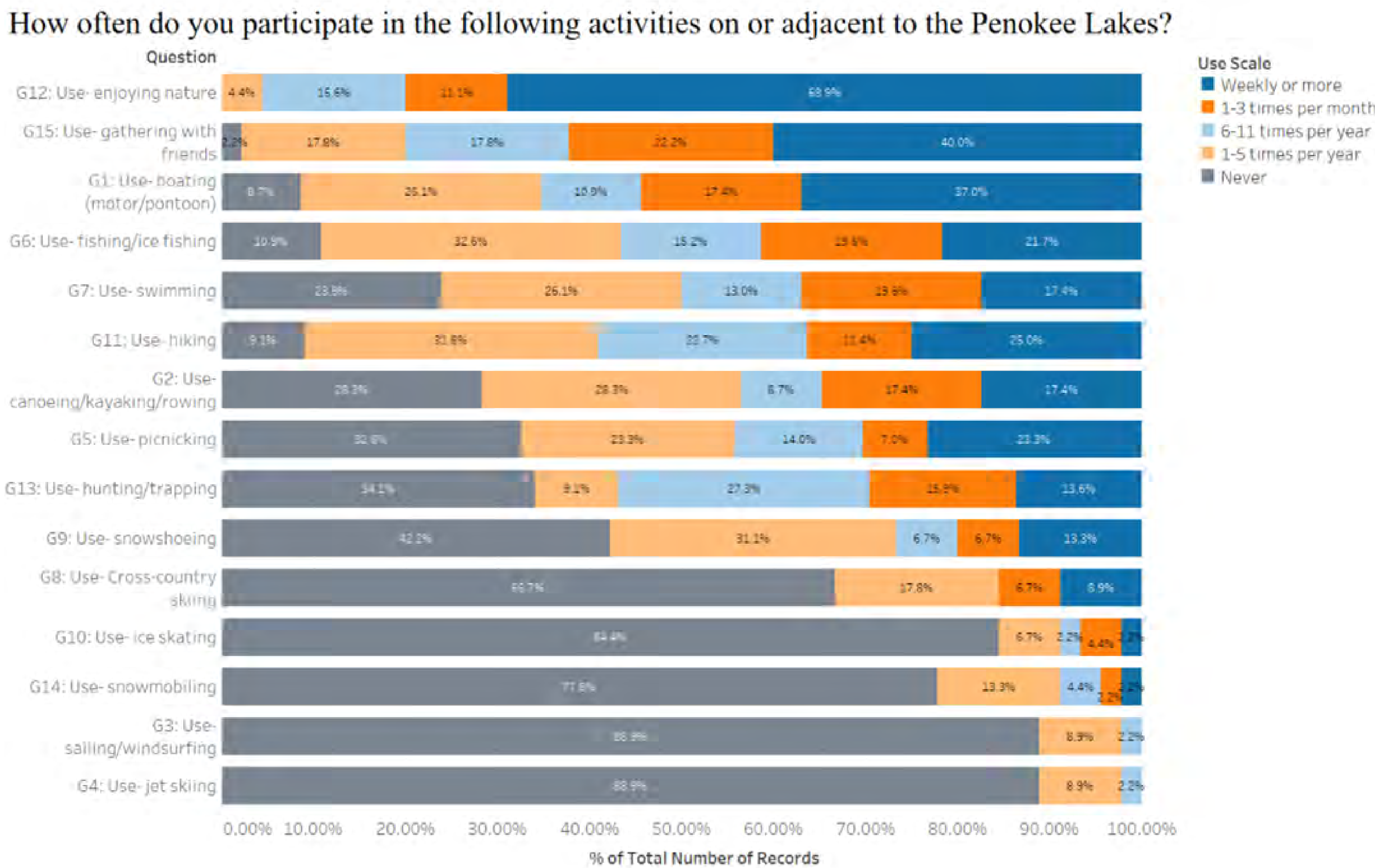


Figure 3.1. Most common uses of the Penokee Lakes by survey respondents.

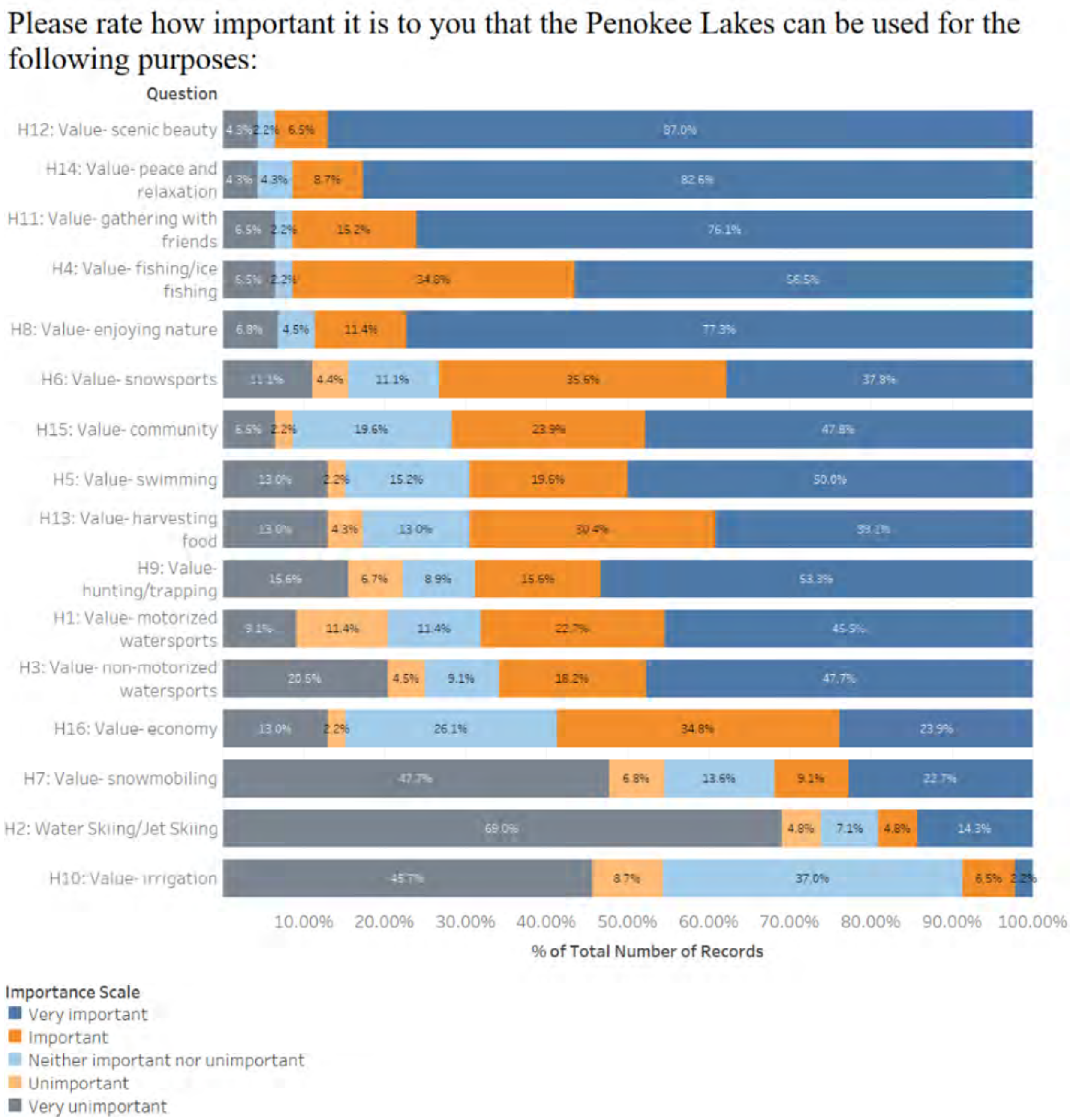


Figure 3.2. Most highly valued uses of the Penokee Lakes by survey respondents.

3.3 Broader Stakeholder Engagement

SOEI/Burke Center staff organized annual stakeholder update and engagement meetings at Northland College in late fall/early winter from 2015-2019 and virtually in May 2021. Project updates and results were presented and the meetings provided a forum for seeking input on project results, ideas for management plan goals, and identifying collaborative research priorities for the next year of the project. The meetings typically included a broad range of participants including Penokee Lake landowners and representatives from the Wisconsin Department of Natural Resources, the Mashkiiziibii Natural Resources Department, the Red Cliff Environmental Department, the Great Lakes Indian Fish and Wildlife Commission, the Ashland and Iron County Land and Water Conservation Departments, The Nature Conservancy, the Galilee Lake Association, the Superior Rivers Watershed Association, and the Northland College Center for Rural Communities.

A virtual meeting held by Burke Center staff on May 21, 2021, included project background and updates, but was mainly focused on a discussion about proposed management goals and implementation strategies. Participants expressed strong support for maintaining and enhancing water quality in the Penokee Lakes and identifying concrete action items following monitoring efforts. Participants were given the option to provide verbal input during the meeting and respond to an online survey after the meeting. All responses were compiled and used to update the draft management plan goals, as well as develop a series of implementation strategies for each of the goals. The updated goals and implementation strategies were shared with the stakeholder group, along with an Executive Summary of the management plan on November 2, 2021 for a 30-day comment period. In the interim period, the main body of the management plan was drafted, additional comments added, and the draft management plan minus appendices was sent out to stakeholders on December 22, 2021. Comments were addressed and incorporated into the draft management plan and appendices were completed. A final draft of the full management plan was sent out to WDNR Biologists for approval on 6/24/2022.

In summary, based on the stakeholder engagement process, it is clear that the Penokee Lakes are an important ecological, social, and cultural resource that are used and valued by different groups for different reasons. Across multiple questions in a landowner survey and through conversations with other lake users and stakeholders, the majority of respondents highlighted the value of the Penokee Lakes as sites for recreational activity and important ecological and cultural resources that should be protected for the benefit of the natural world and use by future generations.

4. Lake Condition Assessment

Conditions and processes that are necessary to support the desired uses identified in Section 3 for the Penokee Lakes are influenced by a variety of physical, chemical and biological processes. This section describes physical characteristics of and the current conditions in and around the Penokee Lakes during the 2015-2020 study period.

4.1. Overview of the Lakes

Morphometry

Table 4.1 describes a range of morphometric characteristics for each of the Penokee Lakes. Watershed areas were delineated in ArcGIS using publicly available Light Detection and Ranging (LiDAR) surface elevation data for Ashland and Iron Counties and the Natural Resources Conservation Service (NRCS) Engineering Toolbox. All other parameters listed were taken from a WDNR spreadsheet titled "WILakeData03292016," which contains data on all named Wisconsin Lakes greater than 5 acres in surface area (Diebel, 2016). Lake volume for Maki, McCarthy and O'Brien Lakes was not available in the spreadsheet, so was estimated by multiplying the mean depth by the lake surface area.

The lakes range from 26 to 212 acres in surface area, with surface watershed areas draining to each lake ranging from 64 to 2,109 acres (Table 4.1, Figure 4.1). Watershed-to-lake-surface-area ratios ranged from 1.6 to 26.8. Most are relatively shallow lakes, with maximum depths ranging from 8 to 28 feet and mean depths between 5 and 12 feet. Shoreline lengths range from 0.83 to 2.9 miles (Table 4.1).

Table 4.1. Morphometric characteristics for each of the eleven Penokee Lakes.

Parameter	East Twin	West Twin	Eureka	Galilee	Meder	Long	Maki	McCarthy	Upson	O'Brien	Caroline
Lake Surface Area (acre)	26	59	39	212	135	111	40	43	49	76	122
Watershed Area (acre)	103	292	470	1088	560	611	64	754	395	2034	2109
Watershed:Surface Area Ratio	4.0	5.0	12.0	5.1	4.1	5.5	1.6	17.5	8.1	26.8	17.3
Lake Maximum Depth (ft)	24	14	28	23	10	13	14	13	17	12	8
Lake Mean Depth (ft)	11	7	12	11	7	7	7	6.5	7	7	5
Lake Volume (acre-ft)	292	379	467	2348	878	782	280	280	299	532	679
Shoreline (mi)	0.83	1.4	1.2	2.9	2.2	2	0.96	1.14	1.14	2.34	2.3

Among the eleven Penokee Lakes, there are developed public access points on Eureka, Galilee, Meder, Long, Upson, O'Brien, and Caroline Lakes. The remaining four lakes are publicly accessible, but with largely undeveloped access points.

Figure 4.1. The eleven Penokee Lakes and their surface watersheds outlined in black.

Climate and Precipitation

Climate in the Penokee Lakes area is considered continental, but it is moderately affected by the Lake Superior climate zone. Summer high temperatures average in the 70s Fahrenheit and low temperatures average in the 50s Fahrenheit. Winter high temperatures average in the 20s Fahrenheit and low temperatures average in the single digits Fahrenheit (Figure 4.2). Annual rainfall precipitation averages 33.3 inches, while average annual snowfall is approximately 103 inches. Based on precipitation frequency data from the middle of the 20th Century, the 100-year, 24-hour precipitation event was expected to yield 5.25 inches (Hershfield, 1963). Precipitation recurrence intervals were recently updated in Atlas 14 (Perica *et al*. 2013) to account for increased spatial resolution in climatological data and account for any shifts in precipitation patterns over the last ~50 years. Based on these updates, the 100-year, 24-hr precipitation event in the Penokee Lakes area is now expected to yield 7.71 inches (a 47% increase; Figure 4.3).

Additional changes in precipitation and atmospheric temperatures are anticipated throughout the region as a part of global climate change. As part of the Wisconsin Initiative on Climate Change Impacts (WICCI; http://www.wicci.wisc.edu/) a series of studies were conducted across Wisconsin to assess existing, and project future, climatically driven changes in environmental conditions. The major findings of this multi-year assessment (as is related to lake management) are that precipitation patterns are likely to become more intense and less frequent (i.e., increased potential for both drought and flooding) and that annual average temperatures are likely to increase. Evidence suggests that some of these changes are already occurring and that the rates of climate change are likely to increase into the future (Perica *et al*. 2013, WICCI 2022).

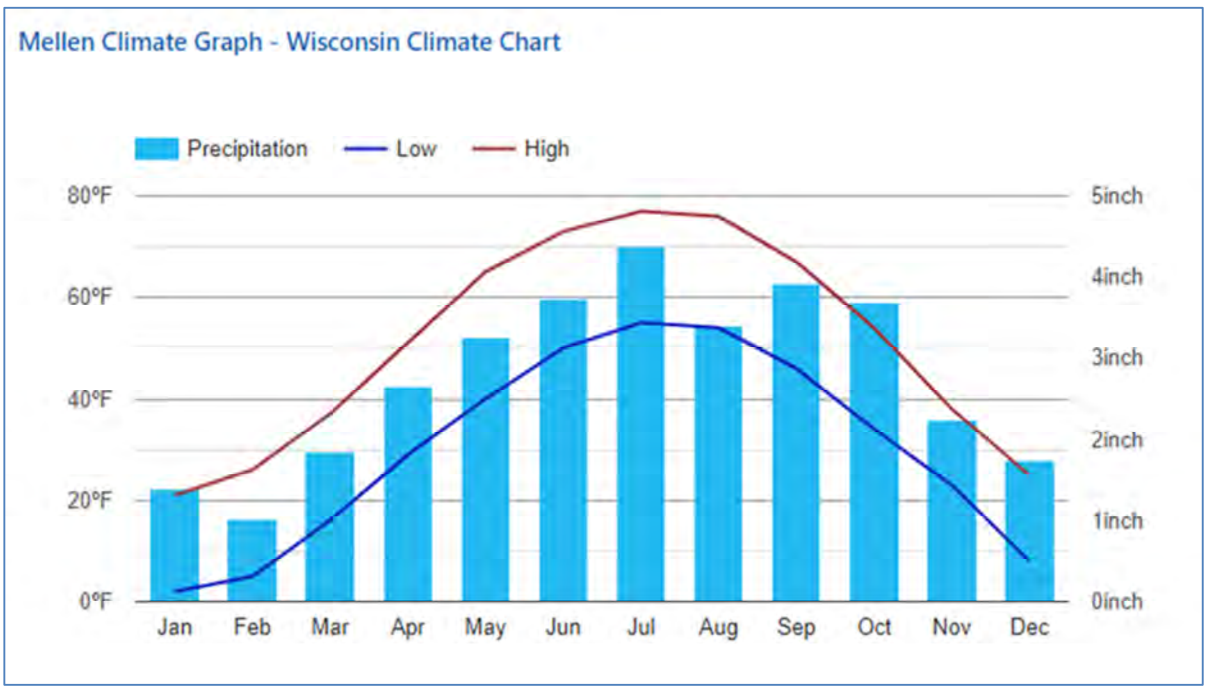


Figure 4.2. Monthly temperature and precipitation data for Mellen, WI (U.S. Climate Data, Accessed 3-22-21).

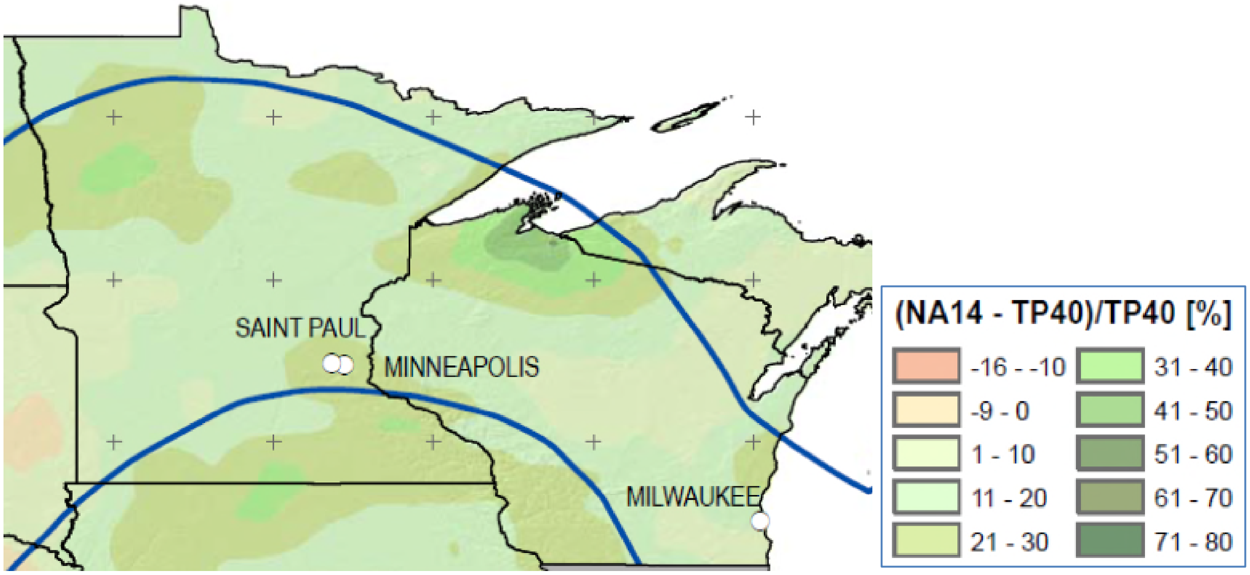


Figure 4.3. A comparison of the percent change in the 100-year, 24-hour precipitation events between the Atlas 14 and TP 40 publications. Adopted from Atlas 14 (Perica *et al*. 2013).

Geology and Soils

The Penokee Iron Range is a segment of the Gogebic Iron Range, an 80-mile stretch of Paleoproterozoic strata that runs from Lake Gogebic in the Upper Peninsula of Michigan into Northern Wisconsin (Cannon *et al*., 2008). The most recent deglaciation of this landscape, occurring around 13,200 years ago, left behind an abundance of lakes and waterways, including the eleven lakes which are the focus of this study. The Penokee Iron Range extends approximately 21 miles from Upson to Mineral Lake, Wisconsin, (Marsden, 1978). The study area, which straddles the iron formation, is mostly embedded in a mix of undivided volcanic rock and metamorphosed diabase and gabbro bedrock (Cannon *et al*., 1996). One of the lakes of interest (Upson) is within the Tyler Formation, made up of quartz-rich graywacke and argillite (Cannon *et al*., 1996).

A groundwater modeling report for the Bad River watershed further describes the hydrogeologic setting for the area where the Penokee Lakes are located (Leaf *et al*. 2015). The lakes are located within what are referred to as the “southern bedrock uplands” of the Bad River watershed, which consists of poorly drained, relatively flat uplands underlain by Archean crystalline basement rock. Overlaying the bedrock are Copper Falls Formation sandy tills and glacial outwash, which are generally less than 100 ft thick (Clayton, 1984). Groundwater flow paths are generally very short (Leaf *et al*. 2015).

The hydrogeologic setting is further confirmed by looking at the hydrologic soil groups within the watersheds of the Penokee Lakes (Figure 4.4 and Table 4.2). Very slow infiltration soils are most dominant (51.3 percent). Even the approximately 25% of the watershed with high infiltration soils occur in wetland areas and other areas of shallow soil above bedrock. High infiltration soils that are not saturated or close to the water table make up only 1.3% of the total watershed area (Table 4.2). This information suggests that surface runoff from poorly drained watershed soils and limited amounts of shallow groundwater inputs are important factors affecting the hydrology of these lakes.

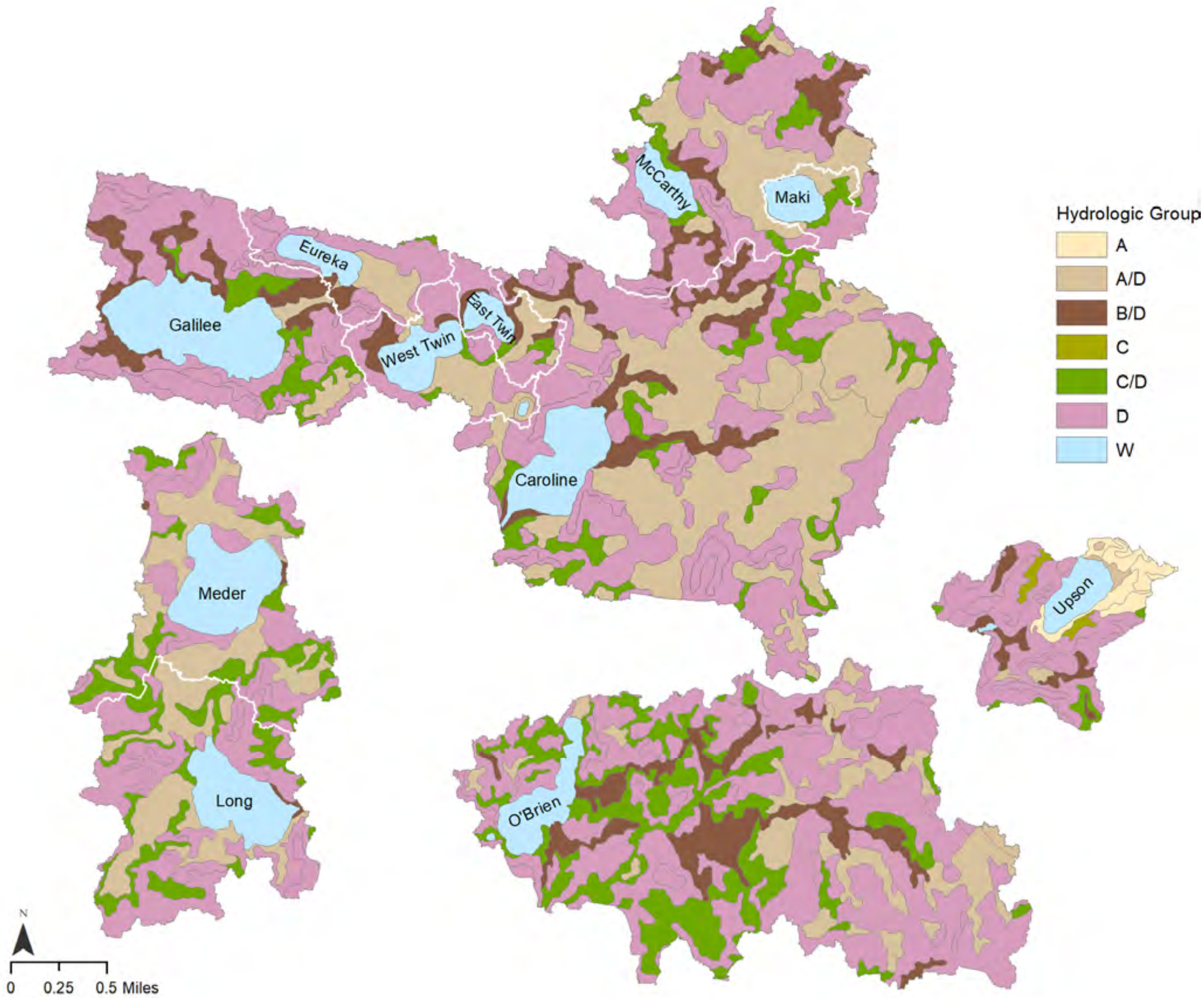


Figure 4.4. Distribution of hydrologic soil groups throughout the Penokee Lakes watershed. Based on Natural Resource Conservation Service (NRCS) SURRGO soil classifications. Group A soils are high infiltration, Group B soils are moderate infiltration, Group C soils are slow infiltration, and Group D soils are very slow infiltration. For dual hydrologic groups A/D, B/D, and C/D, the first letter represents the soil group if the area is drained, and the second letter represents the area's natural condition (USDA-NRCS 2007).

Table 4.2. Hydrologic soil group percentages for the watershed areas draining to all eleven Penokee Lakes.

Hydrologic Soil Group	Percent
A	1.3
A/D	25.1
B/D	9.0
C	0.2
C/D	13.1
D	51.3

Land Cover

Land cover data for each of the lakes was mapped in ArcGIS using publicly available land cover datasets from the WDNR. These datasets include historical land cover data from the mid-1800s (http://data-wi-dnr.opendata.arcgis.com/datasets/original-vegetation-polygons), WISCLAND 1.0 data from 1992 (http://geodata.wisc.edu/opengeoportal/) and WISCLAND 2.0 data from 2014 (https://data-wi-dnr.opendata.arcgis.com/datasets?q=wisc%20land%20cover).

Historically, the watersheds were dominated by forest and wetland. Between the 19th century and 2014, low density residential areas have increased slightly. Because methods of describing and categorizing land cover changed over time, it is challenging to compare land cover types between different time periods. However, it appears that relatively little of the Penokee Lakes watersheds have been subject to development over time (Table 4.3). As was the case historically, land cover throughout the Penokee Lakes watersheds is currently dominated by forests and wetlands, while developed lands make up a very small percentage of the land area (Figure 4.5).

Table 4.3. Percentage of forest and wetland land cover within the watersheds for each of the eleven Penokee Lakes. Data from the 1800s are Wisconsin's Original Vegetation polygons. Data from 1992 and 2014 from the WISCLAND datasets 1.0 and 2.0 respectively.

	1800s	**1992**	**2014**
East Twin	100.0%	97.8%	100.0%
West Twin	100.0%	95.8%	100.0%
Eureka	100.0%	96.4%	100.0%
Galilee	100.0%	96.5%	99.6%
Meder	100.0%	95.8%	98.5%
Long	100.0%	97.7%	99.6%
Maki	100.0%	100.0%	100.0%
McCarthy	100.0%	99.3%	100.0%
O'Brien	100.0%	97.9%	99.7%
Upson	100.0%	99.4%	100.0%
Caroline	100.0%	98.8%	100.0%

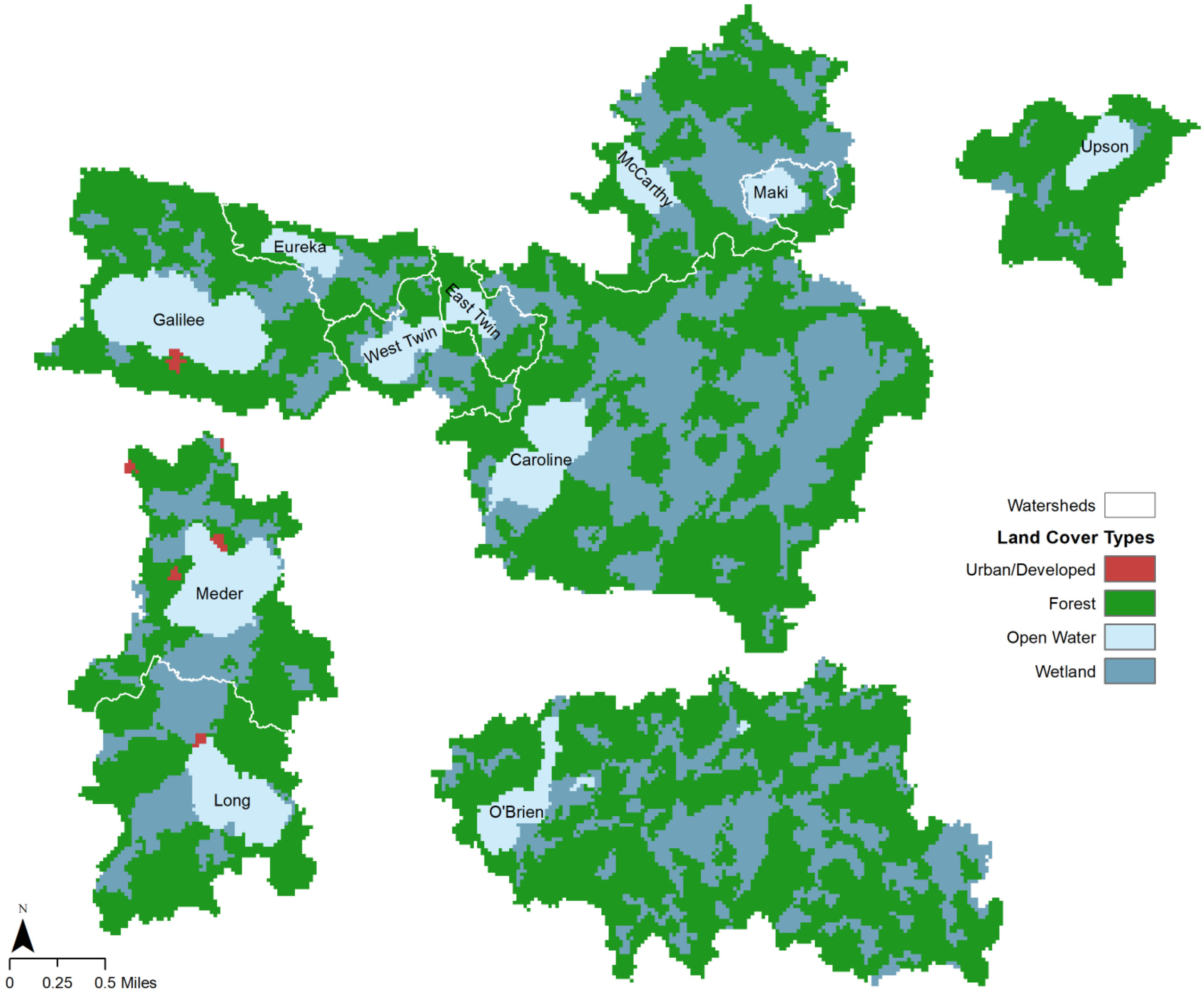


Figure 4.5. Land cover in the Penokee Lakes watershed in 2014 (WISCLAND 2.0; WDNR, 2016).

Shoreland Parcel Ownership

Shoreline parcel ownership, whether it be publicly or privately held, can play a very important role in current or potential future levels of human development in shoreland areas of lakes. As will be discussed further in Section 4.6, "shoreland" development, within areas including the lake shoreline as well as terrestrial riparian areas and shallow lake areas near to the shore, plays a very important role in lake water quality as well as habitat for fish and other aquatic organisms. Shoreline areas in public ownership or in private or land trust ownership with some sort of protected status or limit on development are areas that are most likely to remain undeveloped. Private property without a conservation easement or other limit on potential subdivision is more susceptible to future changes, particularly increases in development that can be detrimental to water quality and aesthetics in lakes.

The majority of the shoreland areas around the Penokee Lakes are privately held and undeveloped. As of 2018, private ownership ranged from more than 95% around O'Brien, Meder, Eureka, Galilee, and Long Lakes to 0% around Upson Lake (Table 4.4 and Figure 4.6).

Table 4.4. Public and privately held percentages of shoreline ownership in each of the eleven Penokee Lakes as of 2018. Parcel data were obtained from the Ashland and Iron County zoning offices.

Parameter	East Twin	West Twin	Eureka	Galilee	Meder	Long	Maki	McCarthy	Upson	O'Brien	Caroline
Shoreline (mi)	0.83	1.4	1.2	2.9	2.2	2	0.96	1.14	1.14	2.34	2.3
Percent Public/Land Trust Shoreline	87.8	57.8	1.1	3.1	0.9	4.2	30.5	17.5	100.0	0.0	83.1
Percent Private Shoreline	12.2	42.2	98.9	96.9	99.1	95.8	69.5	82.5	0.0	100.0	16.9

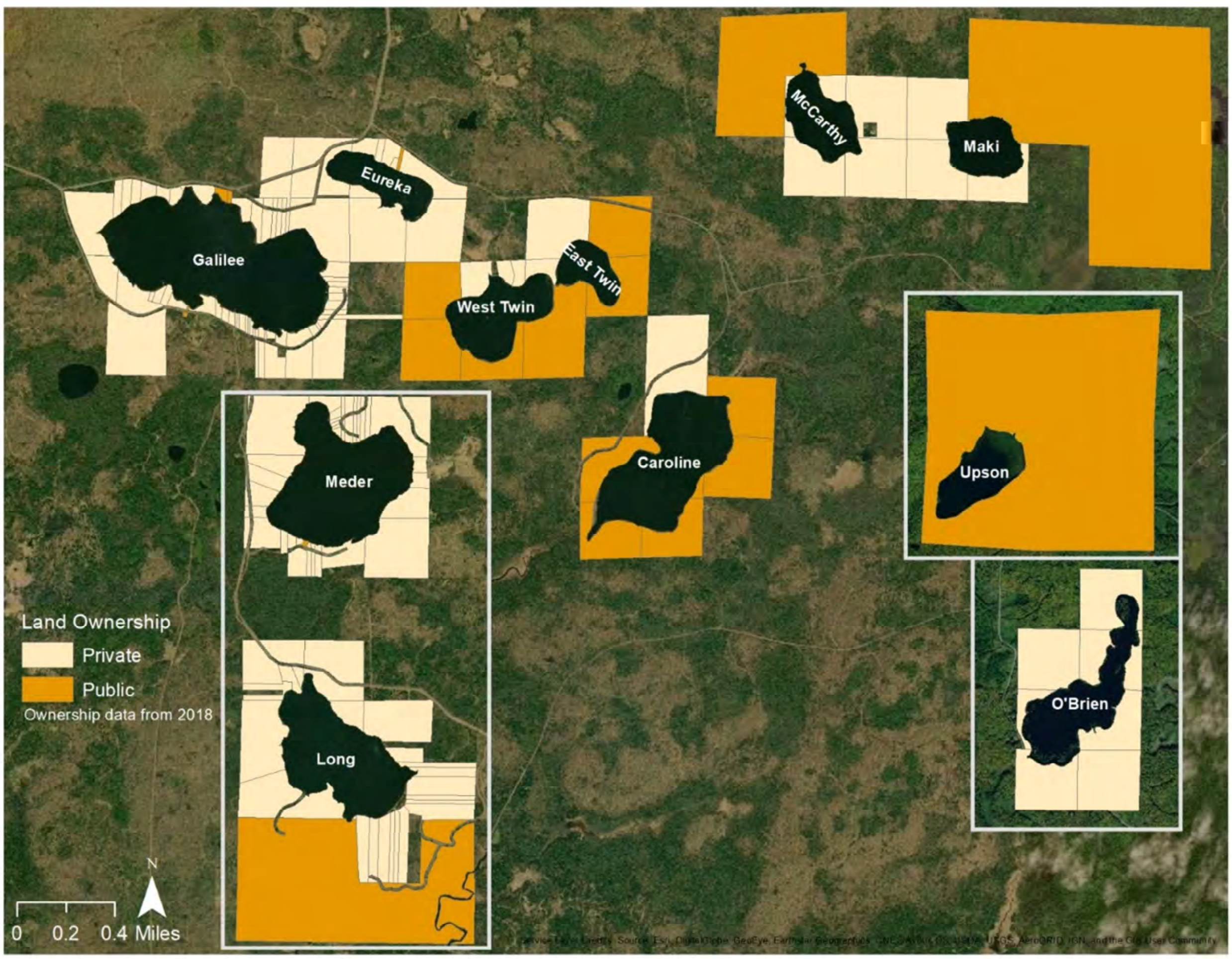


Figure 4.6. Shoreline parcel ownership surrounding the eleven Penokee Lakes. "Public" ownership includes land owned by a government entity or a land trust. Parcel data were obtained from the Ashland and Iron County zoning offices.

State Natural Areas and Important Wildlife Habitat

The Penokee Lakes region is home to a number of state natural areas and important wildlife habitat types. Caroline Lake, West Twin Lake, and East Twin Lake are part of the Caroline Lake State Natural Area. The Caroline Lake State Natural Area provides a wide variety of habitat types, including northern wet forest, northern dry-mesic forest, northern sedge meadow, shrub carr, and open bog. The expansive forested wetlands in this area provide important nesting habitat for several warbler species. Common loons, osprey, bald eagles, and fresh water sponges have been observed at the site.

The Wisconsin Wildlife Action Plan (2008) classifies the Penokee Range as an Important Bird Area and a Conservation Opportunity Area of Continental Significance. This landscape helps to connect the Chequamegon-Nicolet National Forest in northern Wisconsin to the Ottawa National Forest in the Upper Peninsula of Michigan, thereby providing habitat for animals with large home ranges, such as timber wolves and American martens. This habitat is also used by migrant songbirds for nesting ("Iron Mining in the Penokee Range," The Nature Conservancy).

4.2 Lake Classification

The WDNR is required under the federal Clean Water Act to evaluate whether surface waters of the state are meeting water quality standards (known as "305(b) assessments") every two years. Wisconsin's Coordinated Assessment and Listing Methodology (WisCALM 2022; WDNR, 2021) defines methodologies WDNR uses to conduct the assessments. In order to facilitate the assessments for lakes, WDNR classifies lakes based on size, stratification characteristics, hydrology, and watershed size. These characteristics play a major role in determining the natural biological communities each lake type supports. Thus, WDNR has established ten natural community types to classify and assess all Wisconsin lakes (Table 4.5; WDNR, 2021).

Table 4.5. Lake and reservoir natural communities and defining characteristics (from WisCALM 2022; WDNR, 2021).

Natural Community	Stratification Status	Hydrology
Lakes/Reservoirs <10 acres		
• Small	Variable	Any
Lakes/Reservoirs ≥10 acres		
• Shallow Seepage	Mixed	Seepage
• Shallow Headwater		Headwater Drainage
• Shallow Lowland		Lowland Drainage
• Deep Seepage	Stratified	Seepage
• Deep Headwater		Headwater Drainage
• Deep Lowland		Lowland Drainage
Other Classification (any size)		
• Spring Ponds	Variable	Spring Hydrology
• Two-Story Fishery Lakes	Stratified	Any
• Impounded Flowing Waters	Variable	Headwater or Lowland Drainage

The natural community classification determines the thresholds that WDNR uses to determine if lakes are healthy and meeting designated uses or are impaired and not meeting one or more designated uses. The natural community classification is typically established automatically based on known parameters of lakes, but can be updated as new data and information about a lake are generated. Current natural community classifications for the Penokee Lakes are listed in Table 4.6.

All of the Penokee Lakes are greater than 10 acres in size, so are considered "large" lakes for classification purposes (Table 4.1). The lakes currently classified as "drainage" lakes all have a "headwater" classification, indicating they should have a watershed size of less than four square miles. The watershed size for all of the lakes is less than four square miles (2,560 acres; Table 4.1), so the "headwater" classification is confirmed.

An assessment of the current "hydrology" and "stratification status" classification for each of the Penokee Lakes was done to evaluate whether the current natural community listing for each lake is confirmed or may need revision.

Table 4.6. Current natural community classifications for the eleven Penokee Lakes (Beranek, personal communication).

Lake	Natural Community	Stratification Status	Hydrology
East Twin	Deep Seepage	Stratified	Seepage
West Twin	Shallow Seepage	Mixed	Seepage
Eureka	Deep Headwater	Stratified	Drainage
Galilee	Shallow Headwater	Mixed	Drainage
Meder	Shallow Headwater	Mixed	Drainage
Long	Shallow Headwater	Mixed	Drainage
Maki	Shallow Seepage	Mixed	Seepage
McCarthy	Shallow Headwater	Mixed	Drainage
Upson	Deep Headwater	Stratified	Drainage
O'Brien	Shallow Headwater	Mixed	Drainage
Caroline	Shallow Headwater	Mixed	Drainage

Hydrology

The volume of water in a lake is determined by its surface area, bathymetry, and the relative inputs and losses of water to and from the surrounding atmospheric, groundwater and surface water systems (Figure 4.7). The relative influence of these different systems varies among lakes and within each specific lake, as the rate, timing, and form of precipitation varies throughout the season. The relationship between the different inflow and loss processes in the lake (i.e., its water budget) is heavily influenced by its landscape position. In general, groundwater and atmospheric systems are the most important drivers of hydrologic processes in lakes that have a high landscape position (i.e., headwater and/or seepage lakes). In contrast, the further downstream a lake is located in a watershed, the more important surface water becomes as an input and loss mechanism.

Based on field observations, all of the Penokee Lakes should have a "drainage" classification for hydrology except perhaps Maki Lake. Maki Lake is currently listed as a "seepage" lake. There is an outlet to Maki Lake, but not enough field observations were made during the study period to confirm whether it is intermittent or perennial. Thus, a "drainage" classification is likely more reflective of field conditions than "seepage" without further verification. East and West Twin Lakes are currently listed as "seepage." East and West Twin Lakes are effectively one lake with two basins connected by a narrow channel. Minnow Creek flows from the outlet of West Twin Lake and all field observations of this outlet have indicated perennial flow.

While all of the Penokee Lakes are likely best classified as "drainage" lakes, their landscape position and watershed-area-to-lake-surface-area ratios differ, which affects whether more water is delivered to the lake via surface runoff and tributary discharge and/or from groundwater flow. It also affects the residence time of water in the lake, which is the amount of time it takes to fully replace the entire volume of water in the lake. These are important characteristics for understanding biological communities in the lakes and susceptibility to contamination from runoff and development.

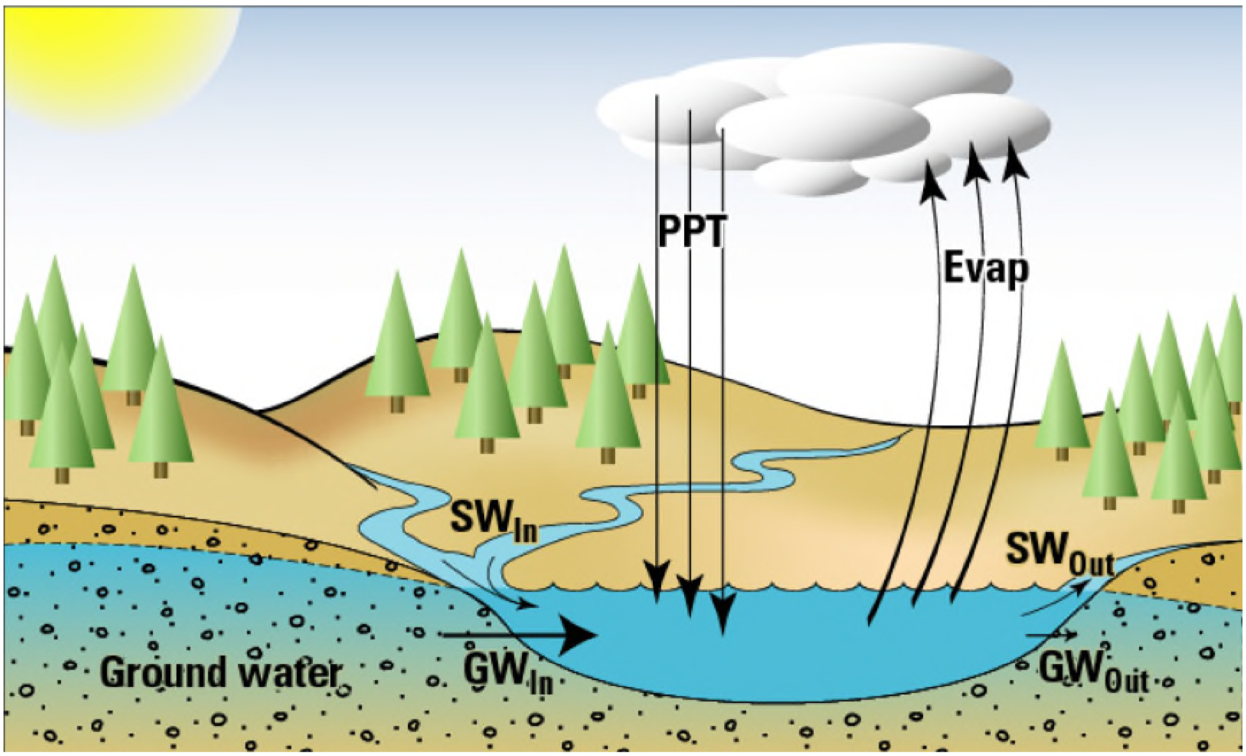


Figure 4.7. Conceptual schematic describing surface water (SW), groundwater (GW), precipitation (PPT) and evaporation (Evap) that determine lake levels (adopted from Robertson *et al*., 2003).

Water residence time and its relationship to watershed area was evaluated for each of the Penokee Lakes. The Wisconsin Lake Modeling Suite (WiLMS; Panuska, & Kreider, 2003) "Hydrologic and Morphometric Module" was used to estimate water residence times for all of the Penokee Lakes. In addition, water residence time estimates were available for some lakes in the "WILakeData03292016" spreadsheet (Diebel, 2016). Table 4.7 shows water residence times from both sources. The "WILakeData03292016" numbers were also generated from WiLMS but with watershed delineations developed using a different elevation model than the current study (which used high-resolution LiDAR data). On a relative basis, the residence times are similar, but the differences in magnitude highlight the variability from using modeled estimates.

Table 4.7. Estimated water residence times for each of the eleven Penokee Lakes.

Lake	Residence Time (days); WiLMS	Median Residence Time (days); Diebel, 2016
East Twin	785	N/A
West Twin	369	N/A
Eureka	299	N/A
Galilee	613	N/A
Meder	434	N/A
Long	365	N/A
Maki	1044	N/A
McCarthy	113	240
Upson	223	280
O'Brien	80	110
Caroline	99	160

The WiLMS model estimates generated with the current study were used to regress against each lake's watershed-area-to-lake-surface-area ratio (Figure 4.8). The power regression model indicates a very strong correlation between these parameters. Lakes with longer residence times (e.g., Maki and East Twin Lakes) have the smallest watershed-area-to-lake-surface-area ratio. In contrast, lakes with shorter residence times (e.g. Caroline and O'Brien Lakes) have larger ratios. What this means in a lake management context is that lakes with long residence times and small watersheds can be particularly vulnerable to degradation from shoreline development and rehabilitation of these lakes can take much longer than lakes with larger watersheds and shorter residence times. However, lakes with larger watersheds may be vulnerable to land cover changes from locations farther from the lake, despite shorter water residence times allowing for a quicker response from rehabilitation efforts.

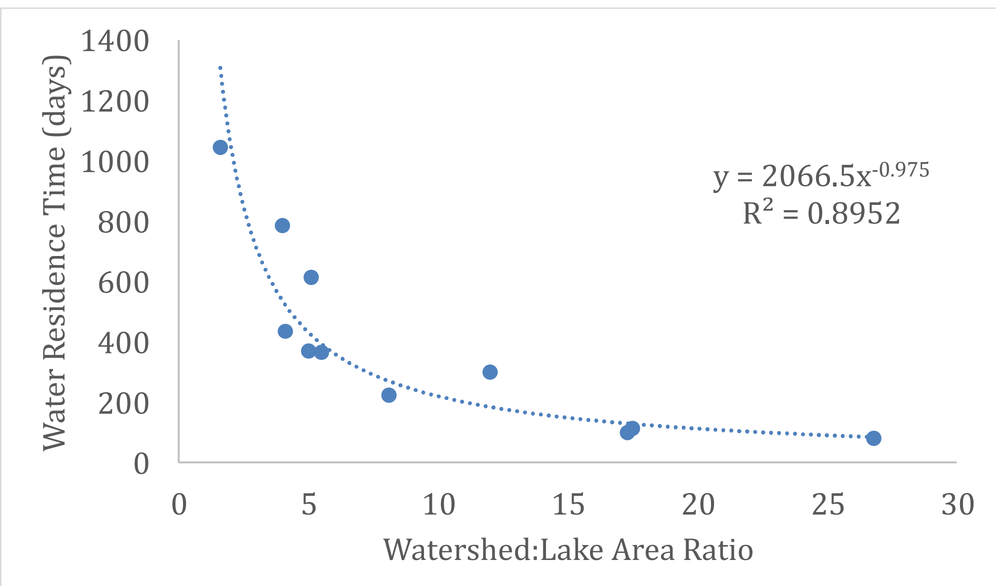


Figure 4.8. Estimated water residence time (calculated using the Wisconsin Lake Modeling Suite; Panuska, & Kreider, 2003) regressed against watershed-to-lake-surface-area ratio for each of the eleven Penokee Lakes. A power regression model equation and R^2 value are given.

Groundwater

A detailed assessment of water budget was not completed for each lake as part of this study. However, some inferences can be made on relative sources of water to each lake, particularly as it relates to groundwater. The USGS recently developed a regional MODFLOW groundwater-surface water interactions model for the Bad River Watershed (Leaf *et al*. 2015). The area covered by the model includes the Penokee Lakes. One of the key findings relevant to the Penokee Lakes is that the region of the Bad River watershed where they are located "*is characterized by shallow, localized flow systems in mostly thin quaternary deposits and fractured bedrock, with relatively short flow paths from local recharge areas to nearby streams and wetlands. As evidenced by the model and consistent with stable isotope results, groundwater in this area appears to be relatively young, on the order of several hundred years old or less,* (Leaf *et al.* 2015). Thus, any groundwater contributions to the Penokee Lakes are likely to come from recharge areas close to the lakes. Eight of the 11 Penokee Lakes, including East Twin, West Twin, Meder, Long, Maki, Upson, O'Brien, and Caroline are effectively headwater drainage lakes with minimal to no surface inflow and perennial outflow (with the possible exception of Maki Lake, which may have an intermittent outflow). This indicates that groundwater inputs sustain perennial tributary outflow from these lakes. Lakes with perennial inflow and outflow, including Eureka, Galilee, and McCarthy (McCarthy inflow may be intermittent), likely receive more of their overall water budget from surface inputs, but groundwater is still an important contributor to these lakes as is evidenced by mean surface specific conductance measurements (Figure 4.9). As water moves through the ground, it dissolves minerals from the deposits it moves through, which increases the conductivity of the water. Because of the relatively low amounts of shoreline development, the increase in specific conductance in these lakes moving from upstream to downstream is likely an indication of increasing groundwater contributions rather than human pollution.

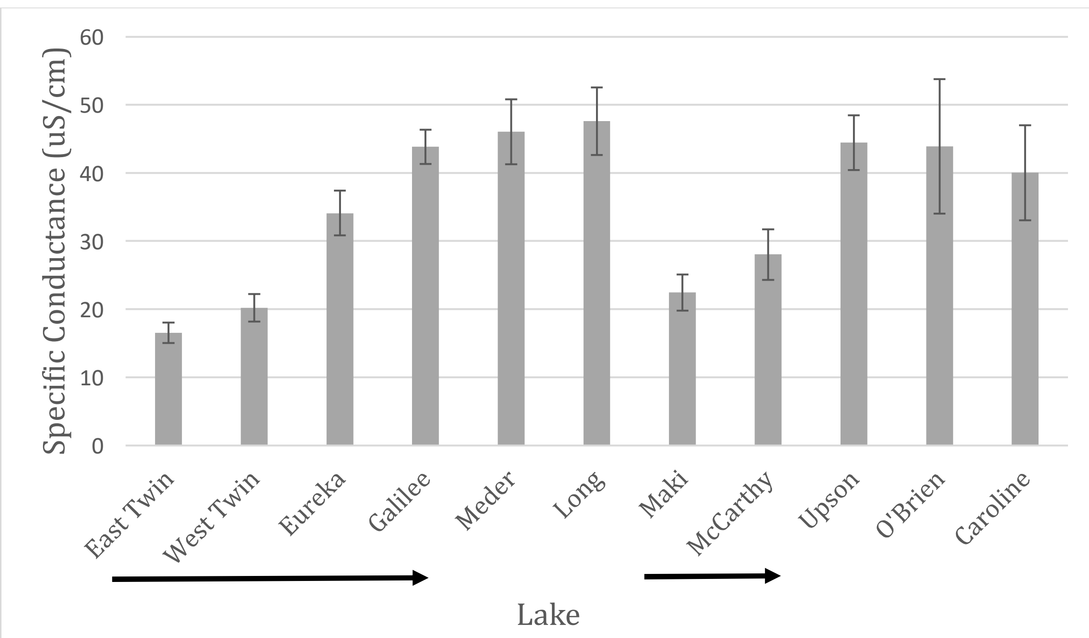


Figure 4.9. Mean and standard deviation of surface (0-2 meters) specific conductance measurements in the eleven Penokee Lakes. The arrows indicate lakes that are connected via tributary flow, ordered from upstream to downstream, with East Twin ultimately connected to Galilee via Minnow Creek and Maki connected to McCarthy via an unnamed tributary.

Water Level Fluctuation

Lake levels fluctuate on annual and multi-year time scales. Throughout any given year, water levels rise and fall in response to the size and timing of precipitation events. Across years (potentially decades), lake levels maintain different points of equilibrium. In drought years, water levels are generally lower, while in wet years, lake levels are generally higher. Water levels are also affected by outlet control structures, including those constructed by beavers. Beaver activity is a particularly important factor affecting water levels and water level fluctuations in the Penokee Lakes. Over time, different high-water events leave marks on the shoreline that designate the Ordinary High Water (OHW) mark, which has important regulatory and management implications. In addition to affecting how humans use and interact with lakes, water level fluctuations affect biological communities in lakes in a wide range of ways. Some of these include affecting water clarity (e.g. Juckem and Robertson 2013), reduced abundance and growth rates of fish species (Gaeta *et al*. 2014), and mercury concentrations in fish (Watras *et al*. 2019).

Continuous water level records were measured for each of the Penokee Lakes during different years of the study period (Table 4.8). Non-vented pressure transducers (Onset HOBO U20-04 and U20L-04 models; Bourne, MA) were suspended within perforated, 2-inch PVC conduit secured to a fence or sign post driven into the lake bed at each site. The loggers were programmed to collect data at one-hour intervals. They were installed shortly after ice-out each spring and removed prior to ice formation in the fall. All reference points and marks used to establish water level elevations were surveyed during logger installation in spring and removal in fall utilizing the Burke Center's "Levels at Gaging Stations" protocol (MGBCFI 2021), which is based on United States Geological Survey (USGS) methods (Kenney, 2010). Water level records were corrected for drift and reference point movement and finalized using AQUARIUS time-series software (Aquatic Informatics, Inc., Vancouver, BC, CA).

Table 4.8. Years in which continuous water level data were collected from each of the eleven Penokee Lakes. East and West Twin Lakes are connected and were assumed to have the same water level.

Lake	2015	2016	2017	2018	2019	2020
East/West Twin	X	X	X	X	X	X
Eureka	X	X	X	X	X	
Galilee			X	X	X	X
Meder				X	X	X
Long				X	X	
Maki		X	X	X	X	X
McCarthy			X	X	X	
Upson			X	X	X	X
O'Brien			X	X	X	X
Caroline		X	X	X	X	X

McCarthy and Maki Lakes showed the least annual water level fluctuation and Upson and O'Brien Lakes showed the greatest annual water level fluctuation. Upson, Long, and O'Brien Lakes showed more variability in their annual fluctuations, while the other lakes showed more consistent fluctuations between years (Figure 4.10). Water levels in most lakes tended to be higher in spring and fall and lowest in mid-summer (see Appendix E). The lakes exhibited strong relationships between water level and precipitation, with spikes in water level being closely preceded by rain events (Figure 4.11).

Beaver dam activity may also cause larger fluctuations in water level and dramatic decreases in water level when beaver dams are either blown out naturally or removed by human activity. Beavers can also increase water levels during otherwise dry periods. The water level record for Caroline Lake illustrates the influence of precipitation events as well as beaver dams (Figure 4.12). Rapid water level increases of over one foot were observed around large precipitation events in July 2016, May 2017, and June 2018. The influence of beaver dams on water levels can be seen from mid-summer into fall for each year except for 2016, as water levels gradually increase and rarely decrease during periods of the year that typically see lower water levels. Water level fluctuations in 2016 indicate less control of the lake outlet by beaver dams as the water level tended to return to a similar base level after precipitation events rather than gradually increase into fall as in other years of the record (Figure 4.12). Water level records for each lake are shown and discussed further in Appendix E.

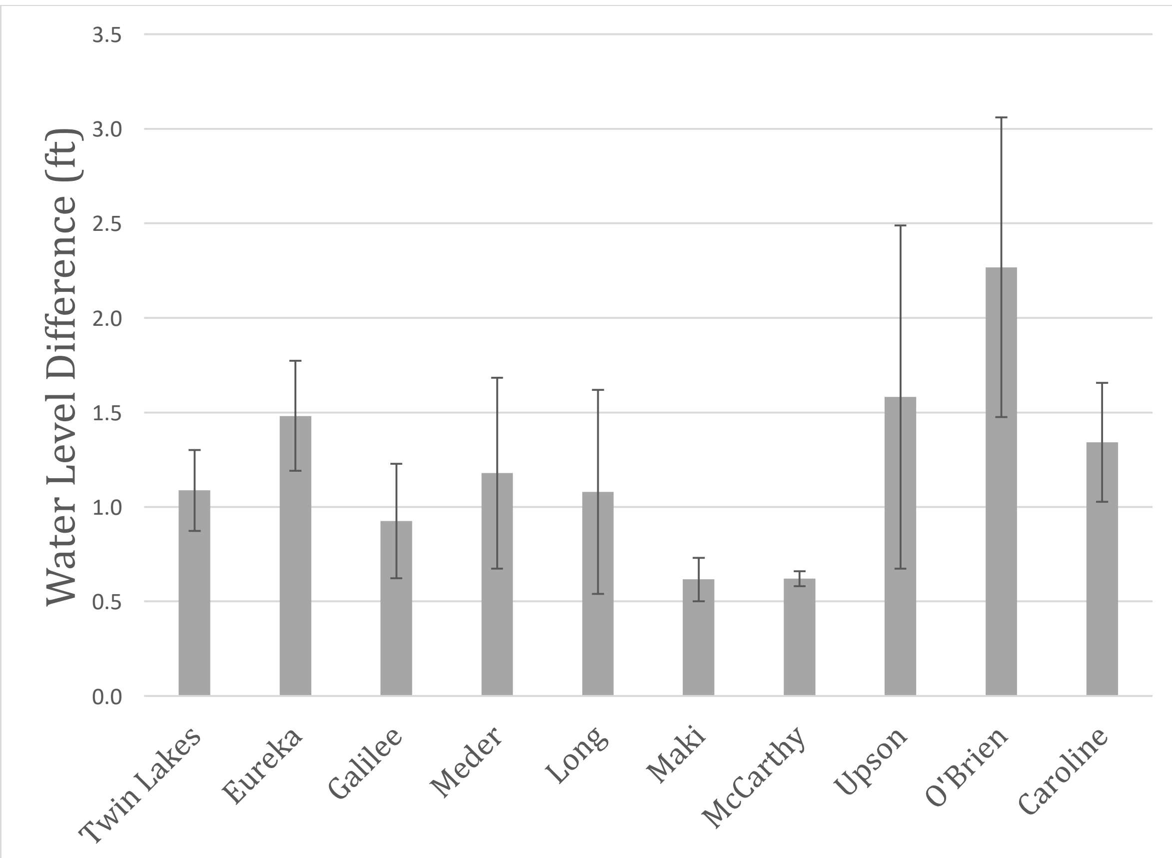


Figure 4.10. Average and standard deviation of the annual difference between the highest and lowest recorded water level for each of the eleven Penokee Lakes.

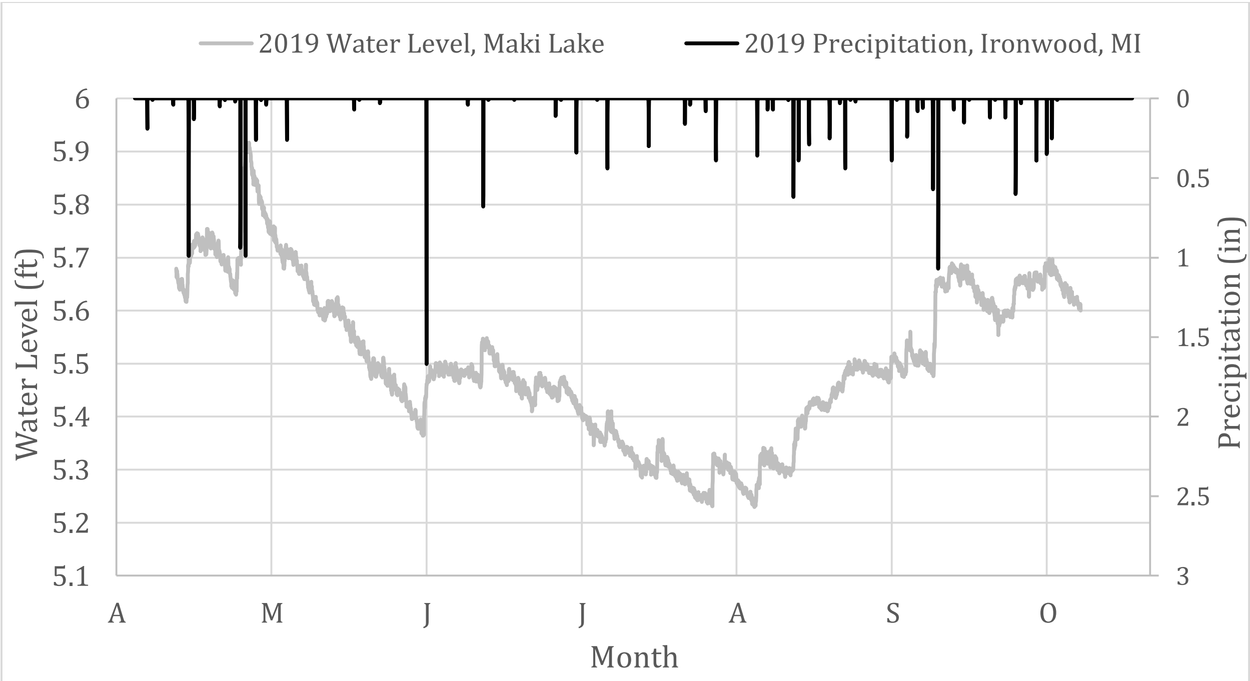


Figure 4.11. 2019 water level (stage) record for Maki Lake with the 2019 precipitation record from Ironwood, MI, overlaid.

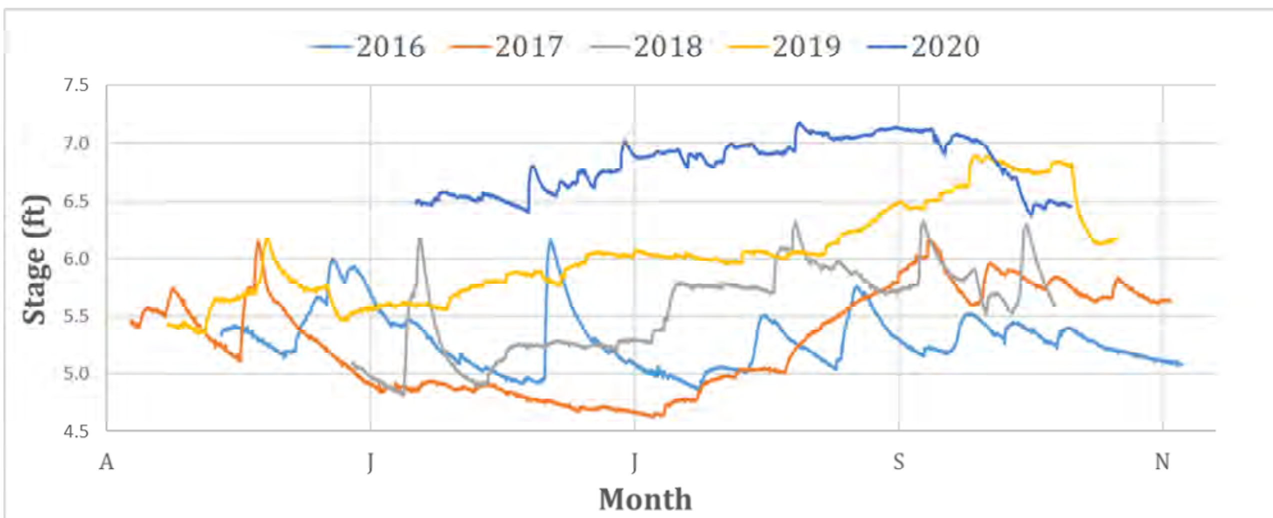


Figure 4.12. Continuous water level (stage) record for Caroline Lake for 2016-2020. Data are for open water periods from April/May (left) to October/November (right) in each year.

Stratification Status

Most deep lakes (>15 feet) in northern Wisconsin develop distinct layers throughout the summer (and occasionally winter) months due to a process known as thermal stratification. Water is most dense (and heaviest) at a temperature just above freezing. As ice and snow melt in the spring and water temperatures become uniform from surface to bottom, the lake becomes well mixed (i.e., it "turns over"). As the lake warms throughout the summer, the surface waters increase in temperature faster than deep water, which often results in the development of three layers that have distinct temperature and chemical profiles. Surface waters (or the epilimnion) are generally warmer and have higher oxygen concentrations. Bottom waters (or the hypolimnion) are generally colder and have lower oxygen concentrations. Middle waters (often referred to as the metalimnion or thermocline) generally represent a transition from surface to bottom conditions.

The Penokee Lakes exhibit different thermal stratification patterns depending on their surface area, depth, and orientation to prevailing wind patterns. The Lathrop/Lillie Equation (Lathrop and Lillie, 1980) is a tool used by the Wisconsin Department of Natural Resources to assist in categorizing lakes greater than ten acres as deep (stratified) or shallow (unstratified or mixed; WDNR 2021). Any value less than or equal to 3.8 predicts a mixed lake, which is placed in the shallow category. Values greater than 3.8 are placed in the deep category. These categories are a key component used in completing biennial "305(b) assessments."

When applying the Lathrop/Lillie Equation to the Penokee Lakes, East Twin, Eureka, and Upson Lakes have values greater than 3.8 and are predicted to be "deep (stratified)" (Figure 4.13). The remaining lakes have values less than 3.8 and are predicted to be "shallow (unstratified or mixed)."

When looking at the measured temperature profile data for each of the lakes over the course of the open water period, the Lathrop/Lillie Equation predictions hold up well for the deepest and shallowest lakes (Figure 4.14). East Twin and Eureka Lakes are the deepest lakes and they both stratify during the open water period with evidence of mixing in spring and fall. Caroline and Meder Lakes are the shallowest lakes and stay completely or nearly completely mixed through the open water period. Although predicted to be "unstratified or mixed", the remaining lakes have varying levels of weak thermal stratification and evidence of actual or potential mixing (Figure 4.14).

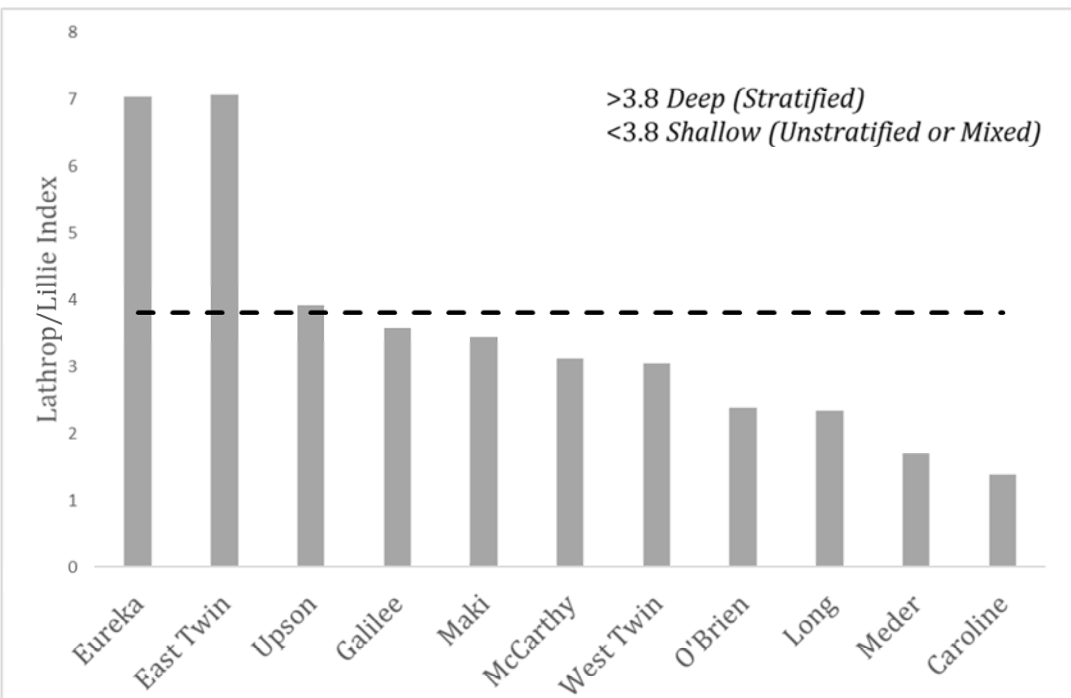


Figure 4.13. Lathrop/Lillie Equation values for each of the eleven Penokee Lakes (Lathrop and Lillie 1980). The model is used by the Wisconsin Department of Natural Resources to assist in categorizing lakes greater than ten acres as deep (stratified) or shallow (unstratified or mixed).

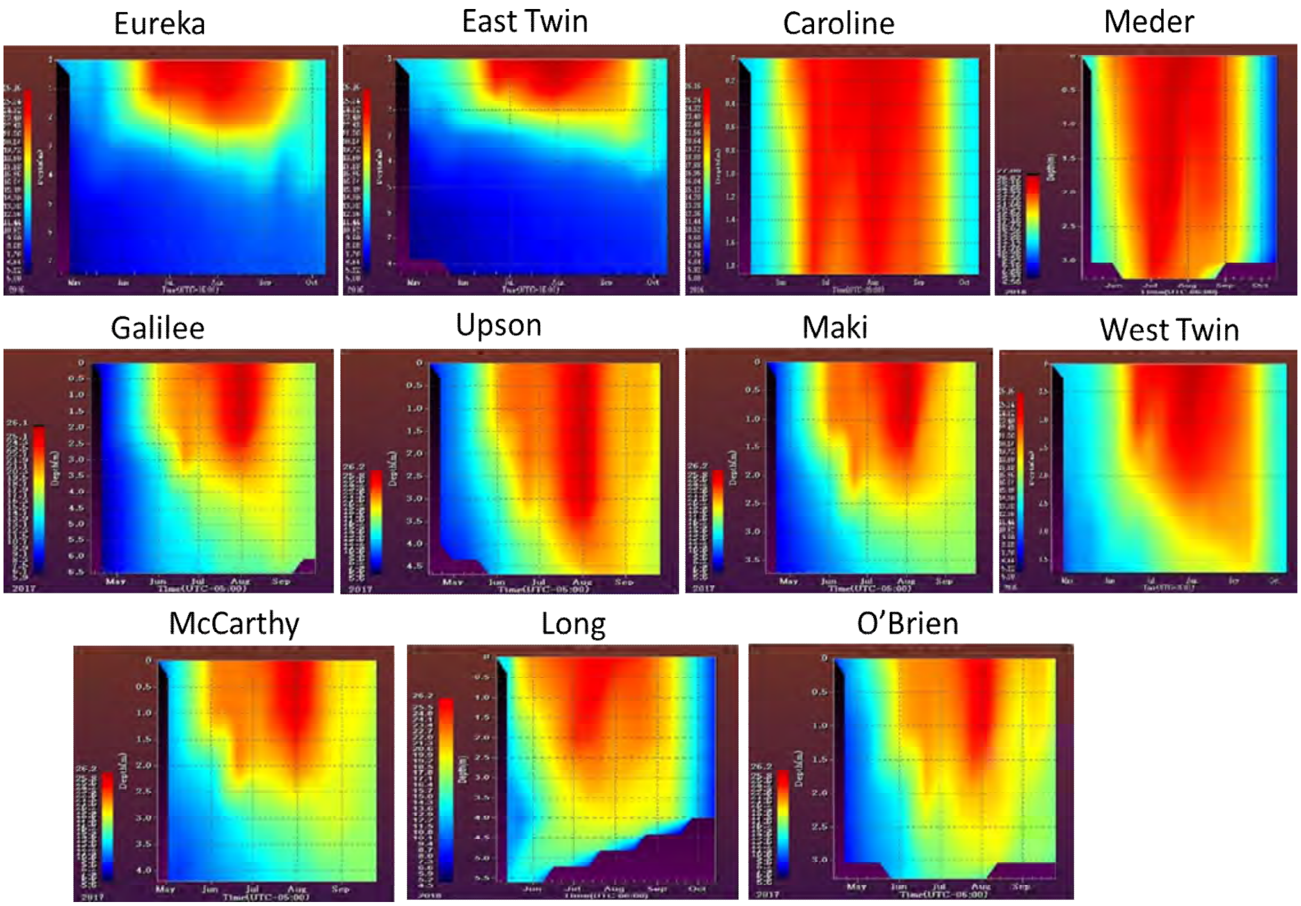


Figure 4.14. Seasonal thermal stratification in the Penokee Lakes. Red colors indicate areas of highest temperature and blue colors lowest. Each profile displays water temperature data from surface (top of each figure) to bottom, with spring data on the left and fall data on the right of the profile for each lake. Each figure represents the typical condition observed in each lake using one year of available data between 2016 and 2018.

After evaluating available data and information collected as part of this study, the current natural community classifications established for some of the Penokee Lakes may need to be revised for future 305(b) assessments. The proposed revisions would influence the total phosphorus criteria that is utilized to evaluate impairment (discussed in section 4.3). Table 4.9 lists the current and proposed revision for natural community classification and total phosphorus criteria for each of the eleven Penokee Lakes. The proposed changes in classification would not affect the chlorophyll-a criteria used to evaluate any of the lakes for impairment.

Table 4.9. Current natural community classification and phosphorus criteria along with potential updates to the classifications and total phosphorus criteria in some of the Penokee Lakes based on data collected through the current study.

	Current Conditions				Potential Updates Based on Study		
Lake	*Natural Community*	*Hydrology*	*Stratification Status*	*Existing TP Criteria (ug/L)*	*Update Stratification Status?*	*Update Natural Community?*	*Update TP Criteria?*
East Twin	Deep Seepage	Seepage	Stratified	≥20	No	Yes-Deep Headwater Drainage	Yes-≥30 µg/L
West Twin	Shallow Seepage	Seepage	Mixed	≥40	Yes-Stratified	Yes-Deep Headwater Drainage	Yes-≥30 µg/L
Eureka	Deep Headwater Drainage	Drainage	Stratified	≥30	No	No	No
Galilee	Shallow Headwater Drainage	Drainage	Mixed	≥40	Yes-Stratified	Yes-Deep Headwater Drainage	Yes-≥30 µg/L
Meder	Shallow Headwater Drainage	Drainage	Mixed	≥40	No	No	No
Long	Shallow Headwater Drainage	Drainage	Mixed	≥40	Yes-Stratified	Yes-Deep Headwater Drainage	Yes-≥30 µg/L
Maki	Shallow Seepage	Seepage	Mixed	≥40	Yes-Stratified	Yes-Deep Headwater Drainage	Yes-≥30 µg/L
McCarthy	Shallow Headwater Drainage	Drainage	Mixed	≥40	Yes-Stratified	Yes-Deep Headwater Drainage	Yes-≥30 µg/L
Upson	Deep Headwater Drainage	Drainage	Stratified	≥30	No	No	No
O'Brien	Shallow Headwater Drainage	Drainage	Mixed	≥40	Yes-Stratified	Evaluate as Deep Headwater Drainage	Yes-≥30 µg/L
Caroline	Shallow Headwater Drainage	Drainage	Mixed	≥40 µg/L	No	No	No

4.3 Water Chemistry

Water chemistry in the Penokee Lakes is influenced by a combination of processes in the lakes and the surrounding watershed. In general, short-term changes in water quality are often attributable to in-lake processes, while long-term trends in lake condition are often attributable to changes in watershed conditions (Shaw *et al*., 2004). Although a wide range of biotic and abiotic factors shape water quality conditions in lakes, the primary driver of water quality conditions in lake ecosystems is their nutrient concentration (particularly phosphorus).

Water chemistry, stratification and turnover processes were assessed in the Penokee Lakes following methods outlined by USEPA (2007). Secchi disk measurements and vertical profiles of dissolved oxygen, temperature, conductivity, and pH were collected at one meter increments (or less) approximately every two weeks between spring and fall from a single site that represents the deepest hole in each of the eleven Penokee Lakes (Figure 4.15). Composite water samples were collected from the top two-meters of the water column (epilimnion) during all field visits. In most years of the study, these samples were analyzed for total and soluble reactive phosphorus and chlorophyll-a. Samples from bottom (hypolimnion) water in each lake were collected in most years

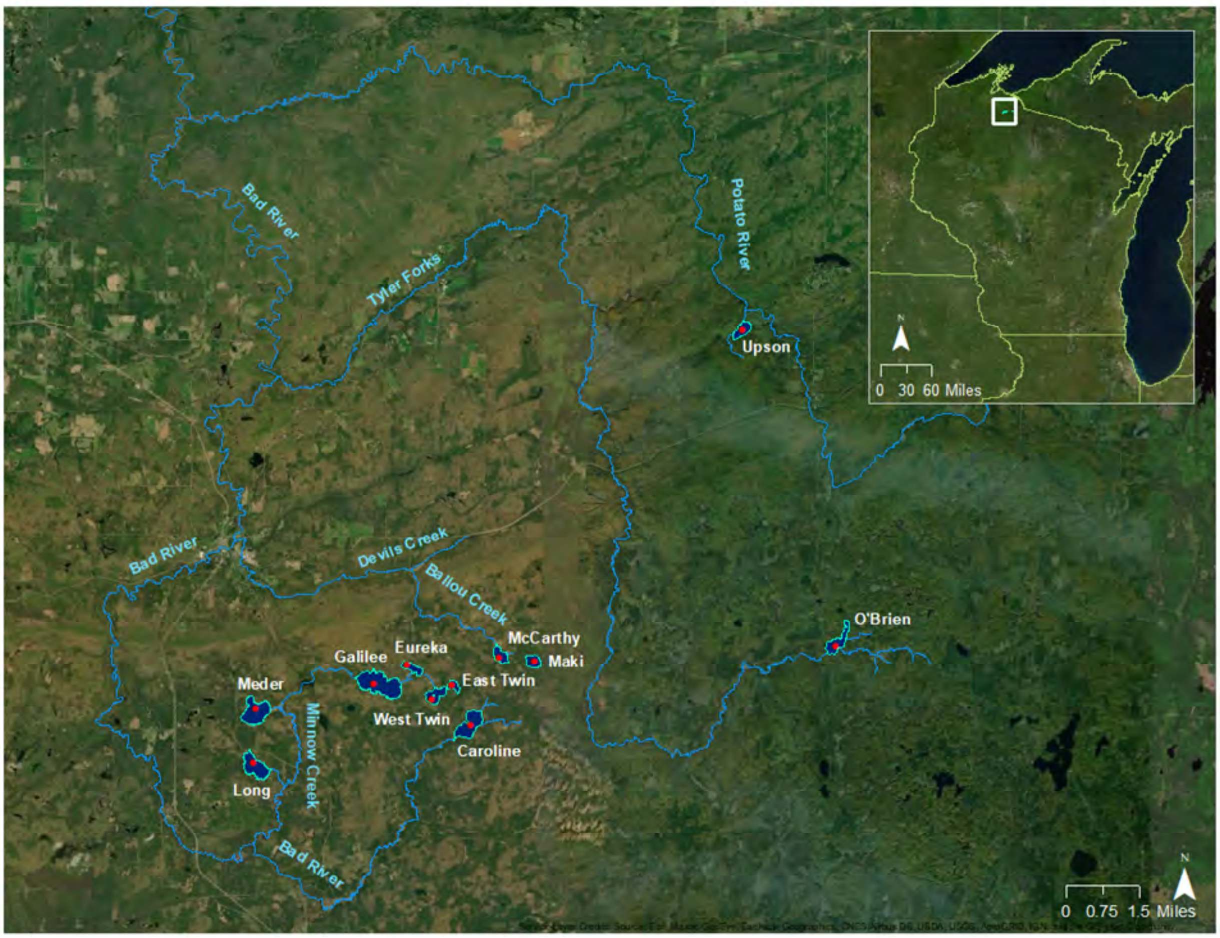


Figure 4.15. Map of the eleven Penokee Lakes showing the approximate location of the “deep hole” regular water chemistry/quality monitoring station on each lake.

using a Kemmerer water sampler during the months of peak stratification between June and August. These samples were analyzed for total and soluble reactive phosphorus. The majority of the water analysis was performed at the Burke Center Laboratory at Northland College, with some 2018 analyses conducted at the Water and Environmental Analysis Lab at UW-Stevens Point and much of the 2019 analysis at the Wisconsin State Laboratory of Hygiene (SLOH) in Madison, WI. All laboratory analyses and vertical profile field measurements from these lakes are stored in the Surface Water Integrated Monitoring System (SWIMS) database (https://dnr.wisconsin.gov/topic/SurfaceWater/SWIMS).

Sampling occurred in staggered years in the eleven lakes due to the nature of the grant funding source (Table 4.10). However, during 2019, savings in the grants allowed for a more comprehensive analysis of water chemistry in all eleven lakes in the same year. Most of these samples were analyzed at the SLOH, although most of the phosphorus and chlorophyll-a analysis were done in the Burke Center Lab, including a number of samples analyzed in both labs that allowed for some comparison between them.

Table 4.10. Years when a full or partial season of water chemistry and lake profiling data were collected from each of the eleven Penokee Lakes.

Lake	2015	2016	2017	2018	2019	2020
East/West Twin	X	X			X	X
Eureka	X	X			X	X
Galilee		X	X		X	X
Meder			X	X	X	X
Long			X	X	X	X
Maki		X	X		X	X
McCarthy		X	X		X	X
Upson			X	X	X	X
O'Brien			X	X	X	X
Caroline	X	X			X	X

All available water chemistry and quality data from each lake over the study period are summarized in Table 4.11. The pH and specific conductance data are summaries of data collected from the top two-meters of the water column. Table 4.12 shows the total number of samples collected for each of the laboratory-analyzed water chemistry parameters along with the total number of samples that were below the laboratory method detection limit. Several of the parameters were frequently below detection limits, most notably soluble reactive phosphorus, alkalinity, nitrate + nitrite, and ammonia. Although not specified in the table, many parameters that were above detection limits were between the detection limit and the limit of quantification. These results reflect the low concentrations of many water chemistry parameters in the Penokee Lakes, which will be discussed further throughout section 4.3. The remaining parts of section 4.3 describe results of the various water chemistry parameters in each lake and what they mean from a lake management planning context.

Table 4.11. Mean (standard deviation) of each surface water chemistry/quality parameter from all eleven Penokee Lakes.

Parameter	Units	E. Twin	W. Twin	Eureka	Galilee	Meder	Long	Maki	McCarthy	Upson	O'Brien	Caroline
Acidity												
pH	SU	5.4 (0.4)	6.3 (0.3)	6.9 (0.3)	7.2 (0.3)	7.4 (0.2)	7.3 (0.4)	6.7 (0.4)	6.7 (0.3)	7.3 (0.5)	7.4 (0.7)	7.0 (0.3)
Hardness	mg/L	6.5 (0.2)	9.1 (0.3)	15.3 (1.2)	20.1 (0.9)	21.5 (2.3)	22.4 (2.9)	10.2 (0.9)	12.4 (1.2)	19.3 (1.3)	21.7 (6.5)	19.4 (4.5)
Alkalinity (as mg/L $CaCO_3$)*	mg/L	ND	ND	ND	ND	20.9 (0.4)	21.8 (0.4)	ND	ND	20.8 (0.3)	23.5 (2.2)	20.2 (0.0)
Salinity												
Specific Conductance	uS/cm	16.5 (1.5)	20.2 (2.0)	34.1 (3.3)	43.9 (2.5)	46.0 (4.8)	47.6 (5.0)	22.4 (2.7)	28.0 (3.7)	44.4 (4.0)	43.9 (9.9)	40.0 (7.0)
Calcium	mg/L	1.7 (0.1)	2.4 (0.04)	4.2 (0.3)	5.5 (0.2)	6.0 (0.7)	6.3 (0.8)	2.7 (0.2)	3.3 (0.3)	5.1 (0.3)	5.9 (1.8)	5.5 (1.3)
Magnesium	mg/L	0.6 (0.03)	0.7 (0.05)	1.2 (0.1)	1.5 (0.1)	1.6 (0.1)	1.6 (0.2)	0.8 (0.08)	1.0 (0.1)	1.6 (0.2)	1.7 (0.5)	1.4 (0.3)
Sulfate*	mg/L	8.4 (4.4)	6.7 (3.7)	5.5 (2.5)	3.9 (1.3)	4.4 (2.1)	4.7 (2.2)	4.7 (1.7)	4.6 (1.6)	2.2 (0.9)	4.6 (2.2)	5.2 (2.4)
Iron*	mg/L	0.9 (0.4)	1.3 (1.2)	1.9 (1.9)	0.9 (1.2)	0.6 (0.0)	1.2 (1.5)	0.5 (0.4)	0.5 (0.6)	0.1 (0.0)	0.3 (0.2)	0.5 (0.2)
Trophic State												
Chl-a*	ug/L	3.6 (4.6)	3.1 (2.3)	2.7 (2.1)	2.1 (1.4)	3.4 (1.6)	3.4 (2.0)	2.5 (2.0)	2.2 (1.7)	1.3 (1.0)	4.0 (3.1)	3.2 (2.4)
Total Nitrogen	mg/L	0.72 (0.074)	0.68 (0.093)	0.72 (0.081)	0.58 (0.048)	0.57 (0.033)	0.60 (0.083)	0.50 (0.042)	0.51 (0.061)	0.39 (0.047)	0.69 (0.227)	0.56 (0.086)
Nitrate + Nitrite*	mg/L	0.083 (0.016)	0.072 (0.037)	0.089 (0.038)	0.073 (0.034)	0.056 (0.012)	0.12 (0.009)	ND	0.061 (0.031)	0.081 (0.039)	0.13 (N/A)	0.047 (N/A)
Ammonia*	mg/L	0.052 (0.036)	0.021 (0.004)	0.051 (0.052)	0.025 (0.009)	0.032 (0.009)	0.016 (0.001)	ND	ND	0.066 (0.018)	0.029 (N/A)	ND
Total Phosphorus	mg/L	0.025 (0.007)	0.024 (0.005)	0.023 (0.005)	0.017 (0.006)	0.024 (0.004)	0.024 (0.005)	0.020 (0.006)	0.019 (0.004)	0.011 (0.005)	0.032 (0.008)	0.029 (0.008)
Sol. Reactive Phosphorus*	mg/L	0.003 (0.002)	0.003 (0.001)	0.003 (0.002)	0.003 (0.002)	0.003 (0.002)	0.004 (0.003)	0.003 (0.002)	0.003 (0.001)	0.004 (0.002)	0.003 (0.001)	0.004 (0.001)
Water Clarity												
Color	SU	175 (25)	135 (15)	120 (0)	67.5 (10.6)	67.5 (7.5)	90 (10)	80 (0)	70 (10)	17.5 (2.5)	96.7 (28.7)	125 (5)
Secchi Depth	meters	0.7 (0.1)	1.0 (0.2)	1.3 (0.3)	2.1 (0.3)	1.4 (0.2)	1.2 (0.2)	1.3 (0.4)	1.4 (0.4)	3.8 (0.9)	1.0 (0.3)	0.9 (0.3)

* indicates mean and standard deviation are calculated from laboratory detected samples only

Table 4.12. Total number of samples collected for each laboratory-analyzed water chemistry parameter and the number of samples below laboratory method detection limits (in parentheses).

Parameter	Units	East Twin	West Twin	Eureka	Galilee	Meder	Long	Maki	McCarthy	Upson	O'Brien	Caroline
Hardness	mg/L	3 (0)	3 (0)	3 (0)	3 (0)	3 (0)	3 (0)	3 (0)	3 (0)	3 (0)	3 (0)	3 (0)
Alkalinity	mg/L	10 (10)	10 (10)	10 (10)	10 (10)	10 (6)	10 (5)	10 (10)	10 (10)	10 (5)	10 (5)	10 (2)
Calcium	mg/L	3 (0)	3 (0)	3 (0)	3 (0)	3 (0)	3 (0)	3 (0)	3 (0)	3 (0)	3 (0)	3 (0)
Magnesium	mg/L	3 (0)	3 (0)	3 (0)	3 (0)	3 (0)	3 (0)	3 (0)	3 (0)	3 (0)	3 (0)	3 (0)
Sulfate	mg/L	13 (0)	13 (0)	13 (0)	13 (0)	13 (0)	13 (0)	13 (0)	13 (0)	13 (10)	13 (0)	13 (0)
Iron	mg/L	6 (0)	6 (0)	6 (0)	6 (0)	6 (0)	6 (0)	6 (0)	6 (0)	6 (2)	6 (0)	6 (0)
Chlorophyll-a	ug/L	42 (1)	43 (0)	41 (2)	40 (0)	22 (0)	21 (1)	38 (0)	39 (0)	31 (1)	32 (0)	39 (1)
Total Nitrogen	mg/L	10 (0)	10 (0)	10 (0)	10 (0)	10 (0)	10 (0)	10 (0)	10 (0)	10 (0)	10 (0)	9 (0)
Nitrate + Nitrite	Number	10 (7)	10 (6)	10 (6)	10 (5)	10 (8)	10 (8)	10 (10)	10 (7)	10 (8)	10 (9)	9 (8)
Ammonia	Number	10 (6)	10 (6)	10 (6)	10 (6)	10 (6)	10 (8)	10 (10)	10 (10)	10 (8)	10 (9)	9 (9)
Total Phosphorus	mg/L	44 (0)	42 (0)	44 (0)	42 (0)	21 (0)	21 (0)	36 (0)	38 (0)	29 (0)	30 (0)	40 (0)
Soluble Reactive Phosphorus	mg/L	42 (4)	41 (14)	46 (16)	39 (25)	20 (6)	20 (8)	20 (13)	35 (13)	29 (22)	29 (7)	39 (2)
Color	SU	2 (0)	2 (0)	1 (0)	2 (0)	2 (0)	2 (0)	2 (0)	2 (0)	2 (0)	3 (0)	2 (0)

Dissolved Oxygen

As discussed earlier, thermal stratification and turnover are key drivers of lake ecosystem processes. Over the course of time, nutrients wash into lakes and when attached to sediment particles, gradually sink to the bottom. As a result, nutrients tend to accumulate in lake sediments over time. When lakes turn over, nutrients that have settled toward the bottom can be re-suspended and made available to stimulate aquatic plant growth (particularly algae). As a lake stratifies, the metalimnion creates a functional barrier between the surface and bottom waters that tends to trap nutrients at the bottom of the lake and minimize the diffusion of oxygen from the atmosphere down into deeper waters. Thus, over the summer, oxygen concentrations tend to decrease in the deep waters (relative to the surface waters).

Low oxygen conditions can directly affect a wide range of chemical and biological processes in lake ecosystems. Most directly, low oxygen conditions can limit habitat availability for fish and can result in localized "fish kills" if oxygen levels fall below a critical threshold. Perhaps more importantly, low oxygen conditions along the bottom sediments change the chemical environment from one of oxidizing conditions to one of reducing conditions. This shift in chemical conditions, often facilitates the release of phosphorus trapped in the sediments into the water column, where it can potentially be used by different organisms (algae in particular).

Caroline and Meder Lakes remained completely or nearly completely mixed throughout the summer due to their shallow depth. Upson, West Twin and O'Brien Lakes remained close to mixed or mixed periodically. The other lakes exhibited varying amounts of thermal stratification (Figure 4.14). Because Caroline Lake remained mixed throughout the summer, there was oxygen present throughout the lake (Figure 4.16). Upson Lake displayed similar patterns. Although Meder Lake is shallow and remained nearly or completely mixed throughout the summer, there were long enough periods without mixing, which led to some oxygen depletion in bottom waters. Deeper lakes like East Twin and Eureka Lakes exhibited oxygen depletion in water as shallow as 6 feet in mid-summer (Figure 4.16).

Oxygen depletion at very shallow depths in the most thermally stratified lakes, along with some oxygen depletion even in the most thermally mixed lakes is an indication that rates of respiration and decomposition (processes that use oxygen) in these lakes are high relative to rates of primary production from algae and aquatic plants (processes that produce oxygen). As will be discussed further in Section 4.3 and in Section 4.4, light attenuation from high amounts of natural tannins or humic acids, play a large role in the chemical and biological interactions in most of these lakes. With respect to dissolved oxygen, these interactions mean any amount of thermal stratification will lower amounts of oxygen and reduce the amount of available habitat for fish and other aquatic life during summer months. The same oxygen-depletion process can occur during winter months, and if severe enough, can lead to "winter kill." Winter fish kills have been observed in Meder Lake in past years (Lawson, personal communication). As the regional climate continues to warm, any increase in thermal stratification due to warming summer lake temperatures could further limit habitat in these lakes and leave them vulnerable to fish kills.

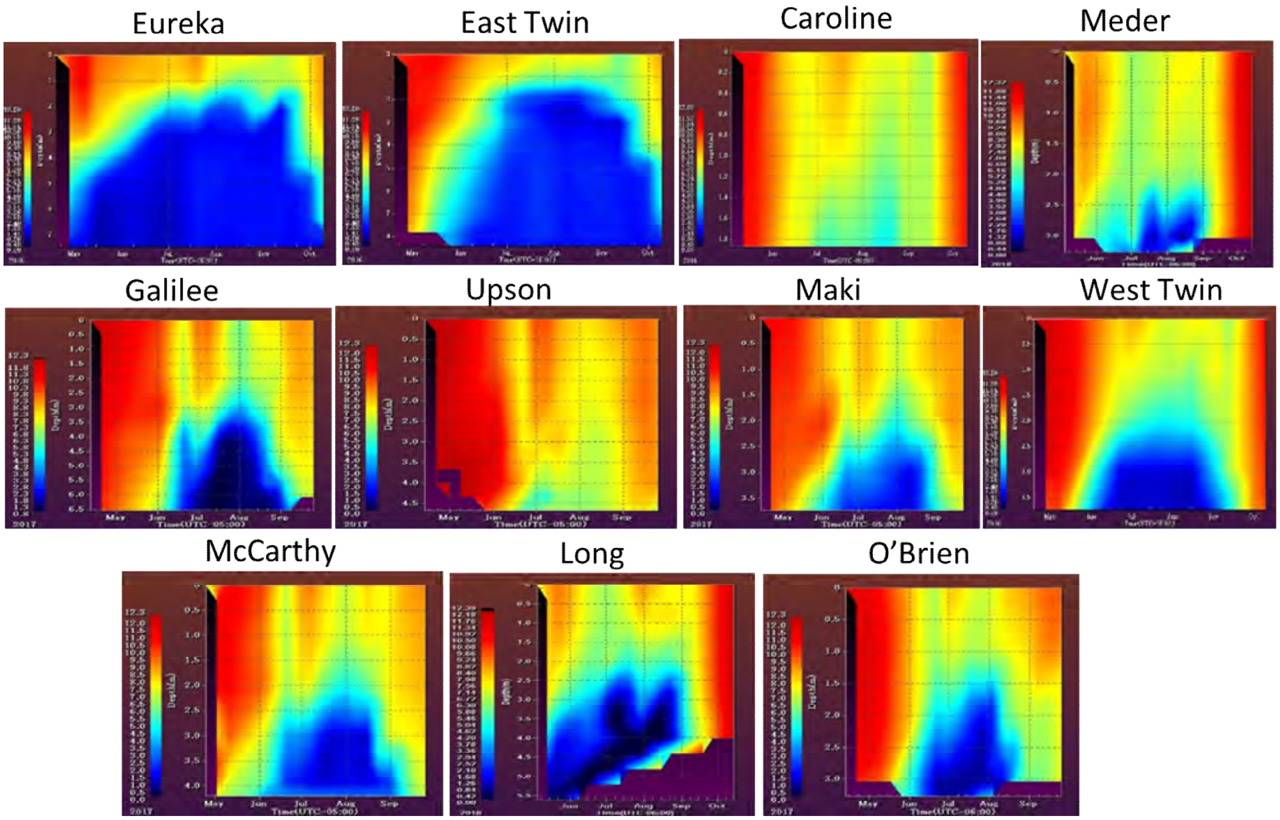


Figure 4.16. Vertical profiles of oxygen concentrations in the Penokee Lakes. Red colors indicate the areas of highest oxygen concentration and blue colors the lowest. Each profile displays dissolved oxygen data from surface (top of each figure) to bottom, with spring data on the left transitioning to fall data on the right of the profile for each lake. Each figure represents the typical condition observed in each lake using one year of available data between 2016 and 2018

pH

pH is a measurement of how acidic or basic the water is and plays an important role in many chemical and biological processes in lakes. The normal pH range for Wisconsin waters is usually 6.0 to 8.0 (WDNR 2021). All the Penokee Lakes fell within this normal range except for East Twin Lake, which had a mean surface pH of 5.4 (Table 4.11). The low pH in East Twin Lake indicates that this lake is bog-like and is heavily influenced by surface runoff of humic acids from the wetlands surrounding it (Figure 4.17). Low pH may exclude some plant and animal species or at least limit their success in this lake.

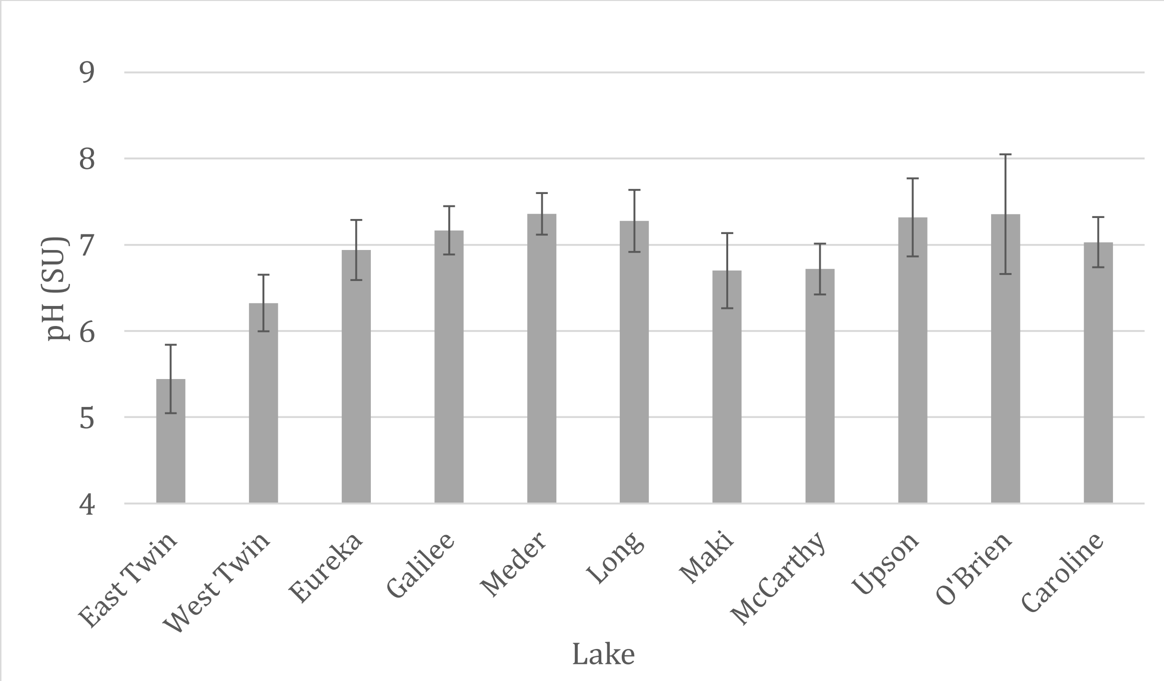


Figure 4.17. Mean and standard deviation of pH measurements (in standard pH units; SU) taken from the top two meters of each of the eleven Penokee Lakes across all study years.

Color and CDOM

Color is dependent on the amount of dissolved substances (e.g. humic acids, other dissolved organic matter) in the water and is an important characteristic related to light penetration and heat absorption. Colored (or chromophoric) dissolved organic matter (CDOM) is the portion of organic matter that absorbs light in the blue and ultra-violet part of the electromagnetic spectrum, staining water a "tea-like" color. Dissolved organic matter occurs in all natural waters, and CDOM is the most abundant DOM fraction in many natural waters, especially in forested watersheds with wetlands (University of Minnesota, 2019).

Color was measured from surface water in all eleven lakes in 2019. Mean color ranged from a high of 175 standard units (SU) in East Twin Lake to a low of 17.5 SU in Upson Lake. Mean color was greater than 67.5 SU in all lakes except Upson. Mean color for all Wisconsin lakes was 39 SU (Lillie and Mason 1983), so with the exception of Upson Lake, color values in the Penokee Lakes are high relative to typical Wisconsin lakes, a reflection of tea-like color from CDOM.

Figure 4.18 shows average CDOM concentration measured using a fluorometer mounted to a water quality sonde (Turner Designs, San Jose, CA) in the top 2 meters of the water column from each lake during 2019 field visits. Error bars are omitted to allow for easier visualization of the trend in each lake. Concentrations of CDOM are similar in all of the lakes except Upson. This is expected because Upson Lake is clear and the rest of the lakes have high color values and are stained a "tea" color. CDOM concentrations fluctuate throughout 2019 and increase in all lakes in October. This is likely a result of rain events that happened in September and October (after a fairly dry summer) that dissolved and flushed organic matter from decaying leaves and other plant material from upland areas into the lakes. Values were also higher in spring, likely a result of spring runoff. Overall, the CDOM results indicate that surface runoff influences water chemistry in these lakes and are consistent with the water color and the forested/wetland influence in the watersheds of these lakes. CDOM and color also play an important role in these lakes in terms of light attenuation and availability of light for plant and algae growth.

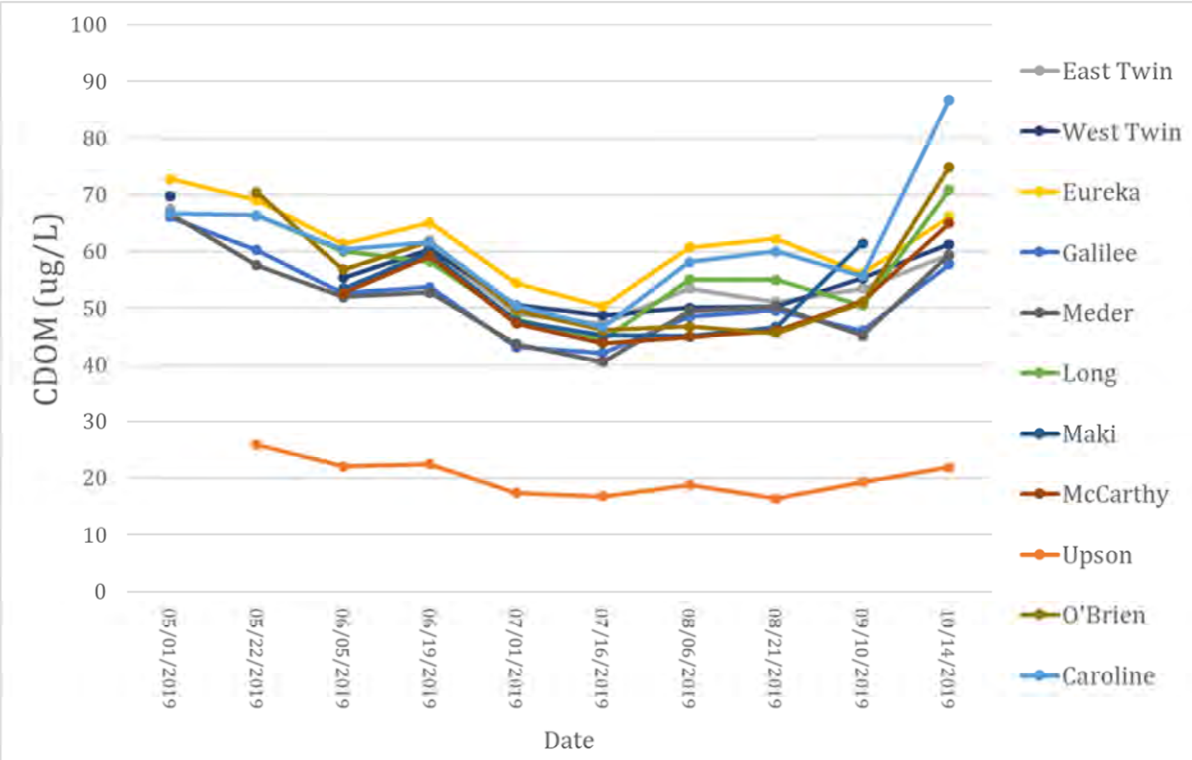


Figure 4.18. Mean colored (or chromophoric) dissolved organic matter (CDOM) concentrations measured from the top two meters of each of the 11 Penokee Lakes during 2019 using a sonde-mounted fluorometer. Error bars are omitted to prevent clutter and allow visualization of general trends across the 2019 field season.

Phosphorus

In freshwater systems, phosphorus is typically the most important nutrient that drives the growth of algae and aquatic plants. This is the case in over 80% of Wisconsin's lakes and is one of the main reasons phosphorus receives so much attention in terms of lake management (Shaw *et al*., 2004). Excess phosphorus can lead to problematic algal blooms that can have a range of effects on the ecology and human and wildlife use of lakes.

Phosphorus is most often measured as "total" phosphorus, which includes all phosphorus in the water column whether dissolved or particulate. Soluble reactive phosphorus (SRP) is the dissolved form of phosphorus that is most readily available for uptake and use by algae and aquatic plants. Total phosphorus is seen as a better indicator of a lake's nutrient status over time because it tends to remain more stable where SRP can fluctuate more frequently because it is constantly being used and released (Shaw *et al*., 2004). However, SRP analysis gives a good indication of readily available phosphorus at any given point in time.

Figure 4.19 displays a box and whisker plot of all surface total phosphorus measurements taken from each of the eleven Penokee Lakes over the study period. Mean and median concentrations were similar across most lakes except they were lower in Galilee and Upson Lakes and higher in O'Brien and Caroline Lakes.

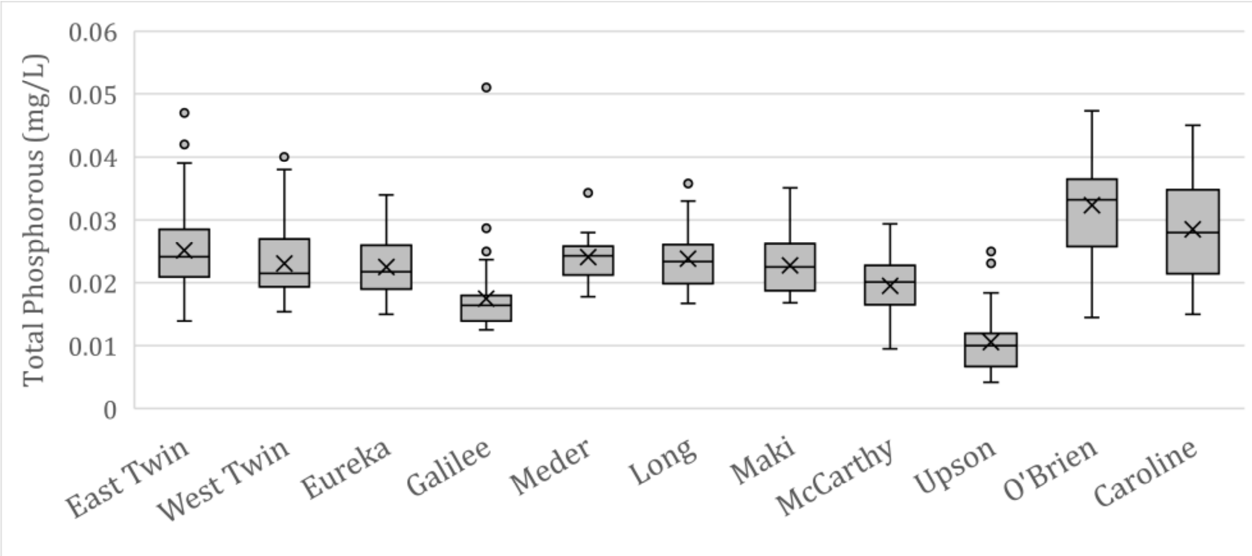


Figure 4.19. Box and whisker plot of total phosphorus concentrations measured from 0-2 meter composite surface water samples for each of the eleven Penokee Lakes. The mean is shown as a line within each box, the median is an "X," the box encompasses the inter-quartile range, the whiskers are the minimum and maximum value, and any dots beyond the whiskers are outlier values.

SRP measurements from surface and bottom water in all eleven lakes were generally low (Figure 4.20). Across all of the lakes, between 5% and 76% of surface and 0% and 78% of bottom SRP measurements were below the laboratory method detection limit. These values were omitted from the summary in Figure 4.20, which biases mean and standard deviations high. However, it illustrates that SRP concentrations in the Penokee Lakes are very low, especially in surface water, and is an important factor limiting the growth of algae in these lakes. Figure 4.20 also illustrates how the most stratified lakes with the greatest hypolimnetic oxygen depletion (Eureka and East Twin) also have the greatest amount of phosphorus release from bottom sediments. Lakes with less stratification and hypolimnetic oxygen depletion show little to no evidence of SRP release from sediments, with the exception of Galilee and perhaps Long and McCarthy Lakes.

Lakes with a combination of weak thermal stratification and hypolimnetic oxygen depletion are susceptible to algal blooms if mixing happens during warm water periods and soluble phosphorus from bottom water is brought to the surface where algae can use it. This does not appear to be an issue in the Penokee Lakes except for perhaps O'Brien Lake, which had an observed algal bloom during the study period. O'Brien Lake showed very weak stratification, some hypolimnetic oxygen depletion, but little evidence of soluble phosphorus release from bottom sediments.

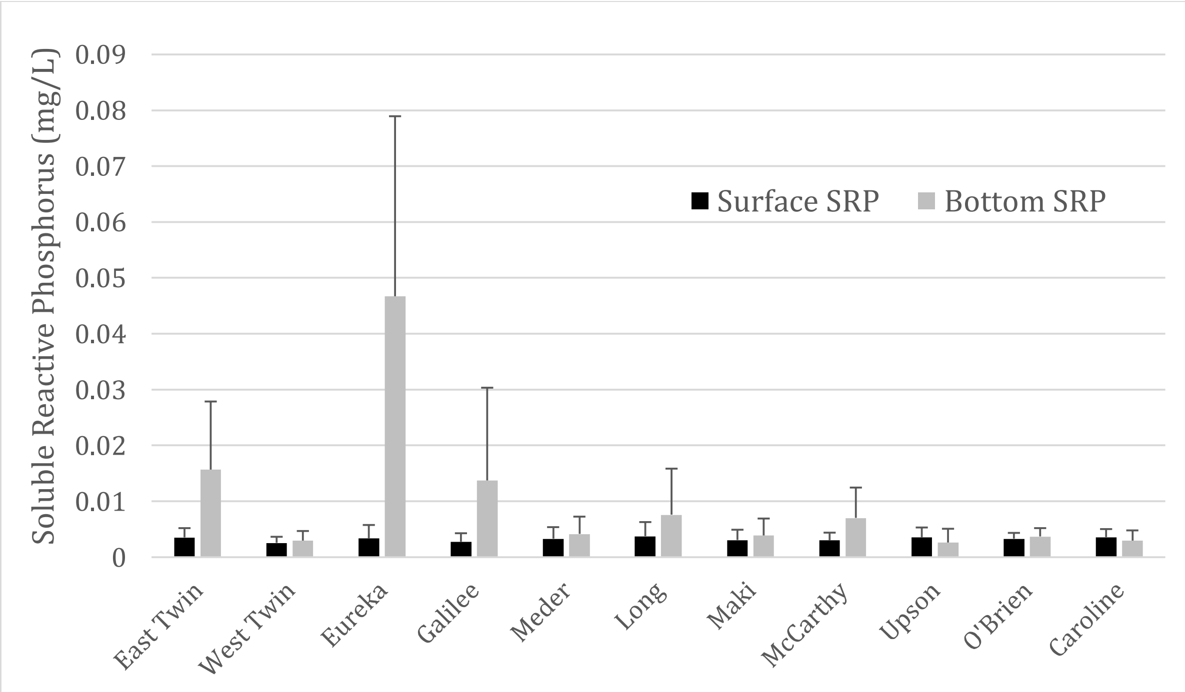


Figure 4.20. Mean and standard deviation of all laboratory detectable soluble reactive phosphorus (SRP) measurements from surface and bottom water of all eleven Penokee Lakes.

Total phosphorus concentrations from all lakes were also summarized into the "growing season mean" concentration (June 1-September 15). The upper and lower confidence limits around the mean were calculated, and these values were compared to impairment thresholds used by WDNR to evaluate lake health based on each lake's natural community classification (see section 4.2; Beranek, personal communication; WDNR 2021). Results of the analysis are displayed in Table 4.13. All lakes except O'Brien Lake clearly meet the total phosphorus criteria, indicating good water quality. O'Brien Lake "may exceed" the total phosphorus criteria if the lake is classified as a "deep headwater drainage" lake. The shallow headwater drainage lake may be more appropriate because the lake stays mostly mixed, but either way, further evaluation of water quality using the trophic state index (pg. 58) will shed more light on water quality in O'Brien and the other lakes.

Table 4.13. Evaluation of growing season (GS) mean total phosphorus concentration from each of the eleven lakes compared to phosphorus criteria used to evaluate impairment based on natural community classification. The lower (L80%) and upper (U80%) confidence limits around the mean are used to determine the criteria evaluation outcome.

Lake	Natural Community (proposed)	Total Phosphorus Criteria (ug/L)	GS Mean TP (ug/L)	L80% (ug/L)	U80% (ug/L)	Criteria Evaluation
East Twin	Deep Headwater Drainage	30	25.1	23.2	27.0	Clearly Meets
West Twin	Deep Headwater Drainage	30	22.5	21.0	24.0	Clearly Meets
Eureka	Deep Headwater Drainage	30	20.4	19.4	21.5	Clearly Meets
Galilee	Deep Headwater Drainage	30	16.6	15.4	17.7	Clearly Meets
Meder	Shallow Headwater Drainage	40	24.3	23.1	25.6	Clearly Meets
Long	Deep Headwater Drainage	30	24.2	22.9	25.7	Clearly Meets
Maki	Deep Headwater Drainage	30	18.3	16.8	19.9	Clearly Meets
McCarthy	Deep Headwater Drainage	30	19.9	18.3	19.7	Clearly Meets
Upson	Deep Headwater Drainage	30	8.5	7.6	9.6	Clearly Meets
O'Brien	Deep Headwater Drainage	30	31.1	28.8	33.5	May Exceed
Caroline	Shallow Headwater Drainage	40	29.8	27.8	31.9	Clearly Meets

Nitrogen

Like phosphorus, nitrogen is an essential nutrient for plant growth and can exist in different forms in lakes. Nitrogen parameters were only measured from surface water in the Penokee Lakes during 2019. Figure 4.21 shows mean (average) concentrations of the nitrogen parameters measured from all eleven lakes. Nitrate and ammonia are readily useable inorganic forms of nitrogen and organic nitrogen refers to nitrogen tied up in some kind of biomass. Organic nitrogen is derived by subtracting nitrate and ammonia concentrations from the total nitrogen concentration. The ratio of organic to inorganic nitrogen describe the biology of these lakes and also whether there are potential sources of pollution such as septic system waste or agricultural runoff present.

Most nitrate and ammonia results were below the detection limit. In order to facilitate the stacked bar chart in Figure 4.21, all results below the laboratory detection limit were assumed to be at the concentration of the detection limit. Thus, error bars are not included. Although this method of summarizing the data biases nitrate and ammonia results high, it provide an idea of how nitrogen forms are distributed in these lakes. Even with this conservative approach, reactive nitrogen (ammonia and nitrate) concentrations are low (generally less than 10% of total nitrogen) so most of the nitrogen in these lakes is bound in the organic form. If the reactive nitrogen percentages were higher, it would be an indication of potential contamination from septic systems or other human influence like agricultural runoff. These results are what we expect for lakes with low human influence.

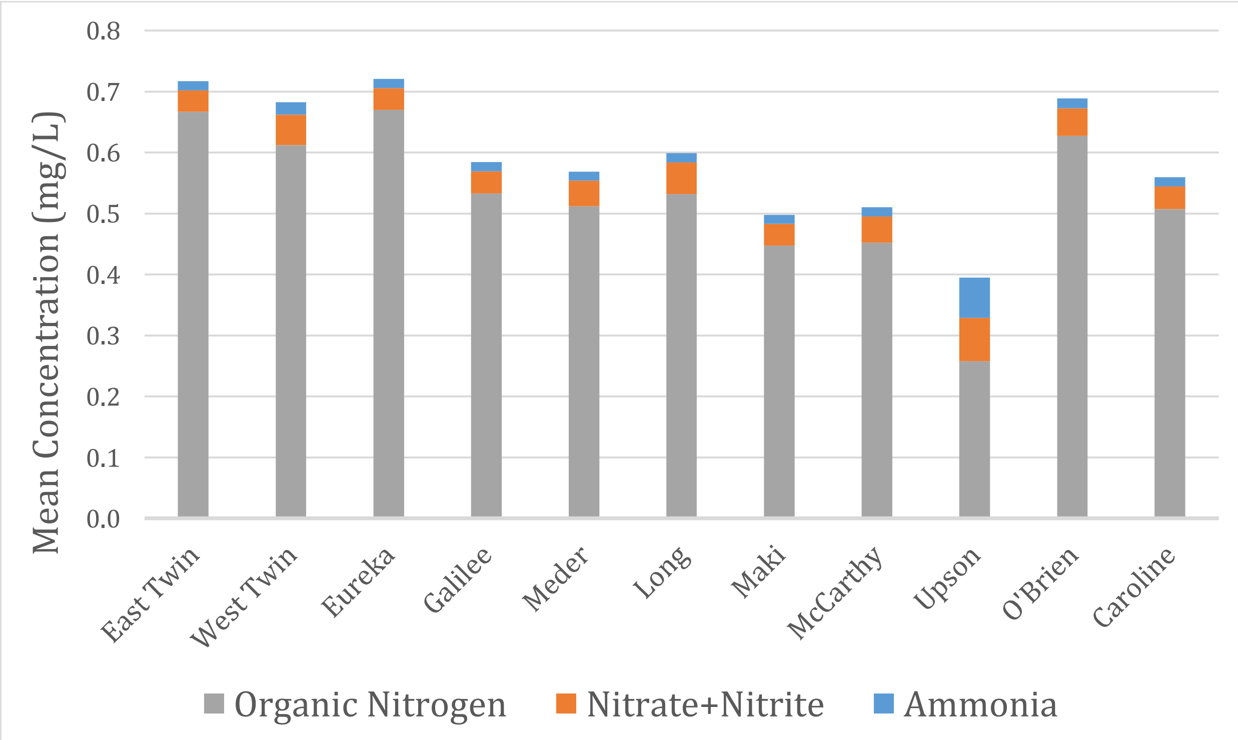


Figure 4.21. Mean concentrations of organic nitrogen, nitrate plus nitrite, and ammonia in surface water from eleven Penokee Lakes. Most nitrate and ammonia results were below the detection limit. In order to facilitate this stacked bar chart, all non-detect results were assumed to be at the concentration of the detection limit in order to calculate statistics. Thus error bars are not included.

Nitrogen-to-Phosphorus Ratio

The ratio between the total concentrations of nitrogen and phosphorus is a key determinant of growth and biological processes in all aquatic systems. In most freshwater lakes, when the mass ratio of total nitrogen to total phosphorus is about 15 to 16:1, phosphorus is typically the nutrient that will limit algal production (Correll 1998, Shaw *et al*. 2004, Juckem and Robertson 2013). The ratio provides a guide for lake managers to understand which nutrient is most important to pay attention to when trying to limit algal blooms.

When comparing the total-nitrogen-to-total-phosphorus ratios (on a mass basis) for each sample date from each lake during 2019 (when both parameters were measured), the ratios were consistently above 15:1, indicating phosphorus is the nutrient limiting algal production in the Penokee Lakes (Figure 4.22).

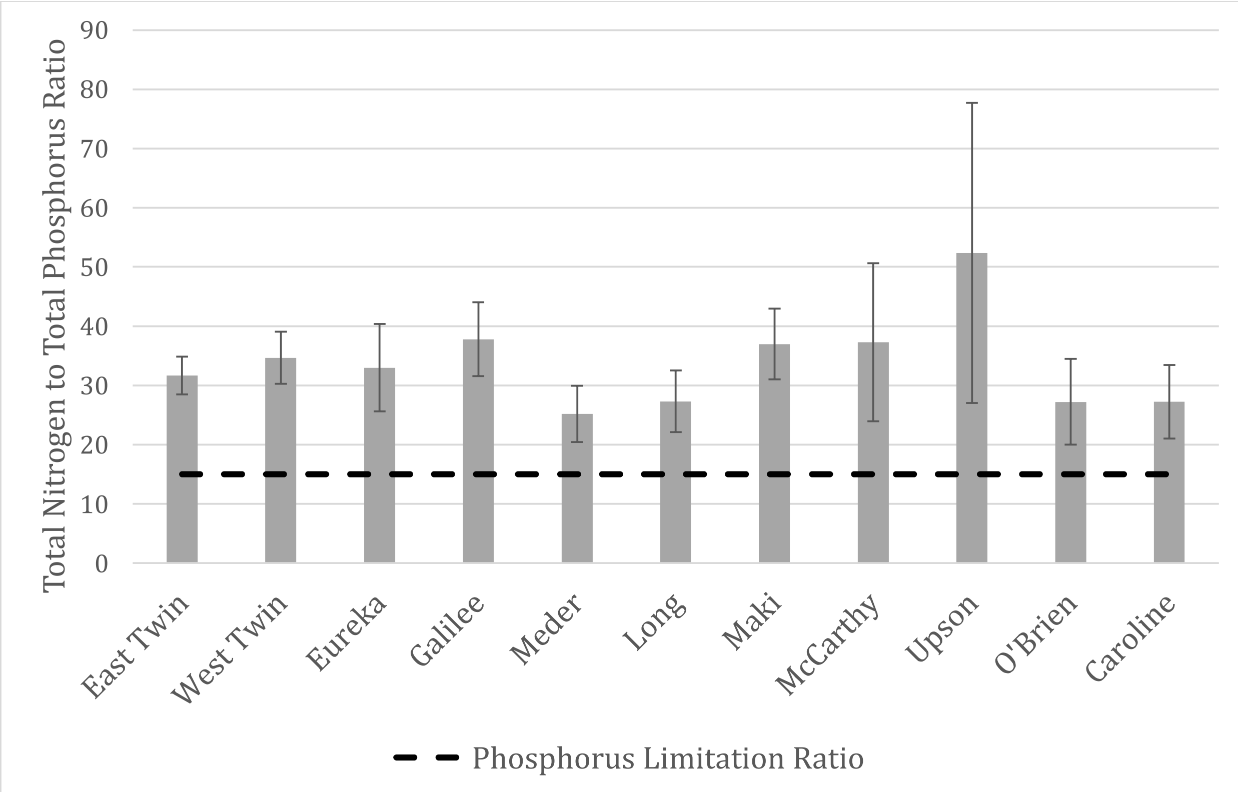


Figure 4.22. Mean and standard deviation of the total nitrogen (N) to total phosphorus (P) ratio (calculated on a mass basis) measured in surface water from each of the eleven Penokee Lakes in 2019. The dashed line indicates the N:P ratio that is a good indication of phosphorus limitation in Wisconsin lakes (Shaw *et al*. 2004).

Chlorophyll-a

The most common method for measuring algal biomass and biological response to phosphorus concentrations in lakes is to measure and track chlorophyll-a concentrations from surface water. High chlorophyll-a concentrations can indicate algal bloom conditions and WDNR uses a threshold of 27 ug/L to assess most lakes for impairment due to chlorophyll-a. This threshold would likely apply to all of the Penokee Lakes. Figure 4.23 displays monthly mean and standard deviation chlorophyll-a concentrations from all eleven Penokee Lakes. Impairment assessments are done using data from the peak algal growth period only (i.e., July 15 – September 15.)

Monthly mean and standard deviation of chlorophyll-a concentrations are well below the impairment threshold of 27 ug/L, an indication of good water quality. Most of the Penokee Lakes had peak algal biomass during July and August. The most notable exception is O'Brien Lake, where algal biomass peaked in September. Algal blooms were observed on O'Brien Lake in August of 2019 and 2020. Bloom conditions persisted in both years through sampling events in October, although appeared to peak in late-August/early September. Analysis under a microscope confirmed the genus of the algae to be *Dolichospermum*, which is in the family Cyanophyta, or "blue green algae." Species-level identification was not possible, but *Dolichospermum* can produce toxins. It is unknown whether toxins were present in the O'Brien Lake blooms. Although fairly uncommon, blue green algae blooms do occur in undeveloped lakes like O'Brien. The presence of these blooms in O'Brien Lake is something that should continue to be monitored in future years.

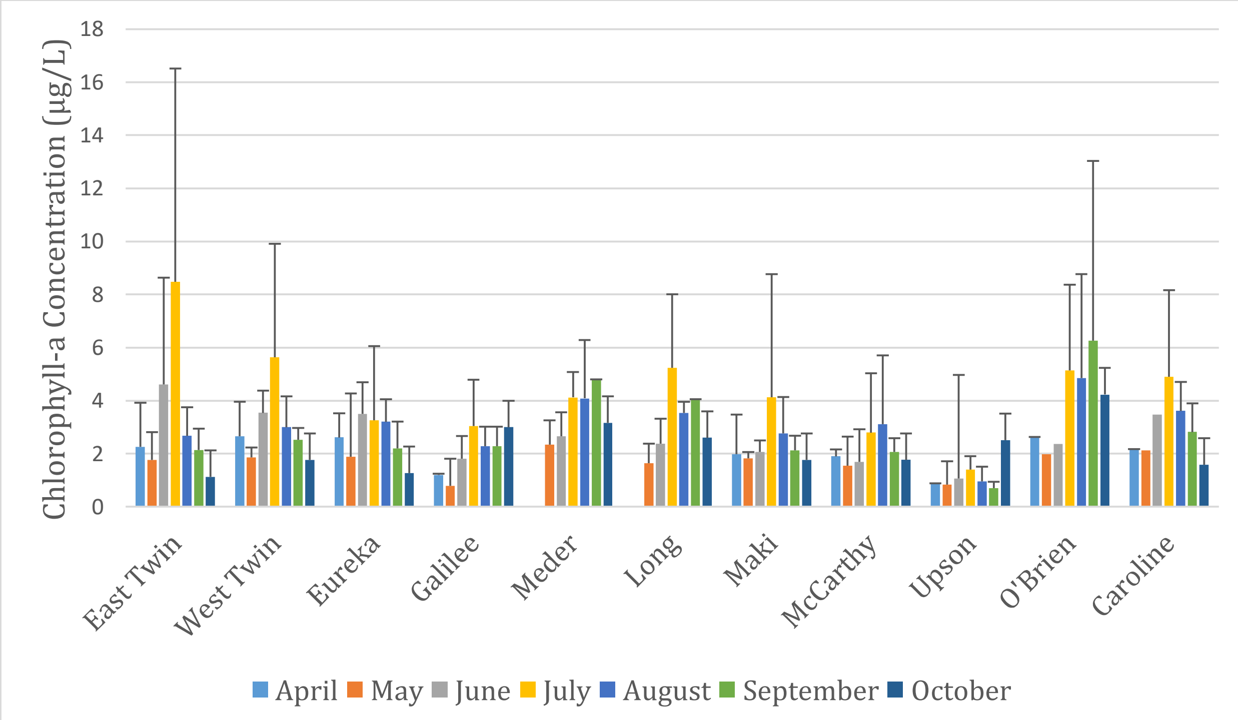


Figure 4.23. Mean and standard deviation of all monthly chlorophyll-a concentrations measured from each of the eleven Penokee Lakes during the study period.

Water Clarity

Average Secchi depths ranged from 0.7 meters in East Twin Lake to 3.8 meters in Upson Lake (Figure 4.24).

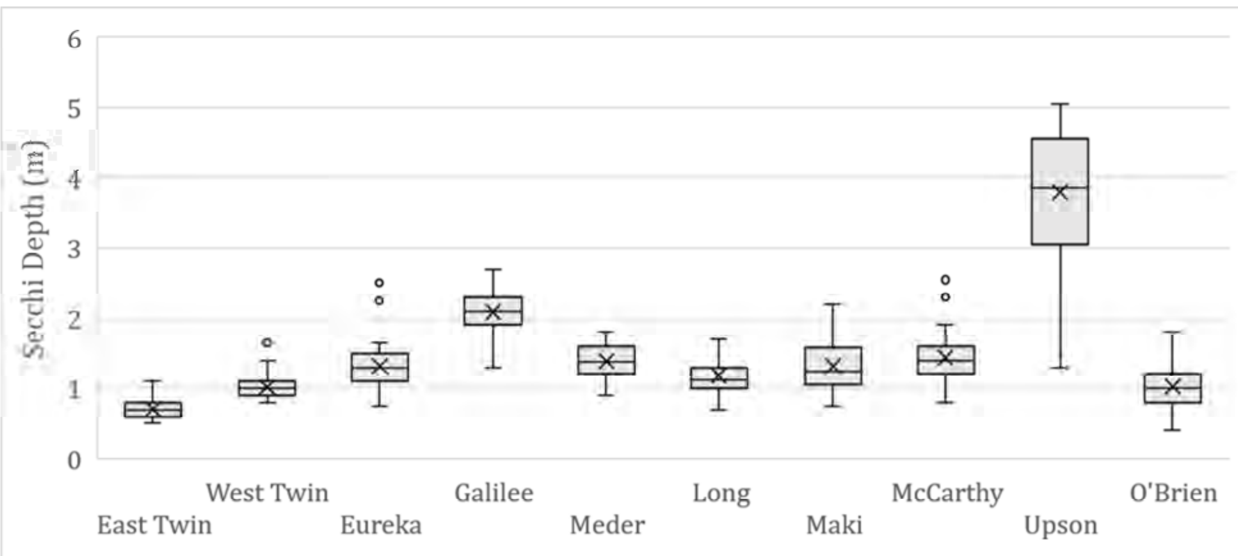


Figure 4.24. Box and whisker plot of Secchi disk measurements for each of the eleven Penokee Lakes. The mean is shown as a line within each box, the median is an "X," the box encompasses the inter-quartile range, whiskers are the minimum and maximum value, and any dots beyond the whiskers are outliers.

Most of the lakes had average Secchi depths between one and two meters. Water clarity in the Penokee Lakes is highly influenced by the presence of tannins or humic acids in all of the lakes except Upson. Tannins prevent light from reaching deeper water in the Penokee lakes, which limits the "photic zone," or the depth to which aquatic plants and algae can grow. The tannins occur naturally and are an indication of the importance of surface runoff and the presence of wetland areas in the watersheds of these lakes.

Trophic State

A common method of measuring the interrelationship of nutrient concentrations (phosphorus), algal response to nutrient concentrations (chlorophyll-a), and light availability (Secchi depth) is the Carlson Trophic State Index (TSI; Figure 4.25). As phosphorus concentrations increase, chlorophyll-a concentrations tend to increase and water clarity decreases. The TSI index gives a measure of the relative "trophic state" of a lake, with lower values indicating "oligotrophic" or low productivity systems and higher values indicating "eutrophic" or high productivity systems. The trophic status of a lake is frequently linked to human development and influence on water quality, but itself is not a measure of pollution because lakes exist across the continuum of trophic status naturally.

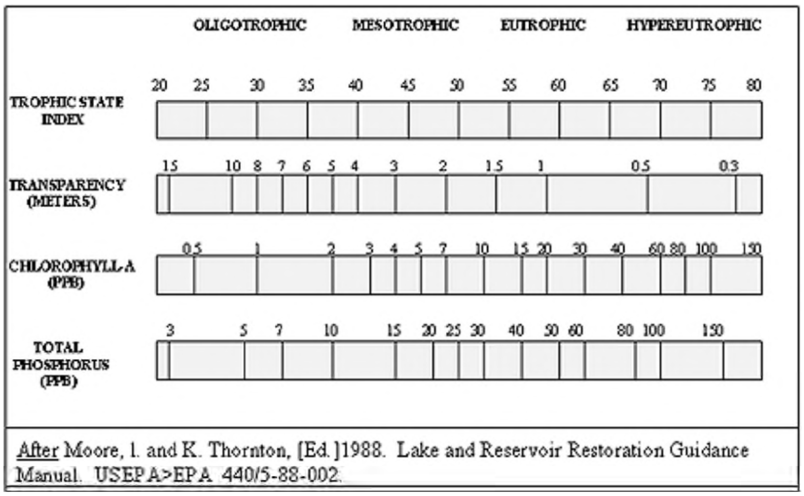


Figure 4.25. Continuum of lake trophic status in relation to the Carlson Trophic State Index (taken from WisCALM 2022; WDNR, 2021).

The TSI index can be calculated using either total phosphorus, Secchi depth, or chlorophyll-a data from a lake. However, because the TSI is ultimately a prediction of algal biomass, calculating it with chlorophyll-a data is the preferred method. WDNR uses the TSI calculation with either chlorophyll-a or Secchi depth to assist in assessing health of lakes for 305 (b) reporting. Data requirements and methods for calculating TSI values and comparing them to assessment thresholds used in determining water quality impairments are described in WisCALM 2022 (Table 4.14; WDNR 2021).

Table 4.14. Trophic Status Index (TSI) thresholds used in the general assessment of lake natural communities in Wisconsin (WDNR 2021).

Condition Level	Shallow			Deep			
	Headwater	Lowland	Seepage	Headwater	Lowland	Seepage	Two-Story
Excellent	< 53		< 45	< 48	< 47	< 43	< 43
Good	53 – 61		45 – 57	48 – 55	47 – 54	43 – 52	43 – 47
Fair	62 – 70		58 – 70	56 – 62	55 – 62	53 – 62	48 – 52
Poor	≥ 71		≥ 71	≥ 63	≥ 63	≥ 63	≥ 53

Adequate chlorophyll-a and Secchi depth data exists for each of the Penokee Lakes to calculate TSI values for these parameters. Total phosphorus TSI values are not used by WDNR for condition assessments, so they were not calculated.

Table 4.15 displays mean chlorophyll-a and Secchi depth TSI values calculated using methods described in WisCALM 2022 (WDNR, 2021), along with an assessment of lake condition level based on the chlorophyll-a TSI and the proposed natural community designation updates for these lakes. Trophic status for each lake based on the Carlson TSI scale is also estimated. Upson Lake is oligotrophic while the rest of the lakes fall on the low end of mesotrophic.

The Secchi TSI values are consistently greater than the chlorophyll-a TSI for all lakes, suggesting that something other than algal production is limiting light penetration in these lakes. This is expected (with the exception of Upson Lake) because of the influence of tannins on light penetration. The TSI results suggest something other than algal production is influencing light penetration in Upson Lake as well.

Overall, between the total phosphorus criteria evaluation and the TSI condition assessment, all of the Penokee Lakes, with the possible exception of O'Brien Lake, are clearly meeting phosphorus impairment criteria and all of the lakes are in excellent condition based on chlorophyll-a TSI values. O'Brien Lake may need additional monitoring to determine the appropriate phosphorus criteria for the lake. Even though the TSI evaluation indicated the lake is in "excellent" condition, the documented presence of blue green algae blooms in this lake suggests additional factors are leading to higher phosphorus concentrations and occasional blooms that should be better-understood through further research.

Table 4.15. Mean Trophic State Index (TSI) calculated using chlorophyll-a and Secchi depth data for each of the eleven Penokee Lakes. Condition levels are based on the proposed natural community designation for each lake and estimated Carlson trophic status is based on the chlorophyll-a TSI.

Lake	Natural Community (proposed)	Mean TSI – Chl-a	Condition Level	Trophic Status	Secchi TSI
East Twin	Deep Headwater Drainage	42.1	Excellent	Mesotrophic	65.3
West Twin	Deep Headwater Drainage	42.2	Excellent	Mesotrophic	59.8
Eureka	Deep Headwater Drainage	40.3	Excellent	Mesotrophic	56.4
Galilee	Deep Headwater Drainage	38.7	Excellent	Mesotrophic	49.6
Meder	Shallow Headwater Drainage	43.5	Excellent	Mesotrophic	55.5
Long	Deep Headwater Drainage	43.9	Excellent	Mesotrophic	57.9
Maki	Deep Headwater Drainage	38.7	Excellent	Mesotrophic	56.5
McCarthy	Deep Headwater Drainage	38.1	Excellent	Mesotrophic	55.2
Upson	Deep Headwater Drainage	31.1	Excellent	Oligotrophic	41.2
O'Brien	Deep Headwater Drainage	43.2	Excellent	Mesotrophic	60.4
Caroline	Shallow Headwater Drainage	42.7	Excellent	Mesotrophic	61.8

Sulfate
Sulfate is a naturally occurring ion that is often associated with mineral deposits and is of particular interest in establishing a baseline of concentrations in the Penokee Lakes because of their proximity

to the Penokee Iron Range. Sulfate is also an important factor in waterbodies that are able to support manoomin (wild rice), an important cultural and subsistence resource for regional Ojibwe tribes. Lakes in northern Wisconsin tend to have sulfate concentrations less than 10 mg/L (Lillie and Mason, 1983).

Mean sulfate concentrations measured in all lakes in 2019 fell below the sulfate criteria of 10 mg/L set by the state of Minnesota for the protection of wild rice (Wisconsin does not have a sulfate criteria; Figure 4.26). However, sulfate concentrations in East and West Twin Lakes sometimes exceeded 10 mg/L, indicating wild rice growth in these lakes may be impeded or not possible because of sulfate levels. Upson and O'Brien Lakes were the only two Penokee Lakes where wild rice plants were observed during the study period.

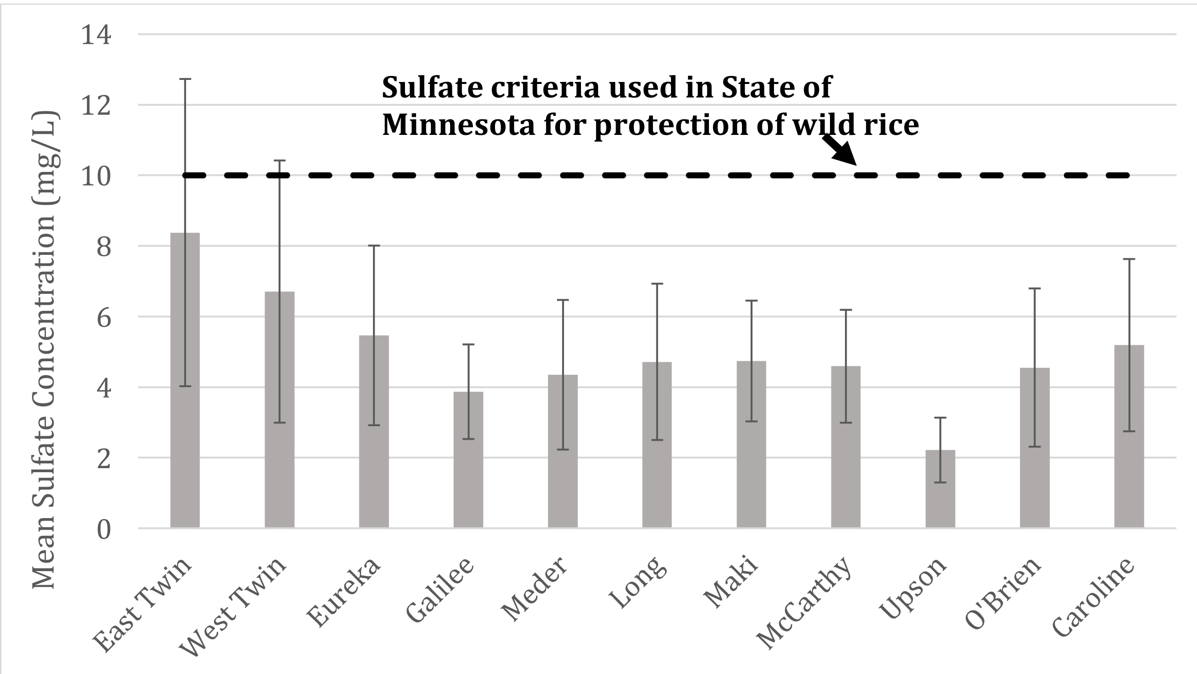


Figure 4.26. Mean and standard deviation of sulfate concentrations in surface water from eleven Penokee Lakes. All data were collected in 2019.

Alkalinity, Hardness, Calcium, and Magnesium

These measurements give an indication of how "hard" or "soft" water is in a lake and the related acid neutralizing capacity of the lake. Lakes with lower acid neutralizing capacity are more susceptible to pollutants like acid mine drainage and acid rain. Lakes in northern Wisconsin tend to have values for alkalinity, total hardness, calcium and magnesium below the statewide average for lakes (Lillie and Mason 1983). Results from the Penokee Lakes are consistent with this.

Alkalinity values in all eleven lakes were almost entirely below detection based on the method used, so these results are not displayed. Mean total hardness concentrations were very low, ranging from 6.5 mg/L in East Twin Lake to 22.4 mg/L in Long Lake (Table 4.11). Generally, total hardness values below 60 mg/L are considered "soft," so concentrations measured in these lakes are very low (USGS, 2018). Hardness increases moving downstream from East Twin through Galilee, another indication of groundwater contributions increasing from upstream to downstream in some of these lakes (Figure 4.27).

Mean calcium concentrations ranged from 1.6 mg/L in East Twin Lake to 6.3 mg/L in Long Lake (Table 4.11). Mean magnesium concentrations ranged from 0.6 mg/L in East Twin Lake to 1.7 mg/L in O'Brien Lake (Table 4.11). The calcium and magnesium concentrations in all lakes were well below mean values for Wisconsin lakes of 12 mg/L for calcium and 8 mg/L for magnesium (Lillie and Mason, 1983). More than half of the total hardness is comprised of other metals besides calcium and magnesium, which are usually the most common ions making up total hardness (Figure 4.27). The alkalinity and hardness concentrations indicate very soft water in these lakes with low acid neutralizing capacity and high susceptibility to pollutants like acid mine drainage and acid rain.

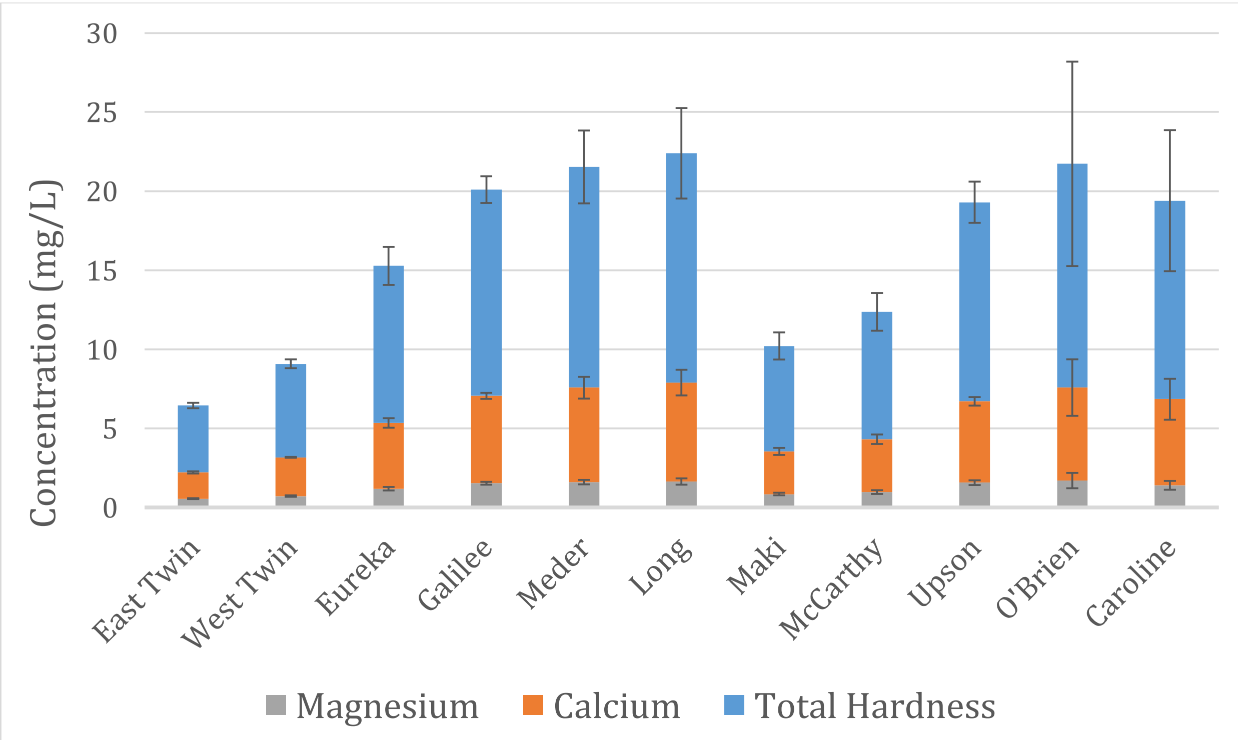


Figure 4.27. Mean and standard deviation of surface water total hardness, calcium, and magnesium concentrations from eleven Penokee Lakes. All data were collected in 2019.

4.4 Ecosystem Forecasting Using WiLMS

The Wisconsin Lake Modeling Suite (WiLMS) is a lake water quality planning tool that simulates the relationship between nutrient runoff, water quality, and water clarity in lakes using land cover percentages and precipitation input data (Panuska, and Kreider, 2003). It is useful as a screening-level tool to look at likely sources of phosphorus to a lake and to investigate potential management options for maintaining or improving the health of a lake using phosphorus concentration as a metric of lake health.

WiLMS was used to investigate and inform the following questions related to the Penokee Lakes in order to inform management plan recommendations:

1. What is the estimated current phosphorus load and primary sources of phosphorus for each Penokee Lake?

2. How might phosphorus concentrations in the Penokee Lakes change under a future development scenario?

Jordan Bremer, a Burke Center Research Associate, completed the WiLMS analysis as part of her senior Capstone thesis project. The full methodologies and assumptions used and results are available in her project report (Bremer, 2021) and are summarized here.

Current Phosphorus Loading and Sources

Estimates of current phosphorus loading and sources to the Penokee Lakes were developed within the "Lake Total Phosphorus Prediction" model within WiLMS. The model uses land-cover-specific phosphorus export coefficients to estimate phosphorus loads from different land cover types and also from septic systems based on estimates of per capita use and efficiency of phosphorus retention in soil from each system. WISCLAND 2.0 land cover data described on page 30 were used to populate the land cover categories within WiLMS.

Estimates on septic systems around each lake began by counting the number of individual houses on each lakeshore. This was done using Google Earth, parcel information available through the Ashland and Iron County websites, and through contacting landowners directly. Previous lake management planning efforts at the Burke Center have used a 2.5-people-per-household assumption to estimate septic system usage (SOEI, 2016). The same assumption was used in this study. One septic system per household was assumed and seasonality versus annual usages of these systems were estimated using results from the use and value survey distributed to Penokee lake property owners in 2015 (Hofstedt, *et al*., 2015; see Section 3). Data and assumptions used in developing the model are further discussed in Bremer, 2021.

The primary sources of phosphorus within all of the Penokee Lakes are watershed runoff from forested and wetland areas and precipitation on the lake surface (Figures 4.28 and 4.29). Lakes with larger watersheds like Caroline, O'Brien, and Galilee Lakes also have a greater phosphorus load, simply by virtue of the greater land area contributing phosphorus to the lake. Lakes with more development are predicted to have a contribution to phosphorus loading from septic systems and rural residential development (Figures 4.28 and 4.29). These estimates are based several assumptions, but give a reasonable starting point for demonstrating the potential contributions of phosphorus to these lakes from human development.

Another likely source of phosphorus to lakes with developed shoreland areas are those where shoreland habitat is negatively impacted by human development. The scale at which the land cover dataset was derived missed most of the developed shoreline areas (i.e., a small amount of "rural residential" land cover was captured in Lake Galilee), although the overall low levels of development suggest these areas would be small contributors of phosphorus at present. The shoreland habitat assessment discussed in section 4.6 identifies areas that could be improved through management. Improving shoreland habitat would also reduce phosphorus contributions to these lakes where there are some issues currently. Overall, the phosphorus load estimates reflect the current low levels of human development within the watersheds of these lakes.

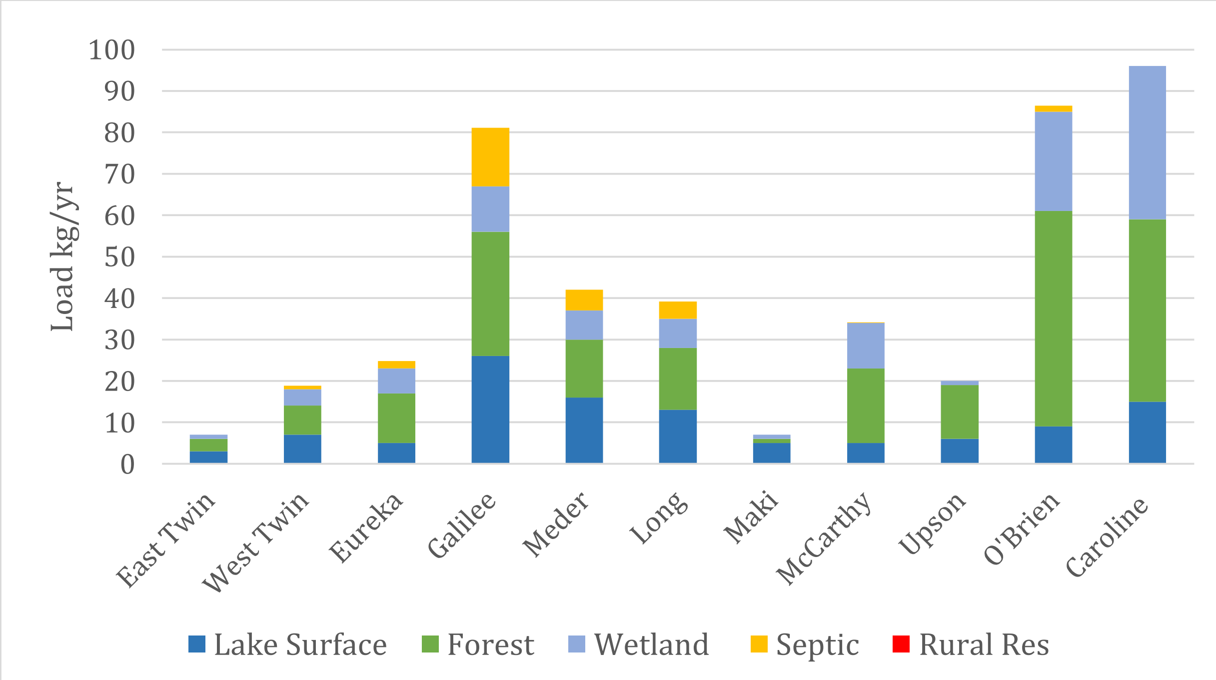


Figure 4.28. Estimated annual phosphorus load to each of the eleven Penokee Lakes. Estimates represent the “most likely” value calculated using Wisconsin Lake Modeling Suite (WiLMS) software (Panuska, & Kreider, 2003).

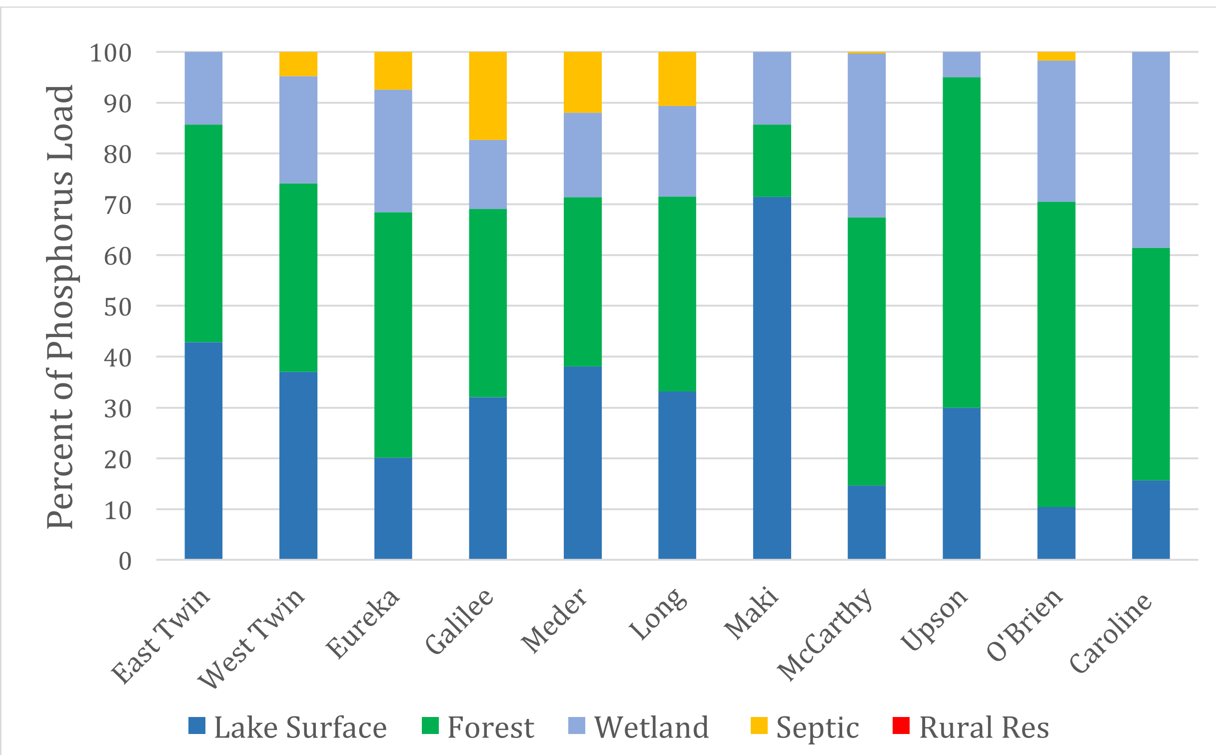


Figure 4.29. Sources of phosphorus to each of the eleven Penokee Lakes and percent of total load from each source.

Modeling Phosphorus Concentrations – Current and Future Development Scenarios

In addition to estimates of current loads and sources of phosphorus to each lake, the "Lake Total Phosphorus Prediction Module" of WiLMS was also used to model current and future growing season mean total phosphorus concentrations. The model uses morphometric characteristics of each lake, along with the land cover and septic system data to predict total phosphorus concentration expected for each lake. A range of models within WiLMS produces spring turnover, growing season mean, and annual average phosphorus estimates for various kinds of lakes based on physical characteristics. The user can then choose the model that best fits the available data and the kind of lake.

The growing season mean total phosphorus concentration predictions are described here because those values are used by WDNR in assessing health of lakes for 305(b) reporting (described in section 4.2). Table 4.16 shows the best-fit modeled growing season mean total phosphorus concentration compared to the observed values. Modeled concentrations were within 10% of observed values for East Twin, West Twin, Eureka, Long, Meder, and Maki Lakes. This included a mix of over- and under-predictions. The model over-predicted phosphorus concentrations in McCarthy Lake by 16% and Lake Galilee by 21%. Upson, Caroline, and O'Brien Lakes all were under-predicted by 24-32% (Table 4.16). The under-predictions, in particular, suggest there may be an additional source of phosphorus to these lakes (like internal loading) that is not captured well by the models for Upson, Caroline, and O'Brien Lakes.

Table 4.16. Observed and predicted growing season mean (GSM) total phosphorus (TP) concentrations for each of the eleven Penokee Lakes. Predictions were made using the "Lake Total Phosphorus Prediction Module" of the Wisconsin Lake Modeling Suite (WiLMS) software (Panuska, & Kreider, 2003).

Lake	Observed	Predicted	Difference	Percent Difference	Best Model Fit
East Twin	26.1	28	1.9	7.3%	Rechow, 1977 Anoxic
West Twin	23.2	22	-1.2	-5.2%	Canfield-Bachmann, 1981 Natural Lake
Eureka	21.0	20	-1.0	-4.8%	Canfield-Bachmann, 1981 Natural Lake
Galilee	17.3	21	3.7	21.4%	Canfield-Bachmann, 1981 Natural Lake
Meder	24.6	23	-1.6	-6.5%	Canfield-Bachmann, 1981 Natural Lake
Long	24.6	24	-0.60	-2.4%	Walker, 1987 Reservoir
Maki	19.2	21	1.8	9.4%	Canfield-Bachmann, 1981 Natural Lake
McCarthy	19.0	22	3.0	15.8%	Canfield-Bachmann, 1981 Natural Lake
Upson	9.26	7	-2.3	-24.4%	Rechow, 1979, General
O'Brien	32.1	22	-10.1	-31.5%	Walker, 1987 Reservoir
Caroline	30.8	23	-7.8	-25.3%	Walker, 1987 Reservoir

In order to model future growing season mean total phosphorus concentrations, privately-owned parcels around each lake were divided to their minimum possible sizes based on current Wisconsin Shoreland Zoning regulations for unsewered lots (WI Administrative Code NR115.05(3)(a)). Thus, the scenario uses a minimum average shoreline width of 100 feet and a minimum area of 20,000 square feet for each parcel. Parcels currently in public or land trust ownership were not divided. The future development scenario was processed within ArcGIS to approximate the maximum number of parcels there could be around each lake.

Each new parcel created was assumed to have one house and one septic system per parcel, as well as 2.5 people per system. The seasonal to annual population ratio was kept the same as the current ratio for the future scenario. No adjustments were made to the land cover data for the development scenario, even though it is likely that land cover changes in shoreland areas would accompany a development scenario like this. The septic system estimates for each lake were added to WiLMS and the growing season mean total phosphorus concentrations were re-calculated using the same model for each lake as was used for the current concentration predictions.

Results clearly show which lakes are more vulnerable to future development. Lakes with large amounts of privately-held parcels, small watershed-to-lake-surface-area ratios, and long water residence times are particularly vulnerable to declines in water quality from future development as compared to lakes with large amounts of shoreline parcels in some form of protected status and/or larger watershed-to-lake-surface-area ratios. Figure 4.30 compares Caroline Lake, a lake with the majority of its shoreline owned by the State of Wisconsin or The Nature Conservancy, having a low amount of shoreline susceptible to development compared to Maki Lake, where about two-thirds of the shoreline is in private ownership. Figure 4.31 shows how the development scenario would affect predicted growing season mean total phosphorus concentrations in each of the lakes. Caroline and Upson Lakes have most or all of their shoreland parcels in some sort of protected status and are less vulnerable to future water quality declines from shoreland development. Even though O'Brien Lake currently has the majority of its shoreline in private ownership, it is less vulnerable to water quality declines from shoreland development because it has a large watershed-to-surface-area ratio.

Lakes including Maki, East Twin, and Long may have total phosphorus concentrations increase above current water quality criteria and are most vulnerable to future development. In lakes like these, efforts to work with landowners on conservation easements or other avenues to protect shoreland areas before they are developed are good strategies to maintain good water quality.

Lake Galilee already has the most shoreland parcels and would see less relative increase in parcels and water quality decline from the development scenario. Thus, in Lake Galilee, efforts to improve shoreland areas already developed and in poor or marginal condition are good strategies to maintain or improve water quality.

While a development scenario like this uses many assumptions and may never play out, it does serve to highlight lakes among the eleven Penokee Lakes that are more vulnerable to water quality declines from development pressure and is useful in recommending management strategies that may be most effective for each lake to help maintain or improve water quality.

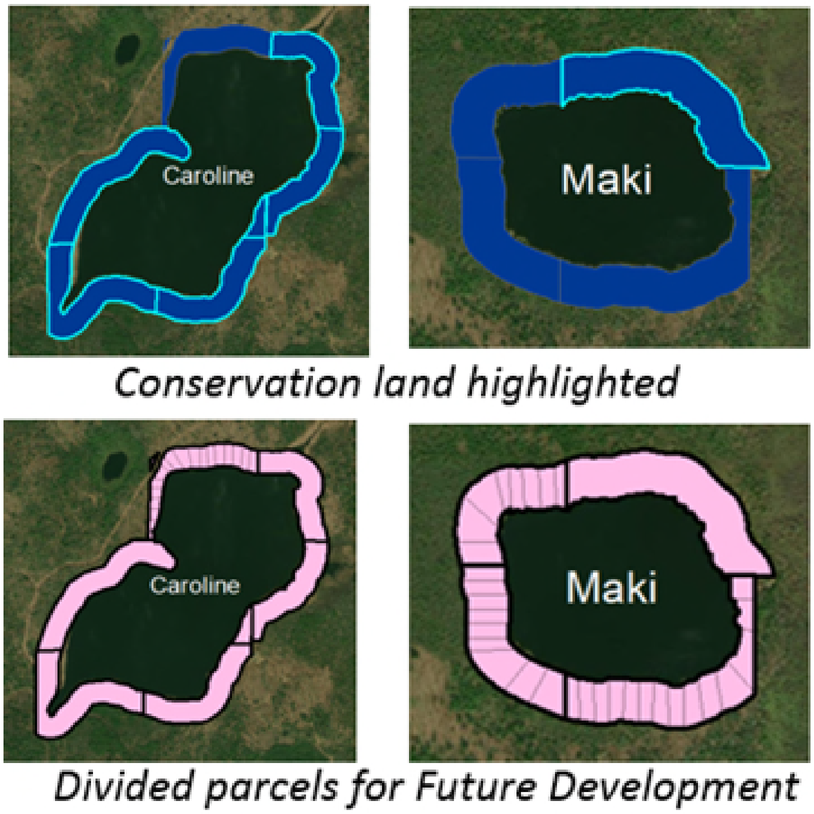


Figure 4.30. Results of dividing private parcels around Caroline and Maki Lakes according to current Wisconsin Shoreland Zoning regulations (NR115.05(3)(a)). The top blue photos depict current parcels with conservation lands highlighted. The bottom pink photos depict a potential future scenario with private property parcels divided to a maximum based on Wisconsin's Shoreland Zoning regulations.

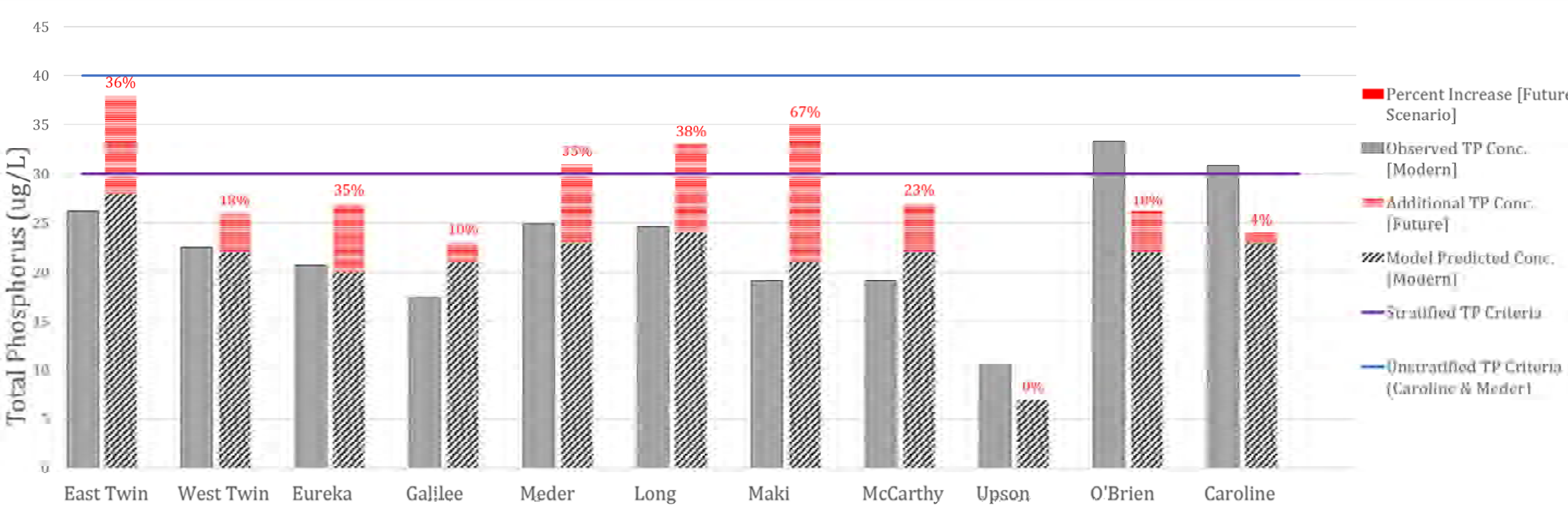


Figure 4.31. Comparison of each lake's observed concentrations to their best-fit predictive model's concentrations under the future development scenario using the Wisconsin Lake Modeling Suite (WiLMS) software (Panuska, & Kreider, 2003). The red patterned bars and numbers indicate the predicted percent difference in total phosphorus concentration between the current conditions and the future development scenario.

4.5 Aquatic Plant Community

Point-Intercept Aquatic Plant Surveys

Aquatic plant communities in all eleven Penokee Lakes were sampled between the summers of 2016 and 2018 using a point-intercept method (Hauxwell *et al*. 2010). Aquatic plant data were analyzed to characterize relative species abundance, species diversity, sensitivity to disturbance, Floristic Quality Index (FQI), and presence/absence of invasive species. Details of collection procedures, data analysis and results are described in Appendix B.

Aquatic plant communities in all lakes were surveyed once between the summers of 2016 and 2018 (Table 4.17). Table 4.18 lists summary statistics and metrics derived from the aquatic plant surveys in each of the eleven Penokee Lakes.

Table 4.17. Date of aquatic plant survey conducted in each of the eleven Penokee Lakes.

	PI Survey Date
East Twin	8/8/2016
West Twin	8/8/2016
Eureka	7/14/2016
Galilee	8/10/2016
Meder	8/6/2018
Long	8/6/2018
Maki	8/9/2016
McCarthy	8/15/2016
O'Brien	8/2/2017
Upson	8/7/2017
Caroline	7/20/2016

Throughout this study, 54 distinct species were identified from all lakes combined (Appendix B). An additional five unique families or aquatic plant groups were identified but not characterized to species-level (Appendix B). When including species identified directly from rake sampling and visual observations, species richness values met or exceeded the regional mean value of 13 species for the Northern Wisconsin Lakes and Forests region (Nichols 1999) in all of the Penokee Lakes except East Twin Lake. Species richness, including visual detections and survey detections, ranged from six species in East Twin Lake to 35 species in Lake Galilee (Figure 4.32, Table 4.18).

Most rake pulls that yielded plant life contained one to three species across all the lakes (Figure 4.33). Ninety-five percent of plants were observed growing in depths less than eight feet across all lakes, with a maximum depth of 15 feet observed in Upson Lake (Figure 4.34). Outside of Upson Lake, plant growth in deeper water was a rare occurrence (Figure 4.33). Upson Lake has clear water, allowing light penetration and plant growth to the bottom in most areas of the lake. Dark water in other lakes limits light penetration and prevents growth in deeper waters. East Twin had the least amount of plant growth and fewest species found in any one rake toss due to high tannin content, low light availability, and possibly low pH. Plant growth in East Twin was limited to floating and emergent plants, further highlighting the conditions in this lake that limit plant growth.

Metrics used to represent the overall sensitivity to disturbance of a lake's plant community and the overall health of the lake based on its plant community include the mean coefficient of conservatism (C) and the FQI. Mean C values were close to or greater than the Northern Wisconsin Lakes and Forests regional mean of 6.7 except for O'Brien Lake (Figure 4.35). Most Penokee Lakes had FQI scores near or above the Northern Wisconsin Lakes and Forests regional average of 24.3, indicating ecosystems capable of hosting disturbance-sensitive plant species. FQI scores ranged from 11.0 (East Twin) to 37.1 (Galilee; Table 4.18, Figure 4.36). Conditions in East Twin Lake that limit plant growth have already been discussed. Low mean C, FQI, and Simpson's Diversity Index scores (Figure 4.37) in O'Brien Lake stand out compared to other lakes besides East Twin. Mean Secchi depth in O'Brien Lake is on the low end when compared to other lakes, but similar to lakes like Caroline and West Twin that had plant metrics close to or above regional averages. Available water chemistry data does not suggest O'Brien Lake is different than other similar Penokee Lakes, or that there is evidence of human influence on water quality. Boat activity and boat-related impacts on the plant community are likely not a factor either. O'Brien Lake had the greatest annual average difference between high and low water levels (2.2 ft, Figure 4.10). That, combined with low light availability, make it more likely that the lower plant metric scores in O'Brien Lake are related to the amount of suitable substrate and conditions for plant growth within the photic zone.

Although not identified during the point-intercept survey, visual observations of wild rice *(Zizania palustris)* were made in Upson and O'Brien Lakes during the sampling period. For further details of the aquatic plant community assessment, see Appendix B.

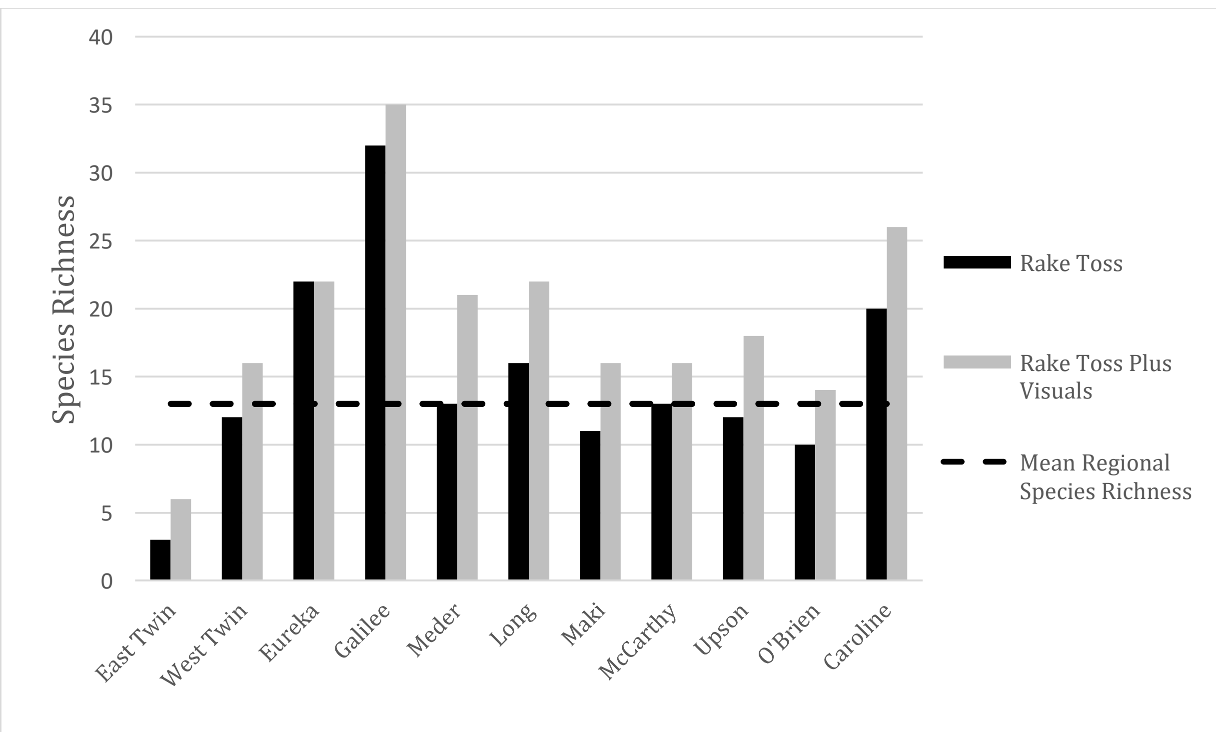


Figure 4.32. Aquatic plant species richness observed in each of the eleven Penokee Lakes. Gray bars indicate plant species identified from rake tosses only. Black bars include species identified from rake tosses and spotted visually. Mean regional species richness value for Northern Wisconsin Lakes and Forests region from Nichols 1999.

Table 4.18. Summary statistics and metrics from the aquatic plant surveys in each of the eleven Penokee Lakes.

Metric	East Twin	West Twin	Eureka	Galilee	Meder	Long	Maki	McCarthy	Upson	O'Brien	Caroline
Total number of sites visited	26	62	106	159	98	171	57	50	173	286	97
Total number of sites with vegetation	11	40	36	95	39	44	32	36	103	57	28
Total number of sites shallower than maximum depth of plants	18	57	86	132	95	60	44	41	155	137	75
Frequency of occurrence at sites shallower than maximum depth of plants	61.1	70.2	41.9	72.0	41.1	73.3	72.7	87.8	66.5	41.6	37.3
Simpson Diversity Index	0.57	0.78	0.92	0.93	0.85	0.89	0.74	0.88	0.80	0.61	0.92
Maximum depth of plants (ft)	5	7	15	8	8	6	6	7	15	6	6
Number of sites sampled using rake on rope	0	0	12	2	0	7	3	0	52	5	0
Number of sites sampled using rake on pole	26	62	84	153	98	86	54	50	121	282	91
Average number of all species per site (shallower than max depth)	0.7	1.2	1.1	1.5	0.6	1.3	1.5	2.5	0.9	0.5	0.8
Average number of all species per site (veg. sites only)	1.1	1.7	2.7	2.1	1.4	1.8	2.1	2.9	1.4	1.2	2.0
Average number of native species per site (shallower than max depth)	0.7	1.2	1.1	1.5	0.6	1.3	1.5	2.5	0.9	0.5	0.8
Average number of native species per site (veg. sites only)	1.1	1.7	2.7	2.1	1.4	1.8	2.1	2.9	1.4	1.2	2.0
Species Richness	3	12	22	32	13	16	11	13	12	10	20
Species Richness (including visuals)	7	16	22	35	21	22	16	16	18	14	26
Mean Coefficient of Conservatism	6.3	7.3	6.4	7.3	7.8	6.8	6.8	6.8	7.2	5.4	6.6
Floristic Quality Index	11.0	25.4	27.3	37.1	27.1	26.3	22.6	24.4	23.8	17.1	27.2

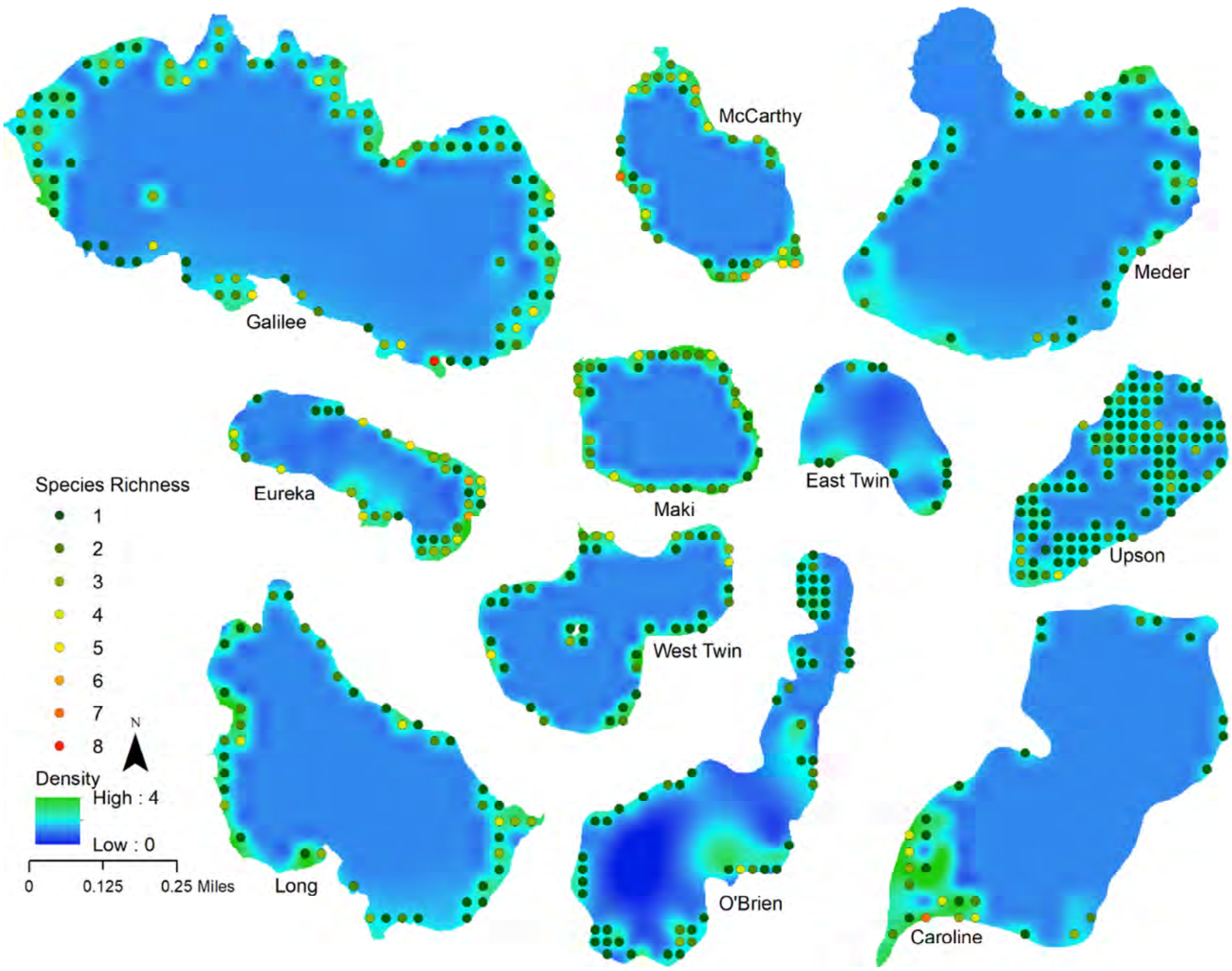


Figure 4.33. Aquatic plant species richness and density for each of the eleven Penokee Lakes. The color of each dot indicates the number of plant species identified at that location. Green shading indicates high plant density (relative to the other lakes) and dark blue shading indicates areas of no plant growth.

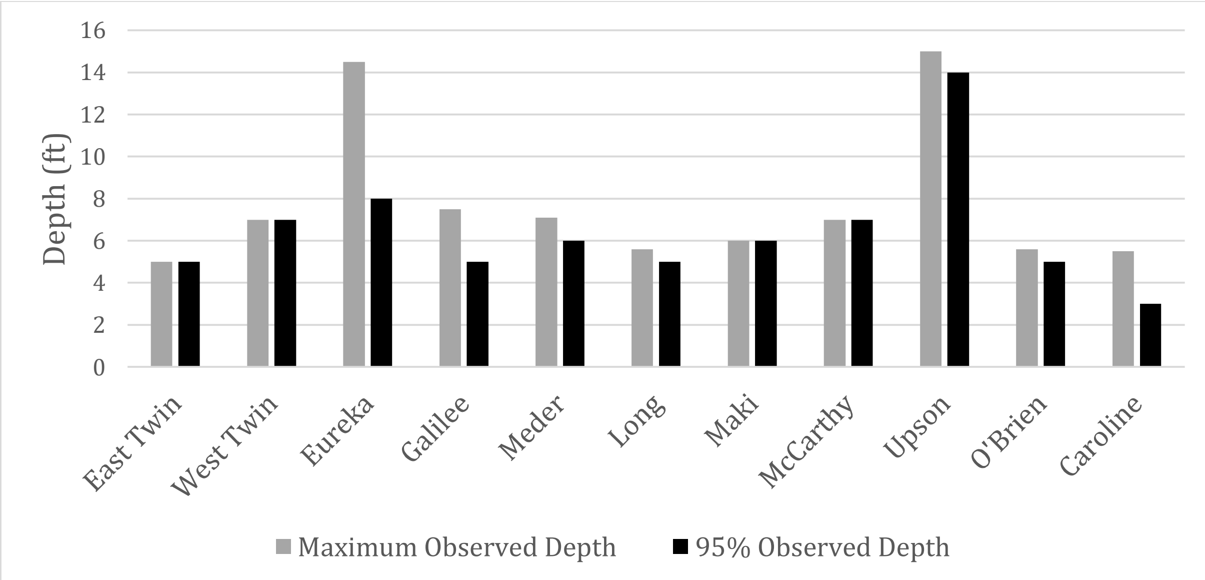


Figure 4.34. Maximum observed depth of aquatic plant growth and depth below which 95% of sites with plants were observed from each of the eleven Penokee Lakes.

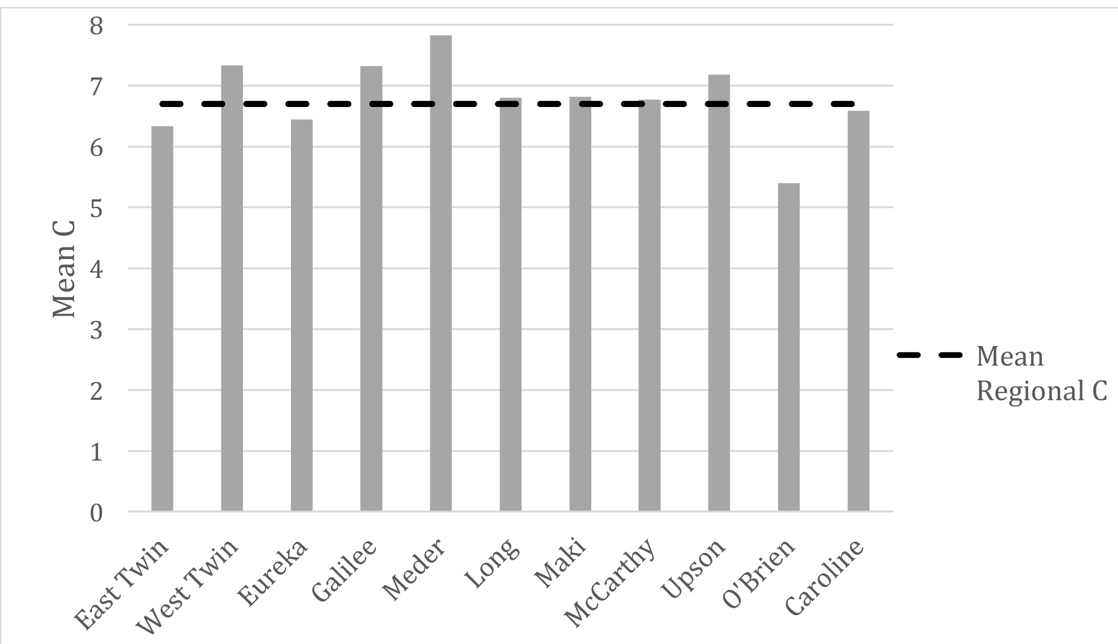


Figure 4.35. Mean coefficient of conservatism (Mean *C*) values calculated from aquatic plant community data from each of the eleven Penokee Lakes. Mean regional *C* is the value for Northern Wisconsin Lakes and Forests region from Nichols 1999.

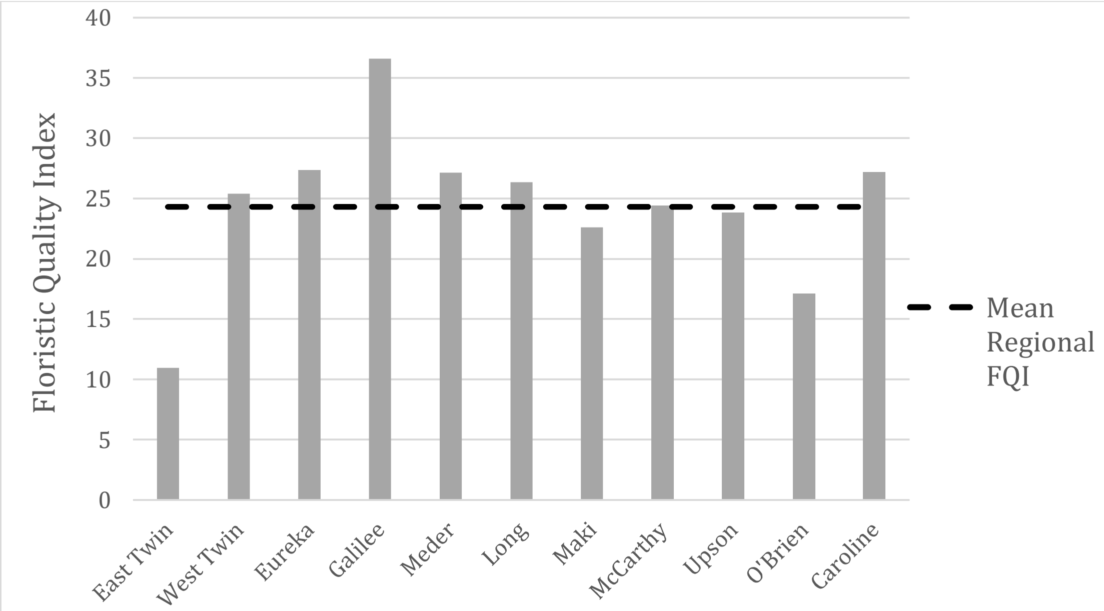


Figure 4.36. Floristic Quality Index (FQI) values calculated for each of the eleven Penokee Lakes. Mean regional FQI is the value for Northern Wisconsin Lakes and Forests region from Nichols 1999.

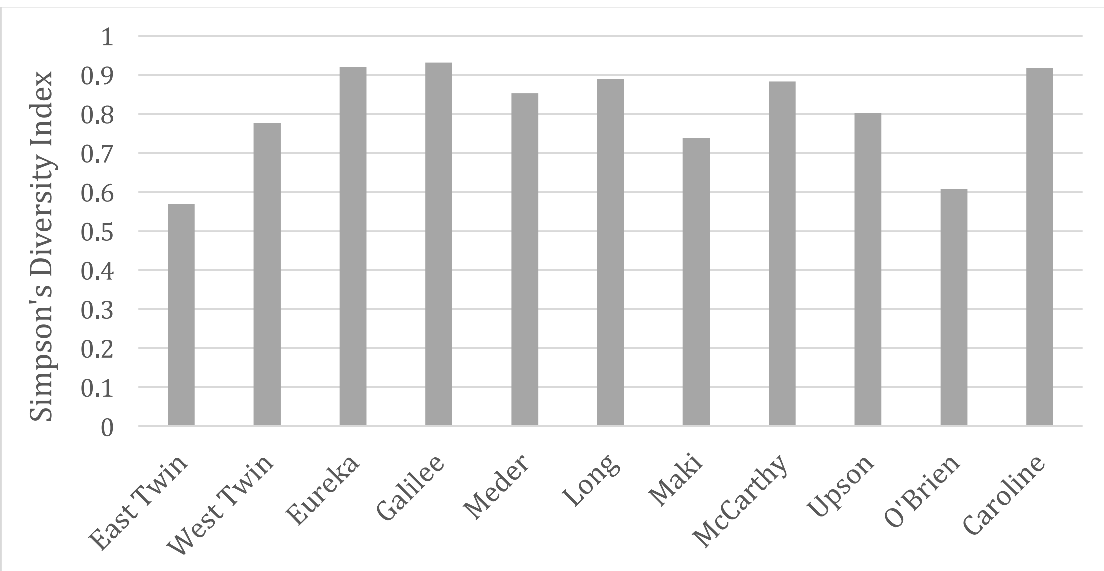


Figure 4.37. Simpson's Diversity Index values calculated for each of the eleven Penokee Lakes. In this application, values closer to 1 indicate high aquatic plant diversity and values closer to 0 low aquatic plant diversity (Simpson 1949).

Invasive Species

Purple loosestrife has been recorded by the Wisconsin DNR in Meder and Galilee Lakes, Chinese mystery snail in Long and O'Brien Lakes, and banded mystery snail in Galilee and O'Brien Lakes. No non-native aquatic plants were observed by Burke Center staff during aquatic plant survey work in the summers of 2016-2018.

Rare, Threatened, and Endangered Aquatic Plants

There were no rare, threatened, or endangered aquatic plant species identified from the Penokee Lakes during plant survey work and a comprehensive search of the statewide endangered resources database was not completed as part of the project.

Substrate Characteristics

Another component of the aquatic plant survey protocol is to collect basic information about the lake bed substrate encountered at each survey point. These data can be useful when interpreting the aquatic plant data, as well as provide information in understanding potential important habitat areas for fish, wild rice, and other aquatic life. Lake substrate data for all eleven Penokee Lakes are displayed in Figure 4.38. Some areas of each lake do not have substrate data recorded. This is because once established, points below the maximum depth of plant growth are not sampled for substrate characteristics.

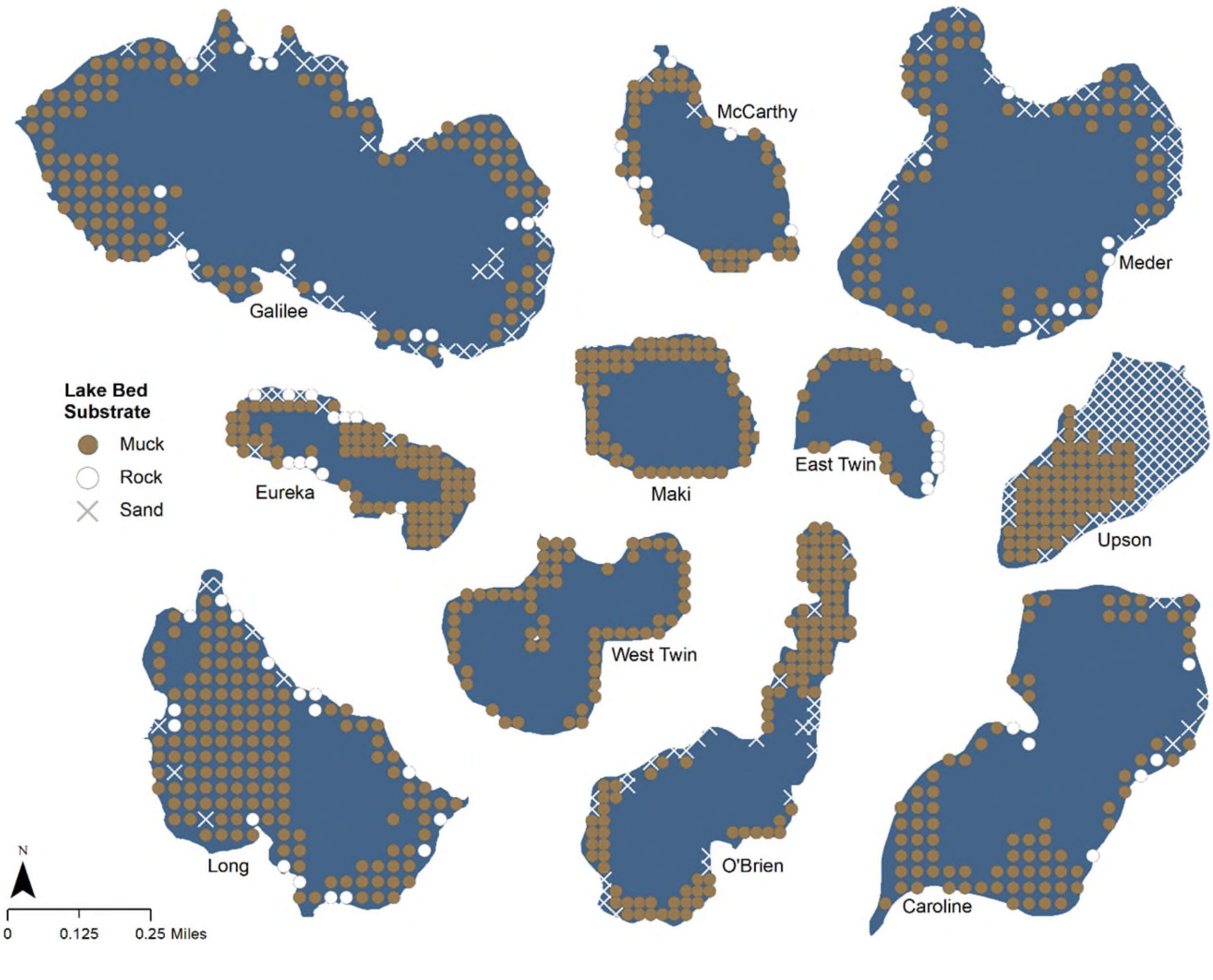


Figure 4.38. Lake bed substrate results from the aquatic plant survey conducted on each of the eleven Penokee Lakes.

4.6 Shoreland Habitat

The area of transition between the terrestrial and aquatic worlds is often collectively referred to as shoreland habitat. Healthy shoreland areas are crucial for fish and wildlife habitat, as well as maintaining good water quality in lakes and other aquatic environments. Human development of shoreland areas is one of the key problems that can lead to declines in water quality and fish and wildlife habitat. Thus, understanding the current condition of shoreland habitat areas in lake is a key component to lake management planning.

Shoreland habitat is often broken up into three distinct zones for purposes of lake management (Figure 4.39). The riparian zone represents lands that are very rarely, if ever, inundated by water, it starts at high water mark (HWM) and extends inland 35 feet. The littoral zone represents the region of the lake where sunlight can penetrate to the sediments, and rooted plants can grow, extending from the current water line, 50 feet into the lake. The bank zone, or shoreline, is a region between the bank lip and the bank toe (beginning of lake bed).

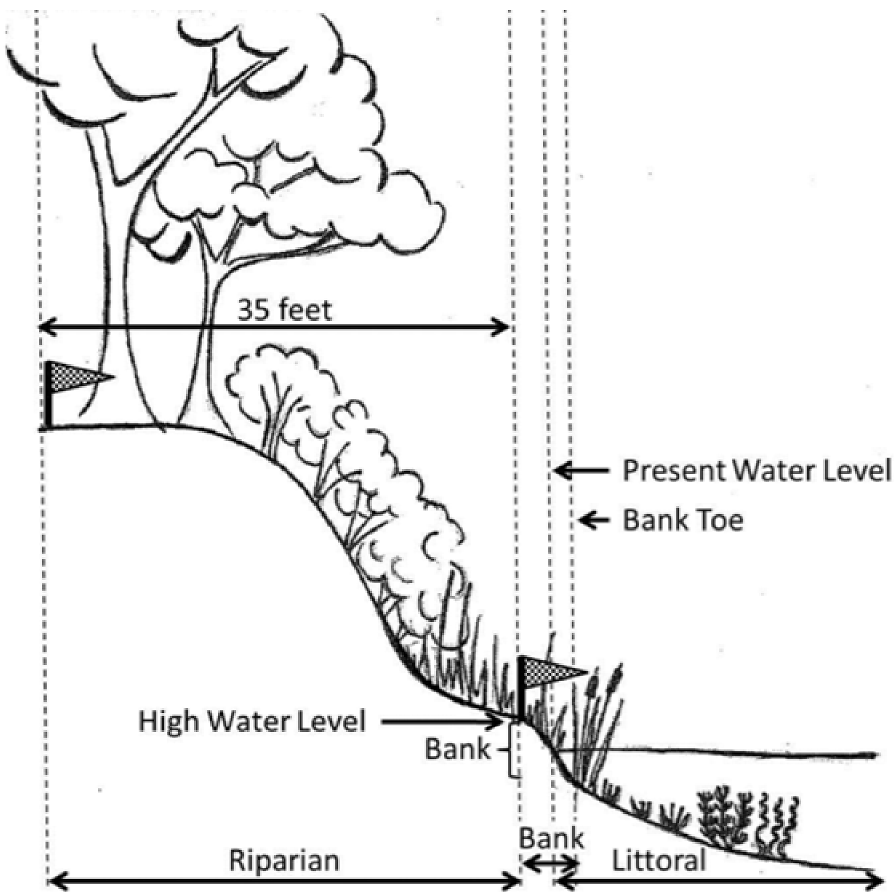


Figure 4.39. Conceptual diagram of the different habitat zones at the land-water interface in a lake. Adopted from WDNR Shoreland Habitat Monitoring Field Protocol, 2016.

To better characterize shoreland habitat around the Penokee Lakes, shoreline and nearshore habitat conditions, along with an assessment of coarse woody debris, were characterized once in each lake over the study period. Shoreland habitat condition was quantified using methods adapted from the WDNR (WDNR, 2016) and the Environmental Protection Agency (USEPA, 2007). The shoreland habitat assessments consisted of three activities, each occurring around the entire shoreline of each lake:

1. Georeferenced photos of the entire shoreline that slightly overlap.
2. Assessment of the riparian, bank, and littoral habitat by parcel.
3. Count and map all pieces of large (coarse) woody habitat in water less than 2 feet deep.

Full details of the shoreland habitat assessment are in Appendix C. Table 4.19 lists the date each component of the shoreland habitat assessment occurred.

Table 4.19. Date/s each element of the shoreland habitat assessment were conducted in each of the eleven Penokee Lakes.

	Photo Survey	Shoreland Parcel Assessment	Coarse Woody Habitat Survey
East Twin	7/1/2016	7/1/2016	7/7/2016
West Twin	6/29/2016	6/29/2016	6/29/2016
Eureka	7/6/2016	7/6/2016	7/6/2016
Galilee	7/5/2016	7/5/2016	7/5/2016
Meder	6/26/2018	6/27-28/2019	6/26/2018
Long	6/25/2018	6/25/2018	6/25/2018
Maki	6/28/2016	6/28/2016	6/28/2016
McCarthy	7/6/2016	7/6/2016	7/6/2016
Upson	6/23/2017	6/23/2017	6/23/2017
O'Brien	6/22/2017	6/22/2017	6/22/2017
Caroline	7/20/2016	7/14/2016	6/15/2021

Georeferenced Shoreline Photos

The entire shoreline of each Penokee Lake was photographed with slightly overlapping, georeferenced images taken from a boat, approximately 50 feet from and perpendicular to shore. The images are intended to document shoreland habitat condition at a single point in time and may be referred to years later. Due to large file size and no statewide repository for the photo data as of completion of this project, all photos are stored by the Burke Center at Northland College and are available upon request.

Shoreland Parcel Assessment

Shoreline parcel data for each lake were obtained through the Ashland and Iron County zoning offices. A total of 154 parcels were assessed and scored across all eleven Penokee Lakes. About one-third (54) of the parcels were located on Lake Galilee. In contrast, Upson Lake only had one parcel. Normally the shoreland habitat assessments are conducted by parcel, but because Upson Lake only had one parcel and other lakes had very few parcels, an adjusted parcel size was needed in order to provide detailed shoreland habitat data from all of the lakes. To remedy this, the average parcel size on Lake Galilee (i.e., 300 ft), which was the most developed of the lakes, was used as a guide to divide large parcels into sub-parcels. Thus, parcels that were greater than 300 feet in length received multiple shoreland habitat scores and a total of 304 parcels plus sub-parcels were assessed and scored across all eleven Penokee Lakes.

For each parcel/sub-parcel segment, data were collected to describe the habitat conditions and level of disturbance in riparian, bank and littoral zones of the lake using a series of semi-quantitative ranking criteria which were then averaged per parcel. A score between one and twelve was given within each zone, with scores between ten and twelve considered “ideal,” seven and nine “very good,” four and six “marginal,” and one and three “poor.” For parcels that contained one or more sub-parcels, the sub-parcel scores were averaged to create one score per parcel to remain consistent with WDNR methods. The sub-parcel scores were also evaluated for additional information related to habitat quality that might be lost by averaging.

Overall, shoreland habitat is of high quality across the Penokee Lakes. Riparian habitat scores were “ideal” or “very good” for 79% of surveyed parcels. Bank habitat scores were “ideal” or “very good” for 82% of surveyed parcels. Littoral habitat scores were “ideal” or “very good” for 90% of surveyed parcels. When looking at the overall average score of riparian, bank, and littoral zone for each parcel, 82% scored within the “ideal” or very good” range (Table 4.20). These scores are reflective of the large amounts of undeveloped shoreline in most areas of the Penokee Lakes.

Of the 29 parcels with overall average shoreland habitat scores in the “marginal” or “poor” category, 17 were located on Meder Lake, 11 were located on Lake Galilee, and one was located on Long Lake. Thus, the greatest “restoration potential” or opportunity for improving shoreland habitat is clustered primarily on Lake Galilee and Meder Lake (Figure 4.40). When considering the individual riparian, bank, and littoral scores, along with the more detailed sub-parcel data, there are some limited, additional areas that could be improved in other lakes, but the overall parcel summary data does a good job of highlighting where the primary shoreland restoration opportunities are located. It also helps to highlight areas for protecting existing high quality shoreland habitat. Further details are available in Appendix C.

Table 4.20. Summary of parcel and sub-parcel shoreland habitat assessment scores for each of the eleven Penokee Lakes. Results are displayed as a percentage of parcels or sub-parcels within each lake that scored “ideal” or “very good” overall and in each habitat zone.

		Percent "Ideal" or "Very Good"					Percent "Ideal" or "Very Good"			
Lake	Parcels	Riparian	Bank	Littoral	Average	Parcels plus Sub-Parcels	Riparian	Bank	Littoral	Average
East Twin	3	100%	100%	100%	100%	13	100%	100%	100%	100%
West Twin	7	100%	100%	100%	100%	20	95%	95%	100%	100%
Eureka	10	100%	100%	100%	100%	19	100%	100%	95%	100%
Galilee	54	69%	81%	85%	80%	54	85%	94%	87%	91%
Meder	32	56%	50%	75%	47%	58	67%	45%	72%	60%
Long	24	88%	96%	100%	96%	24	88%	96%	100%	96%
Maki	4	100%	100%	100%	100%	14	100%	100%	100%	100%
McCarthy	5	80%	100%	100%	100%	15	87%	100%	100%	100%
Upson	1	100%	100%	100%	100%	21	100%	100%	100%	100%
O'Brien	7	100%	100%	100%	100%	35	100%	100%	100%	100%
Caroline	7	100%	100%	100%	100%	31	100%	100%	100%	100%

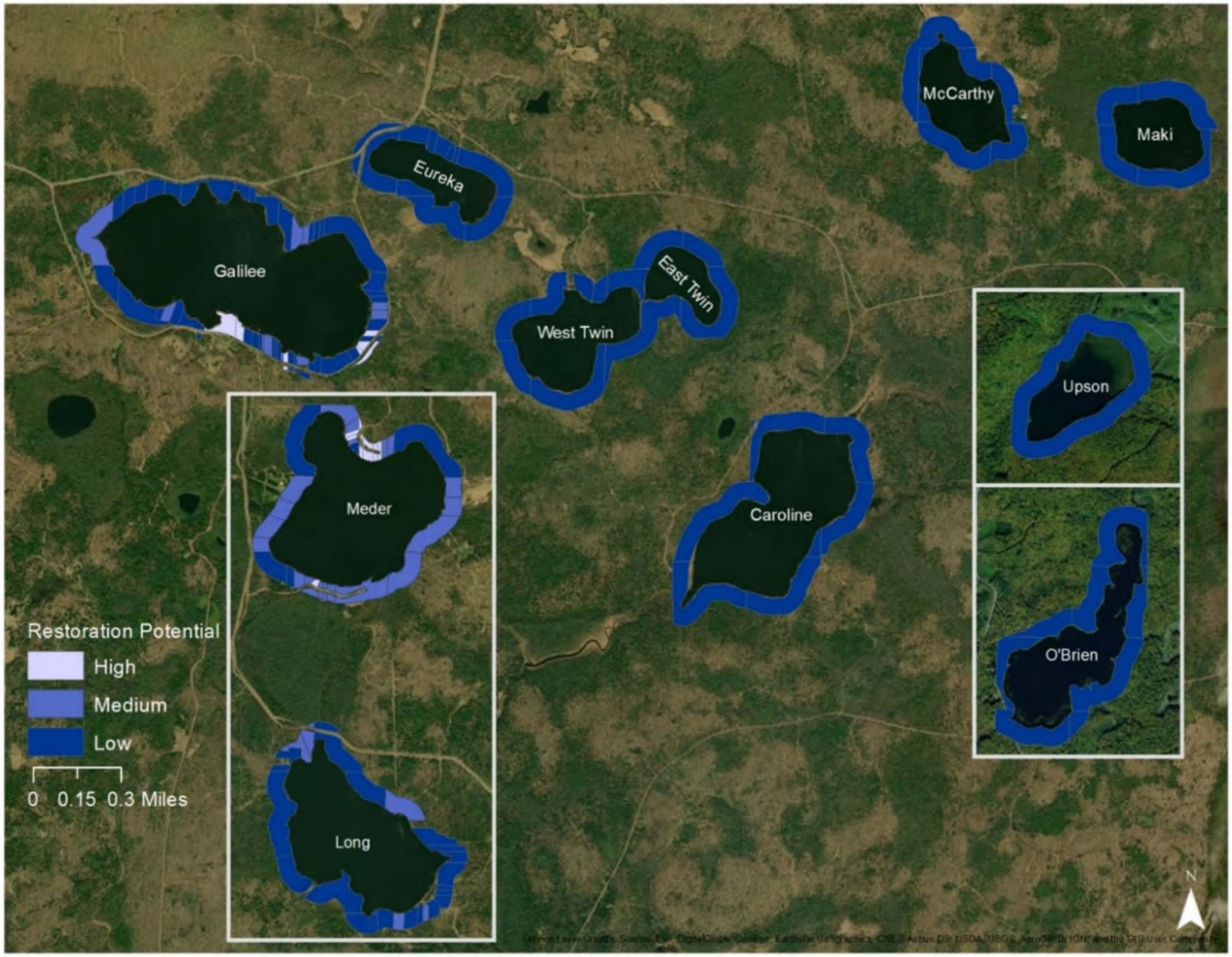


Figure 4.40. Shoreland habitat restoration potential for the eleven Penokee Lakes, high restoration potential is correlated with low habitat quality and low restoration potential is correlated with high habitat quality.

Coarse Woody Habitat

Coarse woody habitat (CWH) is a critical habitat component in the nearshore ecosystems of lakes. Shoreline trees fall into lakes as a result of natural die-off and wind and storm events. Once in the lake, this CWH has the potential to remain underwater for decades. One study of 16 north temperate lakes measured the density of CWH in nearshore areas of undeveloped lakes at an average of 555 logs per kilometer of shoreline (Christensen *et al*., 1996). The amount of CWH decreased as lakeshore development increased. CWH serves as habitat for fish and invertebrates through a variety of processes. Loss of CWH has been shown to alter the structure and function of lake ecosystems (Sass *et al*., 2006).

CWH was surveyed in each lake following WDNR protocols (WDNR, 2016). The protocol involves counting only large wood, defined as being greater than 4 inches in diameter and 5 feet in length, and is in water less than 2 feet deep. The piece of wood must have a 4 inch diameter somewhere along its length, but the widest point may be deeper than 2 feet.

CWH was greatest around East Twin, West Twin, O'Brien, and Upson Lakes, ranging from 191 to 470 pieces per kilometer of shoreline (Figure 4.41). The remaining lakes all had CWH frequencies less than 100 pieces per kilometer of shoreline, with a low of 14 in Caroline Lake (Figure 4.41). The frequency of CWH was generally greater on less developed lakes (Figure 4.42). However, not all lakes, even undeveloped ones, will have high CWH naturally, particularly if shoreline areas cannot support the growth of larger diameter trees. This is the case along many undeveloped shorelines in the Penokee lakes with marsh and bog areas that are more conducive to shrub growth. Despite this, the CWH survey data provide useful information about lakes where fish and invertebrate habitat could be improved by the introduction of coarse wood through tree drops, log additions known as "fish stick" projects, and promotion and management for larger tree species in appropriate shoreline areas to provide a future source of large wood to the lake ecosystems.

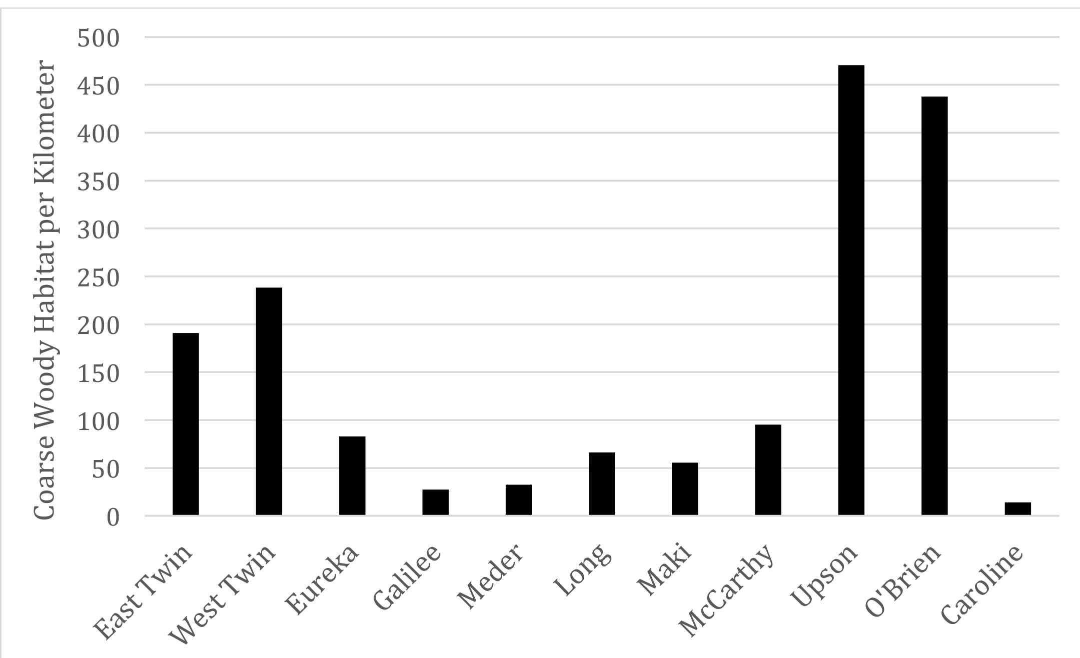


Figure 4.41. Number of coarse woody habitat pieces per kilometer of shoreline from each of the eleven Penokee Lakes.

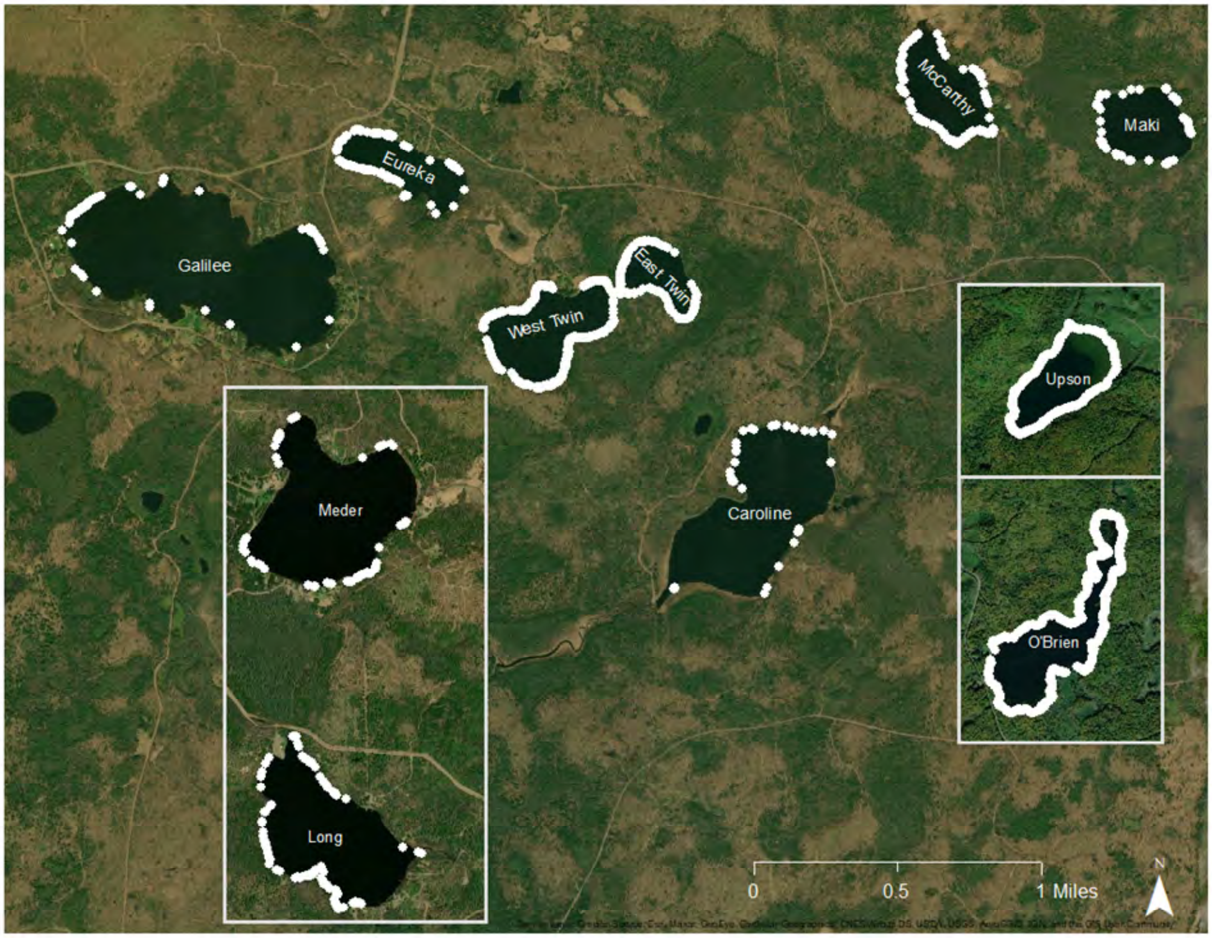


Figure 4.42. Location of coarse woody habitat greater than 4 inches in diameter and 5 feet in length, and in water less than 2 feet deep around each of the eleven Penokee Lakes.

4.7 Fish Community

Fishing is a valued activity for many residents of the Penokee Lakes, as was indicated in the property owner survey in Section 3. Ogaa (walleye) harvest is of particular cultural significance for the Ojibwe tribes of the northern Great Lakes region. Of the eleven Penokee Lakes, this species is only found in Lake Galilee and Meder Lake. Prior to 2018, little was known about fish communities in the Penokee Lakes aside from game fish surveys conducted by the WDNR and/or GLIFWC on lakes with boat landings. Lake Galilee and Meder Lake have received the most fish management attention, both in terms of fish population surveys and fish stocking efforts, because the lakes contain walleye populations. Wisconsin DNR fish stocking records indicate that Lake Galilee was stocked with small fingerling walleyes five times between 1998 and 2010. Since 2014, Lake Galilee has been stocked four times with large fingerling walleye (most recently in 2020), once with large fathead minnows in 2017, and once with large fingerling muskellunge in 2018. Meder Lake has been stocked with small fingerling walleyes ten times since 1998 (most recently in 2019). The only other Penokee Lake covered under this management plan that has received stocked fish since 1972 is O'Brien Lake, which received large fingerling largemouth bass each year from 2012-2014 (Lawson, personal communication).

In spring 2018, WDNR fisheries staff collaborated with researchers at the Burke Center to conduct surveys of fish communities in several of the Penokee Lakes. In June, Burke Center researchers surveyed the fish communities of five Penokee Lakes: East Twin, West Twin, Galilee, Meder, and Caroline. In each lake, three fyke nets were set in the emergent vegetation zone and three in the floating vegetation zone (six nets total). The fyke netting method was intended to capture information about smaller, non-game fish species that are often missed during electrofishing surveys that tend to target gamefish.

Electrofishing surveys to look at fish community metrics were conducted in Eureka, Long, O'Brien, and Caroline Lakes by the WDNR in late spring of 2018 and Lake Galilee in spring 2019. Surveys of Meder Lake occurred in 2015 and Upson Lake in 2011.

In order to evaluate fish survey data, the WDNR uses a lake classification method specifically for fisheries management purposes that is different than natural community classifications for evaluating water quality condition described in Section 4.2. The lake classification scheme and lake class standards for comparing fish population metrics such as catch per effort (CPE; measure of abundance) and proportional stock density (PSD; measure of size structure) are presented in Rypel *et al.*, 2019. Lake class standards for metrics like CPE and PSD are calculated for different regions of the state. Fish survey data collected from the Penokee Lakes were compared to regional class standards for northern Wisconsin lakes in order to indicate how the abundance and size structure of fish species captured in the surveys compare to other similar lakes in this region.

For the purposes of comparing fish populations in the Penokee Lakes with fish populations in other northern Wisconsin lakes, Eureka, Long, Upson, O'Brien, and Caroline Lakes were classified as cool, clear, and simple (less than four sportfish groups present). Galilee and Meder were classified as cool, clear, and complex (four or more sportfish groups present). Classifications were made based on criteria established in Rypel *et al.*, 2019.

CPE was used to evaluate relative abundance and was measured in number of fish caught per mile. Size structure was evaluated using PSD, which is the proportion of fish above stock size that were also longer in length than a given quality size value for each species. For example, PSD for black crappies in a given lake is the proportion of black crappies greater than their established "stock" size of five inches that are also greater than their given "quality" size of eight inches. Regional lake class standards for CPE and PSD were developed from compiling standardized and comparable WDNR fish survey data from 2000-2020 for each respective metric and the classification determined for each type of lake (Lawson, personal communication).

Fyke Netting Survey

During the fyke netting survey, 686 total fish were caught, with 220 caught in Lake Galilee, 133 in West Twin Lake, 132 in Meder Lake, 101 in East Twin Lake, and 100 in Caroline Lake. Species richness ranged from five species in East Twin Lake to ten species in Lake Galilee (Figure 4.43). Centrarchids (sunfishes) made up 74% of all individuals, Cyprinids (minnows) made up 17%, Percids (mostly perch) made up 6%, and predator species made up only 2%. More than half of all individuals were bluegill and spawning-sized bluegill were present in 25 of the 30 nets that were set. Thus, the results of the fyke netting are heavily influenced by the bluegill spawning period. They are useful in terms of understanding species richness, particularly in East and West Twin Lake (where previous fish survey data are not available) but not comprehensive enough for assessing fish community metrics. It is recommended that a similar survey be repeated in the future, prior to the bluegill spawning season.

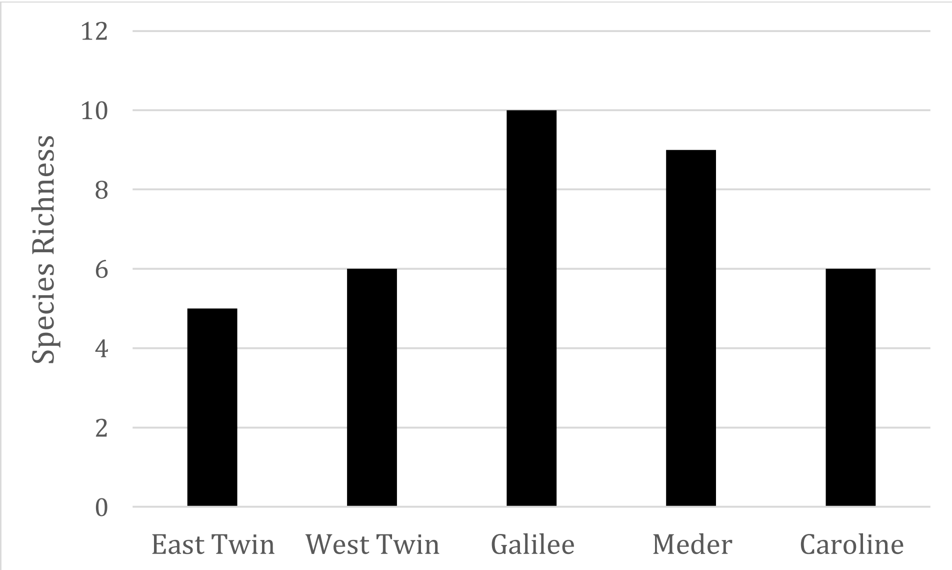


Figure 4.43. Fish species richness by lake using the fyke net method.

Electrofishing Surveys

Species detected when combining results from all seven electrofishing surveys include: black crappie, bluegill, largemouth bass, northern pike, pumpkinseed, rock bass, smallmouth bass, walleye, and yellow perch. Yellow perch was most abundant throughout the Penokee Lakes, followed by bluegill and then black crappie (Figure 4.44).

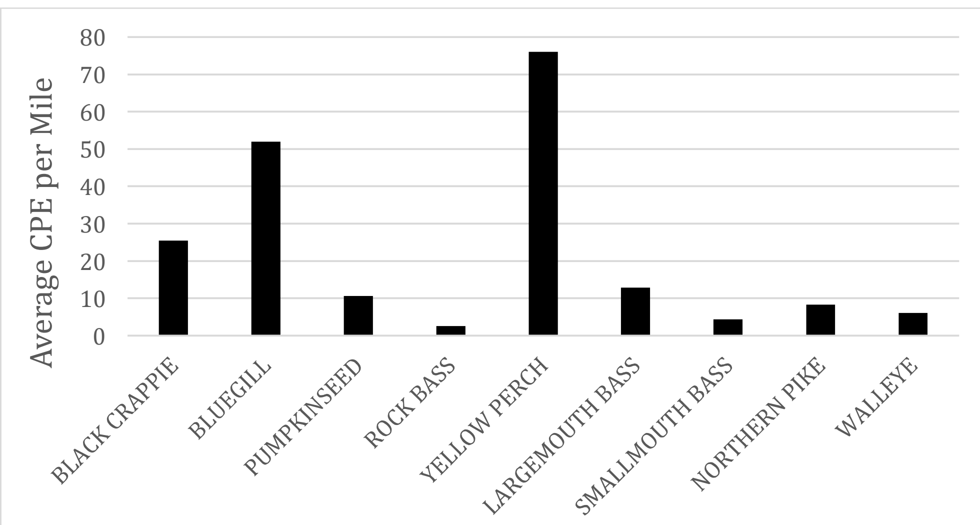


Figure 4.44. Average number of individuals per mile (catch per effort; CPE) by fish species from WDNR electrofishing surveys in Eureka, Galilee, Meder, Long, Upson, O'Brien, and Caroline Lakes.

The following other observations emerged by comparing CPE and PSD values from the Penokee Lakes electrofishing surveys to data from other northern Wisconsin lakes:

- Black crappie were detected in all surveyed lakes except Upson Lake. Black crappie in Eureka, O'Brien, and Caroline Lakes were relatively abundant but small. Black crappie in Long, Galilee and Meder Lakes were abundant and moderate in size compared to other lakes in the region.
- Bluegill were detected in all surveyed lakes. Bluegill in Lake Galilee and Meder Lake were relatively large but not abundant. Bluegill in all other lakes that were surveyed were similar in abundance and size structure relative to other lakes in the region.
- Yellow perch were detected in all surveyed lakes except O'Brien Lake. In lakes where yellow perch were detected, they were abundant and relatively large.
- Largemouth bass were detected in all surveyed lakes. Largemouth bass in Upson Lake were abundant but small. Largemouth bass in all other Penokee Lakes that were surveyed were relatively large but not abundant.
- Northern pike were detected in all surveyed lakes except Upson and O'Brien. Northern pike were abundant in all lakes they were detected. In Caroline Lake, northern pike were also large in size compared to other regional lakes. Northern pike were moderate in size in Long and Meder Lakes and small in size in Eureka Lake and Lake Galilee compared to other regional lakes.

Ogaa (walleye)
The WDNR and GLIFWC completed adult ogaa population estimates during the spring spawning period in Lake Galilee in 2014 and 2019 (mark-recapture surveys that provide absolute adult densities). A spring electrofishing survey was completed in Meder Lake in 2015. Juvenile ogaa surveys were completed in both Lake Galilee and Meder Lake during multiple fall seasons, with the purpose of assessingyoung ogaa recruitment over time.

When looking at the spring electrofishing data, adult ogaa had a moderate relative abundance and large size structure relative to other lakes in the region. Most ogaa that were caught were of quality size (>15" total length). Although the Lake Galilee adult ogaa population in 2019 was at median levels when comparing relative abundance metrics (CPE; #/mile) to other northern Wisconsin lakes, it was below the regional target for adult densities (3.0/acre; more rigorous estimates derived from mark-recapture studies). The adult walleye population declined from 2.21 walleye per acre in 2014 to 0.69 walleye per acre in 2019.

Fall juvenile ogaa recruitment surveys were conducted in Lake Galilee during nine, non-consecutive years ranging from 2001 to 2019. Fall recruitment surveys were conducted in Meder Lake in 1999, 2014, and 2016. Ogaa age-0 year class in Lake Galilee fluctuated from 0 to 18.6 fish per mile, meeting the standard target for quality recruitment of 15 fish per mile (established by GLIFWC and WDNR; Ray, personal communication) in two out of nine survey years. Ogaa age-0 year class in Meder Lake ranged from 0 to 6.4 fish per mile, which was below the recruitment standard in all three years surveyed (Figure 4.45).

Ogaa age-1 year class in Lake Galilee fluctuated from 0 to 5.9 fish per mile, only meeting the recruitment standard for yearlings of five fish per mile (established by GLIFWC and WDNR; Ray, personal communication) once in 2003. Ogaa age-1 year class in Meder Lake ranged from 1.8 to 16.4 fish per mile, falling below the recruitment standard in 2014 and 2016, but and well above it in 1999 (Figure 4.46).

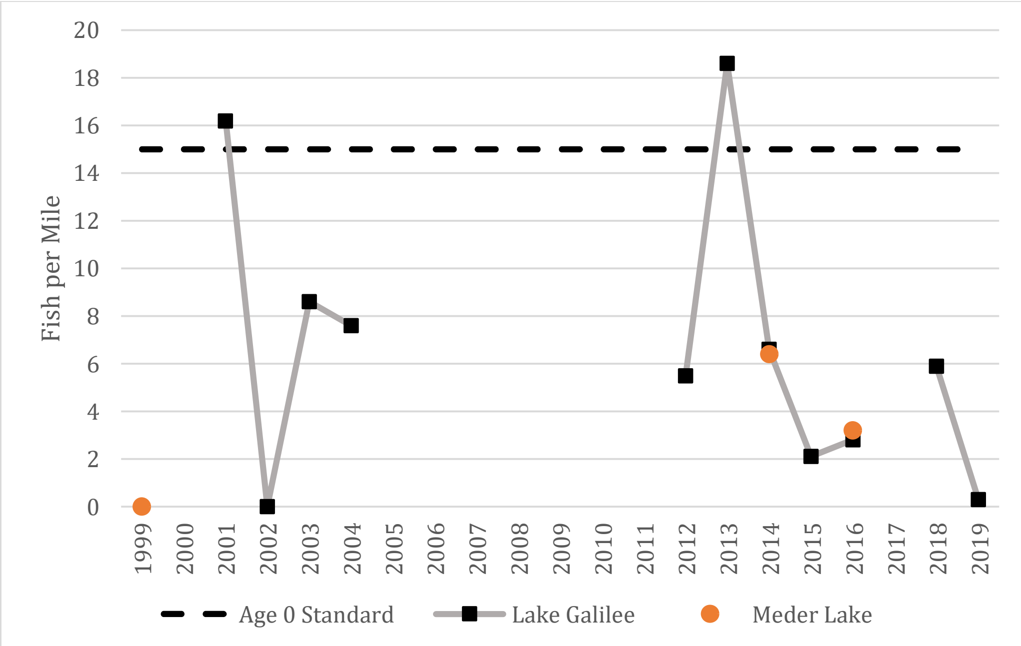


Figure 4.45. Juvenile (Age-0) ogaa catch per effort from fall recruitment electrofishing surveys conducted by WDNR and GLIFWC.

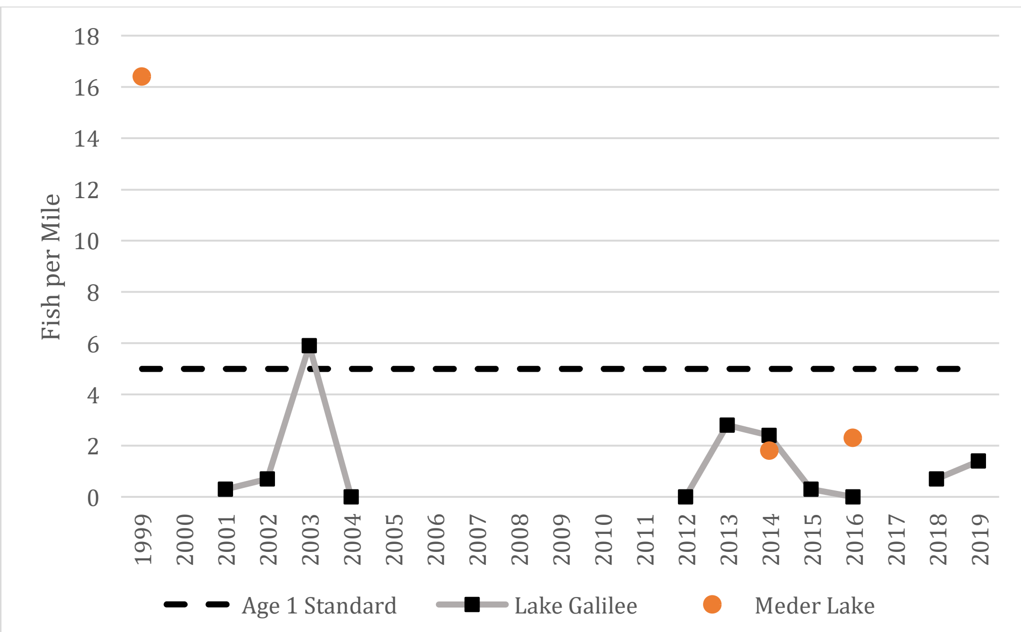


Figure 4.46. Juvenile (Age-1) ogaa catch per effort from fall recruitment electrofishing surveys conducted by WDNR and GLIFWC.

Zach Lawson, Fisheries Biologist with WDNR provided the following interpretation of available data and recommendations related to ogaa (walleye) management in Lake Galilee and Meder Lake:

- Galilee and Meder have both shown that they have the capacity to produce walleye populations with quality size structures.
- Both Galilee and Meder currently support low-density walleye fisheries, although have supported higher density adult populations in the past.
- While walleye populations in both Galilee and Meder Lakes have been supplemented with periodic stocking efforts, each system has also shown the capacity to produce year classes through natural reproduction.
- While both of these systems contain limited walleye spawning habitat, and exhibit characteristics of struggling/transitional walleye fisheries (see Raabe *et al*. 2020), recent data suggest that these systems may indeed support a low-moderate density walleye fishery.

For further details of the fish community assessment, see Appendix D.

4.8 Biomonitoring for Mercury

Mercury has a complicated environmental fate and transport pathway that varies widely across aquatic environments. Understanding mercury concentrations in biota within the Penokee Lakes ecosystem is an important piece to understanding overall ecosystem health due to the detrimental health effects mercury is known to have on humans and wildlife that consume fish and other aquatic life contaminated with mercury.

Dragonfly Larvae

An assessment of total mercury concentrations in dragonfly larvae was conducted on the eleven Penokee Lakes in 2019. Emma Holtan, Burke Center Research Associate, completed the work as a senior Capstone project. Following the framework of the National Park Service and United States Geological Survey's (USGS) Dragonfly Mercury Program (DMP; Eagles-Smith *et al*., 2020), dragonfly larvae were collected from each lake over the month of August 2019, with supplementary sampling in October and November 2019. The goal was to collect ten individuals from two dragonfly families, *Aeshnidae* and *Corduliidae*, from each lake in order to quantify mercury concentrations and variability in mercury within and between the lakes. A total of ten individuals in both families (20 total) were collected from six of the eleven lakes. In the other five lakes, at least 10 individuals from one of the families were collected except for Lake Galilee. No fewer than 12 individuals representing both families were collected from any lake. Following collection, larvae were identified to family-level, measured for length, frozen, and sent to the USGS lab in Corvallis, Oregon for analysis of total mercury (THg).

THg concentrations in dragonfly larvae ranged from 49 parts per billion (ppb) to 672 ppb among the lakes. Mean THg concentration for all eleven lakes was 200 ppb and the geometric mean THg was 180 ppb. Eureka Lake had the greatest THg concentrations among dragonfly larvae compared to the rest of lakes, while Lake Galilee and Meder Lake had the least (Figure 4.47).

Regression analyses were conducted relating mean THg concentrations from each lake with different potential explanatory variables (larval body length, percentage of wetland area in the watershed, CDOM [as a measurement of dissolved organic carbon], pH, and water level variance). Correlations between each of these parameters were weak and insufficient to explain variability in THg concentrations in dragonfly larvae between the lakes.

In order to assess potential hazards to fish and bird predators, geometric mean THg concentrations in dragonfly larvae from each lake were compared to an Integrated Impairment Index (Eagles-Smith *et al.*, 2020). Based on this comparison, Eureka Lake falls within the high-hazard impairment level (i.e., dragonfly larvae pose a risk to fish and bird predators), Meder Lake falls within the low-hazard impairment level, and the rest of the lakes fall in the moderate-hazard impairment level (i.e., dragonfly larvae posing a risk to fish predators; Figure 4.47). Based on these results, it is suggested that further mercury testing be done on fish in Eureka Lake and potentially to all the moderate-hazard lakes for the potential threat mercury levels pose to wildlife and humans who may consume fish from these lakes. Replicating the dragonfly mercury monitoring every five to ten years in the Penokee Lakes will be helpful in tracking long-term trends.

Full results for the assessment of total mercury in dragonfly larvae are in Appendix F.

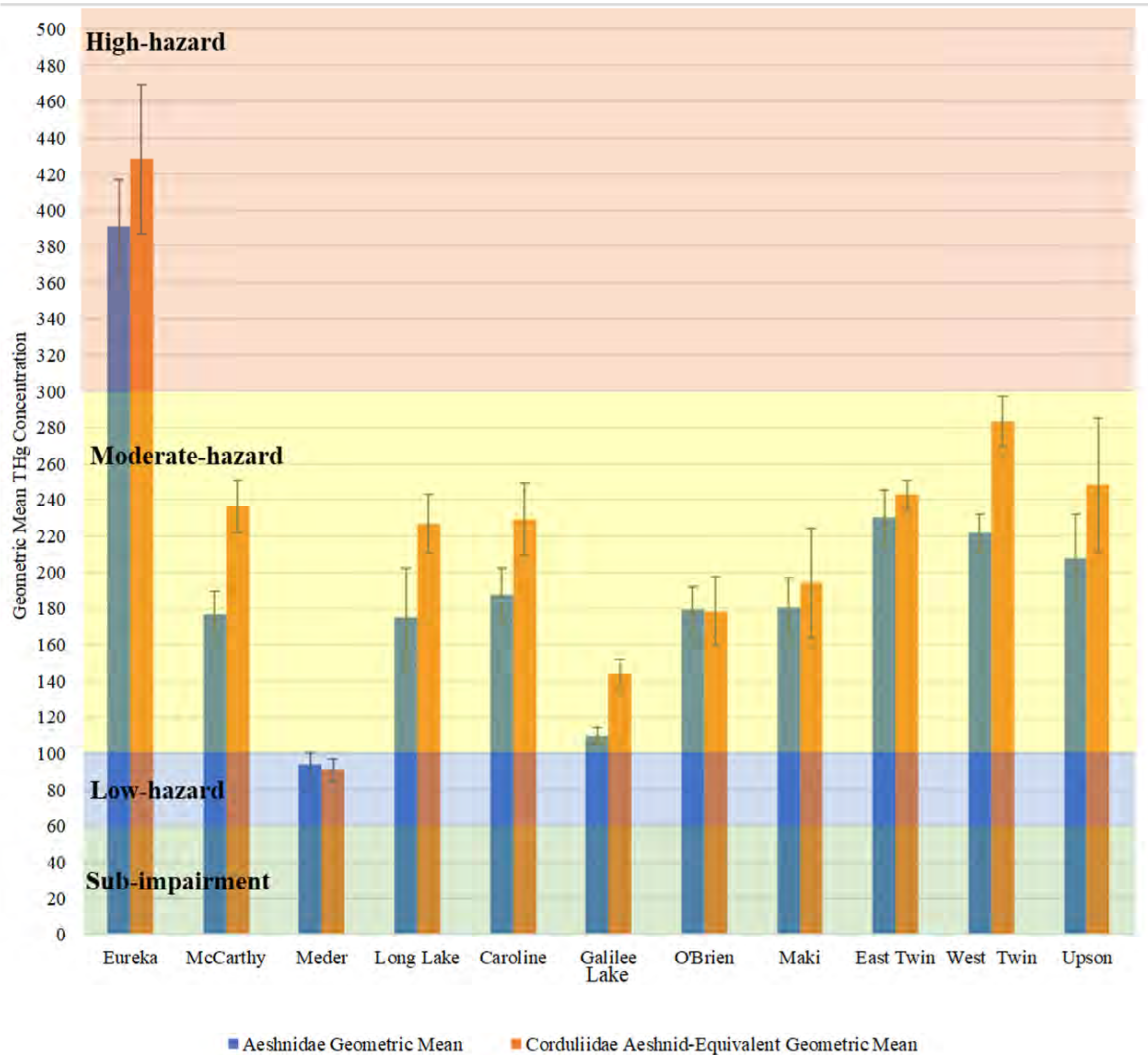


Figure 4.47. *Aeshnidae* geometric mean total mercury (THg) concentration and *Corduliidae Aeshnid*-equivalent THg geometric mean concentration for each of the eleven Penokee Lakes (bars) compared to the Dragonfly Mercury Program's integrated impairment index values (shaded areas; Eagles-Smith *et al.*, 2020).

Fish

Mercury concentrations in fish tissue are regularly monitored in lakes and other waterbodies to give a direct measurement of potential human and wildlife exposure to mercury through fish consumption. These data are used by natural resource and public health agencies to develop fish consumption advisories to advise people on how to reduce mercury exposure from consuming fish. The WDNR publishes fish consumption advisories for waterbodies in the State of Wisconsin (https://dnr.wisconsin.gov/topic/Fishing/consumption). None of the Penokee Lakes have specific fish consumption advice, so the statewide guidance applies to these lakes currently.

GLIFWC publishes a series of consumption advisory maps tailored to subsistence and cultural needs of tribal communities for lakes where ogaa and other fish are harvested: https://sites.google.com/view/glifwcmercury/mercury-maps. Lake Galilee is the only Penokee Lake with specific fish consumption advice, which is as follows: 1 meal or 8 ounces per month for pregnant women, women of childbearing age, and children under 15 years of age; 4 meals per month for women beyond childbearing age and men. GLIFWC recommends that pregnant women, women of childbearing age, and children under 15 years of age do not eat ogaa larger than 20 inches; women beyond childbearing age and men should eat fewer meals of ogaa when consuming ogaa larger than 20 inches.

Very limited fish tissue THg data are available from the Penokee Lakes. Available data were received from the Wisconsin DNR on April 6th, 2020 (Strom, personal communication). The WDNR collected data on THg concentrations in fish from Long Lake (1986), Lake Galilee (1994), and Meder Lake (2013). Mean walleye tissue THg concentration was 488 ppb with a mean total length of 18.3 inches at Meder Lake. Mean walleye tissue mercury concentration was 429 ppb with a mean total length of 16.0 inches at Lake Galilee. Mean northern pike tissue mercury concentration was 340 ppb with a mean total length of 22.0 inches at Long Lake. Mean northern pike tissue mercury concentration was 398 ppb with a mean total length of 18.0 inches at Lake Galilee (Figure 4.48).

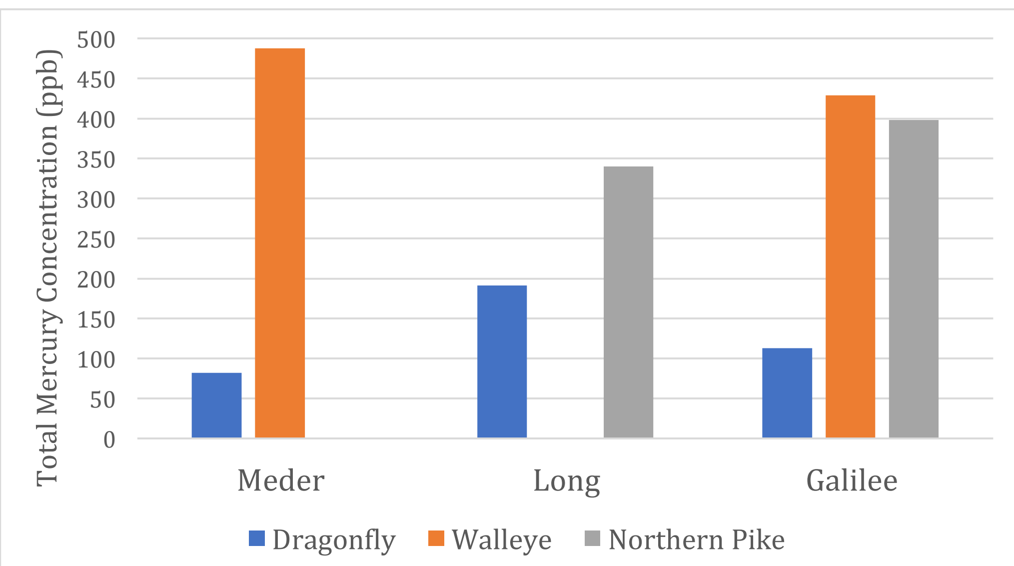


Figure 4.48. Mercury concentrations in dragonfly larvae, walleye, and northern pike in Meder, Long, and Galilee Lakes.

Average THg concentrations were greater in fish than in dragonfly larvae (Figure 4.48). This is expected because mercury biomagnifies in the food chain and fish occupy a higher trophic level than dragonfly larvae. Dragonfly data indicates moderate mercury impairment in all lakes except for Eureka Lake (high impairment) and Meder Lake (low impairment; Figure 4.47). This is in contrast with fish tissue mercury data indicating moderate-high mercury concentrations in Meder Lake and Lake Galilee (Kleinert and Degurse, 1972). The integrated impairment index demonstrated that larval dragonfly mercury concentrations were a reliable surrogate for estimating fish tissue mercury concentrations (Eagles-Smith *et al*. 2020). Not enough fish tissue mercury data exist from the Penokee Lakes to determine whether the integrated impairment index fits well with fish and dragonfly larvae from these lakes. However, if lakes like Meder and Galilee, which were on the lower end of the integrated impairment index, have greater fish tissue mercury concentrations than expected by the model, further investigation of mercury in fish tissue from lakes with high dragonfly larvae mercury concentrations is warranted. This especially holds true for Eureka Lake, where dragonfly mercury concentrations were about double what was seen in most other lakes. Dragonfly mercury monitoring is described further in Holtan, 2020.

5. Management Plan Goals and Implementation Strategies

In general, because of the relatively undisturbed nature of the Penokee Lakes ecosystem, management activities should focus on proactive planning and actions to prevent any future degradation of the lake systems and the development of routine monitoring systems to detect any changes in ecosystem condition and/or user experiences early on. The following is a description and rationale for eight goals and a series of accompanying implementation strategies to maintain and improve the health of the Penokee Lakes.

Goal 1. Maintain ecosystem health in the lakes and surrounding watersheds in a manner that meets subsistence, economic, cultural, medicinal, and spiritual needs for Ojibwe tribes with treaty-reserved rights in the 1842 ceded territory. Signatory Ojibwe tribes to this treaty with the United States government have reserved hunting, fishing, and gathering rights in this territory, to maintain a "lifeway" in a manner that meets their subsistence, economic, cultural, medicinal, and spiritual needs. While this applies broadly to a wide range of plant, animal, and physical beings important to maintaining the Ojibwe lifeway, key areas that were identified during the management planning process include: 1) maintaining harvestable ogaa populations in Lake Galilee and Meder Lake, 2) protecting any and all manoomin populations and 3) protecting the quality of water flowing onto the Bad River Reservation from upstream areas like the Penokee Lakes so federally-approved water quality standards maintained by the Bad River Band of Lake Superior Chippewa are met. Because healthy ecosystems on the land and in the water are needed to support Ojibwe tribal lifeways, this goal is seen as an overarching approach that the remaining goals and implementation strategies are working to achieve.

Goal 2. Maintain and enhance existing water quality conditions.

This goal recognizes that current water quality in the Penokee Lakes is good and that it should be maintained into the future and enhanced in areas where any improvements can be made. The low levels of human development in watershed and shoreland areas are the primary reason water quality in these lakes is currently good. However, the lake condition assessment identified a number of vulnerabilities to future water quality declines from a wide range of human development that the implementation strategies for this and other goals seek to address. Vulnerabilities related to water quality include, but are not limited to:

1. Most of the lakes are shallow and small with very low acid neutralizing capacity and water budgets likely dominated by surface runoff and shallow groundwater contributions. In addition, some of the lakes have long water residence times. All of these factors make them susceptible to environmental stressors such as shoreland and watershed development pressure, acid mine drainage, and acid rain.
2. Potential changes in land use and land cover in watershed and shoreland areas, particularly in shoreland development, along with an increased density of septic systems, could negatively affect water quality in these lakes. Lakes with high percentages of shoreland protected through public or land trust ownership including Caroline, Upson, and West Twin are less vulnerable to future water quality declines due to shoreland development than lakes with high percentages of private ownership including O'Brien, McCarthy, Maki, Eureka, Galilee, Meder, and Long. East Twin Lake has a large percentage of land trust

ownership but is still seen as vulnerable to development because of its small size, small watershed-to-lake-surface-area ratio, and long water residence time.

3. The proximity of the lakes to the Penokee Iron Range and the potential for future iron ore mining has the potential to dramatically alter the condition of these lakes. A greater understanding of the groundwater contributing areas and surface water/groundwater interactions is needed so any future mining plans can adequately maintain the health of the lakes.
4. Future climate predictions for the Penokee Lakes region suggest warmer temperatures and more extremes, including drought and heavy precipitation events. While climate change could lead to a range of unpredictable effects on hydrology and water quality, maintaining healthy watersheds and shoreland areas provide the best opportunity for these lakes to be resilient to the worst effects of a changing climate.
5. Whether related to climate change or not, two cyanobacterial (blue green algae) blooms were observed in O'Brien Lake during the study period. The genus present in at least one of the blooms is a potential toxin producer (*Dolichospermum sp.*), although it is unknown whether toxins were present in either of the observed blooms. While the presence of cyanobacterial blooms in this lake is most likely due to natural conditions, this could be a signal related to climate change and is something to keep an eye on as regional climate is predicted to warm.
6. Total mercury concentrations from Eureka Lake dragonfly larvae were among the highest measured as part of the nationwide Dragonfly Mercury Program. Investigating the cause of this and collecting fish tissue mercury data from Eureka and other Penokee Lakes is important to understand potential risk of human and wildlife exposure to mercury from eating fish from these lakes.

The following implementation strategies are seen as key to meeting goal number two:

a. Ensure compliance with existing county private onsite wastewater treatment systems (POWTS) pumping and maintenance requirements and Chapter SPS 383 of State of Wisconsin Administrative Code.
b. Ensure that timber harvests in the watersheds of these lakes follow best management practices (BMPs) for forest health, water quality, and climate resiliency (https://dnr.wisconsin.gov/topic/forestmanagement/bmp) and broader forest management considers climate change strategies outlined by the Climate Change Response Network (https://forestadaptation.org/field-guide-northern-wisconsin).
c. Continue long-term monitoring of trophic status (nutrients, chlorophyll-a, and Secchi depth) in each lake if feasible or a subset of lakes representing a gradient of development conditions. O'Brien Lake should be a priority because of observed cyanobacterial blooms. The Wisconsin Citizen Lake Monitoring Network is a great way for individuals and lake associations to collect these data for their lakes: https://dnr.wisconsin.gov/topic/lakes/clmn.
d. Comprehensively evaluate the ability of local land use and zoning policies to effectively manage water quality and aesthetics in the Penokee Lakes into the future, with particular attention to the impact of anticipated climate conditions and renewed interest in developing ore deposits in the Penokee Iron Range.
e. Collect fish tissue mercury concentrations with a focus on lakes in the "moderate" and "high" hazard categories from the dragonfly larvae total mercury analyses to

establish relationship between fish tissue and dragonfly larval mercury concentrations. Re-survey lakes for dragonfly larvae total mercury every 5-10 years.

f. Seek opportunities for technical assistance and protection funding through Wisconsin's Healthy Watersheds, High-Quality Waters program (https://dnr.wisconsin.gov/topic/SurfaceWater/HQW.html).

Goal 3. Protect shoreland habitat.

The current low levels of human development in shoreland areas helps maintain good water quality and habitat for fish and other aquatic life. Potential changes in land use and land cover in shoreland areas, particularly in shoreline development, could alter the availability and quality of nearshore habitat, as well as the aesthetics of the shoreland area. The shoreland habitat assessments identified 82% of shoreland parcels were "ideal" or "very good" quality and these areas should be the focus of efforts to protect and maintain their high quality into the future. The following are seen as implementation strategies important to meeting goal number three:

a. Implement shoreland habitat protection program for private landowners focusing on areas with lowest restoration potential (i.e., greatest protection potential) highlighted in the shoreland habitat surveys. A particular focus of the program could include connecting land trusts with private landowners that have large parcels of undeveloped shoreland around any of these lakes to discuss conservation easements, enrolling in carbon markets, and other tools that limit future development while providing financial benefits to landowners. Another potential focus for the program could be to seek Critical Habitat Area designations through WDNR to protect these areas.
b. Consider implementation of a shoreland buffer tax incentive program to incentivize shoreland protection for property owners (at the county or township level). Use Burnett Co. example as a starting point (https://www.burnettcounty.com/1123/Shoreline-Incentive-Program-SIP).
c. Consider slow-no-wake or non-motorized ordinances for lakes where appropriate. Utilize "*A Guideline for Creating Local Boating Ordinances and Placing Waterway Markers in Wisconsin Waters* (https://dnr.wi.gov/files/PDF/pubs/le/LE0317.pdf) for guidance.

Goal 4. Restore shoreland habitat where appropriate.

Only 18% of shoreland parcels were scored as "marginal" or "poor" for overall shoreland habitat, with most of these areas located on Lake Galilee and Meder Lake. Areas with low amounts of coarse woody habitat (CWH) identified in the surveys are also candidates for shoreland habitat improvement. WDNR's Healthy Lakes Program (https://healthylakeswi.com/) describes simple and inexpensive practices and offers grants to lakeshore property owners to improve shoreland areas. The program requires a sponsor such as a lake association, local unit of government, eligible non-profit group, etc., to champion and apply for funding through WDNR's Surface Water Grants Program. It should be noted that about two-thirds of the property owner survey respondents agreed or were undecided that having a grass lawn down to the lake's shore is better than natural vegetation and approximately two thirds also disagreed or were undecided that aquatic plants improve the appearance of the lake nearest their property. Thus, there appears to be a gap between the way some people perceive shoreland property management and what are best shoreland management practices to promote healthy lakes. Any effort to work with shoreland property owners on habitat improvement projects may also need to include a thoughtful education and outreach strategy in order to reach their target audience. The Healthy Lakes Program is one option to consider for addressing the following implementation strategies important to meeting goal number four:

a. Implement a shoreline habitat restoration and stormwater management program focusing on areas with greatest restoration potential highlighted in shoreland habitat surveys. The program could take place in conjunction with the shoreland buffer tax incentive program in implementation strategy 3.g to provide technical and financial project implementation support for property owners. Outreach and education for this program will be needed so property owners understand best practices for maintaining healthy shoreland areas on their property.
b. Implement coarse woody habitat (CWH) additions to shoreline areas with low amounts of CWH to promote habitat for fish and other aquatic life.

Goal 5. Maintain resilient hydrologic processes.

Similar to Goal 2, future climate predictions for the Penokee Lakes region suggest warmer temperatures and more extreme events, including drought and heavy precipitation events. This could lead to changes in the hydrologic processes in these lakes; however, maintaining healthy watersheds and shoreland areas provide the best opportunity for these lakes to be resilient to hydrologic alterations due to a changing climate. The proximity of the lakes to the Penokee Iron Range and the potential for future iron ore mining has the potential to dramatically alter the hydrologic processes in these lakes. A greater understanding of the groundwater contributing areas and surface water/groundwater interactions is needed so any future mining plans can adequately maintain the health of the lakes. Finally, beavers currently play an important role in the hydrology and water levels in many of these lakes that is often in conflict with human desired uses and conditions. Balancing the important role beaver play in lake hydrology and human desires deserves further consideration within the context of meeting this goal. The WDNR has a statewide Beaver Management Plan and offers the following information and guidelines for people with beaver damage problems: https://widnr.widen.net/content/m10ch9z9t4/pdf/beaverdamage.pdf. The following are seen as implementation strategies important to meeting goal number five:

a. Conduct a groundwater study of each lake to understand groundwater contributing areas and surface water/groundwater interactions. Groundwater contributing areas for each lake can be used to further focus priority protection areas.
b. Conduct education and outreach campaign about beaver ecology and beaver management, including resources available to landowners to manage beaver on their property.
c. Continue long-term monitoring of water levels on a subset of lakes to help understand potential climate change effects on hydrology.

Goal 6. Maintain diverse native plant communities.

Aquatic plant survey metrics indicated that the Penokee Lakes have healthy and diverse native aquatic plant communities overall, similar to regional averages for northern Wisconsin lakes. Plant growth is somewhat limited, especially in East Twin and to some extent O'Brien Lakes because of dark stained water that limits light availability. Although there was no evidence of non-native or invasive aquatic plant species during the point-intercept aquatic plant surveys in any of the Penokee Lakes, purple loosestrife has previously been treated along shoreline areas of Lake Galilee (by GLIFWC). This serves as a reminder of the vulnerability of these lakes, particularly those with public boat launches, to introductions of non-native and invasive species (both plants and animals). Wild rice was observed in Upson and O'Brien Lakes during the course of the study. Overall, the aquatic plant communities in these lakes are in good condition and the following are seen as implementation strategies important to meeting goal number six:

a. Protect any and all populations of manoomin (wild rice), including those reported in Upson and O'Brien lakes. Consider establishing Critical Habitat Area designations to protect these areas.
b. Seek opportunities to establish wild rice where appropriate.
c. Protect areas of high aquatic plant diversity identified in the aquatic plant surveys. Consider establishing Critical Habitat Area designations for these areas.
d. Conduct periodic invasive species/non-local beings early detection monitoring such as snorkel surveys at boat launch areas.
e. Conduct point-intercept surveys of the entire aquatic plant community every 5 years to assist in identifying non-local and invasive beings, as well as characterizing any changes that may be resulting from related stressors like climate change and/or shoreline development.

Goal 7. Maintain diverse native fish communities.

Information on the fish community in the Penokee Lakes varies widely. Lakes including Galilee and Meder have received the most attention because they contain ogaa (walleye) populations. Lakes with developed boat landings including Galilee, Meder, Eureka, O'Brien, Upson, Caroline, and Long all have fish surveys conducted at least once between 2011 and 2019. East and West Twin Lakes were surveyed as part of this project, but the data have limited utility in comparing to WDNR electrofishing data. Other lakes without developed boat landings (Maki and McCarthy) have no recorded fish community survey data.

Of the lakes with available surveys, panfish were the most common fish species encountered. Some quality size panfish, largemouth bass, and northern pike are present in many of these lakes, which provide fishing opportunity for lake users. Galilee and Meder have both shown that they have the capacity to produce walleye populations with quality size structures through a combination of stocking and natural reproduction. This species is important in these lakes for both tribal and non-tribal anglers. Musky were stocked into Lake Galilee in 2014 but did not show up in recent survey data. The key to maintaining healthy fish populations in these lakes is maintaining and improving shoreland habitat areas and good water quality. The following are seen as implementation strategies important to meeting goal number seven:

a. Goals 3 and 4 and the implementation strategies related to maintaining and improving shoreland habitat areas are key to maintaining diverse native fish communities.
b. Maintain harvestable ogaa (walleye) populations in Galilee and Meder Lakes by:
    i. Documenting consistent natural reproduction at or above regional recruitment benchmarks.
    ii. Promote favorable walleye habitats, protect limited spawning habitats, promote a conducive fish community for walleye dominance, and maintain a native biotic community.
    iii. Continued monitoring of adult/juvenile walleyes, as well as overall fish community structure to support adaptive walleye management strategies.

Goal 8. Maintain scenic beauty

The most important value that property owner survey respondents considered for the Penokee Lakes was the scenic beauty of the lakes (see section 3). In order to maintain this value, implementation strategies involve cross-referencing several other implementation strategies including 2.b., 3.a., 3.b., and 4.a.

These management plan goals and implementation strategies are seen by managers and stakeholders as the best approaches to protect and enhance the Penokee Lakes and their uses into the future. As with any management plan, implementation of its contents will rely on the continued dedication and support from the many people who use and value these lakes as an ecological, social, and cultural resource.

6. References

Beranek, A. 2022. Personal communication. Wisconsin Department of Natural Resources. Received via email to Matt Hudson, January 27th, 2022.

Bremer, J. 2021. Ecosystem Modeling and Scenario Forecasting in Eleven Lakes of the Penokee Hills in Mellen, WI, using WiLMS. Senior Capstone Thesis. Northland College, Ashland, WI. 42 p.

Cannon, W.F., G.L. LaBerge, J.S. Klasner, and K.J. Schulz. 2008. The Gogebic iron range - A sample of the northern margin of the Penokean fold and thrust belt: US Geological Survey Professional Paper 1730, 44 p. doi:10.3133/pp1730.

Cannon, W.F., Woodruff, L.G., Nicholson, S.W., and Hedgman, C.A., 1996, Digital Bedrock Geologic Map of the Ashland and the Northern Part of the Ironwood 301 × 601 Quadrangles, Wisconsin and Michigan: U.S. Geological Survey Miscellaneous Investigations Series Map I-2566, scale 1:100,000.

Christensen, D. L. (1996). Impacts of Lakeshore Residential Development on Coarse Woody Debris in North Temperate Lakes.pdf. *Ecological Applications*, *6*(4), p. 1143–1149.

Clayton, Lee, 1984, Pleistocene geology of the Superior Region, Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 46, 40 p., plus map (scale 1:250,000).

Correll, D.L. 1998. The role of phosphorus in the eutrophication of receiving waters—A review: Journal of Environmental Quality, 27(2), p. 261–266.

Eagles-Smith, C.A., J.J. Willacker, S. J. Nelson, C. M. Flanagan Pritz, D. P. Krabbenhoft, C. Y. Chen, J. T. Ackerman, E. H. Campbell Grant, and D. S. Pilliod. 2020. A National-Scale Assessment of Mercury Bioaccumulation in US National Parks Using Dragonfly Larvae as Biosentinels Through a Citizen Science Framework. *Environmental Science & Technology,* 54(14), p. 8779-8790. DOI: 10.1021/acs.est.0c01255.

Diebel, M. 2016. Data on all named Wisconsin Lakes greater than 5 acres in surface area. Wisconsin Department of Natural Resources. Excel spreadsheet received via email from Catherine Hein, Wisconsin Department of Natural Resources, 1/23/2020.

Dillman, D. A. 1978. Mail and Telephone Surveys: The Total Design Method. John Wiley & Sons, Inc.

Durand, Loyal, J., and Bertrand, K., 1935, The Forest and Woodland Regions of Wisconsin /209601: Geographical Review, v. 25, p. 264–271.

Gaeta, J.W., G.G. Sass, and S.R. Carpenter. 2014. Drought-driven lake level decline: effects on coarse woody habitat and fishes. Canadian Journal of Fisheries and Aquatic Sciences, 71(2), p. 315-325.

Great Lakes Indian Fish and Wildlife Commission (GLIFWC) 2005. 2005 Dagwaagin (Fall) Supplement Mazina'igan: Lake Superior Fishery Management, The Ojibwe and Gichigami, Co-Management on Gichigami, Lake Superior Treaty Fishing, Fish Modeling, Lake Superior Assessments. https://glifwc.org/publications/pdf/LakeSuperior_Supplement.pdf.

Hauxwell, J., S. Knight, K. Wagner, A. Mikulyuk, M. Nault, M. Porzky and S. Chase. 2010. Recommended baseline monitoring of aquatic plants in Wisconsin: sampling design, field and laboratory procedures, data entry and analysis, and applications. Wisconsin Department of Natural Resources Bureau of Science Services, PUB-SS-1068 2010. Madison, Wisconsin, USA.

Hershfield, D.M. 1963. Rainfall frequency atlas of the United States. Technical Paper Number 40. United State Department of Commerce, Weather Bureau. 61 p.

Hofstedt, B., E. Donaldson, and H. Perkins. 2015. Penokee Lakes 2015 General Management Survey Summary Report. Northland College Center for Rural Communities, Ashland, WI. 18 p.

Holtan, E. 2021. Dragonfly Larvae as Bio-Sentinels for Mercury on Inland Lakes in Northern Wisconsin. Senior Capstone Thesis. Northland College, Ashland, WI. 23 p.

Juckem, P.J., and Robertson, D.M., 2013, Hydrology and water quality of Shell Lake, Washburn County, Wisconsin, with special emphasis on the effects of diversion and changes in water level on the water quality of a shallow terminal lake: U.S. Geological Survey Scientific Investigations Report 2013-5181, 77 p., 2 app., http://dx.doi.org/10.3133/sir20135181.

Kleinert, S. J., and P.E. Degurse. 1972. Mercury levels in Wisconsin fish and wildlife. Wisconsin Department of Natural Resources Technical Bulletin 52.

Lathrop, R.C. and R.A. Lillie 1980. Thermal Stratification of Wisconsin Lakes. Transactions of the Wisconsin Academy of Sciences, Arts and Letters. 68, p. 90-96.

Lawson, Z. Personal communication. Wisconsin Department of Natural Resources.

Leaf, A.T., Fienen, M.N., Hunt, R.J., and Buchwald, C.A., 2015, Groundwater/Surface-Water Interactions in the Bad River Watershed, Wisconsin: U.S. Geological Survey Scientific Investigations Report 2015–5162, 110 p., http://dx.doi.org/10.3133/sir20155162.

Lillie, R.A. and J.W. Mason. 1983. Limnological Characteristics of Wisconsin Lakes. Technical Bulletin No. 183. Wisconsin Department of Natural Resources. Madison, WI.

Kenney, T. A. 2010. Levels at gaging stations. In Applications of Hydraulics (3rd ed., p. 60). United States Geological Survey. http://pubs.usgs.gov/tm/tm3A19/pdf/tm3A19.pdf.

Marsden, R.W. 1978. Iron ore reserves of Wisconsin -- A Minerals Availability Systems Report: Proceedings of the 51st Annual Meeting, Minnesota Section AIME and 39th Annual Minnesota Mining Symposium: p. 24-1 -24-28.

Mary Griggs Burke Center for Freshwater Innovation (MGBCFI). 2021. Levels at Gaging Stations, Version 2, May 2021. 22p.

Minnesota Historical Society (MHS). 2021. The Ojibwe People. Retrieved from: https://www.mnhs.org/fortsnelling/learn/native-americans/ojibwe-people#:~:text=Due%20to%20a%20combination%20of%20prophecies%20and%20tribal,in%20small%20groups%20following%20the%20Great%20Lakes%20westward on 12/20/21.

Nichols, S. A. 1999. Floristic Quality Assessment of Wisconsin Lake Plant Communities with Example Applications. Lake and Reservoir Management 15:133-141.

Panuska, J. and J. Kreider. 2003. Wisconsin Lake Modeling Suite- Program Documentation and User's Manual: Version 3.3.18.1 for Windows: Wisconsin Department of Natural Resources PUBL–WR–363–94, 32 p.

Perica, S., D. Martin, S. Pavlovic, I. Roy, M. St. Laurent, C. Trypaluk, D. Unrun, M. Yekta, and G.Bonnin. 2013. Precipitation-Frequency Atlas of the United States. NOAA Atlas 14, Volume 8, Version 2.0. 289 p.

Raabe, J. K., J. A. VanDeHey, D. L. Zentner, T. K. Cross, and G. G. Sass (2020). Walleye inland lake habitat: considerations for successful natural recruitment and stocking in North Central North America, Lake and Reservoir Management.

Ray, A. 2021. Personal communication. Great Lakes Indian Fish and Wildlife Commission. Received via email to Matt Hudson, July 13th, 2021.

Robertson, D.M., W.J. Rose and D.A. Saad. 2003. Water quality and the effects of changes in phosphorus loading to Muskellunge Lake, Vilas County, Wisconsin. Water Resource Investigations Report 03-4011. US Geological Survey. US Department of Interior. 26 p.

Robertson, D.M., W.J. Rose and H. S. Garn. 2003. Water Quality and the Effects of Changes in Phosphorus Loading, Red Cedar Lakes, Barron and Washburn Counties, Wisconsin. Water-Resources Investigations Report 03–4238. US Geological Survey. US Department of Interior. 42 p.

Rypel, A.L., Simonson, T.D., Oele, D.T., Parks, T.P., Seibel, D., Roberts, C.M., Toshner, S., Tate, L.S., Lyons, J. 2019. Flexible Classification of Wisconsin Lakes for Improved Fisheries Conservation and Management. Fisheries, 44(5), p. 225–238.

Sass, G., Kitchell, J., Carpenter, S., Hrabik, T., Marburg, A., & Turner, M. (2006). Fish community and food web responses to a whole-lake removal of coarse woody habitat. Fisheries, 31(7), p. 321-330.

Shaw, B., C. Mechenich, and L. Klessig. 2004. Understanding Lake Data. University of Wisconsin-Extension, publication G3582.

Sigurd Olson Environmental Institute (SOEI). 2016. Comprehensive Management Plan for the Wisconsin Cisco Chain Lakes. Plan approved April 1, 2016 by Wisconsin Department of Natural Resources. 150 p.

Simpson, E.H. (1949) Measurement of diversity. Nature, 163, 688. doi:10.1038/163688a0.

Strom, S. 2020. Personal communication. Wisconsin Department of Natural Resources. Fish tissue mercury data. Received via email to Matt Hudson, April 6th, 2020.

The Nature Conservancy. Iron Mining In the Penokee Range-What's at Risk. Madison, WI. 8 p.

United States Department of Agriculture, Natural Resources Conservation Service (USDA-NRCS) 2007. Part 630 Hydrology – National Engineering Handbook: Chapter 7 – Hydrologic Soil Groups. https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17757.wba.

United States Environmental Protection Agency (USEPA) 2007. Survey of the Nation's Lakes – Field Operations Manual. Washington, DC. EPA841-B-07-004.

United States Geological Survey (USGS) 2018. Hardness of Water. Water Science School. Retrieved 4/30/22 from: https://www.usgs.gov/special-topics/water-science-school/science/hardness-water#overview.

University of Minnesota. 2019. Color Dissolved Organic Matter (CDOM). Retrieved from: https://water.rs.umn.edu/sites/water.rs.umn.edu/files/cdom_background_text.pdf, 4/14/2022.

Watras, C.J., D. Grande, A.W. Latzka, and L.S. Tate. 2019. Mercury trends and cycling in northern Wisconsin related to atmospheric and hydrologic processes. Can. J. Fish. Aquat. Sci. 76 (5), p. 831–846. https://doi.org/10.1139/cjfas-2018-0157.

Wisconsin Department of Natural Resources (WDNR) 2016. WISCLAND 2 Land Cover (Level 4), Wisconsin 2016. Accessed from: https://gisdata.wisc.edu/public/WI_WISCLAND2_Level4_2016.zip.

Wisconsin Department of Natural Resources (WDNR) 2021. Wisconsin Consolidated Assessemnt and Listing Methodology (WisCALM) for CWA Section 303(d) and 305(b) Integrated Reporting. Assessment Guidance for 2021-2022. Guidance # 3200-2021-01. 96 p.

Wisconsin Department of Natural Resources (WDNR) 2016. Draft Lake Shoreland & Shallows Habitat Monitoring Field Protocol, May 27, 2016. 33 p.

Wisconsin Initiative on Climate Change Impacts (WICCI) 2022. Trends and Projections. Accessed on 2/4/2022 from: https://wicci.wisc.edu/wisconsin-climate-trends-and-projections/ accessed 2/4/2022.

Wisconsin's Wildlife Action Plan (2005-2015) Implementation: Priority Conservation Actions and Conservation Opportunity Areas. 2008. Wisconsin Department of Natural Resources. 93 p.

Appendices

Appendix A. Property Owner Use and Value Survey and Summary Report

Appendix B. Aquatic Plant Community Survey

Appendix C. Shoreland Habitat Assessment

Appendix D. Fish Community Assessment

Appendix E. Water Level Data

Appendix F. Dragonfly Larvae as Bio-Sentinels for Mercury on Inland Lakes in Northern Wisconsin

Appendix G. Summary of Management Plan Comments and Responses

Appendix A – Property Owner Use and Value Survey and Summary Report

Completed and prepared by Brandon Hofsted, PhD, Emily Donaldson, and Haley Perkins at the Northland College Center for Rural Communities, February 2019

Penokee Lakes
2015 General Management Survey Summary Report

Brandon Hofstedt, PhD, Emily Donaldson, and Haley Perkins

Methods

Survey construction
The Mary Griggs Burke Center for Freshwater Innovation at Northland College is utilizing grant funding from the Wisconsin Department of Natural Resources and other sources to implement a stakeholder survey questionnaire illustrating the values, uses, and behaviors that shape the use and management of the Penokee Lakes area. As a result, a group of faculty and student researchers from the Center for Rural Communities at Northland College constructed the survey in 2015 as the primary mechanism to capture stakeholder values, attitudes, uses and behaviors. A resource sociologist with the Wisconsin Department of Natural Resources vetted the final instrument. The final survey is divided into six parts covering a variety of topics including:

(1) participant demographic information,
(2) property information,
(3) participant uses of the lake,
(4) importance of these uses,
(5) participant attitudes toward the lake and its uses, and
(6) general values of the participants.

Sampling strategy and sampling frame
A census sample (i.e., the entire population) of households was drawn within a mile of at least one of the 15 Penokee Lakes. The initial sampling frame included 132 households, which was reduced to 111 households as the final sampling frame after removing undeliverable surveys, duplicate landowners, or vacant properties. Respondents were informed ahead of time about the survey via mail, then received the survey using a modified Dillman method, and were reminded if they did not return the survey. Researchers from Northland College collected surveys from September to November, 2015, yielding a final response rate of 35.6 percent (n=47).

Results

Participants
Survey respondents range in age from 42 to 82 years old with the average age being 63.4 years old. Approximately 66.7 percent of respondents were male; the other 33.3 percent were female. Education levels range from high school graduate to graduate and professional degrees, split up relatively evenly among 4-year degrees (18.2 percent), high school graduates and graduate/professional (22.7 percent), and some college (27.3 percent; Table 1). Respondents most commonly identify with an income rage below $100,000 (see Table 2). When asked what year they first started visiting the Penokee Lakes, a little over half of participants first started visiting the area between 1954 and 1990.

Property Description
Respondents have owned property in the Penokee Lakes area on average for 28.4 years with the range between 2 and 85 years. Most respondents own property on Lake Galilee (42.6 percent), followed by Meder Lake (21.3 percent), Eureka Lake (10.6 percent) and Long Lake (12.8 percent; Table 3). Approximately 86.7 percent of respondents own waterfront property on one of the Penokee Lakes and 56.8 percent of the respondents are full time residents (Table 4).

Participation with the Penokee Lakes Association
Only a quarter of respondents are current members of the Galilee Lake Association (Table 5), with two-thirds of these members reported that they never attend lake association meetings (Table 6).

Participant Uses of the Penokee Lakes
In the section of the survey on participant uses of the Penokee Lakes, respondents were asked: "how often do you participate in the following activities on or adjacent to the Penokee Lakes?" The activities included observing nature, gathering with friends, boating, fishing/ice fishing, swimming, hiking, canoeing or kayaking, picnicking, hunting or trapping, snowshoeing, cross-country skiing, ice skating, snowmobiling, sailing/windsurfing, and jet skiing (Figure 1). Participants could choose how often they participated in these activities from never (gray), 1-5 times per year (peach), 6-11 times per year (light blue), 1-3 times per month (orange), and weekly or more (dark blue). The matrix is organized in a way that puts the activities in descending order from the activities done most often at the top of the matrix and those done least often at the bottom.

The activities that occur most commonly include enjoying nature, gathering with friends or family, motorized boating, fishing or ice fishing, and swimming. 80 percent of participants identified that they engage in enjoying nature monthly or more, whereas the next most common activities – gathering with friends or family and motorized boating – garnered a notable 62.2 percent and 54.4 percent (respectively) of respondents noting at least monthly activity when in season.

The activities with the least participation are ice skating, snowmobiling, sailing or windsurfing, and jet skiing, with most people (i.e., over 77.8 percent on each indicator) never participating. A majority of respondents also noted that they do not engage in cross-country skiing on or around the Penokee Lakes.

Hiking, canoeing/kayaking, picnicking, hunting/trapping, and snowshoeing are also favorable activities (listed in descending order), with majorities stating they participate at least once in a year.

Importance of Uses on the Penokee Lakes
The second section of the survey asked participants to rate "how important it is to you that the Penokee Lakes can be used for the following purposes?" The activities identified in this section were similar – and in some cases identical – to the indicators included in the frequency of use activities. These specific items respondents rated included: enjoying scenic beauty, maintaining sense of peace and relaxation, gathering with family and friends, fishing/ice fishing, enjoying nature, snow sports, encouraging a sense of community, swimming, harvesting food, hunting or trapping, motorized watersports, non-motorized watersports, providing a boost to the local economy, snowmobiling, water skiing/jet skiing, and using water for irrigation (Figure 2). Participants could choose from "very unimportant" (gray), "unimportant" (peach), "neither important nor unimportant" (light blue), "important" (orange), and "very important" (dark blue). The matrix is organized in a way that places activities with a higher rated importance at the top and those found to be least important at the bottom.

The activity most important to people was enjoying the scenic beauty of the lake (93.5 percent responded very or somewhat important), closely followed by peace and relaxation, gathering with friends, and fishing or ice fishing (all 91.3 percent), Enjoying nature was not far behind with 88.7 percent noting its importance. Aside from fishing, the other top four indicators predominantly relate to the intrinsic value and non-utilitarian enjoyment of the Penokee Lakes, all scoring above

75 percent as very important. A majority or half of respondents believe that fishing (56.5 percent), hunting/trapping (53.3 percent, and swimming (50.0 percent) are very important, reflecting the most valued forms of recreation and use of the local ecology.

Most of the remaining indicators clustered around a similar level of importance, where 68.2 percent to 73.4 percent of respondents expressed that non-motorized watersports, snow sports, swimming, encouraging a sense of community, harvesting food, motorized watersports, and hunting and trapping are somewhat or very important. The local economy was also deemed somewhat or very important by a majority of responding property owners (58.7 percent). The majority of the clustered indicators primarily relate to the lake's recreational and utilitarian purposes, this is suggests that there is a diversity of uses and interests surrounding the fifteen Penokee Lakes.

Less than a third of respondents identified snowmobiling, irrigating one's lawn, and water/jet skiing as important; 69.0 percent felt that water/jet skiing is very unimportant, followed by 47.7 percent and 45.7 percent selecting very unimportant for snowmobiling and irrigation, respectively.

Participant Attitudes of the Penokee Lakes and Its Uses

In the third section of the survey, respondents were asked: "Please indicate the extent to which you AGREE or DISAGREE with each of the following statements." Respondents were asked to rate a series of twenty-two items related to objects such as: land, plants, water quality, shoreline, boats, other users, and development (Figure 3). Participants could choose from "strongly disagree" (gray), "disagree" (peach), "undecided" (light blue), "agree" (orange), and "strongly agree" (dark blue). The circle on each line indicates the average response for all respondents for each item in the matrix. The matrix is organized in a way that puts the attitudes with the higher average, or the items that respondents tended to have a stronger agreement with, at the top and those items participants tended to have a stronger disagreement with at the bottom.

Aligning with the importance items from the previous section, the indicators pertaining to the non-utilitarian value of the Penokee Lakes rise to the top. Three of the top five items relate to the intrinsic value of the lake, where participating property owners agreed or strongly agreed by selecting: enjoying a view of wilderness from the water (93.5 percent), the Penokee Lakes is a peaceful place to be (93.3 percent), and maintaining peace and quiet on the lake (84.4 percent). The other two relate to perceptions of lake health, where 87 percent of respondents noted that "I am concerned that if the health of the lake declines, it could decrease my property value" and 86.9 percent asserted that "Property owners and permanent renters care about water quality" (agree or strongly disagree). Despite the high intrinsic value for the Penokee Lakes, responding property owners also suggested they and others care about and hold a financial stake in the health of the lake.

The remaining top items involve individual and collective values and actions of lake property owners. 60.8 percent agree or strongly agree that "Property owners and permanent renters are more respectful of the lake than visiting users," expanding on how much other users care and respect the lake, in comparison the 63.0 percent that voiced "My individual actions have a significant impact on the lake." This latter item suggests that respondents feel their actions, whether good or bad, alter the health and wellbeing of the Penokee Lakes. Most respondents recognize their impacts on their lake, however, they agreed that users, regardless of relationship to the Penokee Lakes, are respectful when utilizing it[1], but more so the property owners and permanent renters.

Four indicators split responses almost evenly between some level of agreement or disagreement. Respondents agreed slightly more than they disagreed that aquatic plants improve the appearance of the lake nearest to their property (37.8 percent versus 33.3 percent, respectively) and that a grass lawn leading down to the lakeshore is better than natural vegetation (37 percent versus 32.6 percent). Respondents generally did not perceive aquatic vegetation as too dense for recreational activity, as 66.6 percent disagreed with that statement to some extent. When asked specifically about algae and swimming, respondents were split straight down the middle, with regards to algae in lakes throughout the Penokees making swimming less enjoyable, 43.1 percent agreed to some extent, 43.5 disagreed. The fourth indicator related to concern over motorized boats increasing erosion, in which 34.8 percent are worried to some extent versus 36.9 percent who are not.

Despite noted importance of motorized water sports and a fairly large majority of at least monthly users, 65.2 percent of respondents prefer non-motorized watersports, as reflected by the popularity in use and importance of kayaking, canoeing, and swimming. About 67.4 percent of the respondents disagree or strongly disagree with the idea that "There are too many boating restrictions (e.g. wake, motor size) on the Penokee Lakes," compared to only 8.6 percent who agree or strongly agree with this statement.

Approximately 76.1 percent of participants selected that they disagree or strongly disagree with the statement "I would prefer to have more people living in and around the Penokee Lakes." A slight majority of participants (57.6 percent) also disagree or strongly disagree with the statement that "There is too much access to the Penokee Lakes for non-residents." Only 8.7 agreed, while the remaining 34.8 percent are undecided. Despite having more negative attitudes regarding increasing the population size of lake property owners, respondents did not have negative attitudes about increasing access to the lake for other users, despite believing that existing property owners and renters are more respectful of the lake.

A sizeable majority of respondents (87 percent) disagree or strongly disagree with the statement that "Lakes throughout the Penokees are crowded by boat traffic," nor do most respondents think that the lake closest to their property has a foul odor (89.1 percent; mean = 1.43). The statement "There are too many homes on lakes throughout the Penokee Lakes" elicited 69.6 percent of participants disagreeing versus 8.7 percent who agree or strongly disagree. The remaining 21.7 percent of respondents were undecided. In tandem with other indicators, attitudes and behaviors intimate the following trend: responding Penokee Lakes property owners prefer less crowding and activity on the lake (contributing to its peacefulness) and do not perceive existing levels of boat traffic, excessive access for non-residents, and homes on the lakes as contributing factors to overcrowding, nor do they observe overcrowding at all, as indicated by the beliefs and perceptions that the Penokee Lakes are tranquil and natural.

Respondents were asked to rate their level of agreement on a variety of indicators related to preference of lakeshore practices. On the three items about personal preference – "I prefer the appearance of landscaped shorelines," "Having a grass lawn leading down to the lake's shore is better than natural vegetation," and "Unmanaged natural vegetation in and around the lakes is

[1] Most respondents felt that Penokee Lakes water quality has either worsened (19.6 percent) or stayed about the same (56.5 percent). Approximately 2.2 percent stated water quality has improved, while a sizable proportion of respondents (21.7 percent) selected the "I don't know" option.

unattractive" – respondents slightly favored non-landscaped shorelines. For example, approximately 28.2 percent stated a personal preference for landscaped shorelines compared to 47.9 percent of respondents who do not. Similarly, 37 percent of respondents thought property owners preferred lawns and landscaping over natural vegetation compared to 26.1 percent who did not, however, 37.0 percent were undecided on the preferences of other lake property owners. A little over half of respondents (52.0 percent) disagreed or strongly disagreed that unmanaged natural vegetation in and around the lake is unattractive.

Ranked Importance for Owning a Penokee Lakes Property

In the next section of the survey, participants identified the most important reasons why they have property in the Penokee Lakes area. They were asked to rank their top three choices by writing "1" on the line next to the most important, "2" next to the second most important, and "3" next to the third most important.

Thirty-six out of the total 47 respondents selected "I want to be in a place where I can enjoy peace and quiet" as one of their top three choices, with 25.0% choosing it as their most important reason, followed by 41.7 percent for their second most important reason, and 33.3 percent for their third. Similarly, 35 respondents chose "I want to experience nature and wilderness," with a marked 62.9 percent identifying that as their primary reason for owning property on or near a Penokee lake. 27 respondents noted "I want to be able to spend time with my family and friends" as an important reason, with a little over half (51.9 percent) choosing that as their second most important reason.

Eleven respondents mentioned that fishing was one of the most important reasons to them, while 8 respondents, to some degree, like to participate in non-motorized sports. Only 6 out of the 47 respondents believe that their property is a financial investment and is one of the main reasons why they hold property in the Penokees. 4 respondents believed that their ability to participate in motorized recreation is an important reason and only 2 chose another factor as the first or third most important reason. Participants' self-identified recreational behavior as well as earlier marked attitudes support their responses here, in that most respondents value being in a serene, natural setting, spending it with family and friends and partaking in mainly non-motorized activities as well as fishing.

Participant Attitudes of Penokee Lakes Management

In this section of the survey, respondents were asked: "Please indicate the extent to which you AGREE or DISAGREE with each of the following statements." Respondents were asked to rate five items related to management of the Penokee Lakes fishery (Figure 4). Participants could choose from "strongly disagree" (gray), "disagree" (peach), "neither agree nor disagree" (light blue), "agree" (orange), and "strongly agree" (dark blue). Respondents were also able to choose "unsure" if they did not know. The matrix is organized in a way that puts the attitudes with the higher average, or the items that respondents tended to have a stronger agreement with, at the top and those items participants tended to have a stronger disagreement with at the bottom.

Overall, the respondents are mainly undecided, however, with varying degrees of negatively skewed perceptions on the quality of management for the Penokee Lakes. Just over 50 percent of the respondents are undecided about whether or not the Penokee Lakes fishery is better than other lakes in the area, while a majority disagree to some extent with the statement (43.5 percent). The "Use of the Penokee Lakes fishery for fishing tournaments enhances its quality" elicited the greatest amount of disagreement, with 60.9 percent of responding property owners disagreeing to some extent (30.4 percent were undecided).

Respondents seem to have a more negative attitude toward Wisconsin Department of Natural Resources, in which 45.6 percent deemed that the agency to some degree does not effectively manage the Penokee Lakes fishery (47.8 percent were undecided). In contrast, 46.6 percent of respondents were undecided and 33.3 percent were in disagreement regarding the statement "Tribal management (e.g., stocking and harvesting) of the Penokee Lakes fishery enhances its quality." The remaining 20 percent served as the largest majority of agreement compared to other questions in this matrix (mean = 2.56).

Angler Attitudes of Penokee Lakes Fishery
Only the respondents who self-identified as anglers (n=40) completed this section. Respondents were asked: "Please indicate the extent to which you AGREE or DISAGREE with each of the following statements" (Figure 5). The matrix above is arranged in the same way as the previous two sections with respondents being asked to rate seven items related to fishing on Penokee Lakes. Participants could choose from "strongly disagree" (gray), "disagree" (peach), "undecided" (light blue), "agree" (orange), and "strongly agree" (dark blue). The matrix is organized in a way that puts the attitudes with the higher average, or the items that respondents tended to have a stronger agreement with, at the top and those items participants tended to have a stronger disagreement at the bottom.

Of the respondents who fish on the Penokee Lakes, the majority (65 percent) consider themselves experienced anglers. The most important element of fishing in the Penokees for these anglers is catching large fish (82.5 percent strongly agree or agree), followed by their interaction with the natural world (70 percent) and catching species that they want (65 percent). Only 32.5 percent, on the other hand, felt social interaction with others while fishing was most important.

Respondents are generally satisfied with the daily catch limit (72.5 percent) and do not place high importance on filling their daily limit (only 12.5 percent). Despite its importance, satisfaction in the species caught divided respondents evenly (45 percent agreed and disagreed, respectively). Satisfaction with the number of fish caught (40 percent) and the size of fish (37.5 percent) was lower than those who expected greater quantities and size (45 percent respectively), although only 12.5 percent believe it is important that they catch as many fish as possible. In general, 45 percent of these Penokee anglers are not concerned with human health advisories for fish in the Penokee Lakes and 42.5 percent are undecided. Only 12.5 percent of respondents are concerned.

When respondents were asked what species of fish they typically fish for and which they would most like fish for (Table 7 and Table 8), a majority typically fish for Crappie (90 percent), Sunfish/Bluegill (80 percent) Walleye (70 percent), Perch (57.5 percent), and Northern Pike (57.5 percent). Not quite half of anglers fish for Largemouth Bass and less than a third fish for Muskie, Smallmouth, Trout, and Whitefish (in descending order). An overwhelming majority (80.0 percent) who would like to fish for Walleye and Crappie as well as Sunfish (70.0 percent) and Perch (62.5 percent). Anglers who want to fish for Largemouth Bass, Northern Pike, Smallmouth Bass, and Muskie, fall between 40 percent and 32.5 percent. Trout, and Whitefish are barely sought after by responding Penokee Lakes anglers.

Participant Willingness to Protect the Penokee Lakes
In this section of the survey, respondents were asked: "The following items are meant to gauge your willingness to participate in certain activities concerning the Penokee Lakes. Your responses are hypothetical and will not indicate any actual commitment to these activities. How willing would you

be to…?" (Figure 6). On the five items in the matrix, participants could choose from "extremely unwilling" (gray), "somewhat unwilling" (peach), "unsure" (light blue), "somewhat willing" (orange), and "extremely willing" (dark blue). The fifth item, unsure, was excluded from analysis. The circle on each line indicates the average response for all respondents for each item in the matrix. The matrix is organized in a way that puts the items respondents are more willing to do at the top and those they are less willing to do toward the bottom.

The majority of respondents would be somewhat or extremely willing to participate in protecting the Penokee Lakes by attending an educational event (47.8 percent) and volunteering with relevant projects (41.3 percent). A smaller, yet still notable majority are willing to support efforts to protect the ecological health of the lake by limiting their current uses (41.3 percent) and modifying the management of their property (37.8 percent). Slightly less respondents than not are willing to offer financial support through taxes and fees (28.3 percent versus 43.5 percent). 47.8 percent are unwilling to support the ongoing protection and restoration of the Penokee Lakes if they moved away and could no longer routinely utilize the lakes in comparison to over a third who still would (39.1 percent)

Participant Values

In the final section of the survey, respondents were asked: "We would like you to tell us your views on various issues. For each statement, please select the circle nearest the statement you most agree with. Selecting the circle furthest left (Choose 1, 2, or 3) indicates total agreement with the left-hand statement; the circle furthest right (Choose 7, 8, or 9) indicates total agreement with the right-hand statement. The circles in between (Neutral: choose 4, 5 or 6) indicate varying levels of agreement. The middle circle suggests you have similar levels of agreement with both statements." The matrix asked respondents to evaluate eleven different sentence pairings on a variety of values. The circle on each line indicates the average response (from 1-7) for all respondents for each item in the matrix (Figure 7).

A marked majority of responding property owners view the location of their property in the Penokees primarily as a place to live and recreate (53.2 percent choosing (7, 8 or 9)). In addition to valuing the Penokees as a place to live and recreate, most respondents noted that the condition of the Penokee Lakes also affects their well-being (63.8 percent) and that they feel closely tied to the community surrounding the Penokee Lakes, as opposed to somewhere else (55.3 percent).

34 percent of respondents believe that people should be limited in how they can develop their property to protect the lakes, although almost a third (26.5 percent) contended that people should develop their property as they see fit. This is somewhat reflected in 61.1 percent of participants purporting that the Penokee Lakes should be managed primarily for the conservation of its natural ecosystem, in contrast to managing the lakes primarily for human uses (12.8 percent).

Further questions on management responsibilities revealed that a majority of these Penokee Lake property owners believe those who live on and around the lakes should have a say in how the lake is managed (34 percent), not just all users of the lakes (17 percent). Participants generally agreed that the natural environment should be protected from human activity (29.8 percent), not as many agreed that the natural environment should be utilized to best meet human needs (14.5 percent), 55.3 percent were neutral. This indicator does not uphold the previous statements regarding managing the natural ecosystems of the Penokees. Respondents also seemed divided on managing more for the short-term or long-term, where 23.4 percent believe that management should primarily focus on future generation versus the 21.9 percent who believe that management should focus on the needs and values of current users. Over half (55.3 percent) remained neutral.

The last two statements also elicited mixed responses, many undecided or neutral. Half of respondents chose not to take a stance on whether individuals or governmental authorities should be primarily responsible for managing the Penokee Lakes, with a slight skew towards individual responsibility (29.9 percent). More respondents leaned towards the necessity of human intervention in maintaining the health of the Penokee Lakes (40.4 percent) as opposed to no human management (14.9 percent); however, a sizeable 44.7 percent remained neutral.

Table 1. Education

Level of Education	
High school graduate (or equivalency)	22.7%
Some college (no degree)	27.3%
Two year degree	9.1%
Four year degree	18.2%
Graduate or professional degree	22.7%

Table 2. Income

Income	
Less than $60,000	42.5%
$60,000-99,999	35.0%
$100,000-149,999	15.0%
$150,000-199,999	2.5%
$250,000 or more	5.0%

Table 3. Property Location

On which lake is your property located?	
Lake Galilee	42.6%
Meder lake	21.3%
Eureka Lake	10.6%
Long Lake	12.8%
Twin Lake	4.3%
Beaver Lake	2.1%
Caroline Lake	2.1%
Maki Lake	2.1%
O'Brien Lake	2.1%

Table 4. Participant Residency

How would you best describe your residency?	
Year-round	56.8%
Full time in summer and more throughout the year	13.6%
Weekends throughout the year	9.1%
Weekends and/or part-time throughout the year	9.1%
Summer weekends and/or part time in the summer	6.8%
Irregular	4.5%

Table 5. Galilee Lake Association Membership

What is your affiliation with the Galilee Lake Association?	
Current member	25.0%
Never been a member	68.2%
Former member	6.8%

Table .6 Attendance of Lake Association Meetings

How often do you attend Lake Association meetings?	
More than once a year	11.4%
Annually	9.1%
Every few years	13.6%
More than once a year	65.9%

Table 7. Species typically fish.

What species do you typically fish for in the Penokee Lakes?	
Crappie	90.0%
Sunfish/Bluegill	80.0%
Walleye	70.0%
Perch	57.5%
Northern Pike	57.5%
Largemouth Bass	47.5%
Muskie	32.5%
Smallmouth Bass	20.0%
Trout	7.5%
Whitefish	5.0%

Table 8. Species most like to fish.

What species would you most like to fish for in the Penokee Lakes?	
Walleye	80.0%
Crappie	80.0%
Sunfish/Bluegill	70.0%
Perch	62.5%
Largemouth Bass	40.0%
Northern Pike	37.5%
Smallmouth Bass	35.0%
Muskie	32.5%
Trout	17.5%
Whitefish	7.5%

Figure 1. Participant Uses of Penokee Lakes

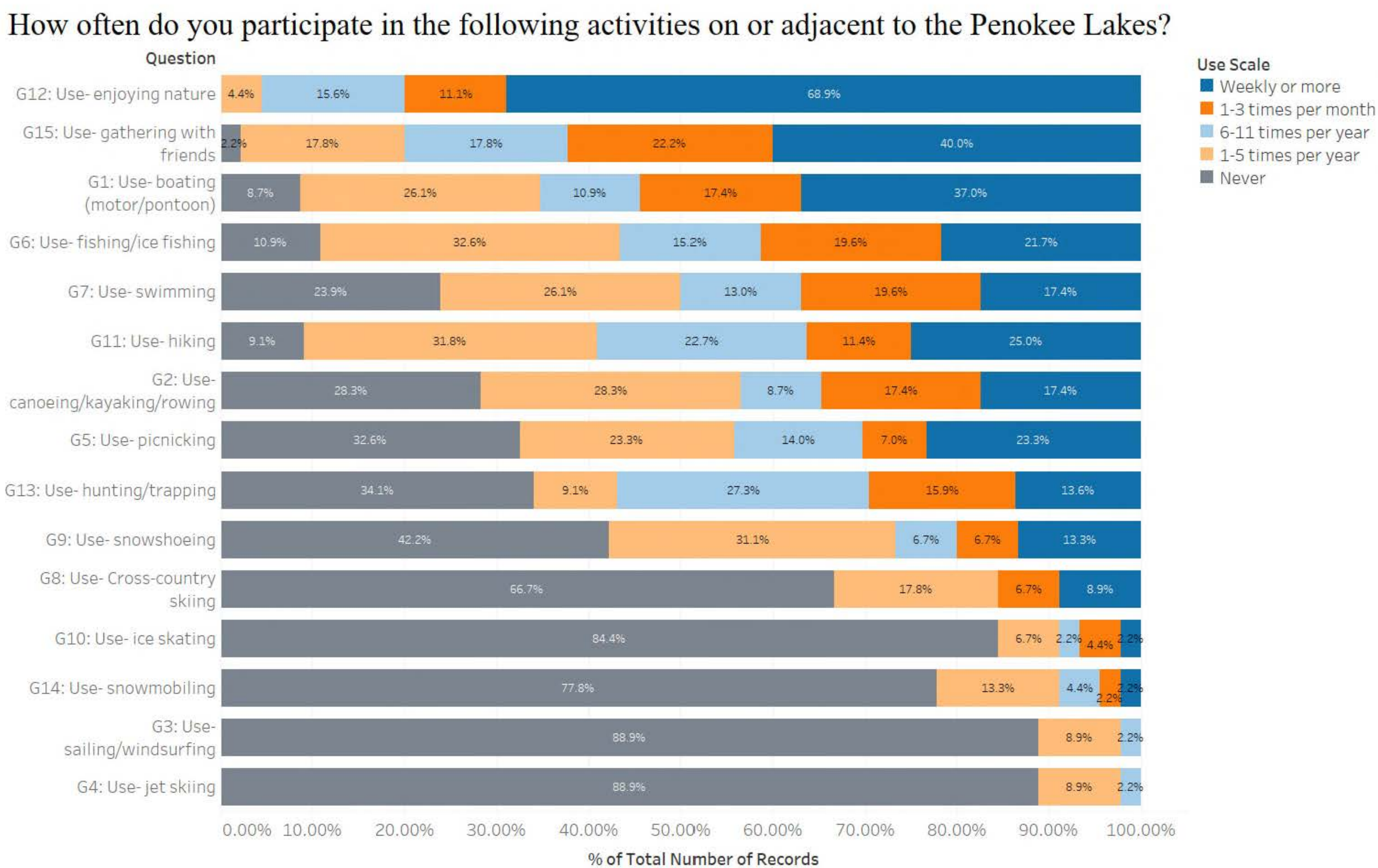


Figure 2. Importance of Uses on Penokee Lakes

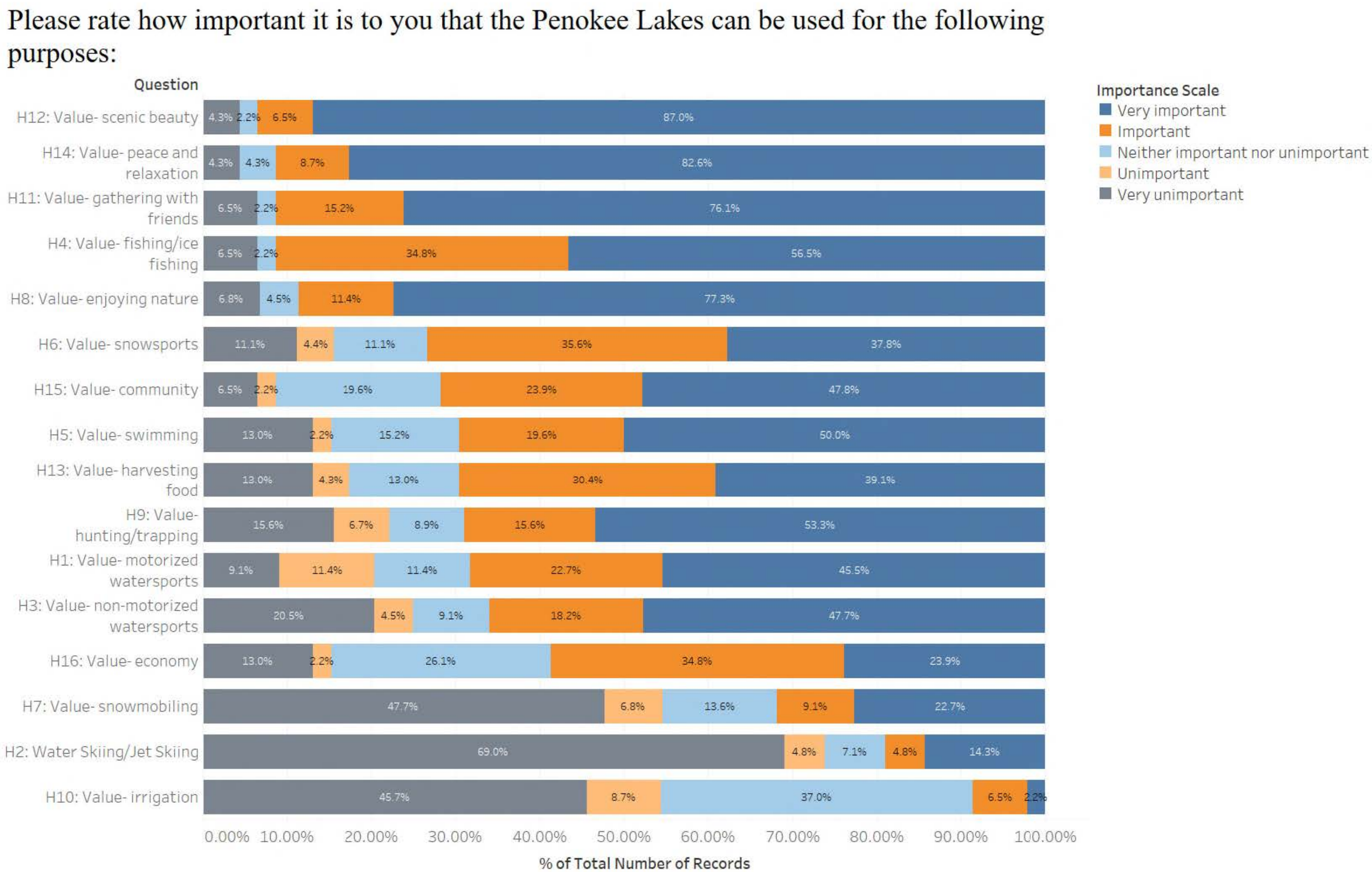


Figure 3. Participant Attitudes of Penokee Lakes and Its Uses

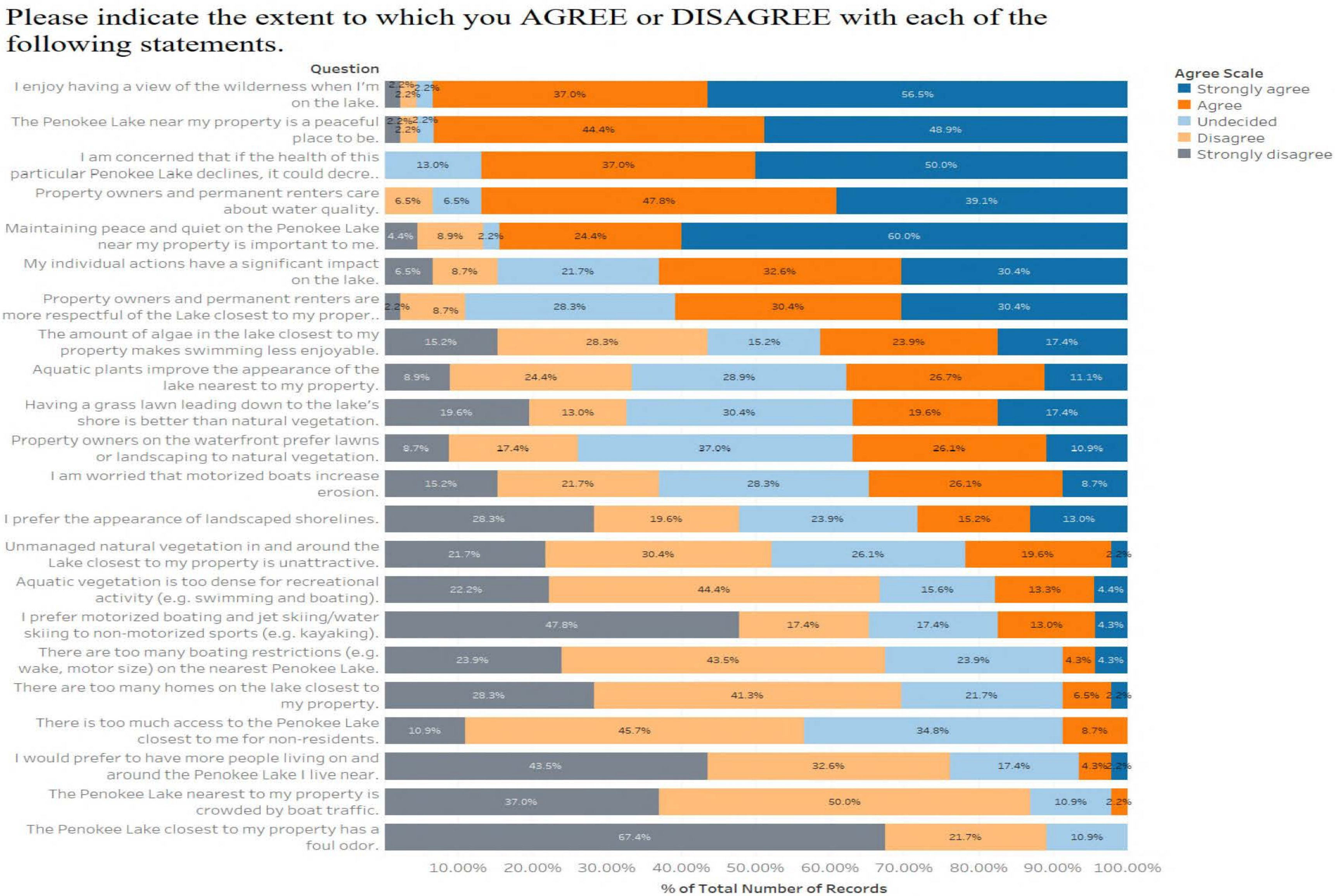


Figure 4. Participant Attitudes of Penokee Lakes Management

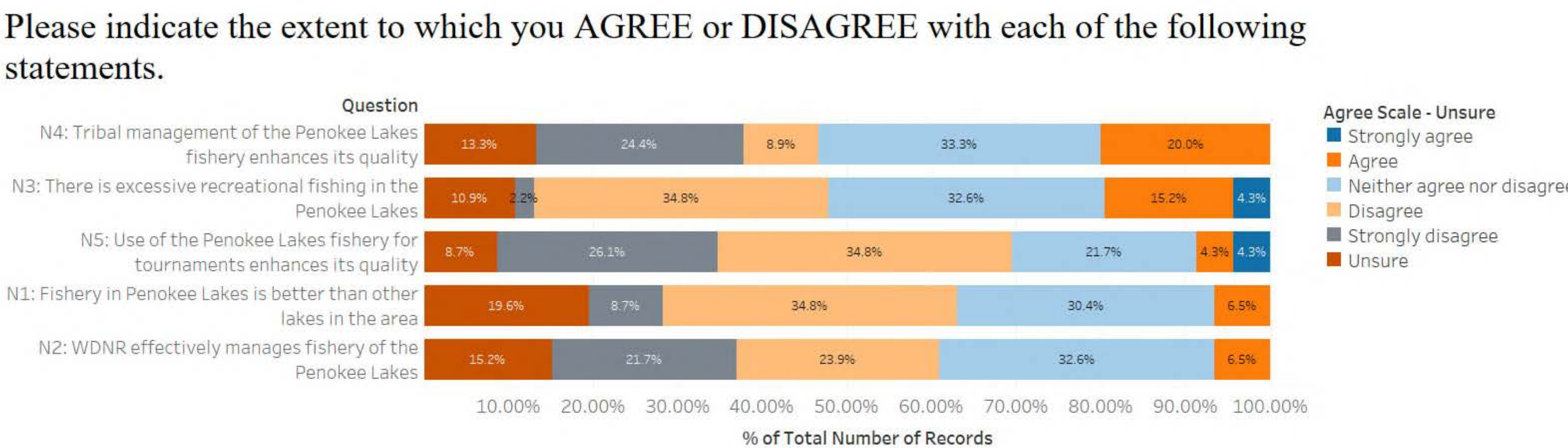


Figure 5. Angler Attitudes of Penokee Lakes Fishery

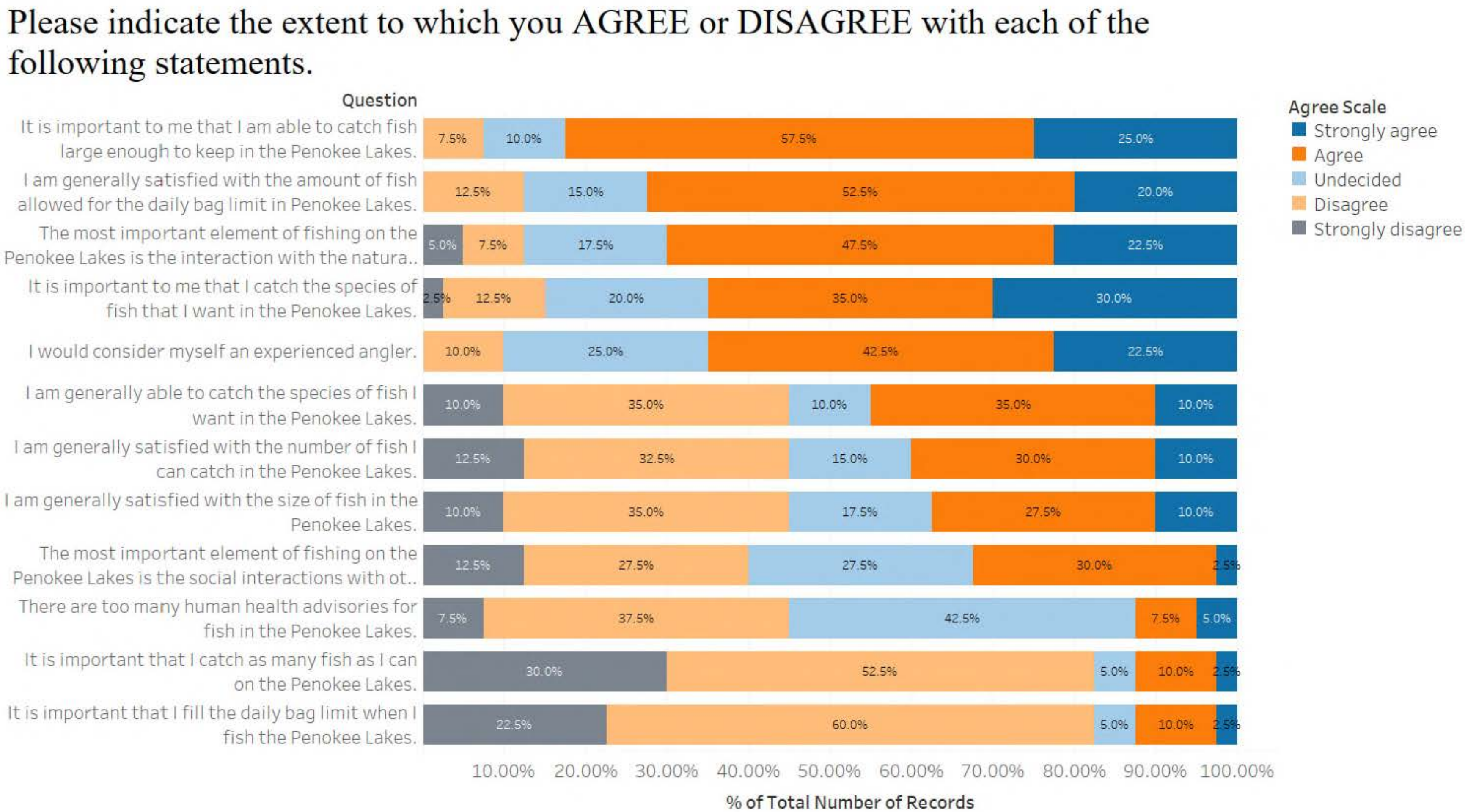


Figure 6. Participant Willingness to Protect Penokee Lakes

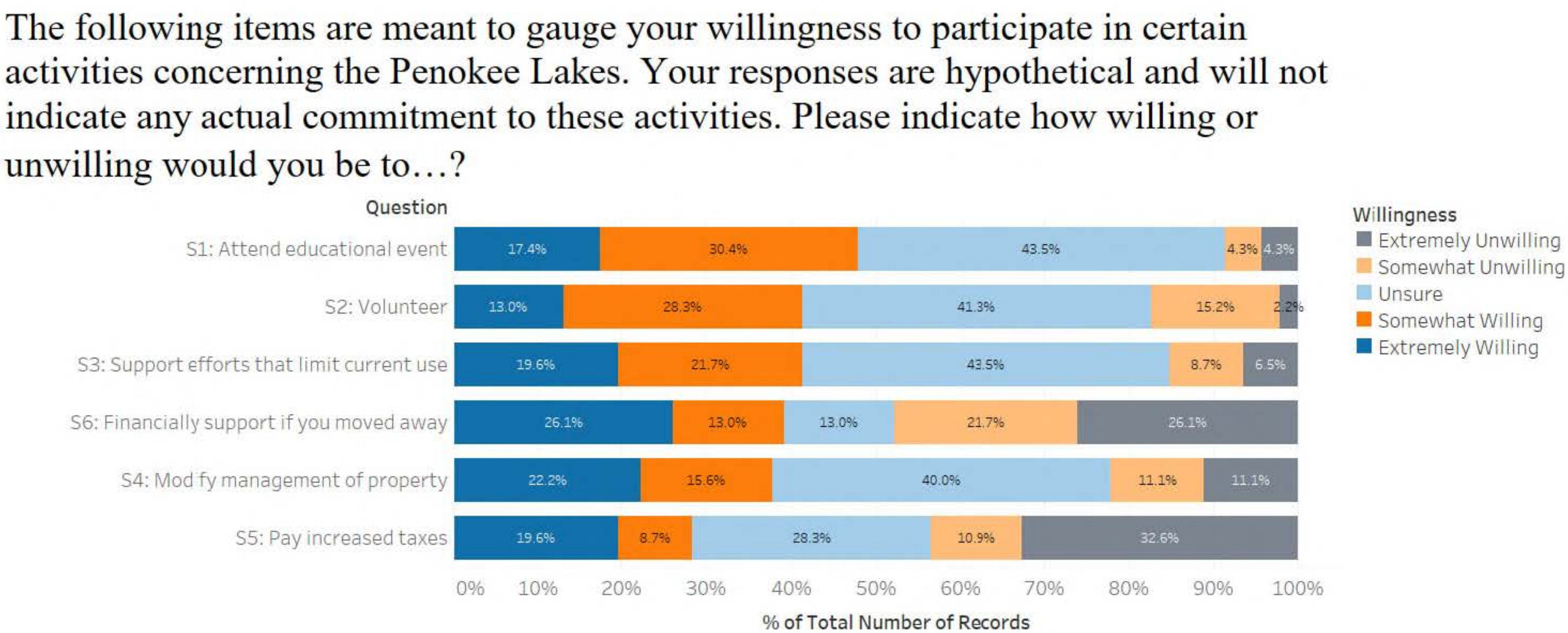
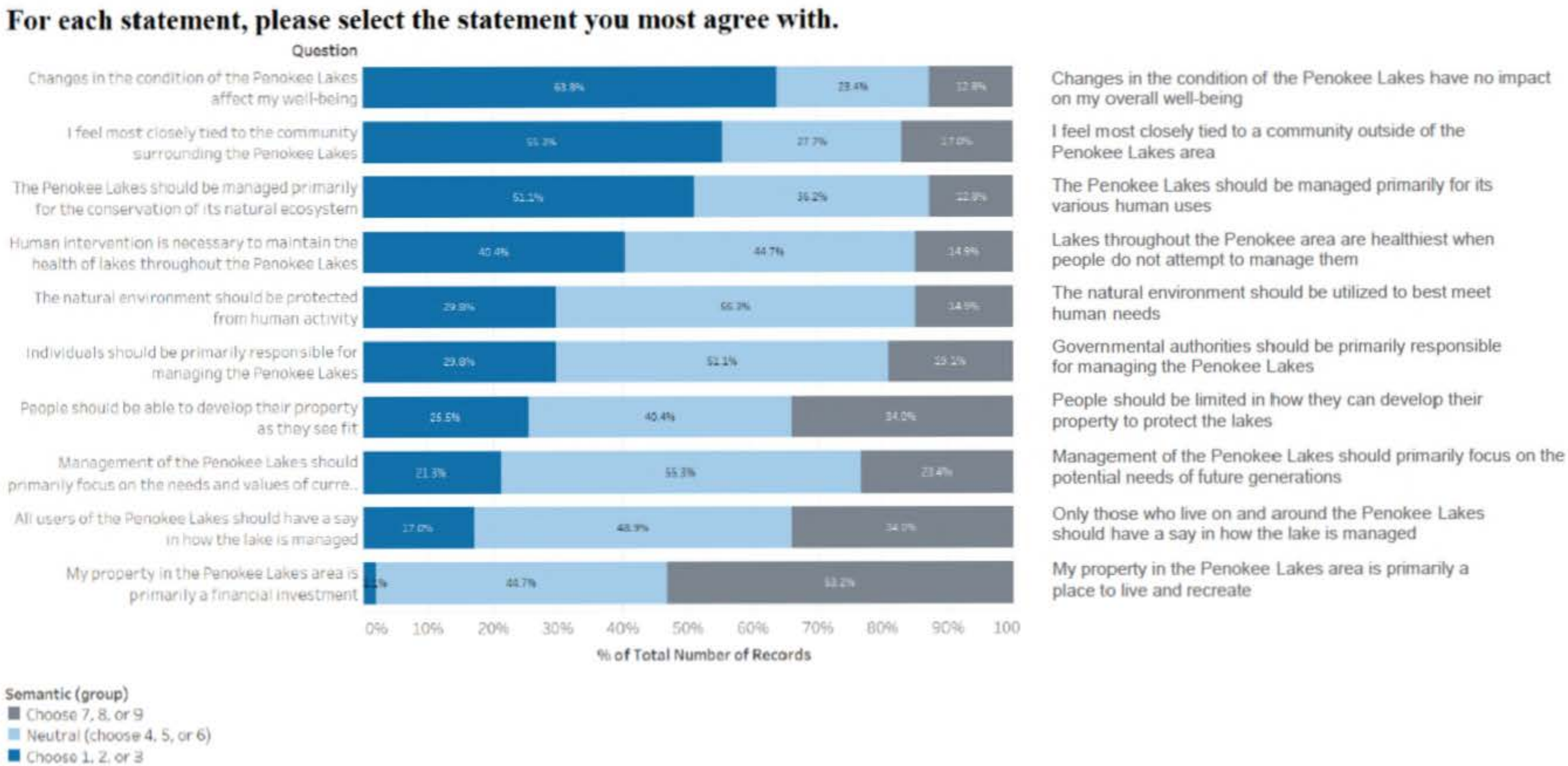


Figure 7. Participant Values



Penokee Lakes
2015 General Management Survey

I. Property Information – Please choose the best answer to the following questions to help us better understand your property on or near the Penokee Lakes. If you own more than one property, answer for that which you consider your primary residence.

A. Do you own or rent/lease property on or near the Penokee Lakes?

- o Own
- o Rent or lease

B. Which lake is your property primarily located on or near?

- o Beaver Lake
- o Caroline Lake
- o Eureka Lake
- o Lake Galilee
- o Long Lake
- o Maki Lake
- o Other:_____________
- o McCarthy Lake
- o Meder Lake
- o O'Brien Lake
- o Snowshoe Lake
- o Twin Lake
- o Upson Lake

C. How would you best describe your residency in the Penokee Lakes area?

- o Year round
- o Full time in summer
- o Full time in summer and more throughout the year
- o Weekends throughout the year
- o Weekends and/or part-time throughout the year
- o Weekends only in summer
- o Weekends and/or part-time in the summer
- o Lot only
- o Other:__________________

D. What year did you purchase or begin renting your property in the Penokee Chain of Lakes area?

____

E. What year did you first start visiting the Penokee Lakes area?

____

G. How would you best describe your property?

- o Waterfront
- o Non-waterfront

II. Uses & Importance – Please choose the best answer to the following questions to help us better understand how you use the Penokee Lakes and to gauge which activities are most important to you.

H. Please note that seasonal residents may find some of the questions inapplicable, but please answer to the best of your ability. How often do you participate in the following activities on or adjacent to the Penokee Lakes?

	Never	1-5 Times a Year	6-11 Times a Year	1-3 Times a Month	Weekly or More
Boating (motor/pontoon)	○	○	○	○	○
Canoeing/Kayaking/Rowing	○	○	○	○	○
Sailing/Windsurfing	○	○	○	○	○
Jet Skiing	○	○	○	○	○
Picnicking	○	○	○	○	○
Fishing/Ice Fishing	○	○	○	○	○
Swimming	○	○	○	○	○
Cross-Country Skiing	○	○	○	○	○
Snowshoeing	○	○	○	○	○
Ice Skating	○	○	○	○	○
Hiking	○	○	○	○	○
Observing or Enjoying Nature	○	○	○	○	○
Hunting or Trapping	○	○	○	○	○
Snowmobiling	○	○	○	○	○
Gathering with friends or family	○	○	○	○	○

I. Please note that the last set of questions asked about your behaviors, whereas this set of questions asks about how important these activities are to you. Please rate how important it is to you that the Penokee Lakes can be used for the following purposes:

	Very Important	Somewhat Important	Neutral	Of Little Importance	Not Important
Motorized watersports (boating, water skiing or jet skiing)	○	○	○	○	○
Non-motorized watersports (canoeing, kayaking, sailing)	○	○	○	○	○
Fishing/ice fishing	○	○	○	○	○
Swimming	○	○	○	○	○
Snow sports (i.e. skiing, snowshoeing, ice skating)	○	○	○	○	○
Snowmobiling	○	○	○	○	○
Observing or enjoying nature	○	○	○	○	○
Hunting or trapping	○	○	○	○	○
Using water for irrigation or lawn watering	○	○	○	○	○
Gathering with family and friends	○	○	○	○	○
Enjoying the scenic beauty of the lake	○	○	○	○	○
Harvesting food (e.g. wild rice, fishing)	○	○	○	○	○
Maintaining a sense of peace and relaxation on the lake	○	○	○	○	○
Encouraging a sense of community among users of the lake	○	○	○	○	○
Providing a boost to the local economy	○	○	○	○	○

I. Do you harvest wild rice from the Penokee Lakes or its tributaries?

- ○ Yes
- ○ No

K. Do you catch and keep fish from the Penokee Lakes as a consistent source of food?

- ○ Yes
- ○ No

III. Attitudes – It is important for us to understand the impact certain factors have on your use of, and experiences with, the **Penokee Lakes**. We are seeking general impressions only, and so there are no wrong answers.

L. Please indicate the extent to which you AGREE or DISAGREE with each of the following statements by filling in the circle under the appropriate category. Responses pertain to the lake most closely associated with your property.

	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
The amount of algae in lakes throughout the Penokee Lakes makes swimming less enjoyable	○	○	○	○	○
Aquatic vegetation is too dense for recreational activity (e.g. swimming and boating)	○	○	○	○	○
Aquatic plants improve the appearance of lakes throughout the Penokee Lakes	○	○	○	○	○
Lakes throughout the Penokee Lakes have a foul odor	○	○	○	○	○
Lakes throughout the Penokee Lakes are crowded by boat traffic	○	○	○	○	○
There are too many homes on lakes throughout the Penokee Lakes	○	○	○	○	○
I would prefer to have more people living on and around the Penokee Lakes	○	○	○	○	○
There is too much access to the Penokee Lakes for non-residents	○	○	○	○	○
The Penokee Lakes is a peaceful place to be	○	○	○	○	○
I prefer the appearance of landscaped shorelines	○	○	○	○	○
Maintaining peace and quiet on lakes throughout the Penokees is important to me	○	○	○	○	○
Having a grass lawn leading down to the lake's shore is better than natural vegetation	○	○	○	○	○
I am concerned that if the health of lakes throughout the Penokee Lakes declines, it could decrease my property value	○	○	○	○	○
I am worried that motorized boats increase erosion	○	○	○	○	○
Unmanaged natural vegetation in and around lakes throughout the Penokee Lakes is unattractive	○	○	○	○	○
There are too many boating restrictions (e.g. wake, motor size) on the Penokee Lakes	○	○	○	○	○
Property owners and permanent renters are more respectful of lakes throughout the Penokee Lakes than visiting users	○	○	○	○	○
I prefer motorized watersports (e.g., boating or jet skiing) to non-motorized sports (e.g., kayaking)	○	○	○	○	○
Property owners and permanent renters care about water quality	○	○	○	○	○
Property owners on the waterfront prefer lawns or landscaping to natural vegetation	○	○	○	○	○
I enjoy having a view of the wilderness from the water	○	○	○	○	○
My individual actions have a significant impact on the lake	○	○	○	○	○

M. In your opinion, what are the most important reasons why you have your property in the Penokee Lakes area? Please rank your top three choices by writing "1" on the line next to the most important, "2" next to the second most important, and "3" next to the third most important.

_____ I want to be in a place where I can enjoy peace and quiet
_____ I want to experience nature and wilderness
_____ I want to be able to spend time with my family and friends
_____ I see my property is a financial investment
_____ I want to fish
_____ I like to participate in non-motorized recreation
_____ I like to participate in motorized recreation

N. Since I first started visiting the Penokee Lakes area, the quality of the water has:

- o Improved
- o Worsened
- o Stayed about the same
- o I don't know

O. The following questions are to understand your perception of the fishery in the Penokee Lakes. Please indicate the extent to which you AGREE or DISAGREE with each of the following statements by filling in the circle under the appropriate category.

	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree	Unsure
The fishery in the Penokee Lakes is better than other lakes in the area	○	○	○	○	○	○
The Wisconsin Department of Natural Resources effectively manages the fishery of the Penokee Lakes	○	○	○	○	○	○
There is excessive recreational fishing in the Penokee Lakes	○	○	○	○	○	○
Tribal management (e.g., stocking and harvesting) of the Penokee Lakes fishery enhances its quality	○	○	○	○	○	○
Use of the Penokee Lakes fishery for fishing tournaments enhances its quality	○	○	○	○	○	○

P. Do you fish on the Penokee Lakes?

- ○ Yes (please ***answer Q and R***)
- ○ No (please ***skip to Section IV* – Values**)

Q. Which Penokee area lake(s) do you fish on (check all that apply)?

- ○ Beaver Lake
- ○ Caroline Lake
- ○ Eureka Lake
- ○ Lake Galilee
- ○ Other:______________
- ○ Long Lake
- ○ Maki Lake
- ○ McCarthy Lake
- ○ Meder Lake
- ○ O'Brien Lake
- ○ Snowshoe Lake
- ○ Twin Lake
- ○ Upson Lake

R. Please indicate the extent to which you AGREE or DISAGREE with each of the following statements by filling in the circle under the appropriate category.

	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
The most important element of fishing on the Penokee Lakes is the interaction with the natural world	○	○	○	○	○
The most important element of fishing on the Penokee Lakes is the social interactions with others	○	○	○	○	○
There are too many human health advisories for fish in the Penokee Lakes	○	○	○	○	○
I am generally able to catch the species of fish I want in the Penokee Lakes	○	○	○	○	○
It is important to me that I catch the species of fish that I want in the Penokee Lakes	○	○	○	○	○
I am generally satisfied with the size of fish in the Penokee Lakes	○	○	○	○	○
It is important to me that I am able to catch fish large enough to keep in the Penokee Lakes	○	○	○	○	○
I am generally satisfied with the number of fish I can catch in the Penokee Lakes or	○	○	○	○	○
It is important that I catch as many fish as I can	○	○	○	○	○
It is important to me that I catch as many fish for the daily bag limit in the Penokee Lakes	○	○	○	○	○
I am generally satisfied with the amount of fish I can catch for the daily bag limit	○	○	○	○	○
I would consider myself an experienced angler	○	○	○	○	○

S. Please help us to understand which species you currently fish for in the Penokee Lakes, and which species you would most like to fish for by indicating below.

	What species do you **typically fish for** in the Penokee Lakes? (Check all that apply)	What species would you **most like to fish for** in the Penokee Lakes? (Check all that apply)
Walleye	o	o
Northern pike	o	o
Sunfish/ Bluegill	o	o
Crappie	o	o
Muskellunge (muskie)	o	o
Smallmouth bass	o	o
Largemouth bass	o	o
Trout	o	o
Whitefish	o	o
Perch	o	o
Other: _______________	o	o

IV. Values – We are almost done. Your help is greatly appreciated! Please answer the following questions to the best of your ability.

T. The following items are meant to gauge your willingness to participate in certain activities concerning the Penokee Lakes. Your responses are hypothetical and will not indicate any actual commitment to these activities. How willing would you be to…?

	Extremely Unwilling	Somewhat Unwilling	Somewhat Willing	Extremely Willing
Attend educational events regarding the management of the Penokee Lakes?	o	o	o	o
Volunteer with projects to improve the quality of the Penokee Lakes?	o	o	o	o
Support efforts to protect the ecological health of the Penokee Lakes (e.g. protection of a rare species) if it limited your current uses of the lakes?	o	o	o	o
Modify the management of your property to protect the quality of the Penokee Lakes?	o	o	o	o
Pay an increase in taxes or fees to help protect or restore the Penokee Lakes?	o	o	o	o
Financially support the ongoing protection and restoration of the Penokee Lakes if you moved away and could no longer routinely utilize the lakes?	o	o	o	o

U. **We would like you to tell us your views on various issues. For each statement, please select the circle nearest the statement you most agree with. Selecting the circle furthest left indicates total agreement with the left-hand statement; the circle furthest right indicates total agreement with the right-hand statement. The circles in between indicate varying levels of agreement. The middle circle suggests you have similar levels of agreement with both statements.**

I feel most closely tied to the community surrounding the Penokee Lakes	○	○	○	○	○	○	○	I feel most closely tied to a community outside of the Penokee Lakes
People should be able to develop their property as they see fit	○	○	○	○	○	○	○	People should be limited in how they can develop their property to protect the lakes
Changes in the condition of the Penokee Lakes affect my well-being	○	○	○	○	○	○	○	Changes in the condition of the Penokee Lakes have no impact on my overall well-being
Individuals should be primarily responsible for managing the Penokee Lakes	○	○	○	○	○	○	○	Governmental authorities should be primarily responsible for managing the Penokee Lakes
Management of the Penokee Lakes should primarily focus on the needs and values of current users	○	○	○	○	○	○	○	Management of the Penokee Lakes should primarily focus on the potential needs of future generations
All users of the Penokee Lakes should have a say in how the lake is managed	○	○	○	○	○	○	○	Only those who live on and around the Penokee Lakes should have a say in how the lake is managed
The Penokee Lakes should be managed primarily for the conservation of its natural ecosystem	○	○	○	○	○	○	○	The Penokee Lakes should be managed primarily for its various human uses
Human intervention is necessary to maintain the health of lakes throughout the Penokee Lakes	○	○	○	○	○	○	○	Lakes throughout the Penokee Lakes are healthiest when people do not attempt to manage them
My property in the Penokee Lakes area is primarily a financial investment	○	○	○	○	○	○	○	My property in the Penokee Lakes area is primarily a place to live and recreate
The natural environment should be protected from human activity	○	○	○	○	○	○	○	The natural environment should be utilized to best meet human needs and facilitate growth

V. Demographics – Please answer the following demographic questions. This information ensures that our survey results will accurately represent all the residents of the Penokee Lakes area.

V. Your age (as of last birthday)? __________ years

W. Are you male or female?
- o Male
- o Female

X. Do you consider yourself to be (check all that apply):
- o White/Caucasian
- o Black/African American
- o Native American/American Indian
- o Hispanic or Latino/a
- o Asian American
- o Other:______________

Y. Highest level of education:
- o Less than high school
- o Some high school, no diploma
- o High school graduate (includes equivalency)
- o Some college (no degree)
- o 2-year degree
- o 4-year degree
- o Graduate or professional degree

Z. What is your approximate gross household income (your household income before taxes)?
- o Less than $60,000
- o $60,000-$99,999
- o $100,000-$149,999
- o $150,000-$199,999
- o $200,000-$249,999
- o $250,000 or more

AA. When receiving information about the Penokee Lakes, which of the following methods of communication do you prefer (Check all that apply)?
- o Telephone
- o Mail
- o Galilee Lake Association Newsletter
- o Social Media
- o Email
- o I do not wish to receive information about the Penokee Lakes

BB. What is your affiliation with the Galilee Lake Association?
- o Current member
- o Former member
- o Never been a member

CC. How often do you attend meetings for the Galilee Lake Association?
- o More than once a year
- o Annually
- o Every few years
- o Never

Thank you for your participation!
If you have any additional comments, please use the space below.

Appendix B – Aquatic Plant Community Survey

Aquatic plant communities in all eleven Penokee Lakes were sampled using the standard point-intercept survey method utilized by the Wisconsin Department of Natural Resources (WDNR; Hauxwell *et al*. 2010). Each lake was surveyed once between 2016 and 2018 (Table B.1).

All work was implemented by staff from the Mary Griggs Burke Center for Freshwater Innovation at Northland College (Burke Center). All field staff were trained at the annual WDNR aquatic plant identification training at the Kemp Natural Resources Station in Woodruff, Wisconsin.

Table B.1. Date of aquatic plant point-intercept (PI) survey conducted in each of the eleven Penokee Lakes.

	PI Survey Date
East Twin	8/8/2016
West Twin	8/8/2016
Eureka	7/14/2016
Galilee	8/10/2016
Meder	8/6/2018
Long	8/6/2018
Maki	8/9/2016
McCarthy	8/15/2016
O'Brien	8/2/2017
Upson	8/7/2017
Caroline	7/20/2016

Sampling Procedure Summary

A grid of Global Positioning System (GPS) points for the aquatic plant survey in each lake was generated by WDNR staff (Figure B.1). The points were loaded onto a boat-mounted sonar/GPS unit (Lowrance, Syosset, NY) and field staff navigated to each point on each lake via boat. At each point, aquatic plant communities were sampled using a double-sided rake (Figure B.2). The rake was dropped to the bottom, turned three times and pulled to the surface. Once in the boat, the different species were identified and the relative density of the individual species and total plant density were recorded as rake fullness (Figure B.2). In addition to species data, water depth, sediment type, and sample site location were measured and recorded at each point. Plants were identified to species using "Through the Looking Glass: A Field Guide to Aquatic Plants" Ed. 2 by Susan Borman, Robert Korth and Jo Temte (2014) and "Aquatic Plants of the Upper Midwest" by Paul M. Skawinski (2011). Voucher specimens were kept for each species.

Following completion of the field survey, all aquatic plant data were entered into the WDNR point-intercept survey spreadsheet template (https://www3.uwsp.edu/cnr-ap/UWEXLakes/Pages/ecology/aquaticplants/default.aspx). Data were analyzed to characterize relative species abundance, maximum depth of plant growth, species diversity, sensitivity to disturbance, Floristic Quality Index (FQI), and presence/absence of invasive species.

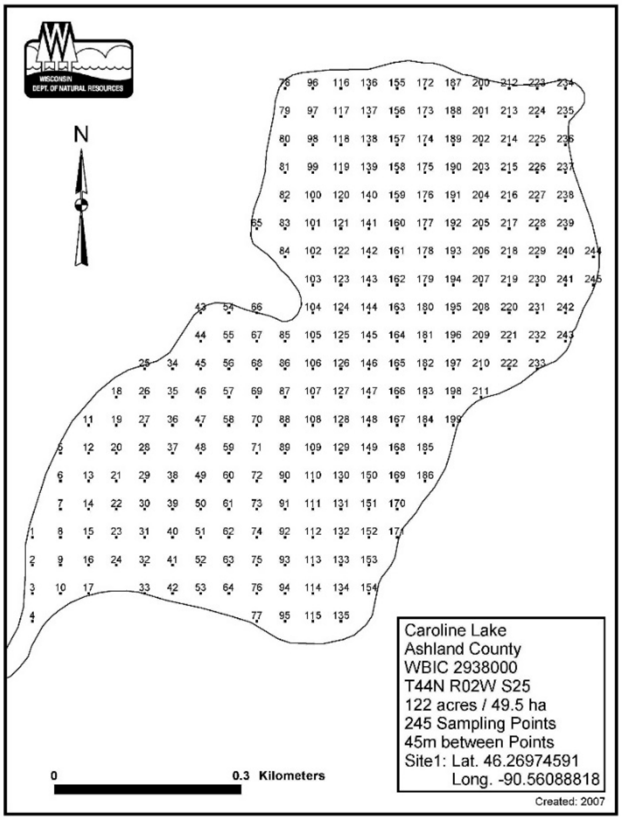


Figure B.1. Example grid of sample points used for the aquatic plant survey in Caroline Lake.

Fullness Rating	Coverage	Description
1		Only few plants. There are not enough plants to entirely cover the length of the rake head in a single layer.
2		There are enough plants to cover the length of the rake head in a single layer, but not enough to fully cover the tines.
3		The rake is completely covered and tines are not visible.

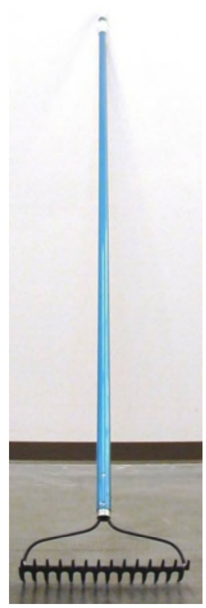


Figure B.2. An example double-sided rake sampler used in the point-intercept aquatic plant surveys and the semi-quantitative criteria used to describe relative plant abundance on each rake toss (Hauxwell *et al.* 2010).

Results

The aquatic plant communities of the Penokee Lakes are robust and diverse. Throughout this study, 54 distinct species were identified from all lakes combined (Table B.2.). An additional five unique families or aquatic plant groups were identified but not characterized to species-level (Table B.2).

Species richness (including visual detections and rake detections) ranged from 6 species in East Twin Lake to 35 species in Lake Galilee (Table B.3, Figure B.3). Of the 1,285 sites sampled, 900 were shallower than the maximum depth of plant growth and 521 had observed plant growth (Table B.3). Ninety-five percent of plant observations were found at depths of eight feet or less, with the maximum occurring at a depth of 15 feet in Upson Lake (Figure B.4 and B.5). The maximum species richness observed on a single rake pull was eight species (Figure B.6). The most commonly-detected species were white water lily *(Nymphaea odorata)* and watershield *(Brasenia schreberi).* Species representing high floristic quality included spiny hornwort *(Ceratophyllum echinatum)*, floating-leaf bur-reed *(Sparganium fluctuans),* and small bladderwort *(Utricularia minor).*

The Simpson Diversity Index is a measure of community diversity (Simpson 1949). The index gives results on a scale of 0 to 1, with numbers closer to 1 indicating greater community diversity. All lakes except East Twin and O'Brien had a Simpson's Diversity Index score between 0.7 and 1, indicating diverse aquatic plant communities in most of the Penokee Lakes (Table B.3). All lakes except for East Twin Lake met or exceeded the regional average of 13 aquatic plant species per lake, further indicating diverse aquatic plant communities in most of the Penokee Lakes (Figure B.3).

Metrics used to represent the overall sensitivity to disturbance of a lake's plant community and the overall health of the lake based on its plant community include the mean coefficient of conservatism (C) and the FQI. Mean C values were close to or greater than the Northern Wisconsin Lakes and Forests regional mean of 6.7 except for O'Brien Lake (Figure B.7). Most Penokee Lakes had FQI scores near or above the Northern Wisconsin Lakes and Forests regional average of 24.3, indicating ecosystems capable of hosting disturbance-sensitive plant species (Figure B.8). FQI scores ranged from 11.0 in East Twin Lake to 36.6 in Lake Galilee (Table B.3).

Conditions in East Twin Lake that limit plant growth and contribute to the low diversity and sensitivity of its aquatic plant community include high dissolved organic carbon/tannin content, low light availability, and possibly low pH. Plant growth in East Twin Lake was limited to floating and emergent plants, further highlighting the conditions in this lake that limit plant growth.

Low mean C, FQI, and Simpson's Diversity Index scores in O'Brien Lake stand out compared to other lakes besides East Twin. Mean Secchi depth in O'Brien Lake is on the low end when compared to other lakes, but similar to lakes like Caroline and West Twin that had plant metrics close to or above regional averages. Available water chemistry data does not suggest O'Brien Lake is different than other similar Penokee Lakes, or that there is evidence of human influence on water quality. Boat activity and boat-related impacts on the plant community are likely not a factor either. O'Brien Lake had the greatest annual average difference between high and low water levels (2.2 ft, Appendix E). That, combined with low light availability, make it more likely that the lower plant metric scores in O'Brien Lake are related to the amount of suitable substrate and conditions for plant growth within the photic zone.

Table B.2. Aquatic plant species presence (1) and absence (0) in each of the eleven Penokee Lakes.

Species	East Twin	West Twin	Eureka	Galilee	Meder	Long	Maki	McCarthy	Upson	O'Brien	Caroline
Aquatic moss*	1	1	1	1	0	0	1	1	0	1	1
Bidens beckii (formerly Megalodonta), Water marigold	0	0	1	1	1	1	1	0	1	0	1
Brasenia schreberi, Watershield	1	1	1	1	0	1	1	1	1	1	1
Caltha sp.*	1	0	0	0	0	0	0	0	0	0	0
Carex Lasiocarpa, Wire Grass Sedge	0	0	0	0	1	1	0	0	0	0	0
Carex sp.*	0	0	0	1	0	0	0	0	0	0	0
Ceratophyllum demersum, Coontail	0	0	1	0	0	0	1	1	0	1	0
Ceratophyllum echinatum, Spiny hornwort	0	0	0	0	0	0	0	0	0	0	1
Chara sp., Muskgrasses	0	0	1	1	0	0	0	1	1	1	1
Dulichium arundinaceum, Three-way sedge	1	1	0	0	1	1	1	1	1	0	0
Eleocharis acicularis, Needle spikerush	0	0	0	1	0	1	0	0	0	0	0
Eleocharis palustris, Creeping spikerush	1	1	0	0	0	0	0	0	0	0	0
Eleocharis robbinsii, Robbins' spikerush	0	0	0	1	0	0	0	0	0	0	1
Elodea canadensis, Common waterweed	0	0	0	0	0	1	0	0	0	1	1
Elodea nuttallii, Slender waterweed	0	0	0	1	0	0	1	1	0	0	0
Equisetum fluviatile, Water horsetail	1	1	1	1	1	1	0	1	1	1	1
Eriocaulon aquaticum, Pipewort	0	1	0	1	1	1	1	1	0	0	0
Filamentous algae*	1	0	1	1	1	1	1	1	1	1	1
Freshwater sponge*	1	1	0	0	0	0	1	0	0	1	0
Glyceria borealis, Northern manna grass	0	0	0	0	0	0	0	0	1	0	0
Heteranthera dubia, Water star-grass	0	0	1	0	0	0	0	0	0	0	0
Hypericum borale, Northern St. John's wort	0	0	0	0	0	1	0	0	0	0	0
Iris versicolor, Northern blue flag	0	0	0	0	0	0	1	0	0	0	0
Isoetes lacustris, Lake quillwort	0	0	0	0	1	0	0	0	0	0	0
Isoetes sp., Quillwort	0	0	0	0	0	1	0	0	0	0	0

Table B.2 continued…

Species	East Twin	West Twin	Eureka	Galilee	Meder	Long	Maki	McCarthy	Upson	O'Brien	Caroline
Juncus effusus, Common rush	0	0	0	1	0	0	0	0	0	0	0
Juncus pelocarpus f. submersus, Brown-fruited rush	0	0	1	0	1	1	0	0	0	0	0
Myriophyllum sibiricum, Northern water-milfoil	0	1	0	0	0	0	0	0	0	0	1
Najas flexilis, Slender naiad	0	0	1	1	0	1	0	1	1	0	1
Najas gracillima, Northern naiad	0	1	0	0	0	0	1	0	0	0	0
Nitella sp., Nitella	0	1	1	1	0	0	1	1	0	1	1
Nuphar variegata, Spatterdock	0	1	1	1	1	1	1	1	1	1	1
Nymphaea odorata, White water lily	1	1	1	1	1	1	1	0	0	1	1
Potamogeton amplifolius, Large-leaf pondweed	0	0	0	1	1	1	0	0	1	0	1
Potamogeton diversifolius, Water-thread pondweed	0	0	0	0	0	0	1	0	0	0	0
Potamogeton epihydrus, Ribbon-leaf pondweed	0	1	0	1	1	0	1	0	0	0	1
Potamogeton foliosus, Leafy pondweed	0	0	0	1	1	0	0	0	1	0	0
Potamogeton gramineus, Variable pondweed	0	0	1	1	0	0	0	1	0	1	1
Potamogeton natans, Floating-leaf pondweed	0	0	1	1	0	0	0	0	0	0	1
Potamogeton obtusifolius, Blunt-leaf pondweed	0	1	0	1	0	1	1	1	0	0	0
Potamogeton robbinsii, Fern pondweed	0	0	0	1	0	1	0	0	1	0	1
Potamogeton spirillus, Spiral-fruited pondweed	0	0	0	1	1	1	0	0	1	1	0
Potamogeton strictifolius, Stiff pondweed	0	0	0	1	0	0	1	0	0	0	1
Potamogeton zosteriformis, Flat-stem pondweed	0	0	0	1	0	0	0	1	0	0	0
Ranunculus flammula, Creeping spearwort	0	0	0	0	0	0	0	0	1	0	0
Sagittaria cristata, Crested arrowhead	0	0	0	0	0	0	0	0	1	0	0
Sagittaria graminea, Grass-leaved arrowhead	0	0	0	0	1	0	0	0	0	0	0

Table B.2 continued…

Species	East Twin	West Twin	Eureka	Galilee	Meder	Long	Maki	McCarthy	Upson	O'Brien	Caroline
Sagittaria latifolia, Common arrowhead	0	0	1	0	0	0	0	0	1	0	0
Sagittaria sp., Arrowhead	0	0	1	1	1	0	0	0	0	0	0
Schoenoplectus acutus, Hardstem bulrush (formerly Scirpus acutus)	0	0	1	1	1	0	0	0	0	0	1
Schoenoplectus tabernaemontani, Softstem bulrush (formerly *Scirpus validus*)	0	0	0	0	1	1	0	0	0	0	1
Schoenoplectus americanus (formerly *Scirpus americanus)*	0	0	0	0	0	0	0	0	0	1	0
Sium suave, Water parsnip	0	0	1	1	0	0	0	0	0	0	0
Sparganium eurycarpum, Common bur-reed	0	1	1	0	1	0	0	0	0	0	1
Sparganium fluctuans, Floating-leaf bur-reed	0	1	1	1	1	1	0	1	1	1	1
Typha latifolia, Broad-leaved cattail	0	0	1	0	0	0	0	0	0	0	1
Typha sp., Cattail	0	0	0	0	0	0	0	0	1	1	0
Utricularia gibba, Creeping bladderwort	0	1	0	0	0	0	0	0	0	0	0
Utricularia minor, Small bladderwort	0	1	0	1	0	0	0	0	0	0	0
Utricularia resupinata, Small purple bladderwort	0	0	0	1	0	0	0	0	0	0	0
Utricularia sp*	0	0	1	0	0	0	0	0	0	0	0
Utricularia vulgaris, Common bladderwort	0	0	1	1	1	1	1	1	0	0	1
Vallisneria americana, Wild celery	0	0	1	1	1	1	0	1	1	1	1

*not counted toward overall species richness

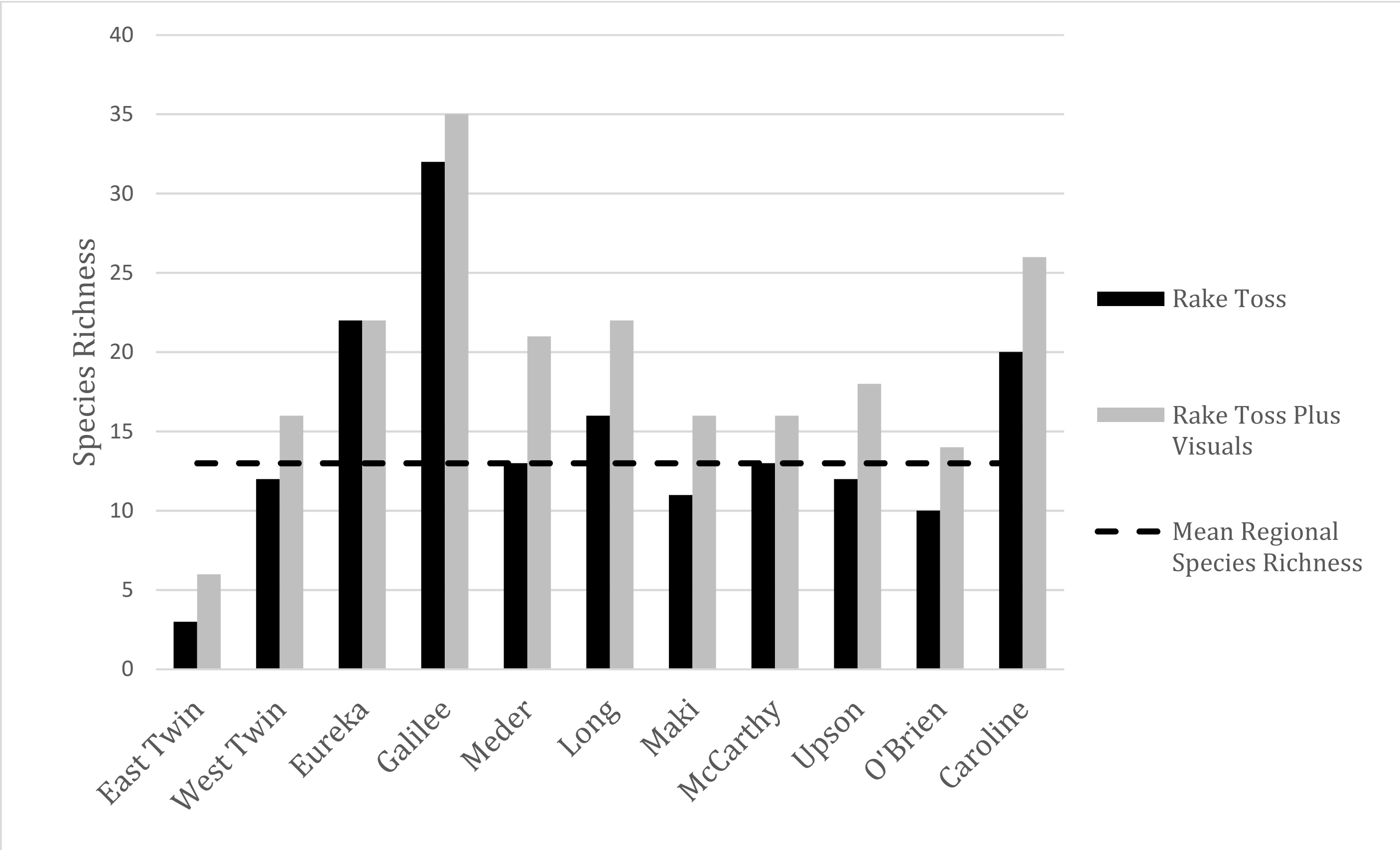


Figure B.3. Aquatic plant species richness observed in each of the eleven Penokee Lakes. Black bars indicate plant species identified from rake tosses only. Gray bars include species identified from rake tosses and spotted visually. Mean regional species richness value for Northern Wisconsin Lakes and Forests region from Nichols 1999.

Table B.3. Summary statistics and metrics from the aquatic plant surveys in each of the eleven Penokee Lakes.

Metric	East Twin	West Twin	Eureka	Galilee	Meder	Long	Maki	McCarthy	Upson	O'Brien	Caroline
Total number of sites visited	26	62	106	159	98	171	57	50	173	286	97
Total number of sites with vegetation	11	40	36	95	39	44	32	36	103	57	28
Total number of sites shallower than maximum depth of plants	18	57	86	132	95	60	44	41	155	137	75
Frequency of occurrence at sites shallower than maximum depth of plants	61.1	70.2	41.9	72.0	41.1	73.3	72.7	87.8	66.5	41.6	37.3
Simpson Diversity Index	0.57	0.78	0.92	0.93	0.85	0.89	0.74	0.88	0.80	0.61	0.92
Maximum depth of plants (ft)	5	7	15	8	8	6	6	7	15	6	6
Number of sites sampled using rake on rope	0	0	12	2	0	7	3	0	52	5	0
Number of sites sampled using rake on pole	26	62	84	153	98	86	54	50	121	282	91
Average number of all species per site (shallower than max depth)	0.7	1.2	1.1	1.5	0.6	1.3	1.5	2.5	0.9	0.5	0.8
Average number of all species per site (veg. sites only)	1.1	1.7	2.7	2.1	1.4	1.8	2.1	2.9	1.4	1.2	2.0
Average number of native species per site (shallower than max depth)	0.7	1.2	1.1	1.5	0.6	1.3	1.5	2.5	0.9	0.5	0.8
Average number of native species per site (veg. sites only)	1.1	1.7	2.7	2.1	1.4	1.8	2.1	2.9	1.4	1.2	2.0
Species Richness	3	12	22	32	13	16	11	13	12	10	20
Species Richness (including visuals)	7	16	22	35	21	22	16	16	18	14	26
Mean Coefficient of Conservatism	6.3	7.3	6.4	7.3	7.8	6.8	6.8	6.8	7.2	5.4	6.6
Floristic Quality Index	11.0	25.4	27.3	37.1	27.1	26.3	22.6	24.4	23.8	17.1	27.2

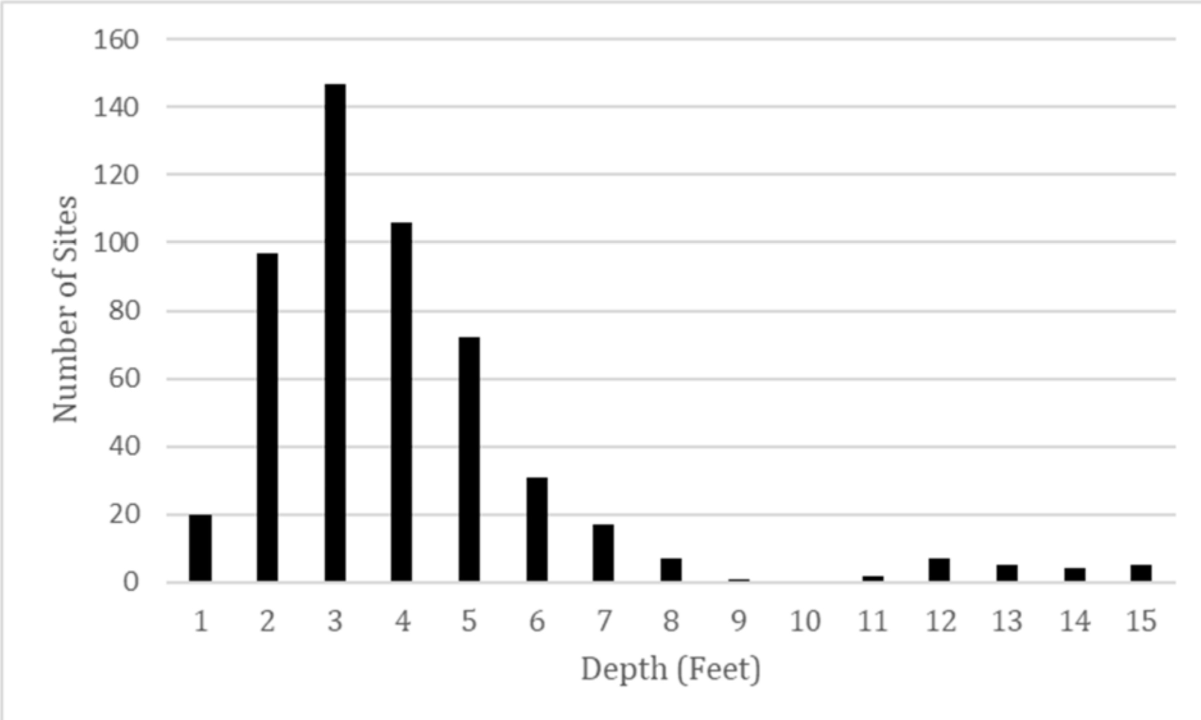


Figure B.4. Total number of sites with observed plant growth at one-foot water depth intervals from the eleven Penokee Lakes.

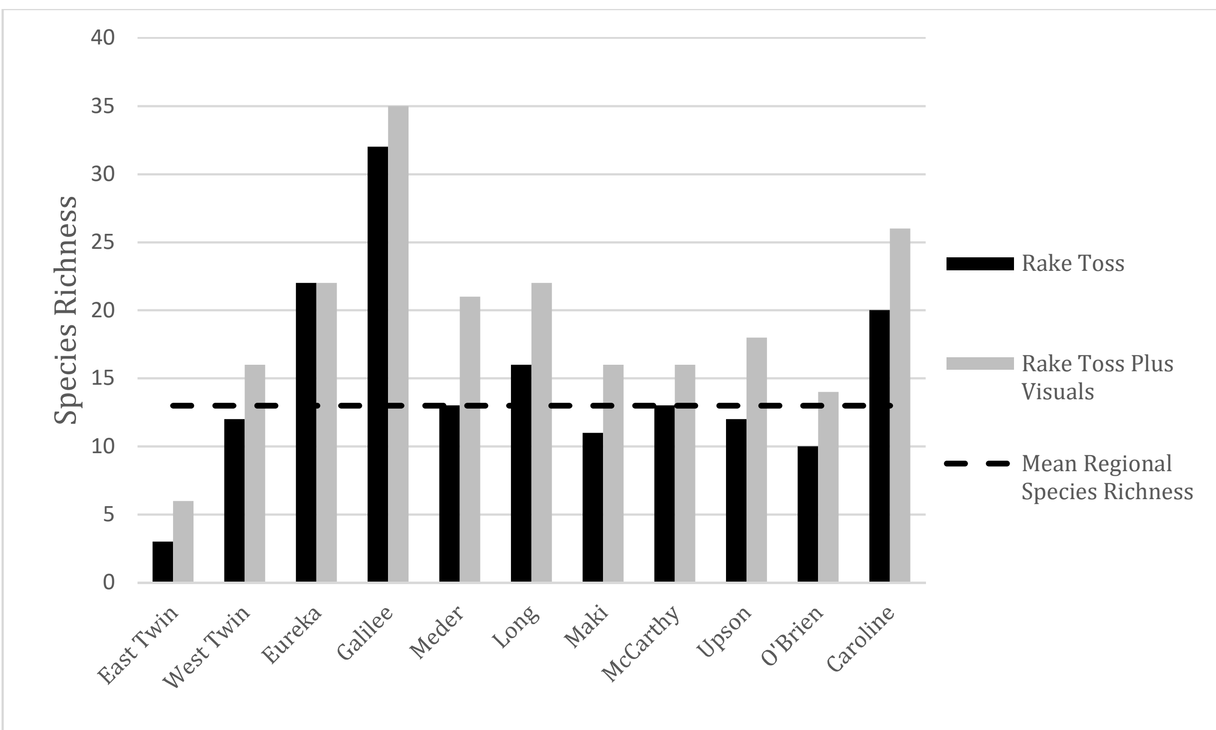


Figure B.5. Maximum observed depth of aquatic plant growth and depth for which 95% of observed plant growth was shallower from each of the eleven Penokee Lakes.

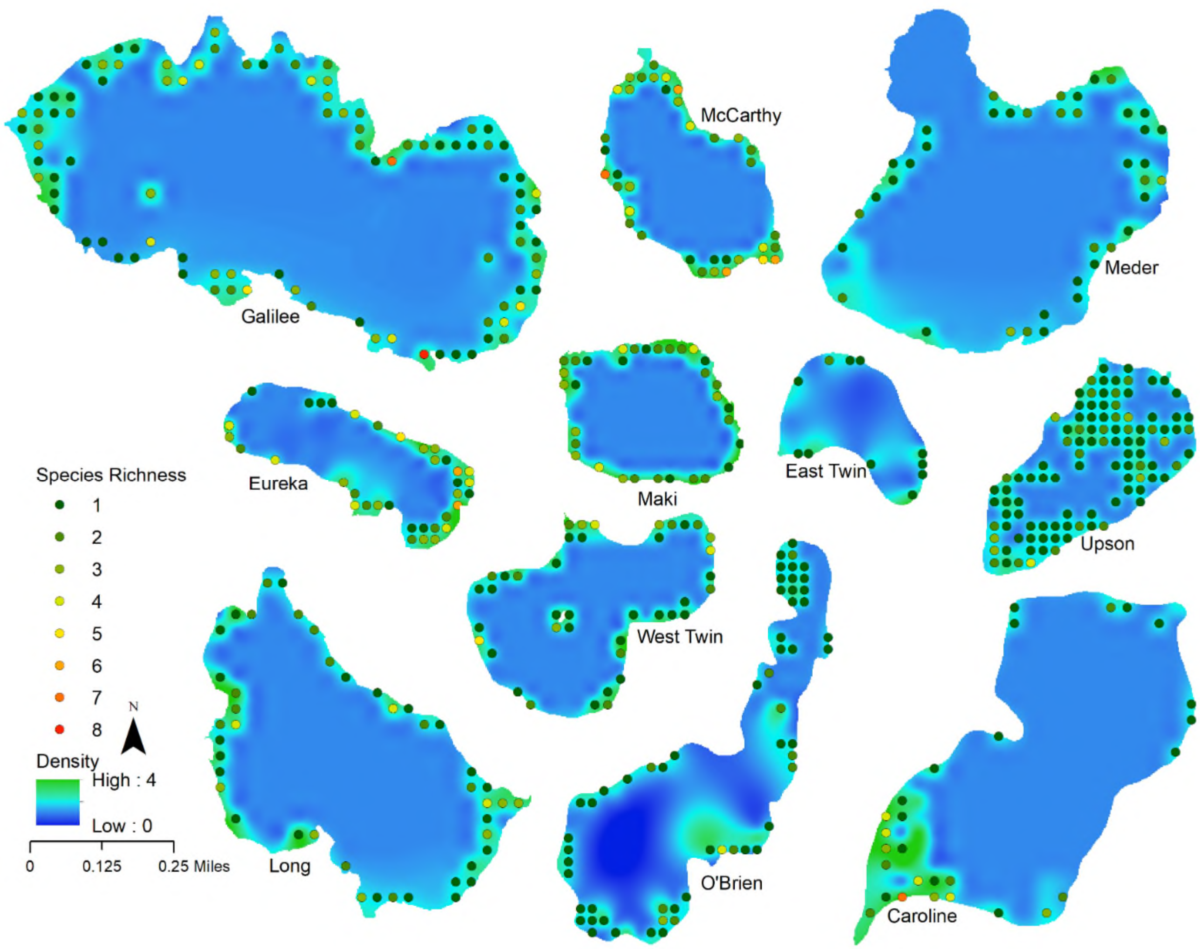


Figure B.6. Aquatic plant species richness and density for each of the eleven Penokee Lakes. The color of each dot indicates the number of plant species identified at that location. Green shading indicates high plant density (relative to the other lakes) and dark blue shading indicates areas of no plant growth.

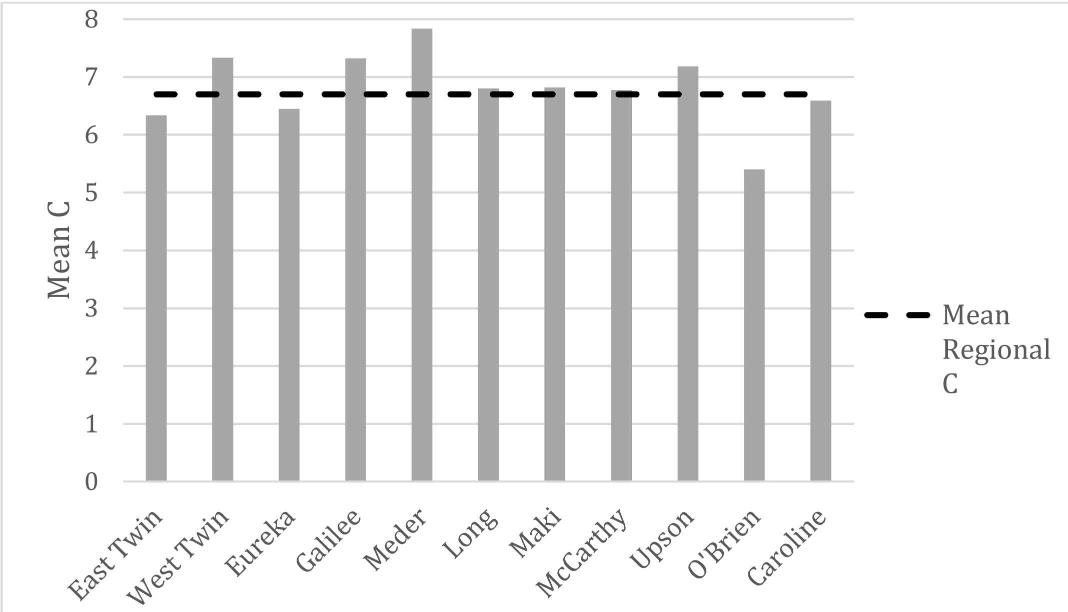


Figure B.7. Mean coefficient of conservatism (Mean C) values calculated from aquatic plant community data from each of the eleven Penokee Lakes. Mean regional C is the value for Northern Wisconsin Lakes and Forests region from Nichols 1999.

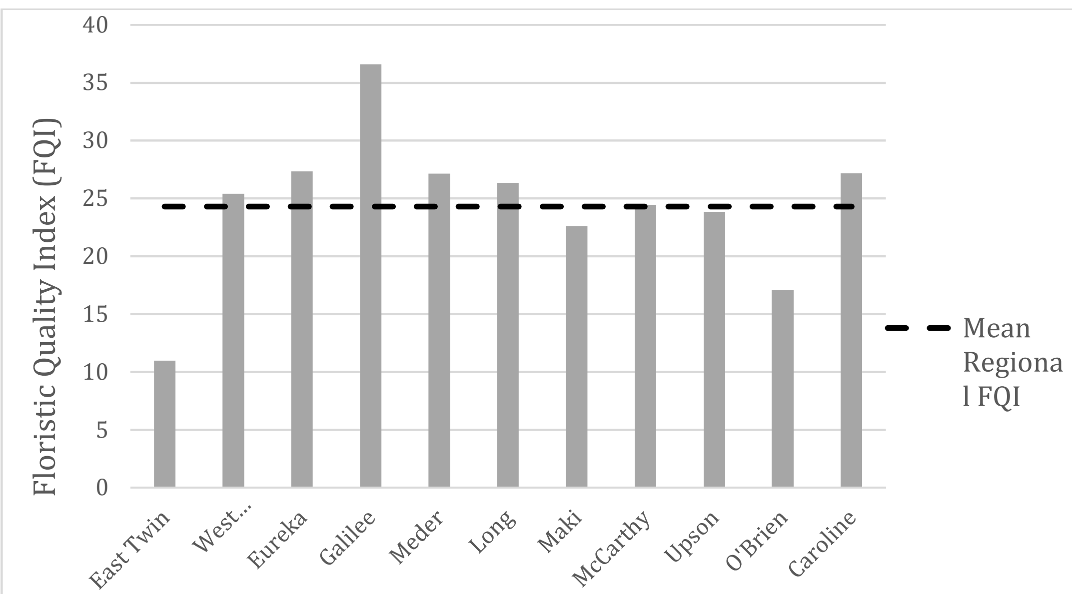


Figure B.8. Floristic Quality Index (FQI) values calculated for each of the eleven Penokee Lakes. Mean regional FQI is the value for Northern Wisconsin Lakes and Forests region from Nichols 1999.

Although not identified during the point-intercept survey, visual observations of wild rice *(Zizania palustris)* were made in Upson and O'Brien Lakes during the sampling period.

Purple loosestrife has been recorded by the WDNR in Meder and Galilee Lakes, Chinese mystery snail in Long and O'Brien Lakes, and banded mystery snail in Galilee and O'Brien Lakes. No non-native aquatic plants were observed by Burke Center staff during aquatic plant survey work in the summers of 2016-2018.

Voucher Specimens

Voucher specimens were retained for all aquatic plant species found in each lake. Voucher specimens were then pressed, dried, and sent to the Freckman Herbarium at the University of Wisconsin – Stevens Point. Unfortunately, the pressing and drying process failed to produce samples of high enough quality for archival purposes at any of the lakes.

Substrate Characteristics

Another component of the aquatic plant survey protocol is to collect basic information about the lake bed substrate encountered at each survey point. These data can be useful when interpreting the aquatic plant data, as well as provide information in understanding potential important habitat areas for fish, wild rice, and other aquatic life. Lake substrate data for all eleven Penokee Lakes are displayed in Figure B.9. Muck was the most common substrate in the point intercept survey (837 points), followed by sand (195 points) and then rock (68 points). Some areas of each lake do not have substrate data recorded. This is because once established, points below the maximum depth of plant growth are not sampled for substrate characteristics.

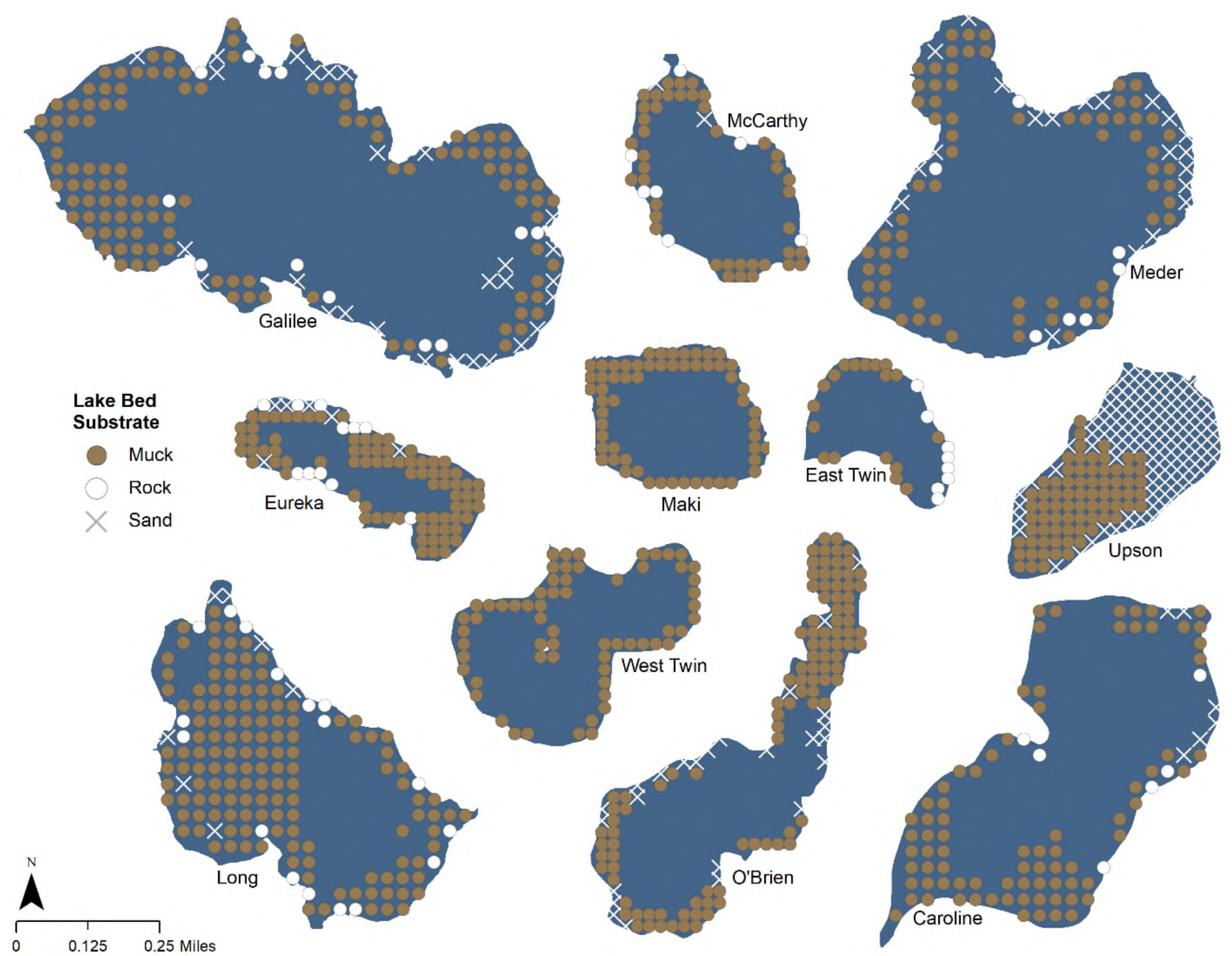


Figure B.9. Lake bed substrate results from the aquatic plant survey conducted on each of the eleven Penokee Lakes.

Appendix C – Shoreland Habitat Assessment

The area of transition between the terrestrial and aquatic worlds is often collectively referred to as shoreland habitat. Healthy shoreland areas are crucial for fish and wildlife habitat, as well as maintaining good water quality in lakes and other aquatic environments. Human development of shoreland areas is one of the key problems that can lead to declines in water quality and fish and wildlife habitat. Thus, understanding the current condition of shoreland habitat areas in lake is a key component to lake management planning.

To better characterize shoreland habitat around the Penokee Lakes, shoreline and nearshore habitat conditions, along with an assessment of course woody habitat, were characterized once in each lake over the study period. Shoreland habitat condition was quantified using methods adapted from the Wisconsin Department of Natural Resources (WDNR, 2016) and the Environmental Protection Agency (USEPA, 2007). The shoreland habitat assessments consisted of three activities, each occurring around the entire shoreline of each lake:

1. Georeferenced photos of the entire shoreline that slightly overlap.
2. Assessment of the riparian, bank, and littoral habitat by parcel.
3. Count and map all pieces of large (course) woody habitat in water less than 2 feet deep.

Table C.1 lists the date each component of the shoreland habitat assessment occurred.

Table C.1. Date each of the elements of the shoreland habitat assessment were conducted in each of the eleven Penokee Lakes.

	Photo Survey	Shoreland Parcel Assessment	Coarse Woody Habitat Survey
East Twin	7/1/2016	7/1/2016	7/7/2016
West Twin	6/29/2016	6/29/2016	6/29/2016
Eureka	7/6/2016	7/6/2016	7/6/2016
Galilee	7/5/2016	7/5/2016	7/5/2016
Meder	6/26/2018	6/27-28/2019	6/26/2018
Long	6/25/2018	6/25/2018	6/25/2018
Maki	6/28/2016	6/28/2016	6/28/2016
McCarthy	7/6/2016	7/6/2016	7/6/2016
Upson	6/23/2017	6/23/2017	6/23/2017
O'Brien	6/22/2017	6/22/2017	6/22/2017
Caroline	7/20/2016	7/14/2016	6/15/2021

Georeferenced Shoreline Photos

The entire shoreline of each Penokee Lake was photographed with slightly overlapping, georeferenced images taken from a boat, approximately 50 feet from and perpendicular to shore. The images are intended to document shoreland habitat condition at a single point in time and may be referred to years later. Due to large file size and no statewide repository for the photo data as of completion of this project, all photos are stored by the Burke Center at Northland College and are available upon request.

Shoreland Parcel Assessment

Shoreline parcel data for each lake were obtained through the Ashland and Iron County zoning offices. A total of 154 parcels were assessed and scored across all eleven Penokee Lakes. About one-third (54) of the parcels were located on Lake Galilee. Upson Lake only had one parcel. Normally the shoreland habitat assessments are conducted by parcel, but because Upson Lake only had one parcel and other lakes had very few parcels, an adjusted parcel size was needed in order to provide detailed shoreland habitat data from all of the lakes. To remedy this, the average parcel size on Lake Galilee (300 ft), the most developed of the lakes, was used as a guide to divide large parcels into sub-parcels. Thus, parcels that were greater than 300 feet in length received multiple shoreland habitat scores and a total of 304 parcels plus sub-parcels were assessed and scored across all eleven Penokee Lakes.

For each parcel/sub-parcel segment, data were collected to describe the habitat conditions and level of disturbance in riparian, bank and littoral zones of the lake using a series of semi-quantitative ranking criteria which were then averaged per parcel. A score between one and twelve was given within each zone, with scores between ten and twelve considered “ideal,” seven and nine “very good,” four and six “marginal,” and one and three “poor.” For parcels that contained one or more sub-parcel, the sub-parcel scores were averaged to create one score per parcel to remain consistent with WDNR methods. The sub-parcel scores were also evaluated for additional information related to habitat quality that might be lost by averaging.

Because the ranking system used by the Burke Center is slightly different than current WDNR protocols, a description of the scoring system used for the habitat assessments and the data sheet are shown in Figures C.1 and C.2 respectively.

Overall, shoreland habitat is of high quality across the Penokee Lakes. Riparian habitat scores were “ideal” or “very good” for 79% of surveyed parcels (Table C.2). Bank habitat scores were “ideal” or “very good” for 82% of surveyed parcels. Littoral habitat scores were “ideal” or “very good” for 90% of surveyed parcels. When looking at the overall average score of riparian, bank, and littoral zone for each parcel, 82% scored within the “ideal” or very good” range (Table C.2). These scores are reflective of the large amounts of undeveloped shoreline in most areas of the Penokee Lakes.

Restoration potential was also assessed using the shoreland habitat assessment data. Restoration potential in this context conveys need for restoration based on habitat degradation. “Low” restoration potential denotes areas of high habitat quality which would be important areas to protect whereas, “high” restoration potential denotes areas which have been degraded from an ideal state and therefore should be targets for restoration efforts. Of the 154 parcels surveyed, the majority (97) averaged “low” restoration potential. Areas with the highest restoration potential are concentrated on the most developed lakes – Galilee and Meder (Figures C.3, C.4, C.5 and C.6). Habitat conditions were relatively consistent across the riparian, bank and littoral zones—although some within parcel variability does exist. Aggregated shoreland habitat assessment scores for each of the 154 parcels surveyed are shown in Table C.3.

Figure C.1. Description of shoreland habitat assessment semi-quantitative ranking system utilized to assess each parcel during survey of each of the eleven Penokee Lakes.

Mary Griggs Burke Center for Freshwater Innovation, Northland College
Lake Habitat Assessment: Field Habitat Description

Habitat parameters to be evaluated

Habitat Parameter	Condition Category			
	Ideal	Very Good	Marginal	Poor
Riparian (HWM to 35 ft inland: tree canopy, shrubs, and groundcover species	90%+ upland area with dense native canopy trees, shrubs & ground species; or other natural features (such as rock outcrop) prevents establishment of vegetation. Less than 5% of lot is *impervious surface, minimal shoreland maintenance, no invasive species. Upland runoff/ erosion is not present.	Moderate to dense (70-90%) ground vegetation and canopy trees w/ shrub layer reduced; or few canopy trees with moderate to dense natural shrub layer, 5%-15% *impervious surfaces, less than 30% shoreland manicured, few or no invasives. Minimal or no runoff/erosion.	Established lawn with moderate-dense (30-70%) canopy trees; shrub layer absent; 15%-20% *impervious surface; 30%-50% or more of shoreland manicured/ maintained, invasive species present. Upland runoff/ erosion present to moderate.	Native tree canopy, shrubs and groundcover vegetation 0-30%; established lawn with few canopy trees, 20%-30% *impervious surface, more than 50% of shoreland manicured, invasive species present. Upland erosion moderate to substantial.
SCORE	12 11 10	9 8 7	6 5 4	3 2 1
Bank Zone (Bank Lip to Lake Bed): tree, shrub and groundcovers along the shore where land & water meet	Littoral woody logs/snags 5+ per 30 m; overhanging vegetation; shore vegetated >90% w/ native groundcovers, shrubs and trees; no bare soil; little potential for future problems; or natural feature prevents vegetation; buffer extends 30'+ back from shore; human disturbance/shore alteration/access (tree removal, brushing, mowing, armored banks/riprap) <10m or not present.	Some littoral woody habitat; well-suited for organisms; overhanging vegetation; riparian buffer 10m deep covered 70-90% w/ native vegetation, but one class of plants not well established; disruption evident but not affecting potential; minimal bare soil (5-20%); minimal vegetation removed from 30'-75' feet inland; shore alteration/disturbance minimal 10-20m.	Littoral woody habitat minimal to absent; riparian buffer 5-10m deep covered with 50-70% vegetation but minimal or no shrub layer and tree canopy or buffer depth only 5-10m; disruption obvious; bare soil/closely cut veg. common; no extended buffer greater than 30' inland; moderate bare soil (30-60% of bank); moderate shore alteration (tree removal, mowing, established lawn, armored banks/ riprap).	Littoral woody habitat absent; riparian buffer with minimal or no shrub layer and tree canopy (<50% vegetation) or less than 5 m deep; no extended buffer 30' -75' feet inland; unstable shore 60-100% of bank/ exposed soil; moderate human disturbance and /or shore alteration (tree removal, mowing, established lawn, armored banks/ riprap).
SCORE	12 11 10	9 8 7	6 5 4	3 2 1
Littoral Zone (CWL to 50 ft out): abundance of emergent, submerged, and floating vegetation	Dense or abundant emergent, submerged or floating vegetation or rocky substrate unable to support vegetation; abundant fish habitat; minimal or no human disturbance including recreational use.	Scattered or patchy emergent, submerged or floating vegetation; minimal human disturbance including recreational use.	Lack of emergent or floating veg.; minimal submerged veg.; vegetation limited by rec. use (swimming, boating, etc); disturbed lakebed; invasives present or likely.	Minimal or no native aquatic vegetation present; invasives present or likely; lakebed altered (boat landing); several structures (dock/pier/PWC lifts) prevent aquatic plant growth, heavily used swimming area.
SCORE	12 11 10	9 8 7	6 5 4	3 2 1

***Note: impervious surface is defined as any surface that does not allow water to infiltrate (sidewalks, building, shed, hard packed parking,etc)**

Figure C.2. Shoreland habitat assessment field datasheet.

Mary Griggs Burk Center for Freshwater Innovation, Northland College
Lake Habitat Assessment: Lake Information-*One per parcel*

Date ____________ WBIC ____________________ Lake Name ______________________________

Parcel ID________________ Observers________________________ Parcel Length (GPS):________

RIPARIAN BUFFER ZONE (HWM to 35 ft inland)				
Percent Cover			Percent	
Canopy (>16 ft tall trees)			(0-100)	
Deciduous				
Coniferous				
Mixed				
Shrub/Herbaceous (<16 ft tall plants)				
	Shrub___		Herbaceous ___	
Impervious Surface				
Manicured Lawn				
Agriculture				
Duff				
Other (e.g. mulch)				
Description:				
Habitat Type:				
Quality	Ideal	Very Good	Marginal	Poor
	12 11 10	9 8 7	6 5 4	3 2 1
Human Structures			Number	
Buildings				
Boats on Shore				
Fire Pits				
Other				
Description:				
Runoff Concerns in Riparian Zone (RZ) or Entire Parcel			*Present in RZ*	*Present out of RZ*
Point Source				
Channlized Water Flow/Gully				
Stair/Trail/Road to Lake				
Lawn/Soil Sloping to Lake				
Bare Soil				
Sand/Silt Deposits				
Other				
Description:				
Soil Composition:	Boulders	Gravel	Till	
	Sandy	Clay/silt	Muck	
Soil Strength:				
Very soft	Soft	Average	Difficult	Impossible

BANK ZONE (Variable: Bank Lip to Lake Bed)				
Structures			Length (ft)	
Vertical Sea Wall				
Rip Rap				
Other Erosion Control Structures				
Artificial Beach				
Bank Erosion > 1 ft Face				
Bank Erosion < 1 ft Face				
Bank Angle	<5%	5-30%	30-75%	>75%
Habitat Type:				
Habitat Quality	Ideal	Very Good	Marginal	Poor
	12 11 10	9 8 7	6 5 4	3 2 1

LITTORAL ZONE (Present Water Line to 50 ft into lake)				
Human Structures			**Number**	
Piers				
Boat Lifts				
Swim Rafts/Water Trampolines				
Boathouses (Overwater)				
Marinas				
Other				
Description:				
Aquatic Plants			**Present**	
Emergents				
Floating				
Plant Removal				
Habitat Type:				
Quality	Ideal	Very Good	Marginal	Poor
	12 11 10	9 8 7	6 5 4	3 2 1

EXPOSED LAKE BED ZONE (If Applicable: low water level)	
Plants	**Present**
Canopy	
Shrubs	
Herbaceous	
Disturbed	**Present**
Plants (mowed or removed)	
Sediment (tilled or dug)	

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Lake Habitat Assessment: Lake Information-*One per parcel*

Invasive Species Present:

If invasive species are suspected, take a sample, bag it appropriately, label it with the date, location, and suspected species, so it can be mailed to the DNR for confirmation testing.

NOTES:

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Table C.2. Summary of parcel and sub-parcel shoreland habitat assessment scores for each of the eleven Penokee Lakes. Results are displayed as a percentage of parcels or sub-parcels within each lake that scored "ideal" or "very good" overall and in each habitat zone.

		Percent "Ideal" or "Very Good"					Percent "Ideal" or "Very Good"			
Lake	Parcels	Riparian	Bank	Littoral	Average	Parcels plus Sub-Parcels	Riparian	Bank	Littoral	Average
Caroline	7	100%	100%	100%	100%	31	100%	100%	100%	100%
East Twin	3	100%	100%	100%	100%	13	100%	100%	100%	100%
Eureka	10	100%	100%	100%	100%	19	100%	100%	95%	100%
Galilee	54	69%	81%	85%	80%	54	85%	94%	87%	91%
Long	24	88%	96%	100%	96%	24	88%	96%	100%	96%
Maki	4	100%	100%	100%	100%	14	100%	100%	100%	100%
McCarthy	5	80%	100%	100%	100%	15	87%	100%	100%	100%
Meder	32	56%	50%	75%	47%	58	67%	45%	72%	60%
O'Brien	7	100%	100%	100%	100%	35	100%	100%	100%	100%
Upson	1	100%	100%	100%	100%	21	100%	100%	100%	100%
West Twin	7	100%	100%	100%	100%	20	95%	95%	100%	100%

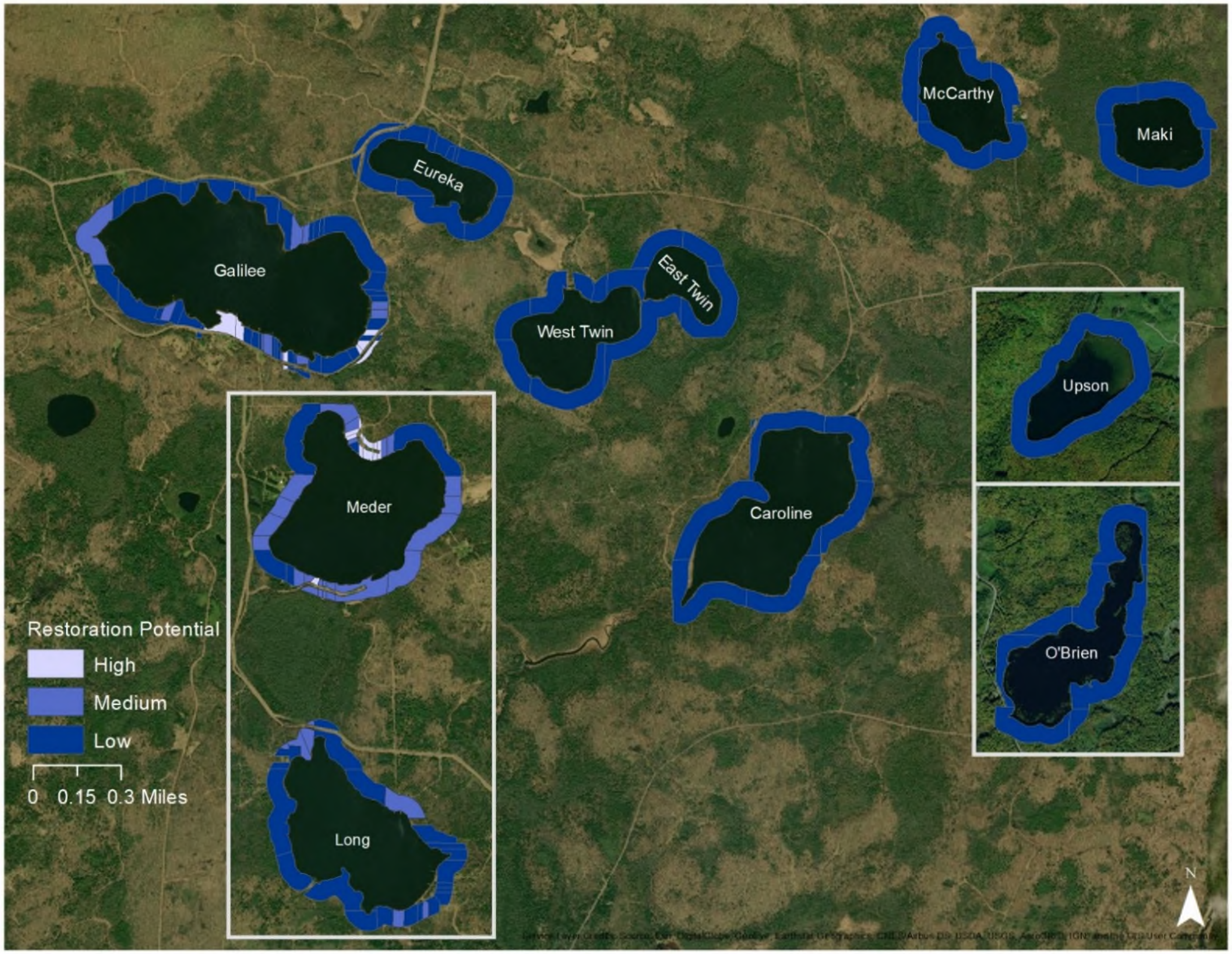

Figure C.3. Shoreland habitat restoration potential (combination of bank, littoral, and riparian cores) for the eleven Penokee Lakes, high restoration potential is correlated with low habitat quality and low restoration potential is correlated with high habitat quality.

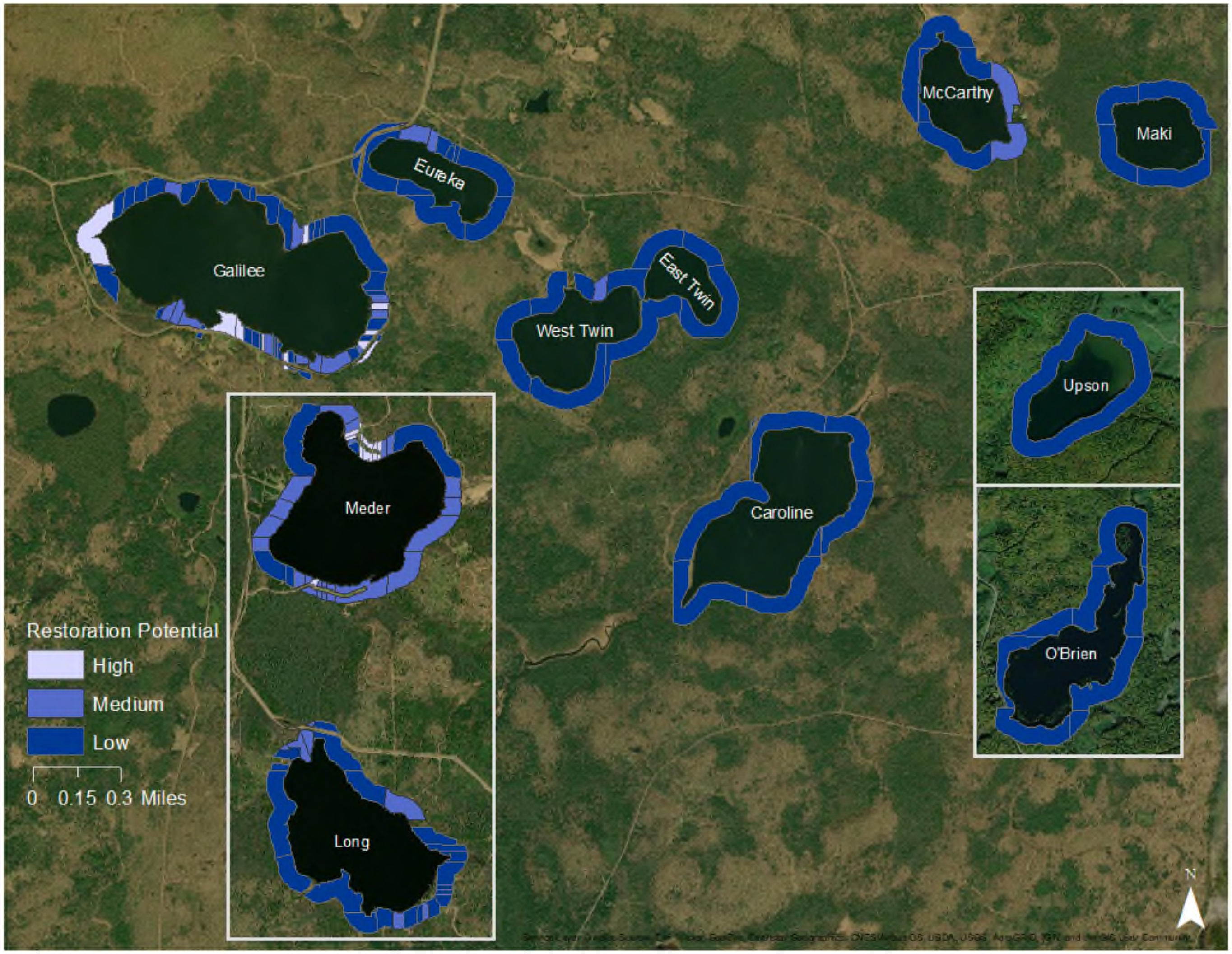

Figure C.4. Restoration potential of riparian areas for the eleven Penokee Lakes. High restoration potential is correlated with low habitat quality and low restoration potential is correlated with high habitat quality.

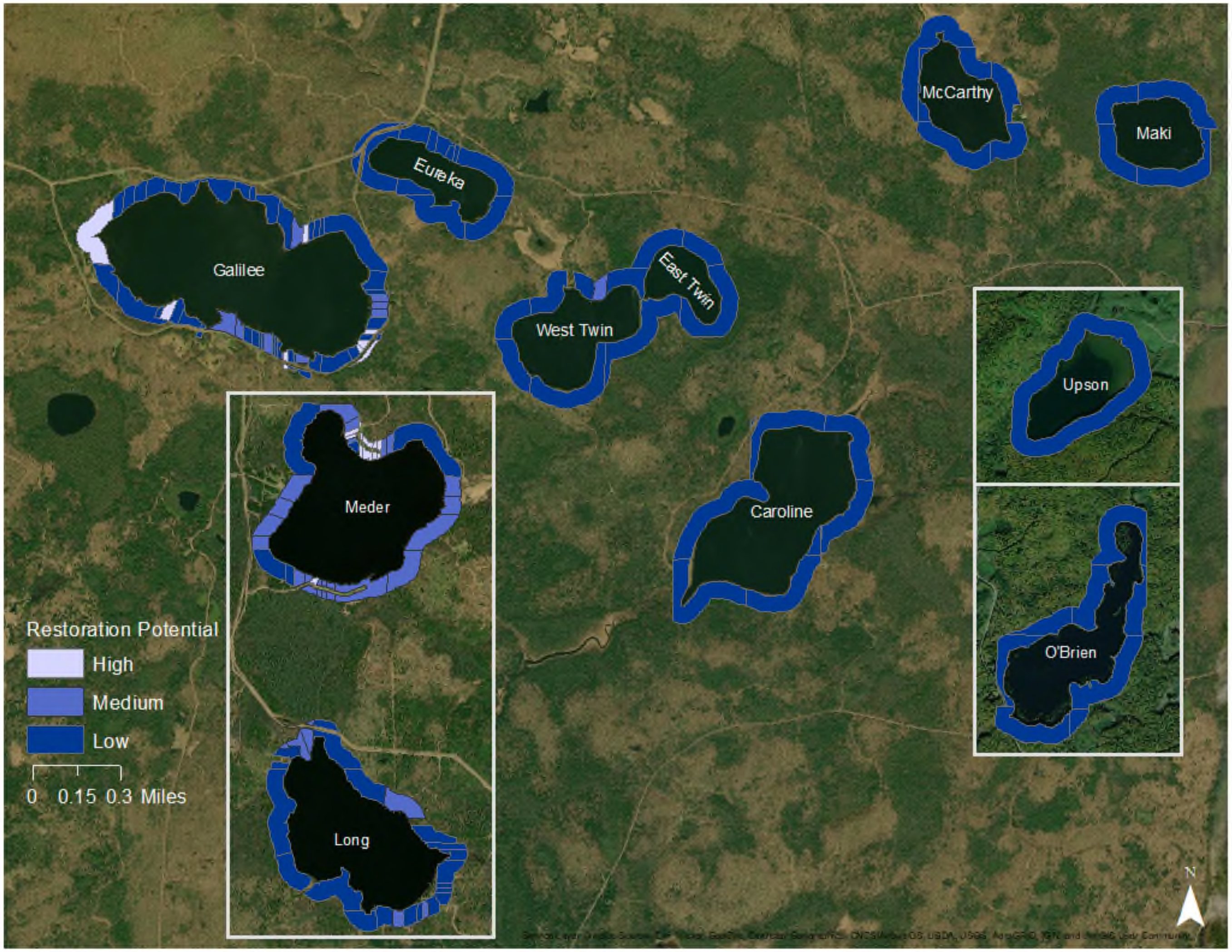

Figure C.5. Average restoration potential of bank areas for the eleven Penokee Lakes. High restoration potential is correlated with low habitat quality and low restoration potential is correlated with high habitat quality.

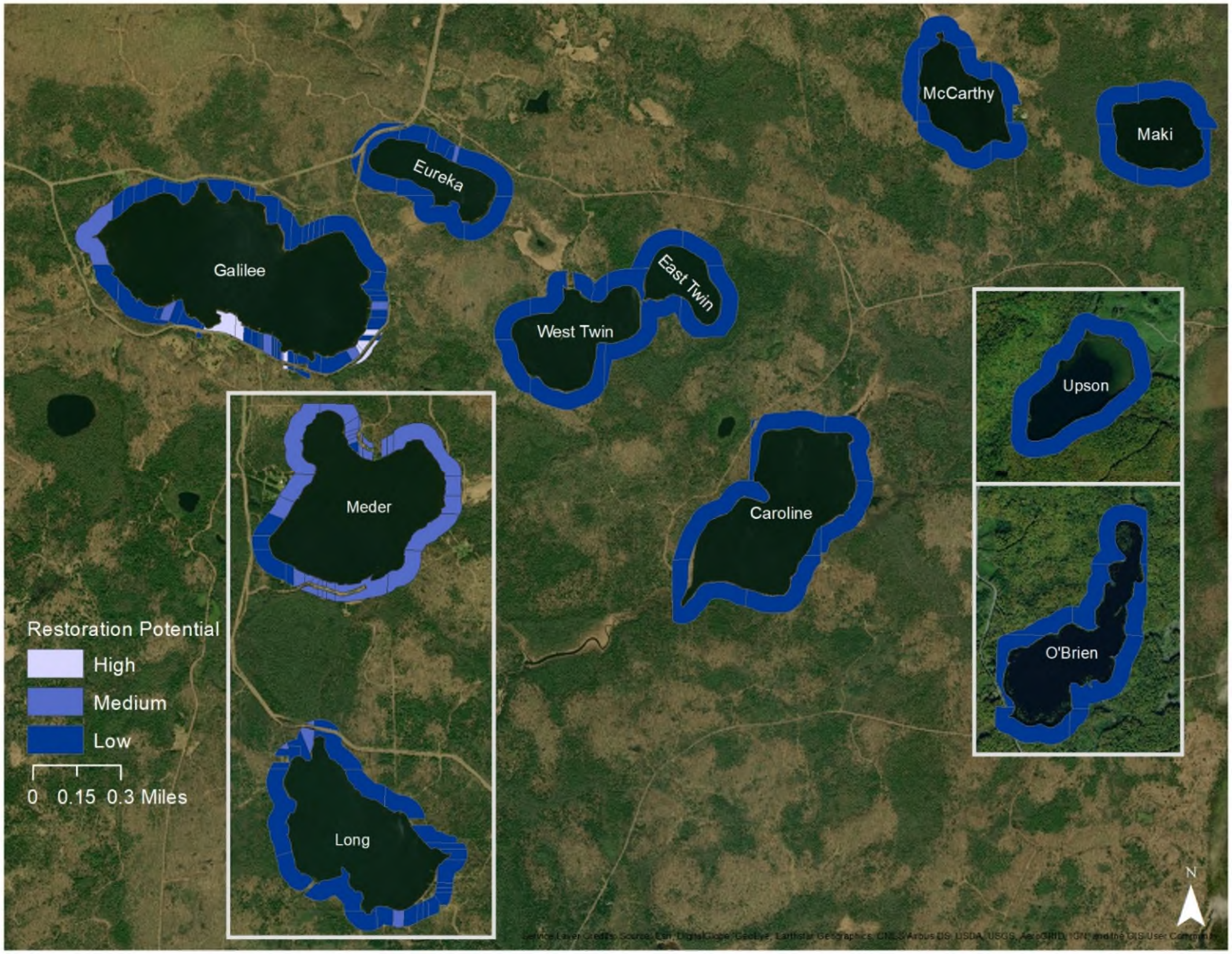

Figure C.6. Average restoration potential for littoral areas for the eleven Penokee Lakes. High restoration potential is correlated with low habitat quality and low restoration potential is correlated with high habitat quality.

Table C.3. Shoreland habitat assessment scores for each parcel assessed for each of the eleven Penokee Lakes. *Denotes parcels where scores are an average of aggregated sub-parcel scores.

Lake	Parcel_ID	LONGITUDE	LATITUDE	Riparian	Bank	Littoral	Avg. Score
East Twin	018002060000*	-90.56441439	46.28638373	12	12	12	12.0
East Twin	018002050000*	-90.55879752	46.28641801	12	12	12	12.0
East Twin	018003660000*	-90.55848284	46.28267822	12	12	12	12.0
West Twin	018003630210	-90.56752371	46.28358929	7	7	11	8.3
West Twin	018003630220*	-90.57062958	46.28334687	10	10	12	10.7
West Twin	018003650000*	-90.56414718	46.27979622	12	12	12	12.0
West Twin	018003550000*	-90.57509384	46.28260354	12	12	12	12.0
West Twin	018003560000*	-90.57512462	46.27891184	12	12	12	12.0
West Twin	018003640000*	-90.5694426	46.27823613	12	12	12	12.0
West Twin	018003630100*	-90.56553661	46.28388202	12	12	12	12.0
Eureka	018002320700	-90.58069215	46.2910647	7	10	10	9.0
Eureka	018002320500	-90.57947948	46.29085624	7	10	10	9.0
Eureka	018002330000*	-90.57974532	46.28596002	11	11	12	11.5
Eureka	018002320600	-90.57821146	46.29004496	10	9	9	9.3
Eureka	018002320300	-90.5785895	46.29072639	10	9	10	9.7
Eureka	018002320200*	-90.58103295	46.28828374	10	10	10	10.0
Eureka	018002320800	-90.57775026	46.29028597	12	10	6	9.3
Eureka	018002310000*	-90.58491476	46.28977421	12	12	12	12.0
Eureka	018002320900*	-90.57502497	46.28916874	12	12	12	12.0
Eureka	018002340000*	-90.57454231	46.28593099	12	12	12	12.0
Galilee	018003450902	-90.59319315	46.28133568	2	5	3	3.3
Galilee	018003540800	-90.58381614	46.28118191	3	3	3	3.0
Galilee	018003520700	-90.58989504	46.2786521	3	3	3	3.0
Galilee	018003450903	-90.59433864	46.28155167	3	5	3	3.7
Galilee	018002210600	-90.588486	46.28669364	3	4	10	5.7
Galilee	018003521500	-90.59153697	46.28070922	3	9	11	7.7
Galilee	018003530400	-90.58365965	46.27889956	4	3	1	2.7
Galilee	018003540500	-90.58303335	46.28251256	4	6	5	5.0
Galilee	018002370200	-90.60421731	46.28659061	4	4	7	5.0
Galilee	018003530300	-90.58467784	46.28038298	5	1	1	2.3
Galilee	018003450300	-90.59829869	46.28211876	5	2	7	4.7
Galilee	018003521100	-90.59116174	46.28059647	5	7	5	5.7
Galilee	018002210500	-90.58911568	46.28658464	5	8	10	7.7
Galilee	018003520200	-90.58872641	46.27981957	5	8	11	8.0
Galilee	018003450500	-90.59764488	46.28211751	5	9	11	8.3
Galilee	018003540600	-90.5831116	46.28210419	6	7	10	7.7
Galilee	018003450800	-90.5968044	46.28167823	6	9	11	8.7
Galilee	018003520100	-90.58775917	46.27961506	7	11	10	9.3
Galilee	018003520800	-90.59016264	46.27997741	8	8	8	8.0
Galilee	018003540400	-90.5831383	46.28285074	8	8	9	8.3
Galilee	018002350500	-90.59800414	46.28819891	8	10	12	10.0
Galilee	018003530100	-90.58625897	46.27859412	8	11	12	10.3
Galilee	018003520500	-90.58847316	46.2782068	9	9	11	9.7
Galilee	018002210700	-90.5880862	46.28676291	9	10	11	10.0

Table C.3 continued…

Lake	Parcel_ID	LONGITUDE	LATITUDE	Riparian	Bank	Littoral	Avg. Score
Galilee	018002350800	-90.60116185	46.28808047	9	10	12	10.3
Galilee	018003450100*	-90.60031493	46.27981762	10	9	9	9.3
Galilee	018003521000	-90.5907891	46.28047381	10	9	10	9.7
Galilee	018003450700	-90.59607329	46.28097563	10	10	10	10.0
Galilee	018002350400	-90.59694069	46.28805658	10	9	11	10.0
Galilee	018003520600	-90.58949985	46.27868093	10	10	12	10.7
Galilee	018003540700	-90.58323253	46.28160008	10	11	12	11.0
Galilee	018003540900	-90.58091405	46.2809319	10	11	12	11.0
Galilee	018002351000	-90.59233599	46.28797991	10	12	12	11.3
Galilee	018003530200	-90.58504888	46.28018006	11	10	8	9.7
Galilee	018003521600	-90.59171017	46.28078651	11	11	11	11.0
Galilee	018003540100	-90.58312347	46.28369619	11	10	12	11.0
Galilee	018002350700	-90.60035041	46.28825082	11	12	12	11.7
Galilee	018002350200	-90.59459301	46.288237	11	12	12	11.7
Galilee	018002210800	-90.5876863	46.28682536	11	12	12	11.7
Galilee	018003540200	-90.58324625	46.28314204	11	12	12	11.7
Galilee	018002350600	-90.59933821	46.28831153	12	11	12	11.7
Galilee	018002210100	-90.58825273	46.28961561	12	12	12	12.0
Galilee	018002350900	-90.60190002	46.287868	12	12	12	12.0
Galilee	018002351100	-90.59303045	46.28817779	12	12	12	12.0
Galilee	018002220000	-90.5841519	46.28631714	12	12	12	12.0
Galilee	018002210300	-90.59109062	46.28732211	12	12	12	12.0
Galilee	018002210400	-90.5899352	46.28671888	12	12	12	12.0
Galilee	018003440300	-90.60296208	46.28334015	12	12	12	12.0
Galilee	018003450200	-90.59893739	46.28204976	12	12	12	12.0
Galilee	018003450901	-90.59261158	46.28099736	12	12	12	12.0
Galilee	018003521700	-90.59205184	46.28080861	12	12	12	12.0
Galilee	018003520900	-90.590605	46.28039154	12	12	12	12.0
Galilee	018003522100	-90.59038037	46.28029714	12	12	12	12.0
Galilee	018002351200	-90.59625934	46.28847464	12	12	12	12.0
Meder	018003220600	-90.64574049	46.28024649	2	2	5	3.0
Meder	018003220400	-90.64469979	46.27949853	3	4	4	3.7
Meder	018003220500	-90.64521273	46.2795007	3	3	5	3.7
Meder	018003250300	-90.64882363	46.27250502	3	3	5	3.7
Meder	018003221200	-90.64638419	46.27941146	3	4	5	4.0
Meder	018003221100	-90.64644846	46.27918543	3	4	5	4.0
Meder	018003220300	-90.64440119	46.27948905	4	4	4	4.0
Meder	018003220700	-90.645993	46.27834195	2	4	8	4.7
Meder	018003250400	-90.65006832	46.27225929	3	4	8	5.0
Meder	018003221300	-90.64635644	46.27977885	5	3	8	5.3
Meder	018003220100	-90.64360313	46.27951017	5	5	8	6.0
Meder	018003260200	-90.64854982	46.27103282	5	5	8	6.0
Meder	018003240200*	-90.65077402	46.27666636	6	6	7	6.3
Meder	018003280100*	-90.64101077	46.27678951	7	6	6	6.3
Meder	018003260300	-90.64822761	46.27111819	7	4	8	6.3

Table C.3 continued…

Lake	Parcel_ID	LONGITUDE	LATITUDE	Riparian	Bank	Littoral	Avg. Score
Meder	018003280300*	-90.6409367	46.27584472	8	4	7	6.3
Meder	018003250600	-90.64951169	46.27105079	7	5	8	6.7
Meder	018003240300*	-90.65125126	46.27563543	7	7	7	7.0
Meder	018003240100*	-90.6519724	46.27478529	6	7	9	7.3
Meder	018003240400*	-90.65129959	46.27391491	7	6	9	7.3
Meder	018003260100*	-90.64595158	46.27227708	9	6	7	7.3
Meder	018003221000	-90.64639947	46.27899155	9	6	8	7.7
Meder	018003280200*	-90.64094044	46.27448924	10	6	7	7.7
Meder	018003260400	-90.64777497	46.27108482	10	5	8	7.7
Meder	018003221400*	-90.64706905	46.28049586	9	7	8	8.0
Meder	018003220200	-90.64406082	46.27942526	9	7	8	8.0
Meder	018003290000*	-90.64101445	46.27182389	11	6	7	8.0
Meder	018003250100*	-90.65176509	46.27277213	8	8	9	8.3
Meder	018003190000*	-90.65158783	46.27909066	9	9	7	8.3
Meder	018003220800	-90.64621496	46.27869706	9	8	9	8.7
Meder	018003250500	-90.6507096	46.27216532	9	9	9	9.0
Meder	018003150000*	-90.64089438	46.27905051	10	9	8	9.0
Long	018004050200	-90.64888905	46.26382571	4	7	8	6.3
Long	018004040600	-90.65000087	46.26397182	6	6	9	7.0
Long	018004400300	-90.64087301	46.25406925	6	8	10	8.0
Long	018004040100	-90.65168552	46.26507991	7	7	7	7.0
Long	018004400600	-90.64283217	46.25392662	7	9	7	7.7
Long	018004110100	-90.64091243	46.26148687	7	7	9	7.7
Long	018004040300	-90.65236473	46.26287804	7	7	11	8.3
Long	018004040200	-90.65181868	46.26351775	7	10	11	9.3
Long	018004120300	-90.63705673	46.25769915	8	9	10	9.0
Long	018004400500	-90.64193665	46.25397422	8	8	11	9.0
Long	018004020000	-90.65039509	46.25681056	9	9	10	9.3
Long	018004120600	-90.637136	46.25700739	9	10	10	9.7
Long	018004400700	-90.64372249	46.25404978	10	9	11	10.0
Long	018004120700	-90.63716256	46.25677113	10	11	11	10.7
Long	018004400400	-90.64126734	46.25403867	11	11	12	11.3
Long	018004390000	-90.64503044	46.25173388	12	12	12	12.0
Long	018004050100	-90.6461147	46.26468315	12	12	12	12.0
Long	018004060000	-90.64495687	46.2620325	12	12	12	12.0
Long	018004120100	-90.63737774	46.25895929	12	12	12	12.0
Long	018004120200	-90.63681495	46.25854792	12	12	12	12.0
Long	018004400200	-90.64028173	46.25416691	12	12	12	12.0
Long	018004120500	-90.6369764	46.25621044	12	12	12	12.0
Long	018004030000	-90.65249566	46.26039314	12	12	12	12.0
Long	018004110200	-90.64123582	46.25953734	12	12	12	12.0
Maki	00200490000*	-90.5170278	46.29260923	12	12	12	12.0

Table C.3 continued…

Lake	Parcel_ID	LONGITUDE	LATITUDE	Riparian	Bank	Littoral	Avg. Score
Maki	00200510000*	-90.52657601	46.28981716	12	12	12	12.0
Maki	00200560000*	-90.53178953	46.29353507	12	12	12	12.0
Maki	00200630000*	-90.53178846	46.28992073	12	12	12	12.0
McCarthy	00200550000*	-90.53679099	46.29376777	6	12	12	10.0
McCarthy	00200640000*	-90.53690726	46.28989173	8	12	12	10.7
McCarthy	00200570000	-90.5459566	46.29597869	12	12	12	12.0
McCarthy	00200580000*	-90.54070061	46.29477273	12	12	12	12.0
McCarthy	00200590000*	-90.54257135	46.28970558	12	12	12	12.0
Upson	00201490000*	-90.43437255	46.39221949	12	12	12	12.0
O'Brien	01002220000*	-90.39554039	46.30356572	12	12	12	12.0
O'Brien	01002240000*	-90.40093832	46.30005974	12	12	12	12.0
O'Brien	01002250000*	-90.39706817	46.30033252	12	12	12	12.0
O'Brien	01003600000*	-90.39490224	46.29594161	12	12	12	12.0
O'Brien	01003610000*	-90.40188514	46.29792988	11	12	12	12.0
O'Brien	01003620000*	-90.40113316	46.29254667	12	12	12	12.0
O'Brien	01003630000	-90.39567769	46.29279493	12	12	12	12.0
Caroline	018003780000*	-90.55975914	46.26795652	10	12	12	11.3
Caroline	00200760000*	-90.54787165	46.27592005	12	12	12	12.0
Caroline	00200770000*	-90.54819065	46.27193024	12	12	12	12.0
Caroline	018003670000*	-90.55404175	46.27867384	12	12	12	12.0
Caroline	018003690000*	-90.55968929	46.27250213	12	12	12	12.0
Caroline	018003700000	-90.55194481	46.27082211	12	12	12	12.0
Caroline	018003770000*	-90.55381433	46.26805976	12	12	12	12.0

Coarse Woody Habitat

Coarse woody habitat (CWH) was surveyed in each lake following WDNR protocols (WDNR, 2016). The protocol involves counting only large wood, defined as being greater than 4 inches in diameter and 5 feet in length, and is in water less than 2 feet deep. The piece of wood must have a 4 inch diameter somewhere along its length, but the widest point may be deeper than 2 feet. The sheet shown in Figure C.7 was used to collect CWH data.

CWH was greatest around East Twin, West Twin, O'Brien, and Upson Lakes, ranging from 191 to 470 pieces per kilometer of shoreline (Table C.4, Figure C.8). The remaining lakes all had CWH frequencies less than 100 pieces per kilometer of shoreline, with a low of 14 in Caroline Lake. The frequency of CWH was generally greater on less developed lakes (Figure C.8). However, not all lakes, even undeveloped ones, will automatically have a lot of CWH, particularly if shoreline areas cannot support the growth of larger diameter trees. This is the case along many undeveloped shorelines in the Penokee lakes with marsh and bog areas that are more conducive to shrub growth. Despite this, the CWH survey data provide useful information about lakes where fish and invertebrate habitat could be improved by the introduction of course wood through tree drops, log additions known as "fish stick" projects, and promotion and management for larger tree species in appropriate shoreline areas to provide a future source of large wood to the lake ecosystems.

Figure C.7. Coarse woody habitat assessment field datasheet.

Mary Griggs Burke Center for Freshwater Innovation, Northland College
Lake Habitat Assessment: Coarse Woody Habitat Inventory

Date_____________ Lake Name_____________________________ WBIC_____________________
Observers______________________ GPS #/Lowrance ID: _________ Secchi Depth_________(ft)
Present water level is.......the High Water Mark: _____ Below ______ At ______ Above

ID	Branch	Touch Shore	In Water	GPS	ID	Branch	Touch Shore	In Water	GPS	ID	Branch	Touch Shore	In Water	GPS	ID	Branch	Touch Shore	In Water	GPS
1					41					81					121				
2					42					82					122				
3					43					83					123				
4					44					84					124				
5					45					85					125				
6					46					86					126				
7					47					87					127				
8					48					88					128				
9					49					89					129				
10					50					90					130				
11					51					91					131				
12					52					92					132				
13					53					93					133				
14					54					94					134				
15					55					95					135				
16					56					96					136				
17					57					97					137				
18					58					98					138				
19					59					99					139				
20					60					100					140				
21					61					101					141				
21					62					102					142				
23					63					103					143				
24					64					104					144				
25					65					105					145				
26					66					106					146				
27					67					107					147				
28					68					108					148				
29					69					109					149				
30					70					110					150				
31					71					111					151				
32					72					112					152				
33					73					113					153				
34					74					114					154				
35					75					115					155				
36					76					116					156				
37					77					117					157				
38					78					118					158				
39					79					119					159				
40					80					120					160				

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Table C.4. Survey data for coarse woody habitat (CWH) greater than 4 inches in diameter and 5 feet in length, and in water less than 2 feet deep around each of the eleven Penokee Lakes.

Lake	CWH (count)	Shoreline (mi)	Shoreline (km)	CWH/mi shoreline	CWH/km shoreline
East Twin	255	0.83	1.3	307	191
West Twin	537	1.4	2.3	384	238
Eureka	160	1.2	1.9	133	83
Galilee	127	2.9	4.7	44	27
Meder	114	2.2	3.5	52	32
Long	213	2	3.2	107	66
Maki	86	0.96	1.5	90	56
McCarthy	175	1.14	1.8	154	95
Upson	863	1.14	1.8	757	470
O'Brien	1649	2.34	3.8	705	438
Caroline	51	2.3	3.7	22	14

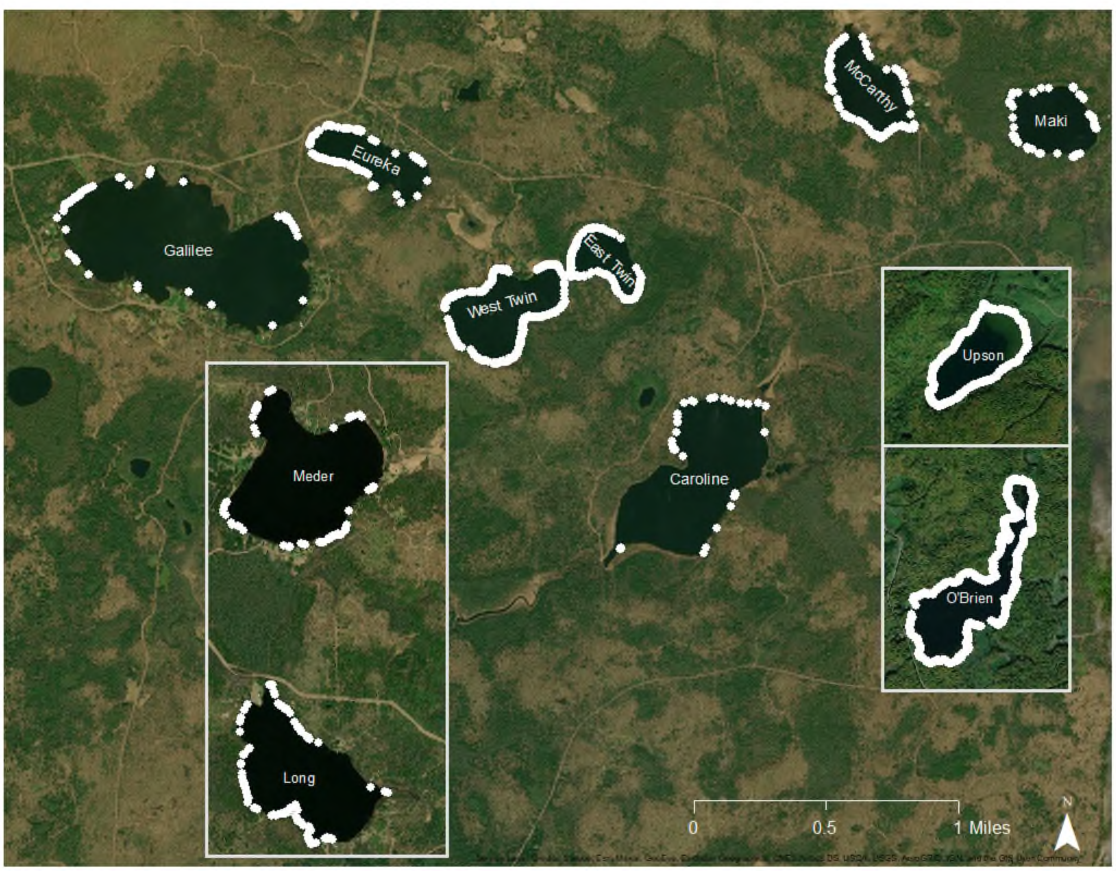

Figure C.8. Location of coarse woody habitat greater than 4 inches in diameter and 5 feet in length, and in water less than 2 feet deep around each of the eleven Penokee Lakes.

Appendix D – Fish Community Assessment

Prior to 2018, little was known about fish communities in the Penokee Lakes aside from game fish and juvenile recruitment surveys conducted by the Wisconsin Department of Natural Resources (WDNR) and Great Lakes Indian Fish and Wildlife Commission (GLIFWC) on lakes with known walleye (ogaa) populations (Meder Lake and Lake Galilee). In 2018, WDNR fisheries staff collaborated with researchers at the Mary Griggs Burke Center for Freshwater Innovation (Burke Center) to conduct the broadest survey of fish communities in the Penokee Lakes to date. The Burke Center used fyke nets to target all age ranges, including, younger, smaller fish. The WDNR used electrofishing techniques to target the adult fish community.

Methods

Fyke Netting
In June of 2018, researchers at the Mary Griggs Burke Center for Freshwater Innovation surveyed the fish communities of five Penokee Lakes: Meder, Galilee, West Twin, East Twin, and Caroline. In each lake, three fyke nets were set in the emergent vegetation zone and three in the floating vegetation zone (six nets total). The cod end was tied above the water level to allow any captured turtles to breathe. Nets were left overnight and retrieved in the morning. Each net-night was approximately nineteen to twenty-four hours. Fyke nets were emptied into an aerated water bucket. Each fish was identified to species and the total length of each fish was measured. Fish were then released back into the lake. A total of 30 nets were set for one net-night each.

Electrofishing
Electrofishing surveys were conducted in O'Brien, Long, Eureka, and Caroline Lakes by the WDNR in late spring of 2018. These surveys were designed to assess bass and panfish populations. A similar survey was conducted by WDNR on Upson Lake in 2011, so it was not surveyed in 2018.

The WDNR and/or GLIFWC completed adult walleye population estimates during the spring spawning period in Lake Galilee in 2014 and 2019 (mark-recapture surveys that provide absolute adult densities). In 2015, the WDNR conducted an early-spring electrofishing survey targeting walleye and northern pike populations, and a late-spring electrofishing survey to assess bass and panfish populations in Meder Lake. Juvenile walleye surveys were completed in both Lake Galilee and Meder Lake during multiple fall seasons, with the purpose of assessing young walleye recruitment over time. In total, seven of the eleven Penokee Lakes (all lakes with public boat launches) had at least one electrofishing survey conducted between 2011 and 2019.

For the purposes of comparing fish populations observed with the electrofishing surveys in the Penokee Lakes with fish populations in other regional lakes, each lake was classified based on established physical, limnological, and biological criteria (Rypel *et al.,* 2019). Caroline, Eureka, Long, O'Brien, and Upson Lakes were classified as cool, clear, and simple (less than four sportfish groups present). Galilee and Meder were classified as cool, clear, and complex (4 or more sportfish groups present).

Catch-per-effort (CPE) was used to evaluate relative abundance and was measured as number of fish caught per mile. Size structure was evaluated using proportional stock density (PSD), which is a ratio (expressed as a percentage) of larger fish of "quality" length to the number of fish of stock-size length. The quality and stock lengths vary for each species. The CPE and PSD comparisons were based on standardized and comparable WDNR survey data from 2000-2020 for each respective metric and the classification determined for each type of lake (WDNR Fisheries Management Information System, June 2021).

Results and Discussion

Fyke Netting

During the fyke netting survey, 686 total fish were caught, with 220 caught in Lake Galilee, 133 in West Twin Lake, 132 in Meder Lake, 101 in East Twin Lake, and 100 in Caroline Lake. Species richness ranged from 5 species in East Twin Lake to 10 species in Lake Galilee (Figure D.1). Centrarchids (sunfishes) made up 74% of all individuals, Cyprinids (minnows) made up 17%, Percids (mostly perch) made up 6%, and predator species made up only 2% (Figure D.2). More than half of all individuals were bluegill (Figure D.3) and spawning-sized bluegill were present in 25 of the 30 nets that were set. Thus, the results of the fyke netting are useful in terms of understanding species richness, particularly in East and West Twin Lake, where previous fish survey data are not available, but not comprehensive enough for assessing fish community metrics. It is recommended that a similar survey be repeated in the future, prior to the bluegill spawning season.

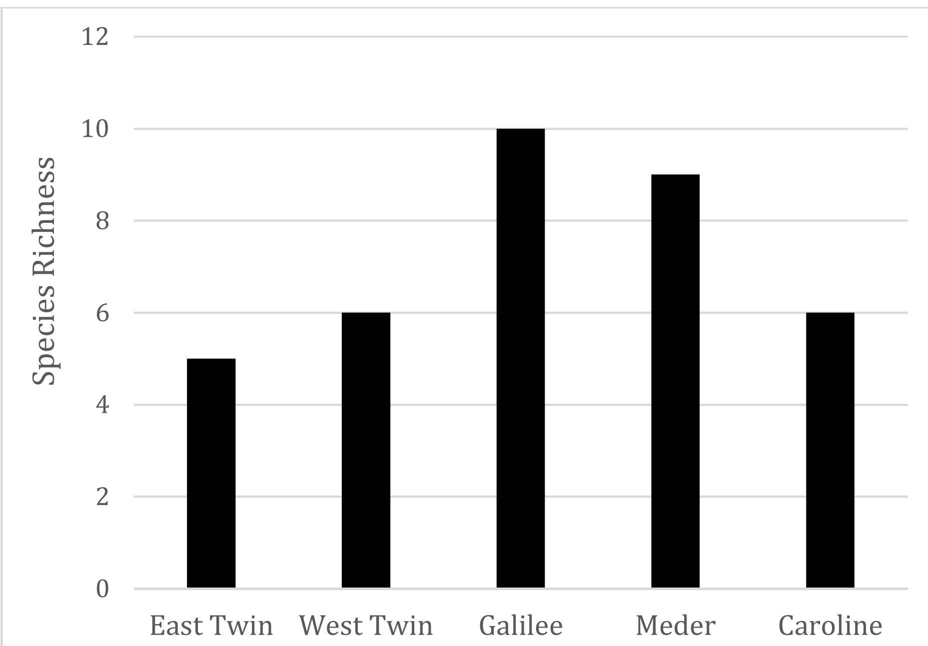

Figure D.1. Fish species richness by lake using the fyke net method.

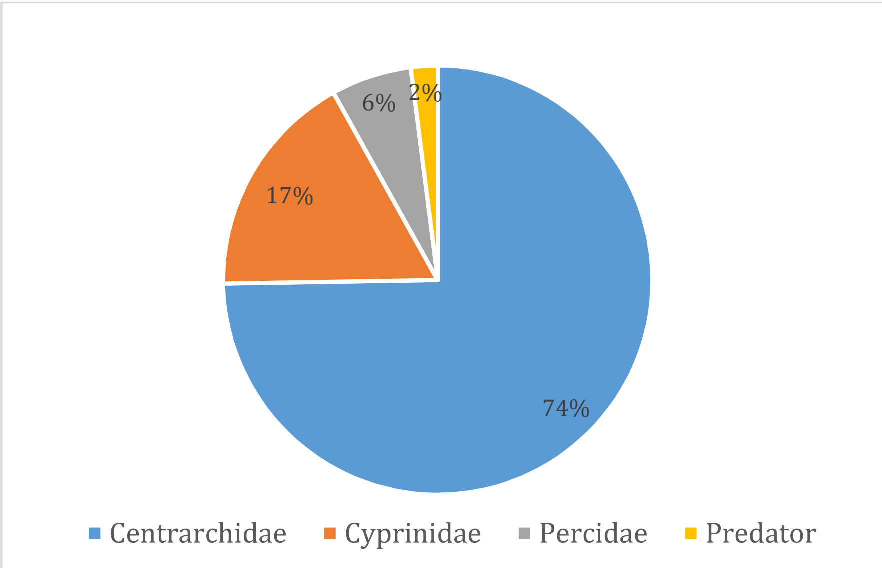

Figure D.3. Percentage of fish caught by family during fyke netting at five Penokee Lakes in June, 2018. Predator species were northern pike, walleye, and brown bullhead. Walleye were reported in the predator group rather than with Percidae.

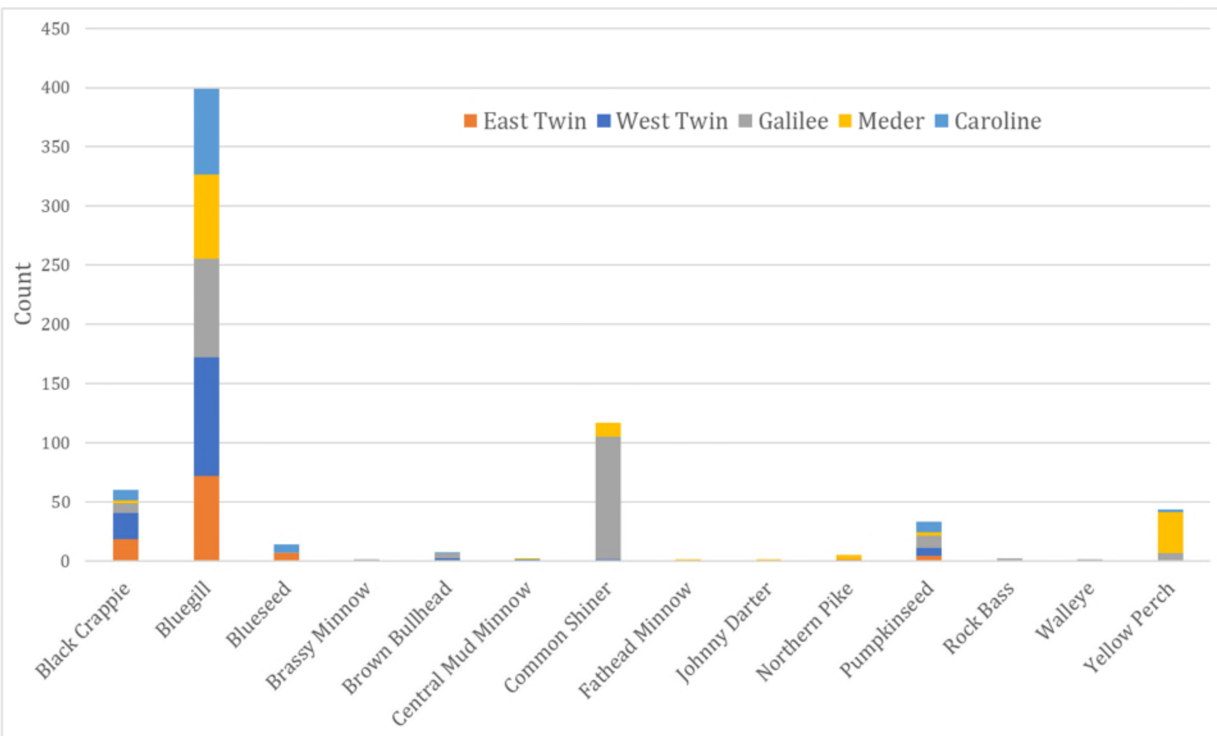

Figure D.3. Number of individuals caught by species during fyke netting in five Penokee Lakes. The stacked bar chart colors denote the number of individuals of each species caught in each lake.

Electrofishing

Species detected when combining results from all seven electrofishing surveys include: black crappie, bluegill, largemouth bass, northern pike, pumpkinseed, rock bass, smallmouth bass, walleye, and yellow perch. Yellow perch was most abundant throughout the Penokee Lakes, followed by bluegill and then black crappie (Figure D.4).

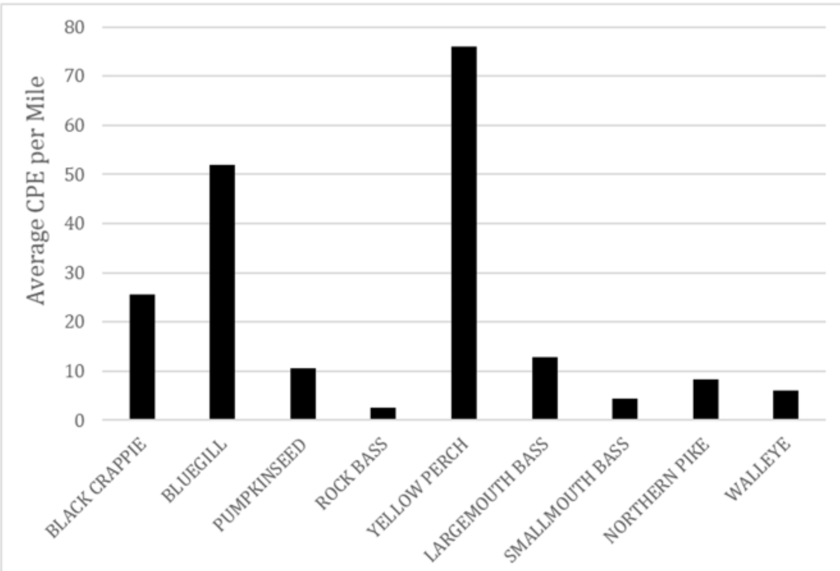

Figure D.4. Average catch per effort by species collected during electrofishing surveys of seven Penokee Lakes (Eureka, Galilee, Meder, Long, Upson, O'Brien, and Caroline).

The CPE and PSD values for the most recent survey year in each lake are listed in Tables D.1 and D.2. Often but not always, lakes with low CPE for a species exhibited high PSD for the same species.

Table D.1. Catch-per-effort (CPE) values (in fish per mile) from most recent electrofishing survey year. 50th percentile values for CPE from simple (in *italics*) and complex lakes are derived from Wisconsin Department of Natural Resources fisheries data (2000-2020). "ND" indicates the species was not detected in the given lake.

Species	*Eureka*	*Long*	*Upson*	*O'Brien*	*Caroline*	Galilee	Meder	*Simple 50th Percentile*	Complex 50th Percentile
Black Crappie	80	34	ND	8.0	38	21	20	7.0	7.3
Bluegill	275	46	39.2	106	44	15	4.0	75.6	104
Pumpkinseed	25	20	ND	8.0	12	3.0	ND	8.4	8.0
Rock Bass	ND	ND	1.7	2.0	ND	4.0	ND	2.0	10
Yellow Perch	145	236	24.2	ND	68	14	56	24	12.7
Largemouth Bass	15.5	1.9	68.3	2.04	5.7	3.3	2.3	15.5	13.5
Smallmouth Bass	ND	ND	ND	ND	ND	4.3	ND	0.56	4.9
Northern Pike	11.6	9.5	ND	ND	5.7	7.0	13.8	2.5	2.4
Walleye	ND	ND	ND	ND	ND	5.7	6.4	1.0	5.3

Table D.2. Proportional stock density (PSD) values (percentage of fish of quality length compared to the number of fish of stock length) from most recent survey year. 50th percentile values for CPE from simple (in *italics*) and complex lakes are derived from Wisconsin Department of Natural Resources fisheries data (2000-2020). "ND" indicates the species was not detected in the given lake. Cells with a PSD of "0" indicates that none of the individuals of the fish species captured in the given lake were above the quality size metric for that species.

Species	*Eureka*	*Long*	*Upson*	*O'Brien*	*Caroline*	Galilee	Meder	*Simple 50th Percentile*	Complex 50th Percentile
Black Crappie	31.3	66.7	ND	0	5.9	85.7	66.7	66.7	66.7
Bluegill	20	61.1	34.9	35.3	68.2	80	50	37.2	31.2
Pumpkinseed	20	66.7	ND	100	50	100	ND	66.7	50
Rock Bass	ND	ND	0	100	ND	25	ND	52.7	47.6
Yellow Perch	7.7	0	44.8	ND	0	0	50	0	0
Largemouth Bass	87.5	100	5.2	100	100	100	100	64.1	69.5
Smallmouth Bass	ND	ND	ND	ND	ND	84.6	ND	77.8	0
Northern Pike	0	17.4	ND	ND	91.7	0	37	37.0	20
Walleye	ND	ND	ND	ND	ND	100	77.8	35	39.3

Black crappie were detected in all surveyed lakes except Upson Lake. In the lakes with black crappie, CPE was greater than the 75th percentile in all lakes except O'Brien Lake, where CPE was slightly greater than the 50th percentile (Figure D.5). PSD fell between the 25th and 75th percentile in all lakes with black crappie except O'Brien and Caroline, where PSD was less than the 25th percentile (Figure D.6). Black crappie in Eureka, O'Brien, and Caroline Lakes were relatively abundant but small. Black crappie in Long, Galilee and Meder Lakes were abundant and moderate in size compared to other lakes in the region.

Bluegill were detected in all surveyed lakes. Bluegill CPE fell between the 25th and 75th percentile in all Penokee lakes except in Lake Galilee and Meder Lake, where bluegill CPE was less than the 25th percentile (Figure D.7). Bluegill PSD fell between the 25th and 75th percentile for all lakes except Caroline Lake and Lake Galilee, where bluegill PSD was greater than the 75th percentile (Figure D.8). Bluegill in Lake Galilee and Meder Lake were relatively large but not abundant. Bluegill in all other lakes that were surveyed were relatively similar in abundance and size structure compared to other lakes in the region.

Yellow perch were detected in all surveyed lakes except O'Brien Lake. Yellow perch CPE fell near to or greater than the 75thth percentile in Eureka, Long, Caroline, and Meder Lakes and was near the 50th percentile in Upson Lake and Lake Galilee (Figure D.9). Yellow perch PSD was greater than the 75th percentile in Eureka, O'Brien, Upson, and Meder Lakes and at the 50th percentile in all other lakes where yellow perch were detected (Figure D.10). In the surveyed Penokee Lakes where they were detected, yellow perch were abundant and relatively large.

Largemouth bass were detected in all surveyed lakes. CPE for largemouth bass fell near to or less than the 25th percentile for northern Wisconsin lakes for all lakes except Upson Lake (Figure D.11). Largemouth bass PSD was greater than the 75th percentile in all lakes except Upson Lake (Figure

D.12). Largemouth bass in Upson Lake were abundant but small. Largemouth bass in all other Penokee Lakes that were surveyed were relatively large but not abundant.

Northern pike were detected in all surveyed lakes except Upson and O'Brien. Northern pike CPE was greater than the 75th percentile in all lakes where they were detected (Figure D.13). Northern pike PSD was greater than the 75% percentile in Caroline Lake, near the 50th percentile in Long and Meder Lakes, and below the 25% percentile in Eureka Lake and Lake Galilee (Figure D.14). Northern pike were abundant in all lakes they were detected. In Caroline Lake, northern pike were also large in size compared to other regional lakes. Northern pike were moderate in size in Long and Meder Lakes and small in size in Eureka Lake and Lake Galilee compared to other regional lakes.

Walleye were only detected in Lake Galilee and Meder Lake. Spring electrofishing surveys targeting adult walleye populations revealed that CPE was slightly greater than the 50th percentile in both Lake Galilee and Meder Lake (Figure D.15). Walleye PSD was greater than the 75th percentile in Lake Galilee and slightly less than the 75th percentile in Meder Lake (Figure D.16). Walleye had a moderate relative abundance and large size structure relative to other lakes in the region. Most walleye that were caught were of quality size (>15" total length). Although the Lake Galilee adult walleye population in 2019 was at median levels when comparing relative abundance metrics (CPE; #/mile) to other northern Wisconsin lakes, it was below the regional target for adult densities (3.0/acre; more rigorous estimates derived from mark-recapture studies). The adult walleye population declined from 2.21 walleye per acre in 2014 to 0.69 walleye per acre in 2019 (Table D.3).

Fall juvenile walleye recruitment surveys were conducted in Lake Galilee in 9 non-consecutive years between 2001 and 2019 and in Meder Lake in 1999, 2014, and 2016 (Tables D.4 and D.5). Walleye age-0 year classes in Lake Galilee fluctuated from 0 to 18.6 fish per mile, meeting the standard target for quality recruitment of 15 fish per mile as established by GLIFWC and the WDNR (Ray, personal communication) in two out of nine survey years. Walleye age-0 year classes in Meder Lake ranged from 0 to 6.4 fish per mile, never meeting the recruitment standard (Figure D.17). Walleye age-1 year classes in Lake Galilee fluctuated from 0 to 5.9 fish per mile, only in 2003 meeting the recruitment standard of 5 fish per mile for yearlings as established by GLIFWC and the WDNR (Ray, personal communication). Walleye age-1 year classes in Meder Lake ranged from 1.8 to 16.4 fish per mile, falling below the recruitment standard in 2014 and 2016 and well above it in 1999 (Figure D.18).

Zach Lawson, Fisheries Biologist with WDNR provided the following interpretation of available data and recommendations related to ogaa (walleye) management in Lake Galilee and Meder Lake:

- Galilee and Meder have both shown that they have the capacity to produce walleye populations with quality size structures.
- Both Galilee and Meder currently support low-density walleye fisheries, although have supported higher density adult populations in the past.
- While walleye populations in both Galilee and Meder lakes have been supplemented with periodic stocking efforts, each system has also shown the capacity to produce year classes through natural reproduction.
- While both of these systems contain limited walleye spawning habitat and exhibit characteristics of struggling/transitional walleye fisheries (see Raabe *et al*. 2020), recent data suggest these systems may indeed support a low-moderate density walleye fishery.

Fish Stocking
Wisconsin DNR fish stocking records for the Penokee Lakes indicate that Lake Galilee was stocked with small fingerling walleyes five times between 1998 and 2010. Since 2014, Lake Galilee has been stocked four times with large fingerling walleye (most recently in 2020), once with large fathead minnows in 2017, and once with large fingerling muskellunge in 2018. Meder Lake has been stocked with small fingerling walleyes ten times since 1998 (most recently in 2019). The only other Penokee Lake covered under this management plan that has received stocked fish since 1972 is O'Brien Lake, which received large fingerling largemouth bass each year from 2012-2014. Fish stocking records are displayed in Table D.6.

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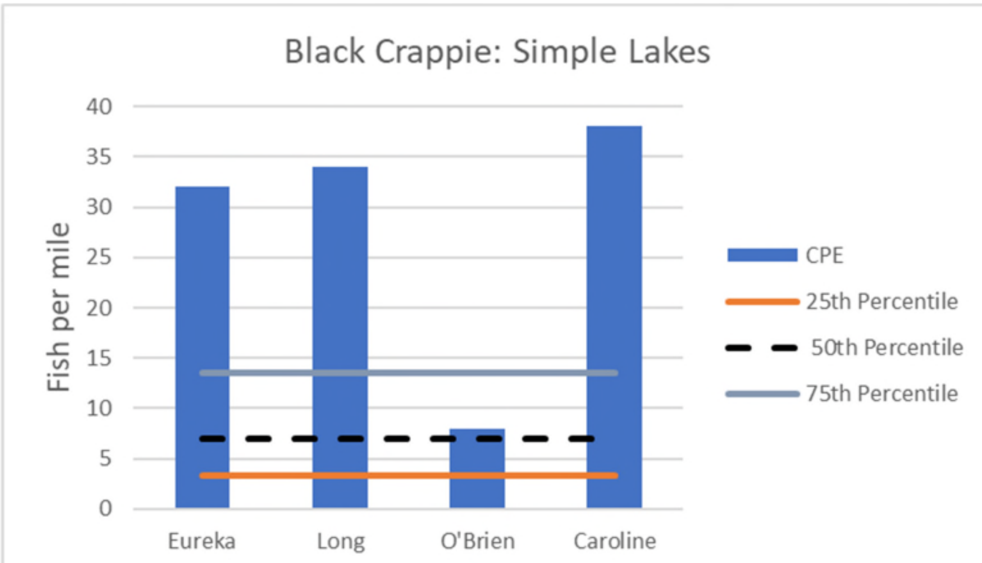

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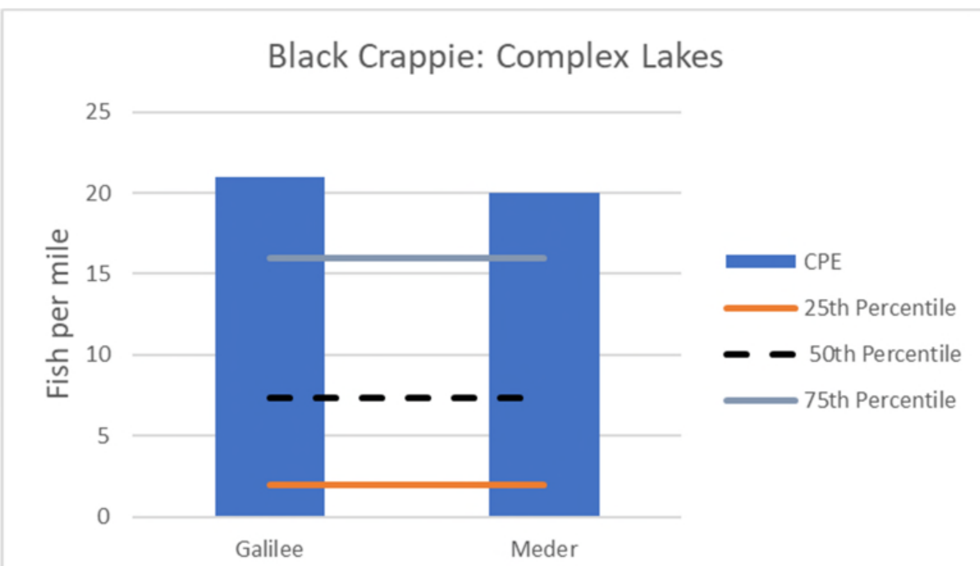
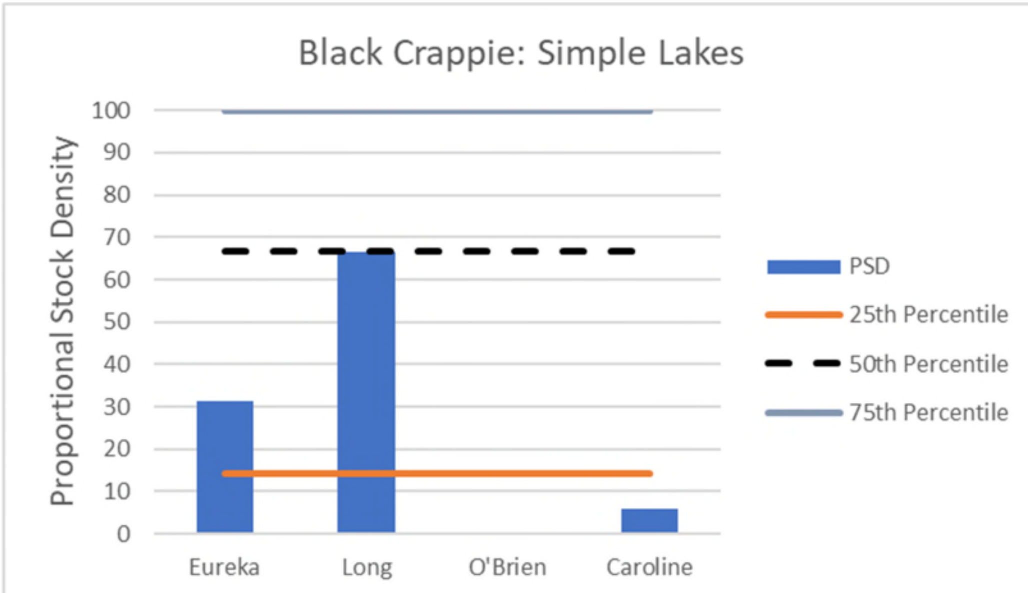


Figure D.5. Comparison of black crappie catch per effort (CPE; fish per mile) in the Penokee Lakes to regional black crappie CPE metrics in a) simple lakes and b) complex lakes. Data for this analysis was taken from each lake's most recent survey year: 2018 for Caroline Lake, 2018 for Eureka Lake, 2019 for Lake Galilee, 2018 for Long Lake, 2015 for Meder Lake, and 2011 for Upson Lake.



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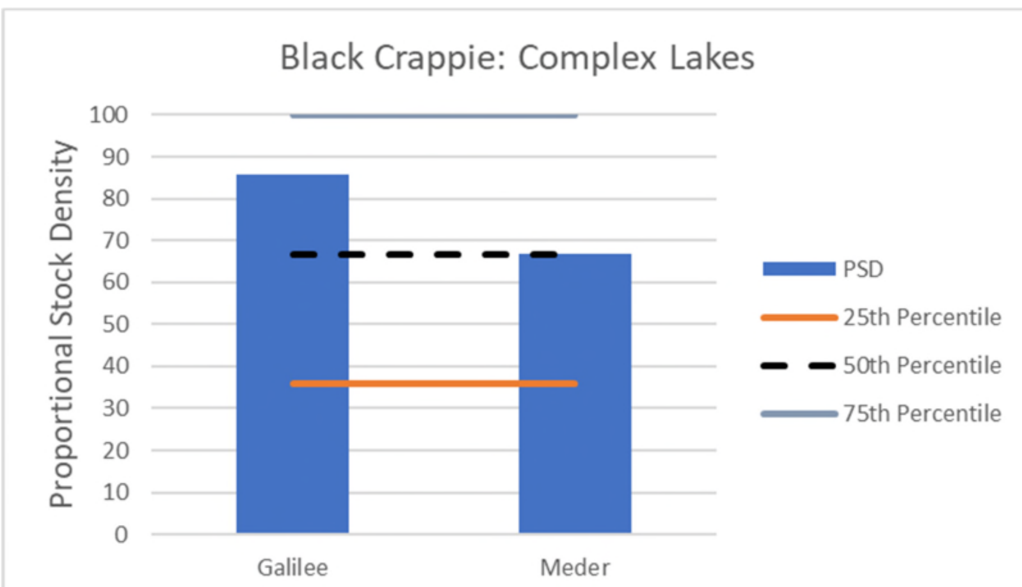

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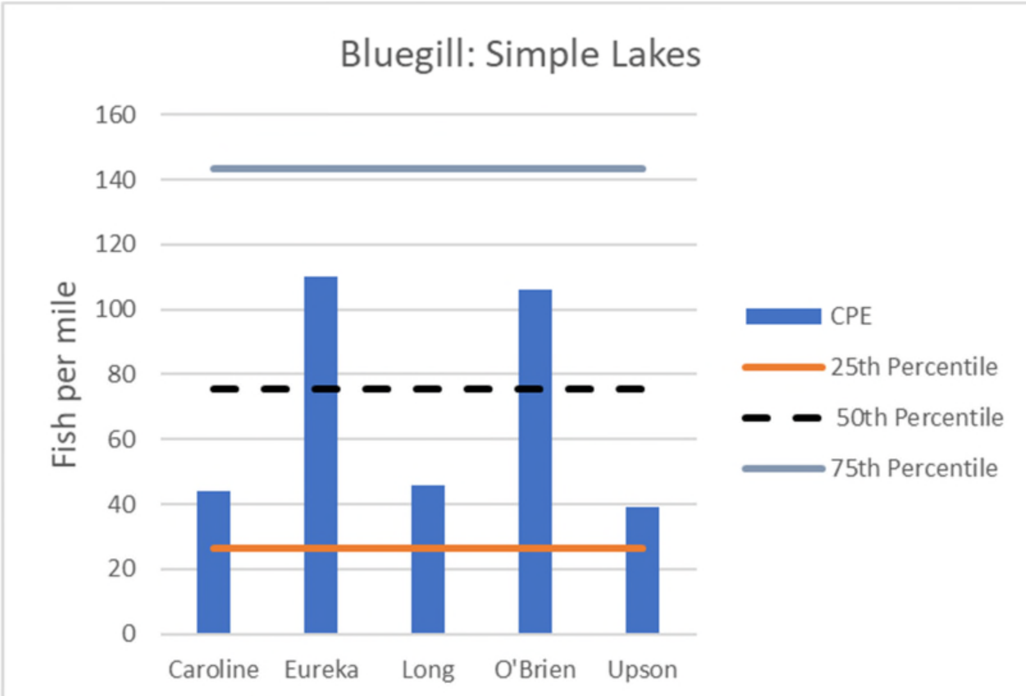
Figure D.6 Comparison of black crappie proportional stock density (PSD) in the Penokee Lakes to regional black crappie PSD metrics in a) simple lakes and b) complex lakes. Data for this analysis was taken from each lake's most recent survey year: 2018 for Caroline Lake, 2018 for Eureka Lake, 2019 for Lake Galilee, 2018 for Long Lake, 2015 for Meder Lake, and 2018 for O'Brien Lake.



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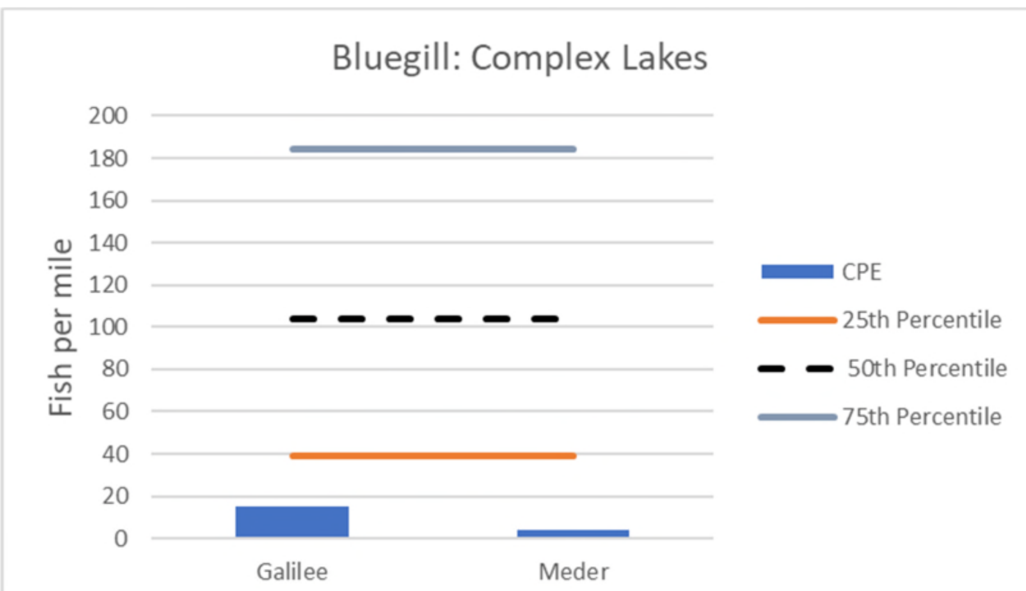

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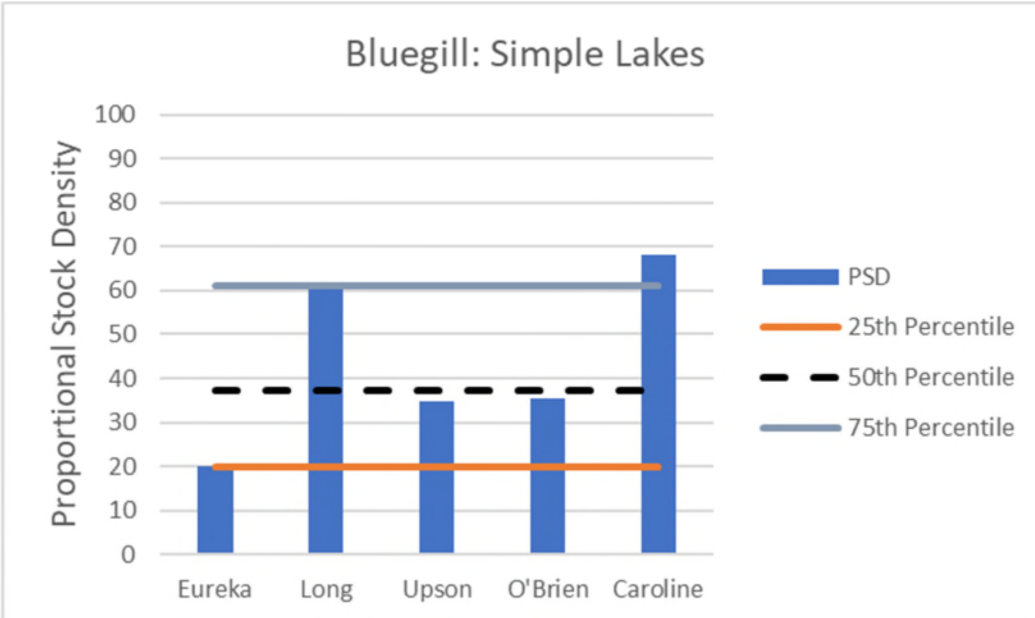
Figure D.7. Comparison of bluegill catch per effort (CPE; fish per mile) in the Penokee Lakes to regional bluegill CPE metrics in a) simple lakes and b) complex lakes. Data for this analysis was taken from each lake's most recent survey year: 2018 for Caroline Lake, 2018 for Eureka Lake, 2019 for Lake Galilee, 2018 for Long Lake, 2015 for Meder Lake, 2018 for O'Brien Lake, and 2011 for Upson Lake.



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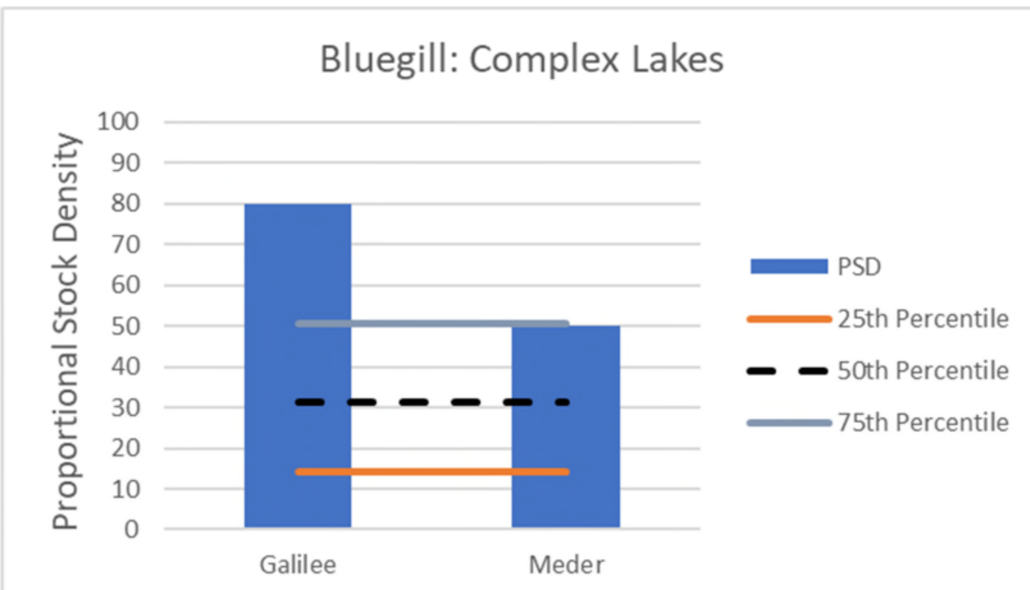

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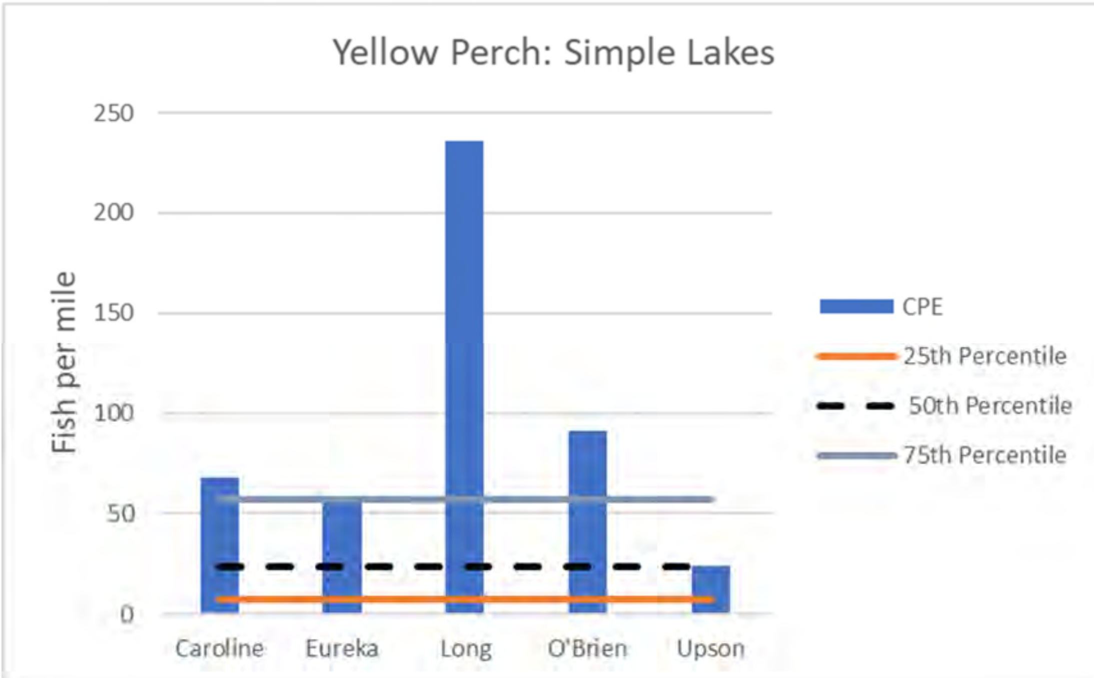
Figure D.8. Comparison of bluegill proportional stock density (PSD) in the Penokee Lakes to regional bluegill PSD metrics in a) simple lakes and b) complex lakes. Data for this analysis was taken from each lake's most recent survey year: 2018 for Caroline Lake, 2018 for Eureka Lake, 2019 for Lake Galilee, 2018 for Long Lake, 2015 for Meder Lake, 2018 for O'Brien Lake and 2011 for Upson Lake.



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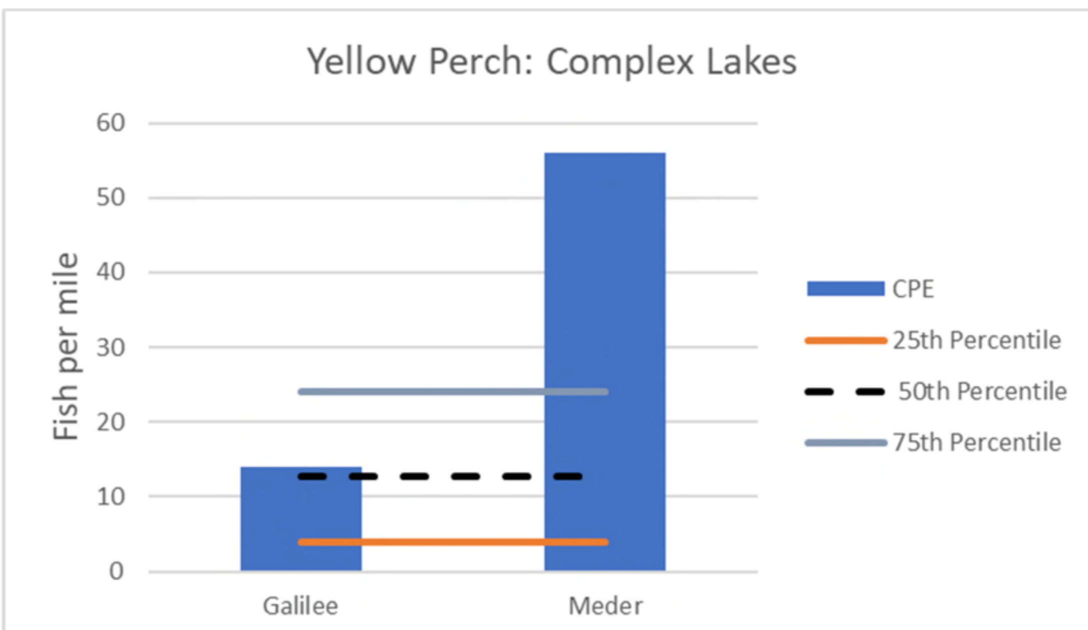

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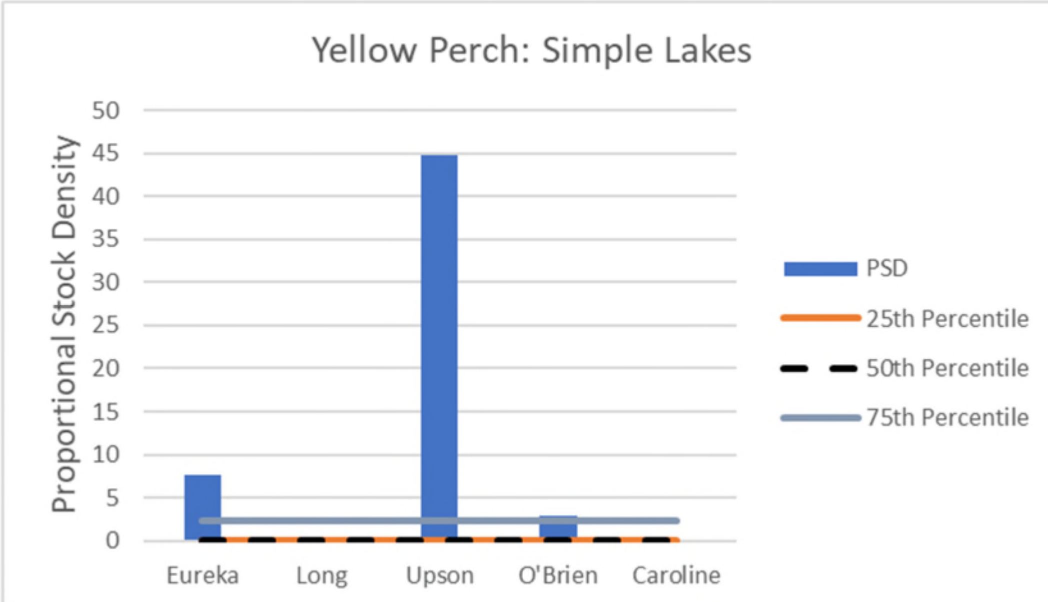
Figure D.9. Comparison of yellow perch catch per effort (CPE; fish per mile) in the Penokee Lakes to regional yellow perch CPE metrics in a) simple lakes and b) complex lakes. Data for this analysis was taken from each lake's most recent survey year: 2018 for Caroline Lake, 2018 for Eureka Lake, 2019 for Lake Galilee, 2018 for Long Lake, 2015 for Meder Lake, 2018 for O'Brien Lake, and 2011 for Upson Lake.



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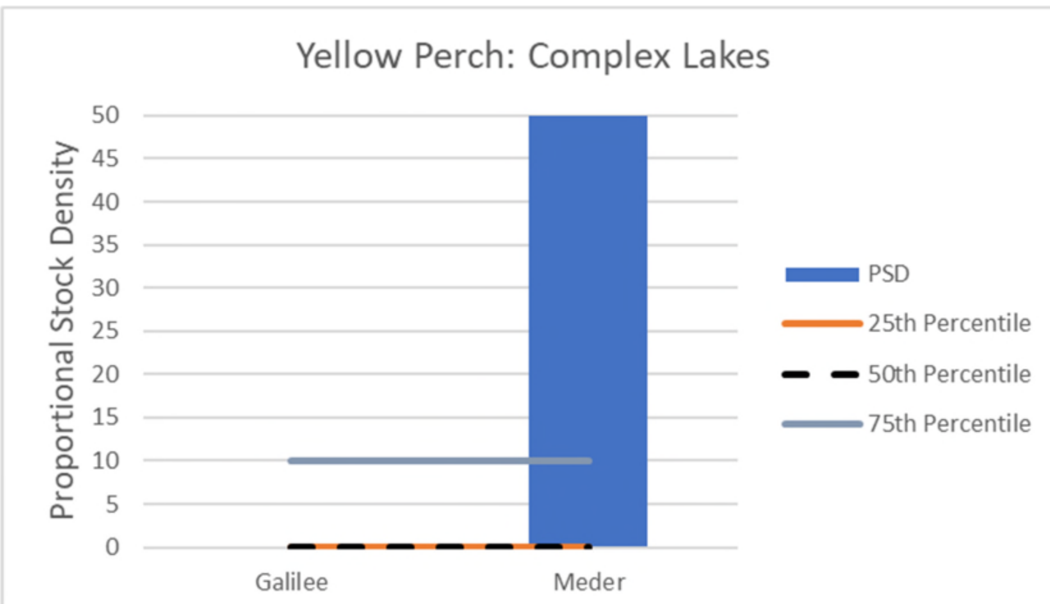

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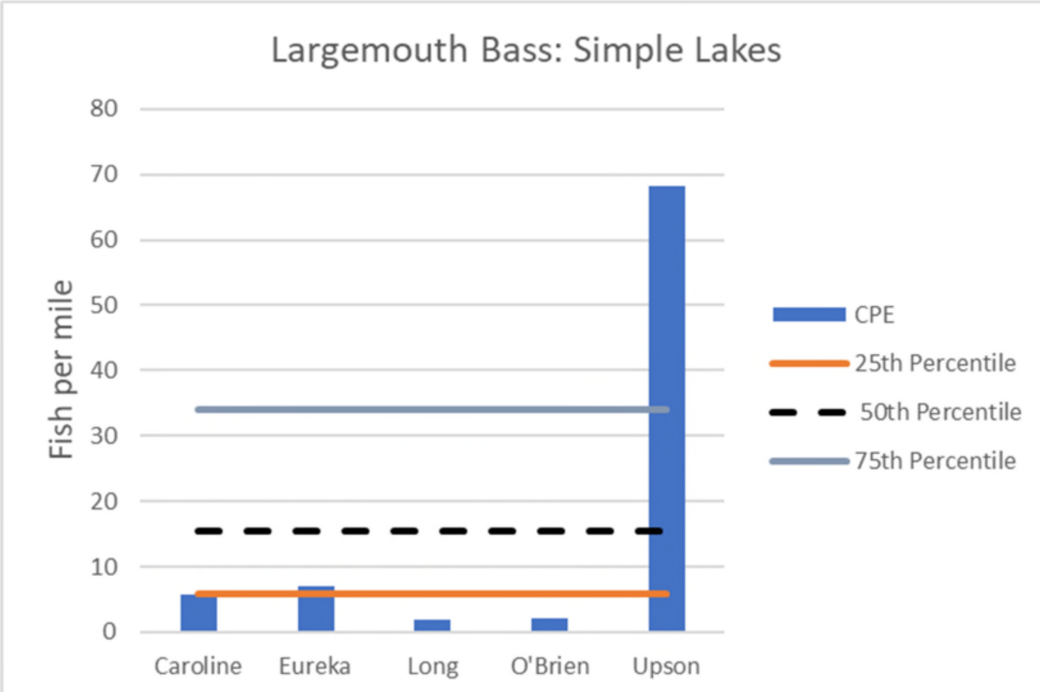
Figure D.10. Comparison of yellow perch proportional stock density (PSD) in the Penokee Lakes to regional yellow perch PSD metrics in a) simple lakes and b) complex lakes. The proportion scale goes from 0-50 instead of 0-100 to show percentile breakpoints more clearly. Data for this analysis was taken from each lake's most recent survey year: 2018 for Caroline Lake, 2018 for Eureka Lake, 2019 for Lake Galilee, 2018 for Long Lake, 2015 for Meder Lake, 2018 for O'Brien Lake and 2011 for Upson Lake.



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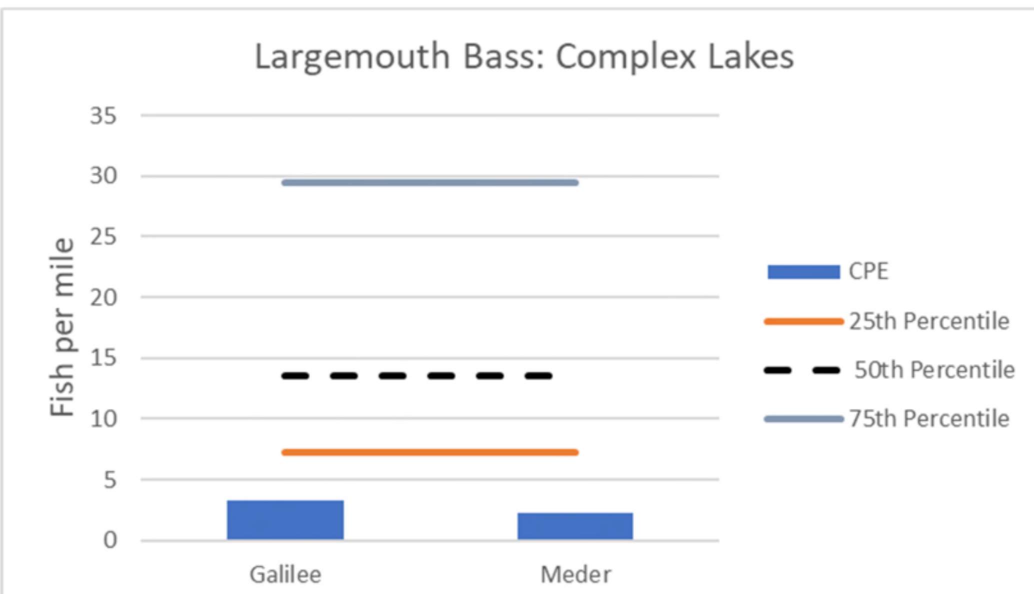

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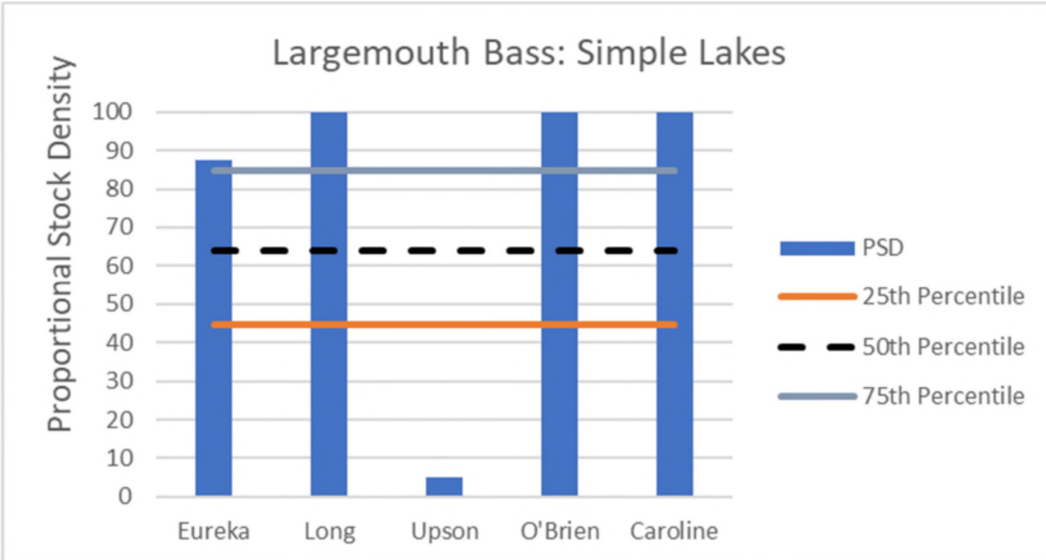
Figure D.11. Comparison of largemouth bass catch per effort (CPE; fish per mile) in the Penokee Lakes to regional largemouth bass CPE metrics in a) simple lakes and b) complex lakes (Rypel *et al.,* 2019). Data for this analysis was taken from each lake's most recent survey year: 2018 for Caroline Lake, 2018 for Eureka Lake, 2019 for Lake Galilee, 2018 for Long Lake, 2015 for Meder Lake, 2018 for O'Brien Lake, and 2011 for Upson Lake.



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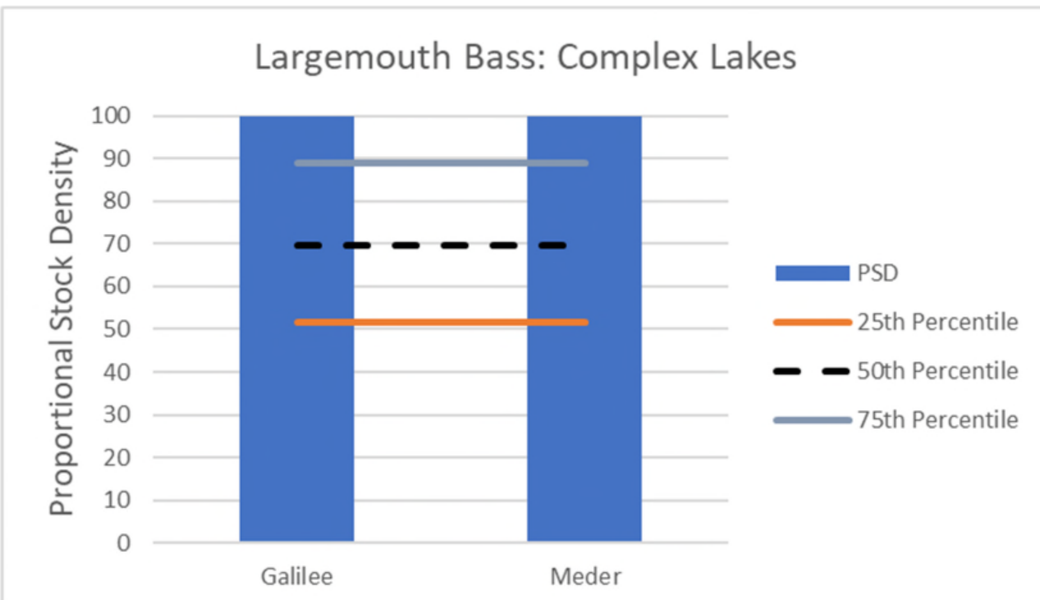

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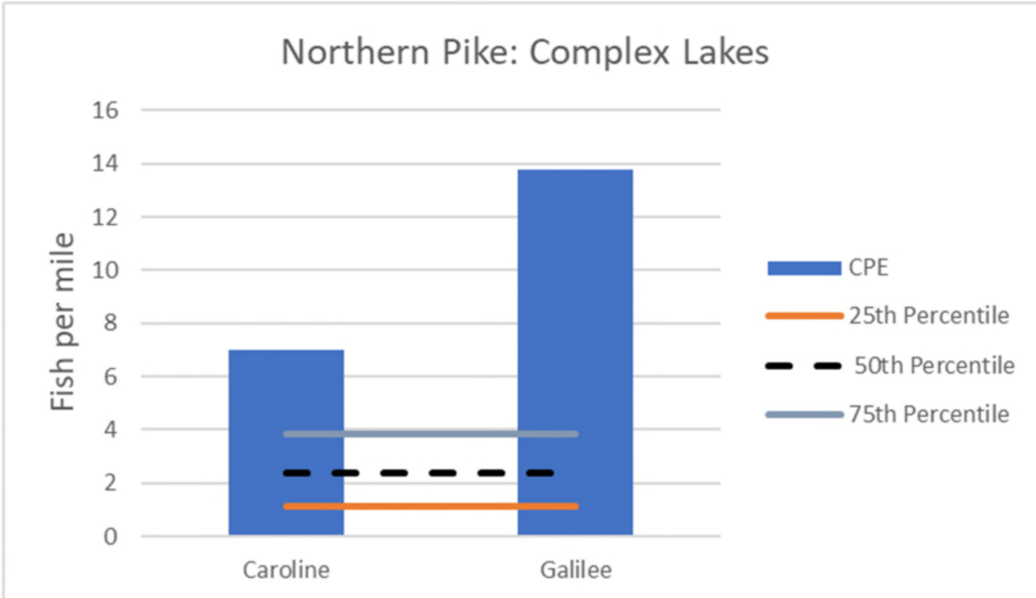
Figure D.12. Comparison of largemouth bass proportional stock density (PSD) in the Penokee Lakes to regional largemouth bass PSD metrics in a) simple lakes and b) complex lakes. Data for this analysis was taken from each lake's most recent survey year: 2018 for Caroline Lake, 2018 for Eureka Lake, 2019 for Lake Galilee, 2018 for Long Lake, 2015 for Meder Lake, 2018 for O'Brien Lake and 2011 for Upson Lake.



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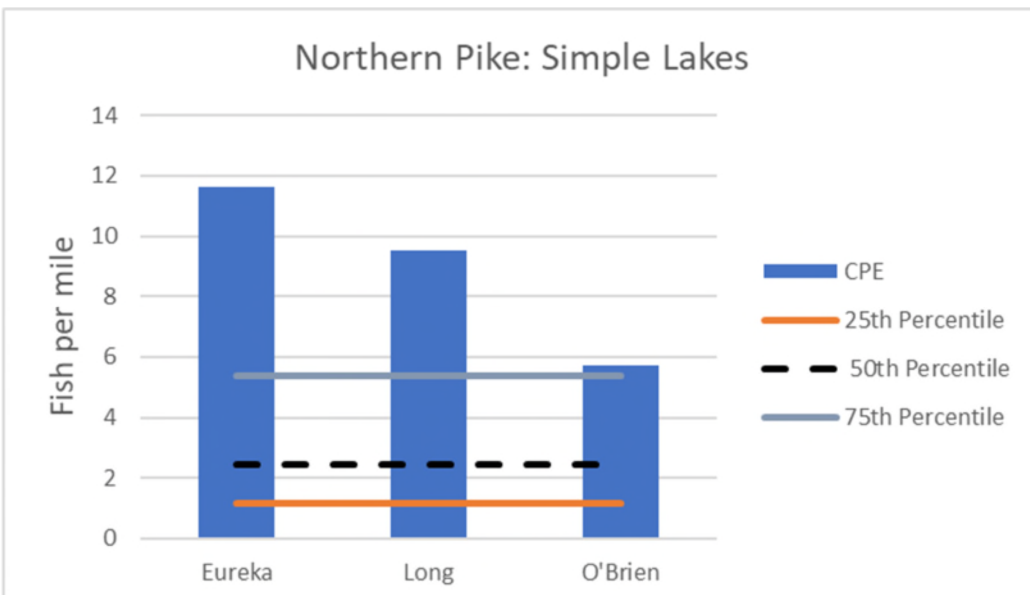

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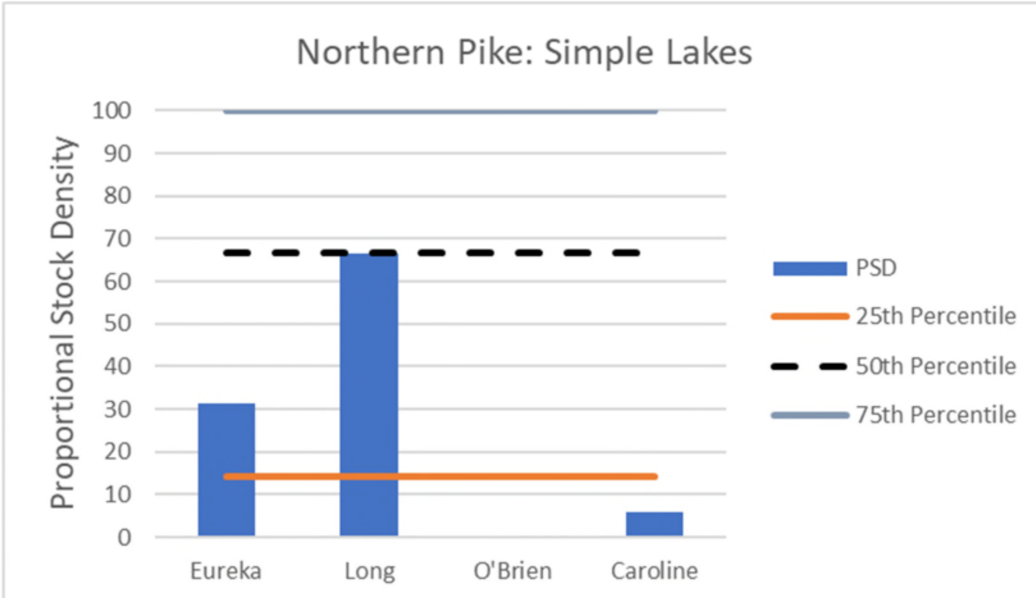
Figure D.13. Comparison of northern pike catch per effort (CPE; fish per mile) in the Penokee Lakes to regional northern pike CPE metrics in a) simple lakes and b) complex lakes (Rypel *et al.,* 2019). Data for this analysis was taken from each lake's most recent survey year: 2018 for Caroline Lake, 2018 for Eureka Lake, 2019 for Lake Galilee, 2018 for Long Lake, 2015 for Meder Lake, 2018 for O'Brien Lake, and 2011 for Upson Lake.



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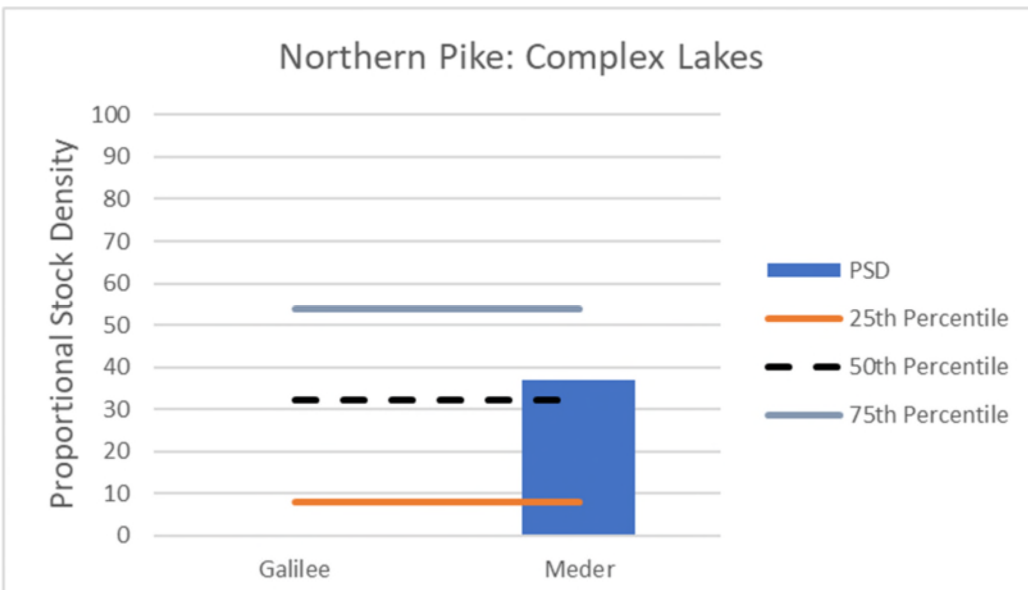

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Figure D.14. Comparison of northern pike proportional stock density (PSD) in the Penokee Lakes to regional northern pike PSD metrics in a) simple lakes and b) complex lakes. Data for this analysis was taken from each lake's most recent survey year: 2018 for Caroline Lake, 2018 for Eureka Lake, 2019 for Lake Galilee, 2018 for Long Lake, 2015 for Meder Lake, 2018 for O'Brien Lake and 2011 for Upson Lake.

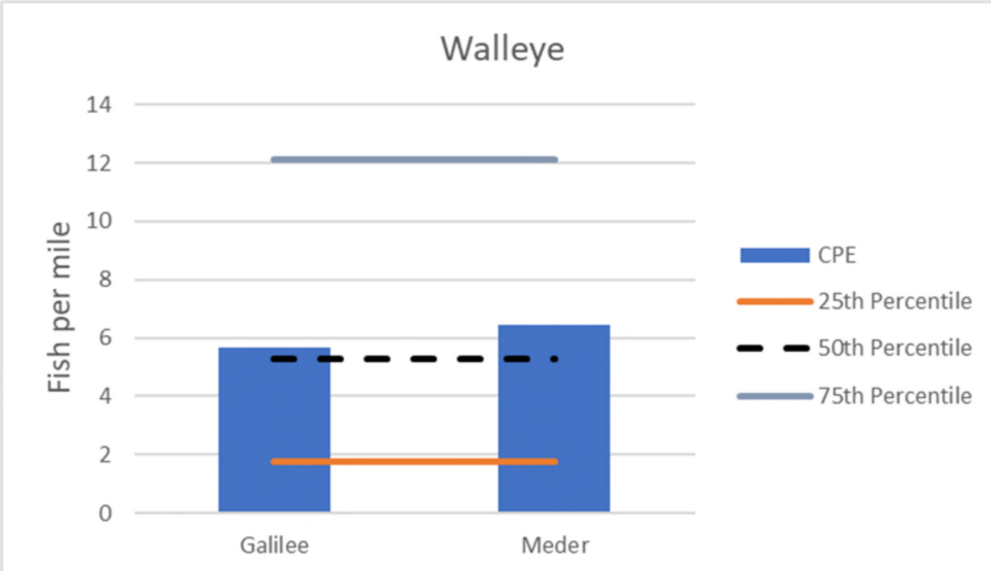

Figure D.15. Comparison of walleye catch per effort (CPE; fish per mile) in the Penokee Lakes to regional walleye CPE metrics. Data for this analysis was taken from each lake's most recent survey year: 2019 for Lake Galilee and 2015 for Meder Lake. The data shown are all size classes of walleye that were captured in each survey.

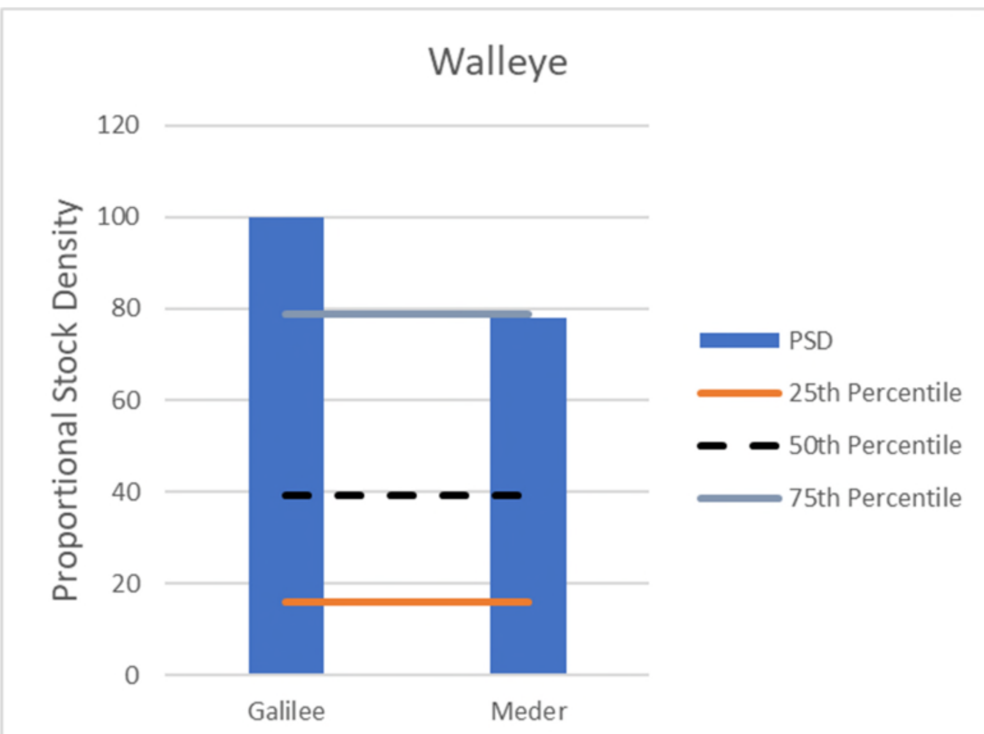

Figure D.16. Comparison of walleye proportion of stock density (PSD) in the Penokee Lakes to regional walleye PSD metrics. Data for this analysis was taken from each lake's most recent survey year: 2019 for Lake Galilee and 2015 for Meder Lake. The data shown are all size classes of walleye that were captured in each survey.

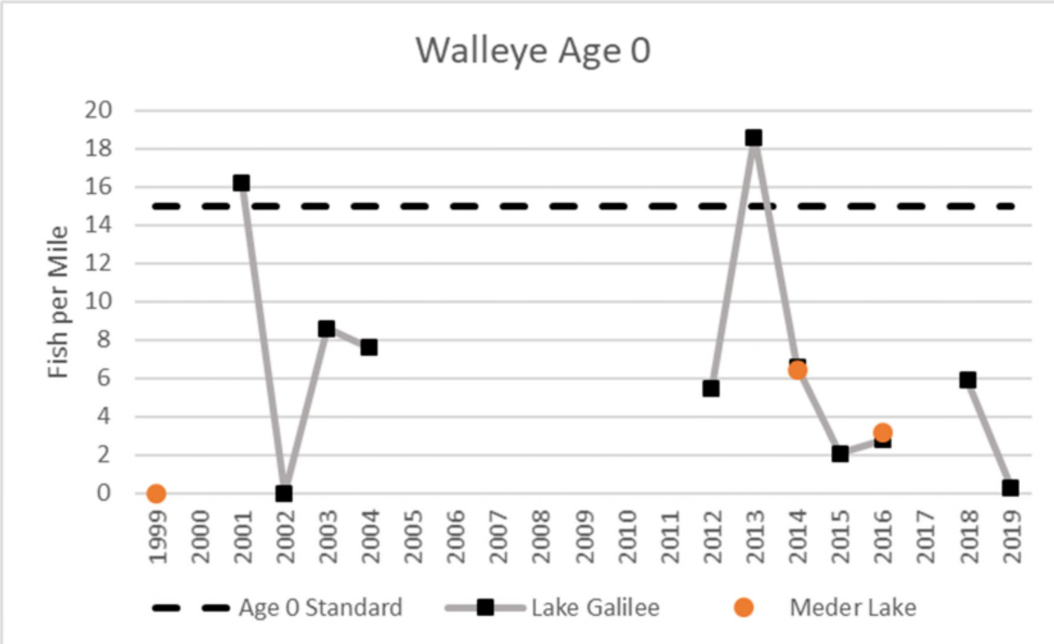

Figure D.17. Juvenile, Age-0 walleye catch per effort over time from fall recruitment electrofishing surveys in Lake Galilee and Meder Lake. The 15 fish per mile standard is utilized by the GLIFWC and WDNR as a goal for indicating healthy, naturally reproducing walleye populations in lakes (Ray, personal communication).

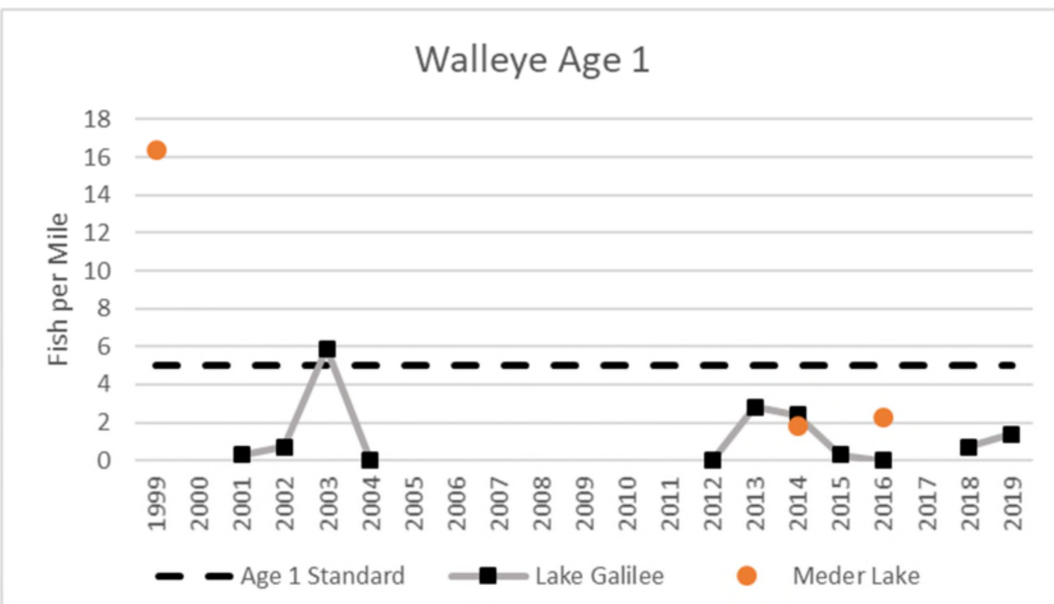

Figure D.18. Juvenile, Age-1 walleye catch per effort over time from fall recruitment electrofishing surveys in Lake Galilee and Meder Lake. The 5 fish per mile standard is utilized by the GLIFWC and WDNR as a goal for indicating healthy, naturally reproducing walleye populations in lakes (Ray, personal communication).

Table D.3. Adult walleye per acre from electrofishing surveys in Lake Galilee in 2014 and 2019 (Ray, personal communication).

Year	Lake Acres	Population Estimate	Adults/Acre
2014	213	471	2.2
2019	213	146	0.69

Table D.4. Juvenile walleye per mile in Lake Galilee from fall electrofishing surveys. Greater than 15 age-0 walleye per mile and/or 5 age-1 walleye per mile are ideal metrics used by GLIFWC and WDNR for evaluating healthy natural reproducing walleye population (Ray personal communication).

Year	Miles	Age-0 Walleye	Age-0/Mile	Age-1 Walleye	Age-1/Mile
2001	2.9	47	16	1	0.30
2002	2.9	0	0.0	2	0.70
2003	2.9	25	8.6	17	5.9
2004	2.9	22	7.6	0	0.00
2012	2.9	16	5.5	0	0.00
2013	2.9	54	19	8	2.8
2014	2.9	19	6.6	7	2.4
2015	2.9	6	2.1	1	0.30
2016	2.9	8	2.8	0	0.00
2018	2.9	17	5.9	2	0.70
2019	2.9	1	0.30	4	1.4

Table D.5. Juvenile walleye per mile in Meder Lake from fall electrofishing surveys. Greater than 15 age-0 walleye per mile and/or 5 age-1 walleye per mile are ideal metrics used by GLIFWC and WDNR for evaluating healthy natural reproducing walleye populations (Ray personal communication 2021).

Year	Miles	Age 0 Walleye	Age0/Mile	Age 1 Walleye	Age1/Mile
1999	2.2	0	0.00	36	16
2014	2.2	14	6.4	4	1.8
2016	2.2	7	3.2	5	2.3

Table D.6. Fish stocking records from WDNR for the Penokee Lakes (records received 8/10/2021; Lawson, WDNR).

Year	Waterbody Name	Species	Age Class	Stocking Date	Number Fish Stocked	Avg. Length
1998	LAKE GALILEE	WALLEYE	SMALL FINGERLING	1-Jun-98	10550	1.5
2004	LAKE GALILEE	WALLEYE	SMALL FINGERLING	22-Jul-04	13886	2.2
2005	LAKE GALILEE	WALLEYE	SMALL FINGERLING	16-Jun-05	11215	1.5
2006	LAKE GALILEE	WALLEYE	SMALL FINGERLING	9-Jun-06	9423	1.5
2010	LAKE GALILEE	WALLEYE	SMALL FINGERLING	10-Jun-10	7515	1.8
2014	LAKE GALILEE	WALLEYE	LARGE FINGERLING	10-Oct-14	3274	7.11
2016	LAKE GALILEE	WALLEYE	LARGE FINGERLING	15-Sep-16	3173	7
2017	LAKE GALILEE	FATHEAD MINNOW	ADULT	30-Apr-17	9980	2
2018	LAKE GALILEE	WALLEYE	LARGE FINGERLING	2-Oct-18	3173	6.3
2018	LAKE GALILEE	MUSKELLUNGE	LARGE FINGERLING	21-Sep-18	131	12.1
2020	LAKE GALILEE	WALLEYE	LARGE FINGERLING	9-Oct-20	3172	6.9
1998	MEDER LAKE	WALLEYE	SMALL FINGERLING	1-Jun-98	6550	1.5
2001	MEDER LAKE	WALLEYE	SMALL FINGERLING	20-Jun-01	6750	1.6
2002	MEDER LAKE	WALLEYE	SMALL FINGERLING	27-Jun-02	6550	1.4
2004	MEDER LAKE	WALLEYE	SMALL FINGERLING	21-Jun-04	7776	1.1
2005	MEDER LAKE	WALLEYE	SMALL FINGERLING	16-Jun-05	7305	1.5
2006	MEDER LAKE	WALLEYE	SMALL FINGERLING	9-Jun-06	5849	1.5
2010	MEDER LAKE	WALLEYE	SMALL FINGERLING	10-Jun-10	4747	1.8
2012	MEDER LAKE	WALLEYE	SMALL FINGERLING	8-Jun-12	4770	1.7
2014	MEDER LAKE	WALLEYE	SMALL FINGERLING	1-Jul-14	4749	1.7
2019	MEDER LAKE	WALLEYE	SMALL FINGERLING	27-Jun-19	5198	1.6
2012	O'BRIEN LAKE	LARGEMOUTH BASS	LARGE FINGERLING	22-Aug-12	4320	3
2013	O'BRIEN LAKE	LARGEMOUTH BASS	LARGE FINGERLING	20-Aug-13	2485	2.1
2013	O'BRIEN LAKE	LARGEMOUTH BASS	LARGE FINGERLING	20-Aug-13	250	4.4
2014	O'BRIEN LAKE	LARGEMOUTH BASS	LARGE FINGERLING	22-Aug-14	1975	3.2

Appendix E – Water Level Data

Continuous water level records were measured for each of the Penokee Lakes during different years of the study period (Table E.1). Understanding water level fluctuations over short time scales gives insight into the influence of precipitation events, dry periods, and beaver dams on lake hydrology. Understanding water level fluctuations over multiple years allows for a greater understanding of lake hydrology across wet years, dry years, and eventually the influence of broader climate changes on lake levels. It is also important baseline information that can be used to evaluate biological changes in lakes and whether future developments, such as mining, have an influence on lake hydrologic condition.

Methods

Non-vented pressure transducers (Onset HOBO U20-04 and U20L-04 models; Bourne, MA) were suspended within perforated, 2-inch PVC conduit secured to a fence or sign post driven into the lake bed at each site (Figure E.1). The loggers were programmed to collect data at one-hour intervals. They were installed shortly after ice-out each spring and removed prior to ice formation in the fall. Non-vented pressure transducers measure total pressure, meaning when suspended in water, they measure the total water and air pressure above their location. Thus, they require a separate barometric pressure dataset (collected in air outside of the water) to generate water level data. For this purpose, two additional non-vented pressure transducers were installed outside of the water in centrally-located positions near the lake water level monitoring locations.

A series of reference points and reference marks were used at each site to establish water level elevations. Primary reference points were typically a ¾-inch or one-inch rebar driven into the lake bed next to the water level logger. The primary reference point was typically given an arbitrary elevation of 5.00 feet, and it was used to collect field measurements of water level in order to calibrate the pressure transducer data and convert it to a water level elevation or stage. Water level data were not corrected to sea level elevation.

Table E.1. Years in which continuous water level data were collected from each of the Penokee Lakes. East and West Twin Lakes are connected and were assumed to have the same water level.

Lake	2015	2016	2017	2018	2019	2020
East/West Twin	X	X	X	X	X	X
Eureka	X	X	X	X	X	
Galilee			X	X	X	X
Meder				X	X	X
Long				X	X	
Maki		X	X	X	X	X
McCarthy			X	X	X	
Upson			X	X	X	X
O’Brien			X	X	X	X
Caroline		X	X	X	X	X

Figure E.1. Survey work to establish water level elevations (left), typical water level logger installation at the Penokee Lakes (right), and HOBO water level loggers used in the study (middle pictures).

All reference points and marks were surveyed during logger installation in spring and removal in fall utilizing the Burke Center's "Levels at Gaging Stations" protocol (MGBCFI 2021), which is based on United States Geological Survey (USGS) methods (Kenney, 2010). Surveying the reference points and marks allowed for water level data to be corrected for any movement of the primary reference point and for water level data to be comparable across multiple years.

Data from the loggers were downloaded and compensated for barometric pressure (using the Barometric Compensation Assistant feature in Onset's HOBOware Pro software) in order to generate a raw water level record for each lake in each year. Raw water level records were corrected for drift and reference point movement and finalized using AQUARIUS time-series software (Aquatic Informatics, Inc., Vancouver, BC, CA).

Results

McCarthy and Maki Lakes showed the least annual water level fluctuation and Upson and O'Brien Lakes showed the greatest annual water level fluctuation (Figure E.2). Upson and O'Brien Lakes also showed the most variability in their annual fluctuations, while McCarthy and Maki Lakes showed the least. When looking at the range of all available water level data for each lake as a box and whisker plot, there is a similar pattern (Figure E.3).

The years in which water level data were collected from all lakes at the same time were 2018 and 2019. These years provide the best direct comparison between water level conditions between the lakes because all of the lakes experienced similar weather conditions. In these years, the same general patterns were observed as in the overall dataset, where Upson and O'Brien Lakes showed the greatest annual water level fluctuation and McCarthy and Maki Lakes had the least (Figure E.4).

Water level records for each lake over the available period of record between 2015 and 2020 are displayed in Figures E.5 – E.14. Water levels in most lakes tended to be higher in spring and fall and lowest in mid-summer. Water levels in the lakes responded rapidly to precipitation events indicating the importance of surface runoff to the overall water budget of the lakes (Figure E.15). All lakes, with perhaps the exception of Maki Lake, had water levels influenced by beaver activity (Figure E.16). This influence can be seen in the water level records for Upson and Caroline Lakes in

2019. Most lakes exhibited a gradual decrease in water level through summer 2019, driven by an extended period of dry weather conditions. There are two rapid decreases in water level in Upson Lake in early summer and mid-summer 2019 that indicate removal of debris (such as a beaver dam) from the outlet of the lake leading to the rapid water level declines (Figure E.13). Water levels in Caroline Lake gradually increased throughout summer 2019 (while other lakes decreased), indicating the presence of a beaver dam or other debris backing up water during an otherwise dry weather period (Figure E.14).

Overall, the water level records from these lakes provide important baseline information that can be used to evaluate whether things like climate change or future developments (e.g., mining) are having an influence on lake hydrologic condition.

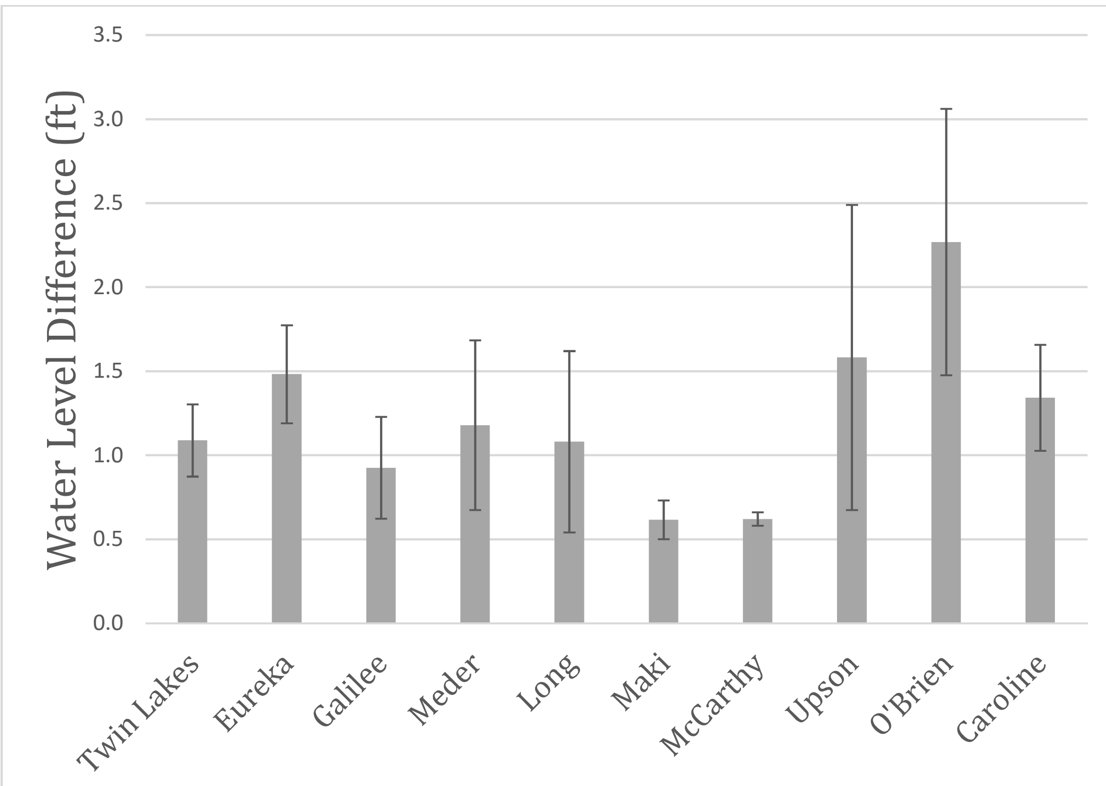

Figure E.2. Average and standard deviation of the annual difference between the highest and lowest recorded water level for each of the eleven Penokee Lakes.

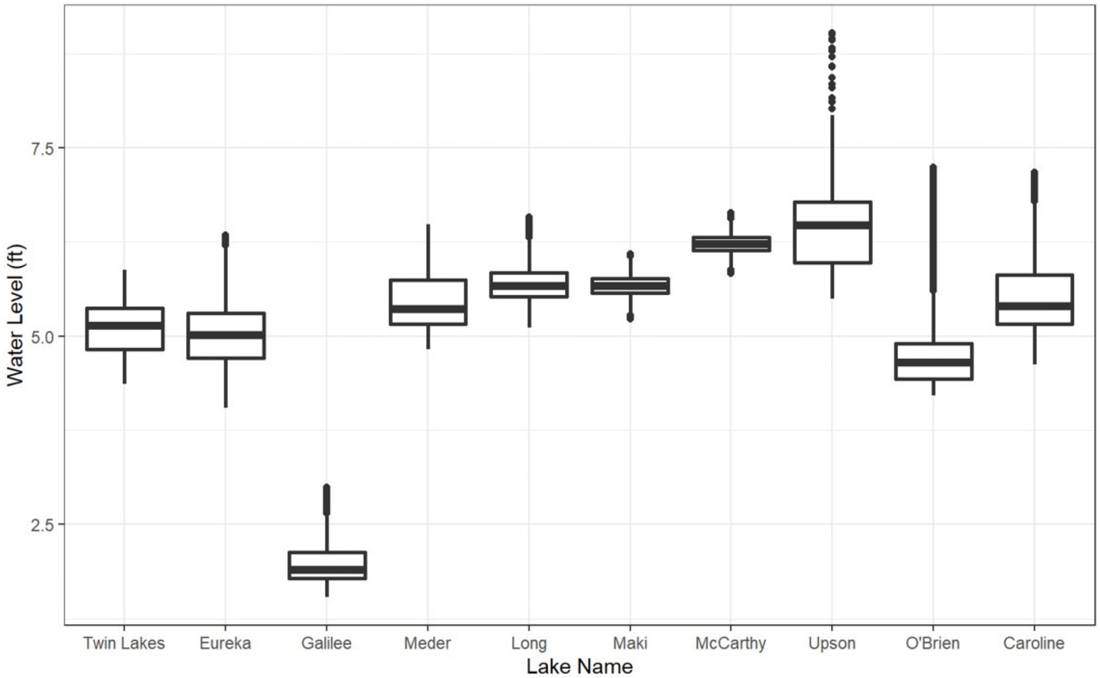

Figure E.3. Box and whisker plot showing the range of all water level data recorded for each of the Penokee Lakes. The dark lines in each box represent the median water level values, the upper and lower extent of each box represent the 25th and 75th quartiles, the whiskers represent the minimum and maximum water level values, and the dots represent outliers. Water level values for each lake are based on an arbitrary elevation datum and are not tied to sea-level elevation.

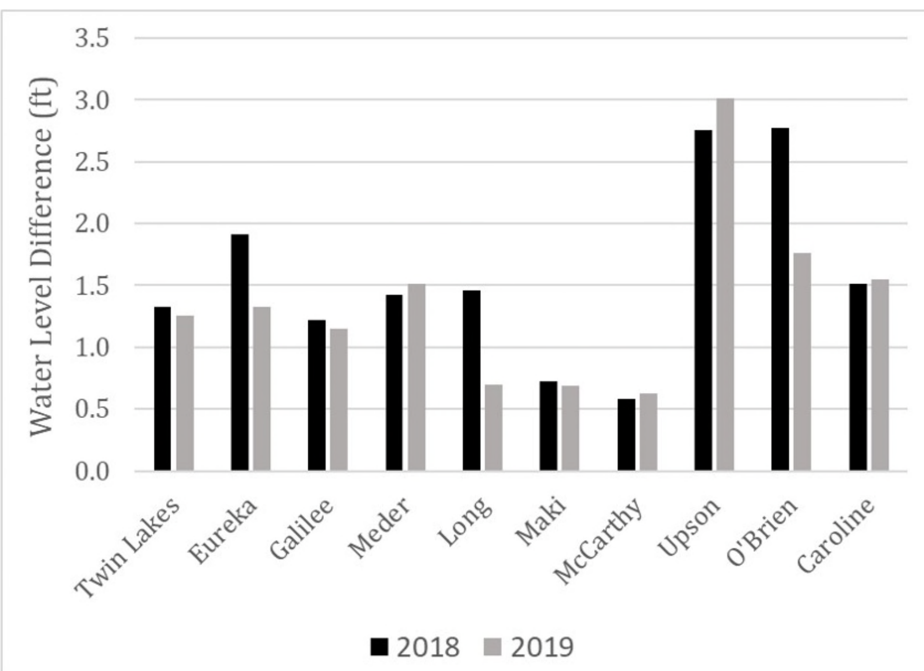

Figure E.4. Difference between minimum and maximum water level observed at each of the Penokee Lakes during 2018 and 2019.

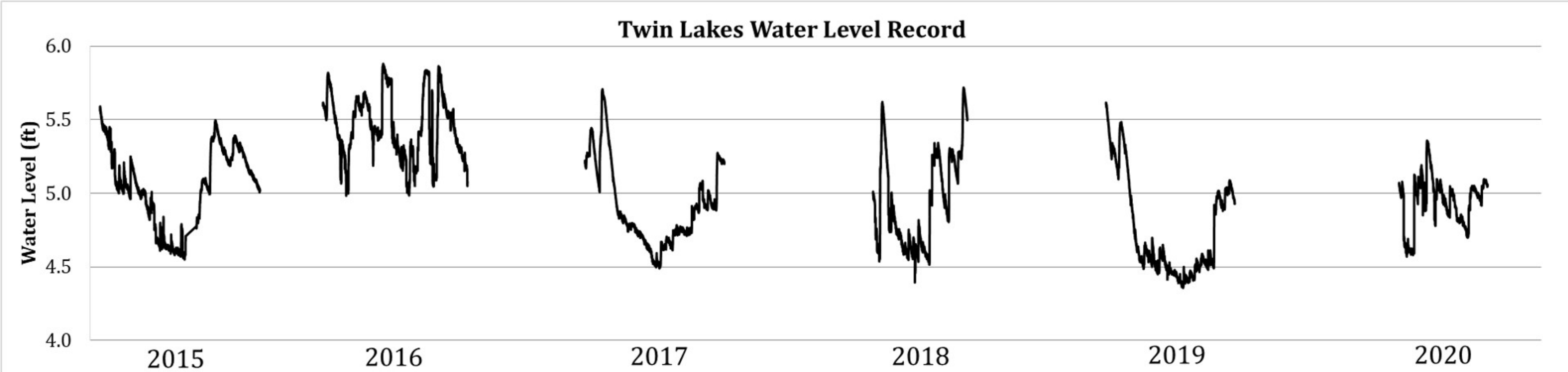

Figure E.5. Annual water level data (in feet) collected from Twin Lakes (East and West Twin Lake) between 2015 and 2020.

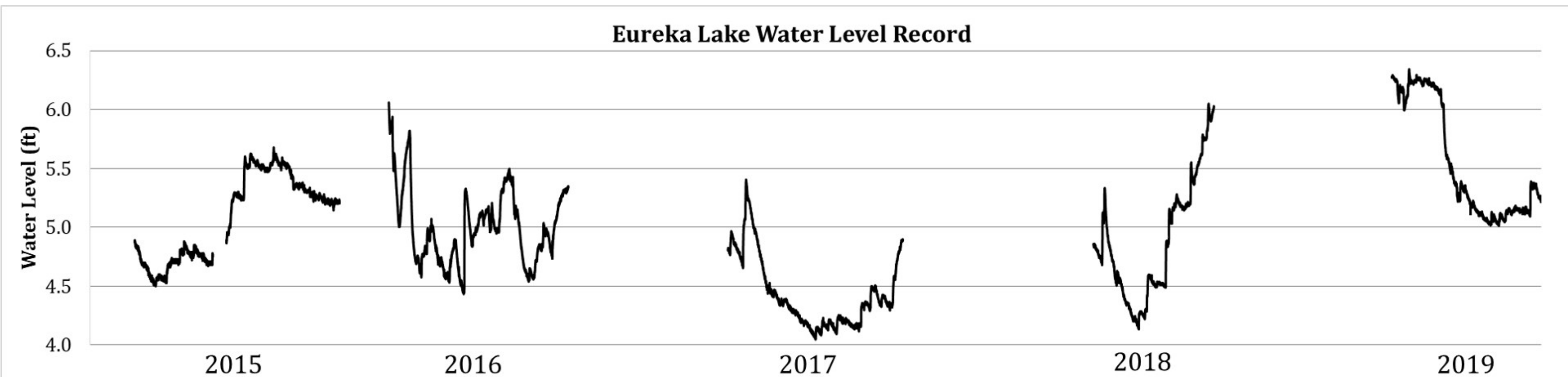

Figure E.6. Annual water level data (in feet) collected from Eureka Lake between 2015 and 2019.

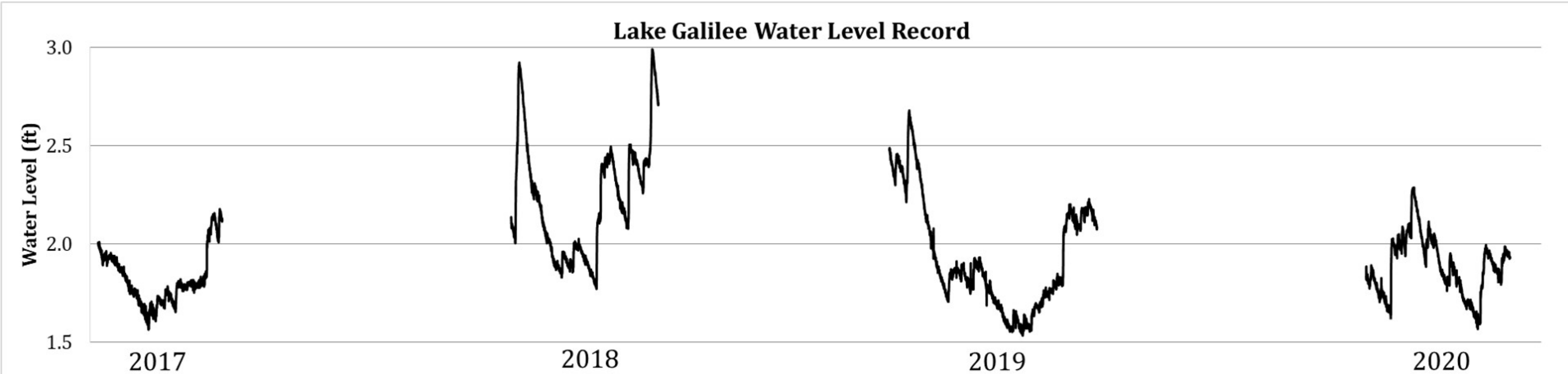

Figure E.7. Annual water level data (in feet) collected from Lake Galilee between 2017 and 2020.

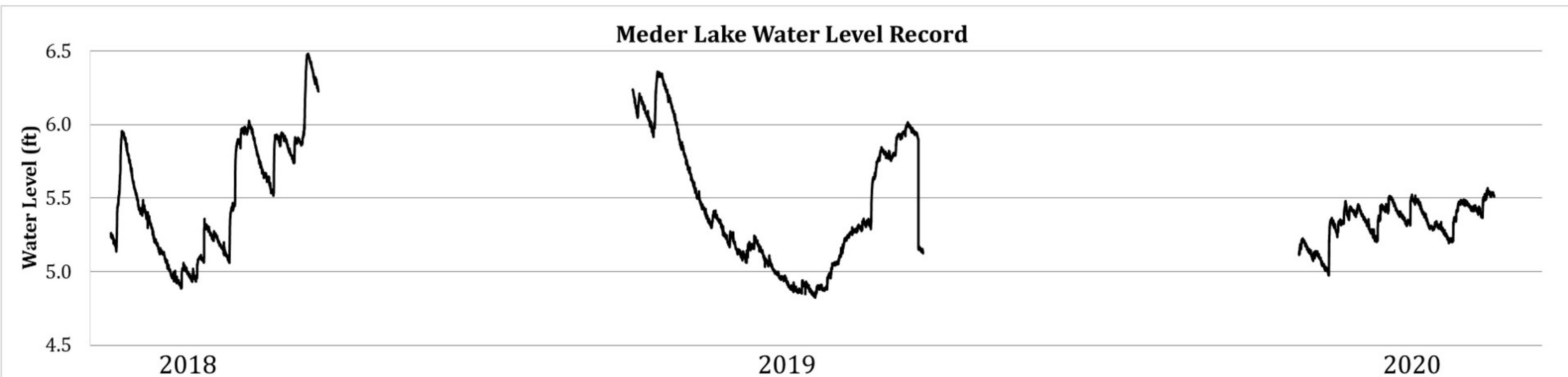

Figure E.8. Annual water level data (in feet) collected from Meder Lake between 2018 and 2020.

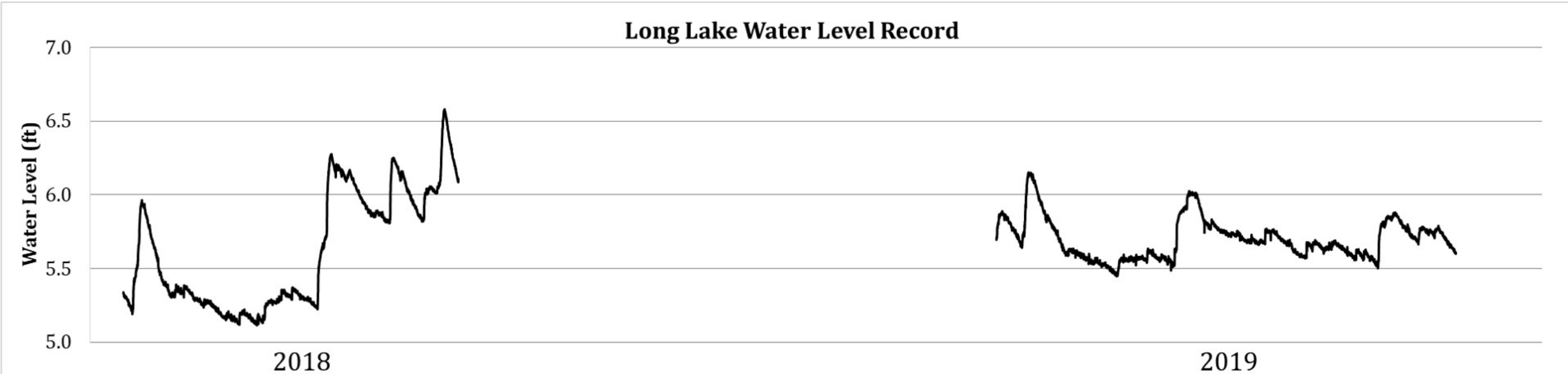

Figure E.9. Annual water level data (in feet) collected from Long Lake between 2018 and 2019.

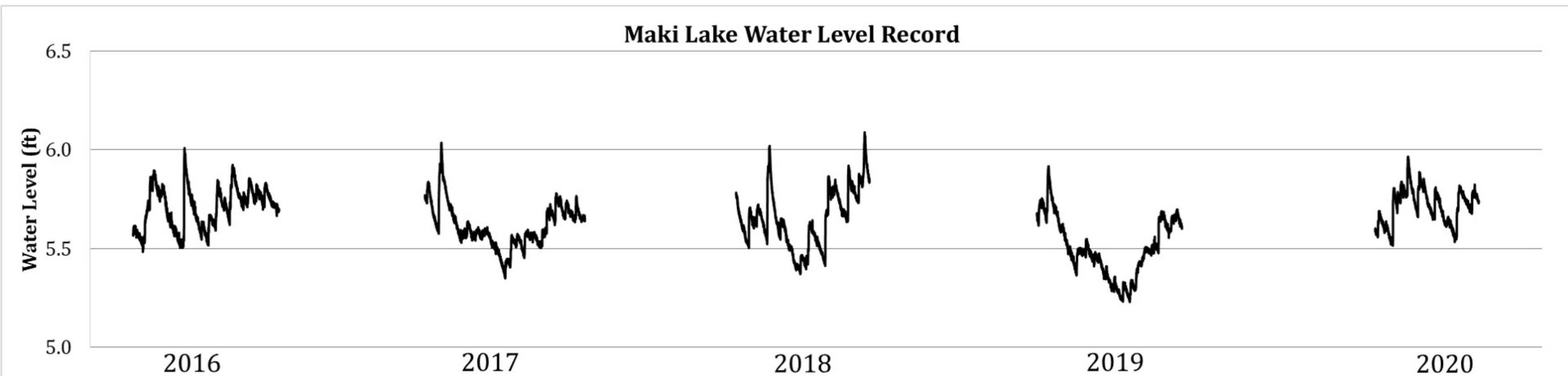

Figure E.10. Annual water level data (in feet) collected from Maki Lake between 2016 and 2020.

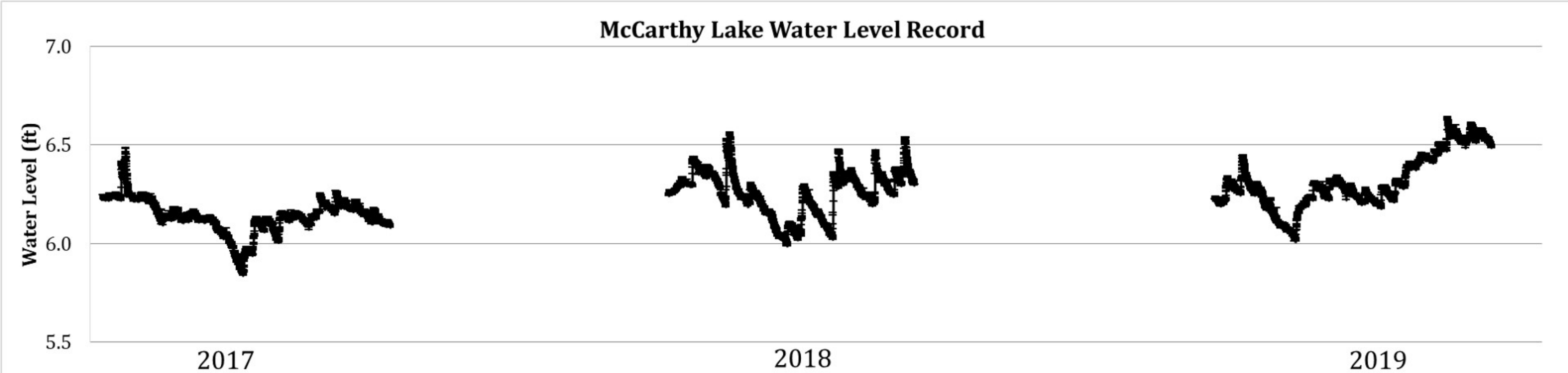

Figure E.11. Annual water level data (in feet) collected from McCarthy Lake between 2017 and 2019.

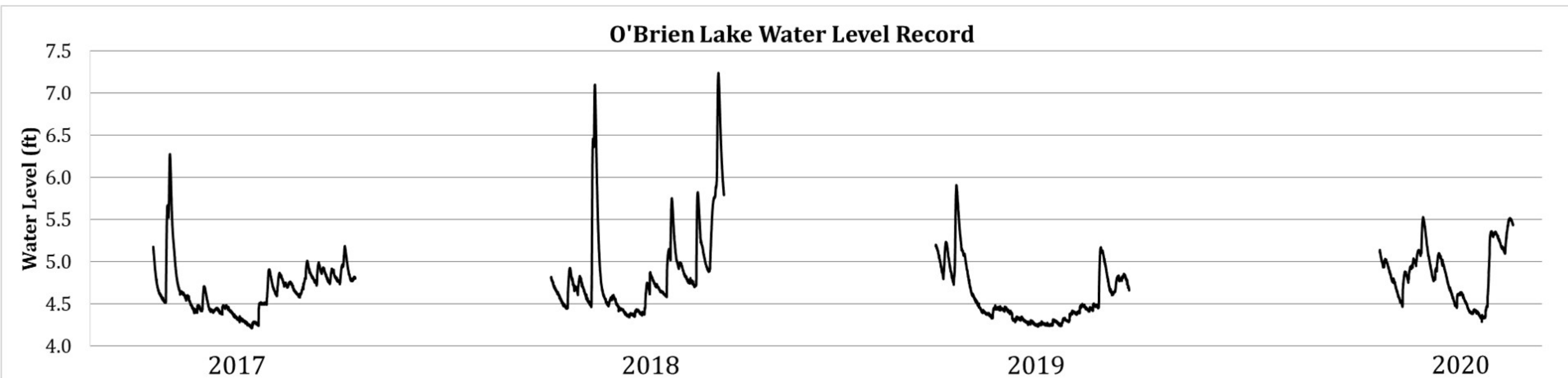

Figure E.12. Annual water level data (in feet) collected from O'Brien Lake between 2017 and 2020.

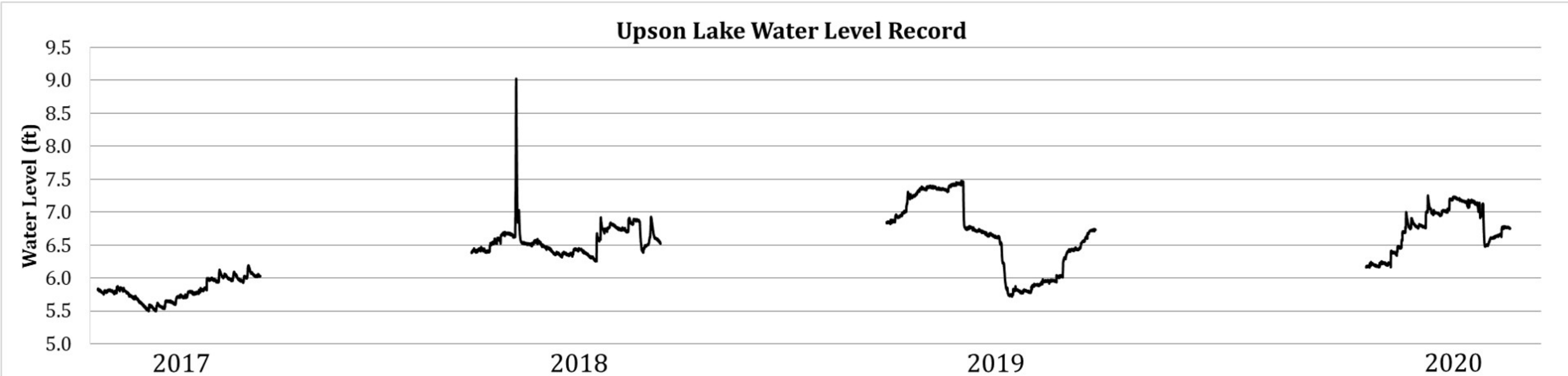

Figure E.13. Annual water level data (in feet) collected from Upson Lake between 2017 and 2020.

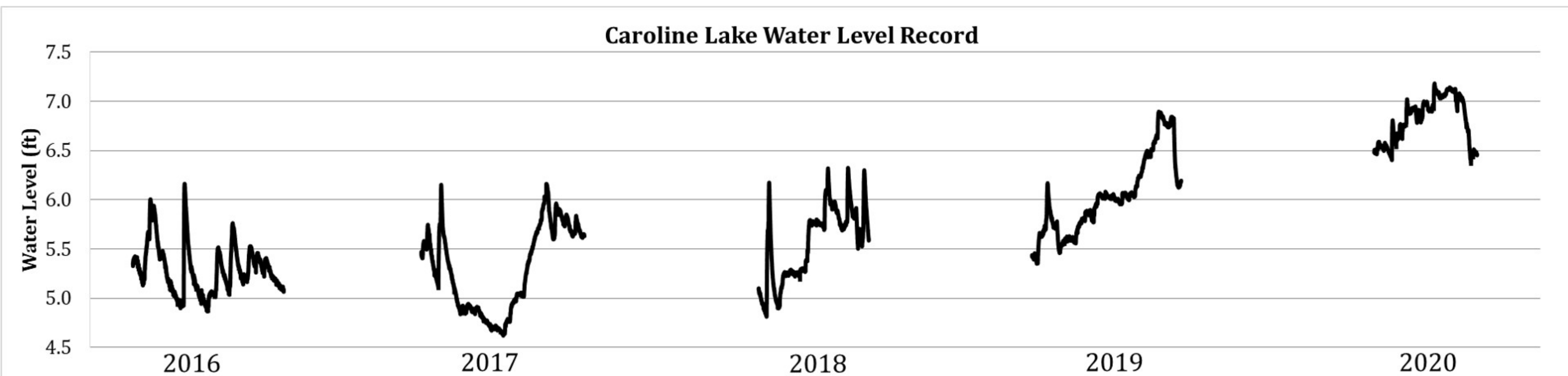

Figure E.14. Annual water level data (in feet) collected from Caroline Lake between 2016 and 2020.

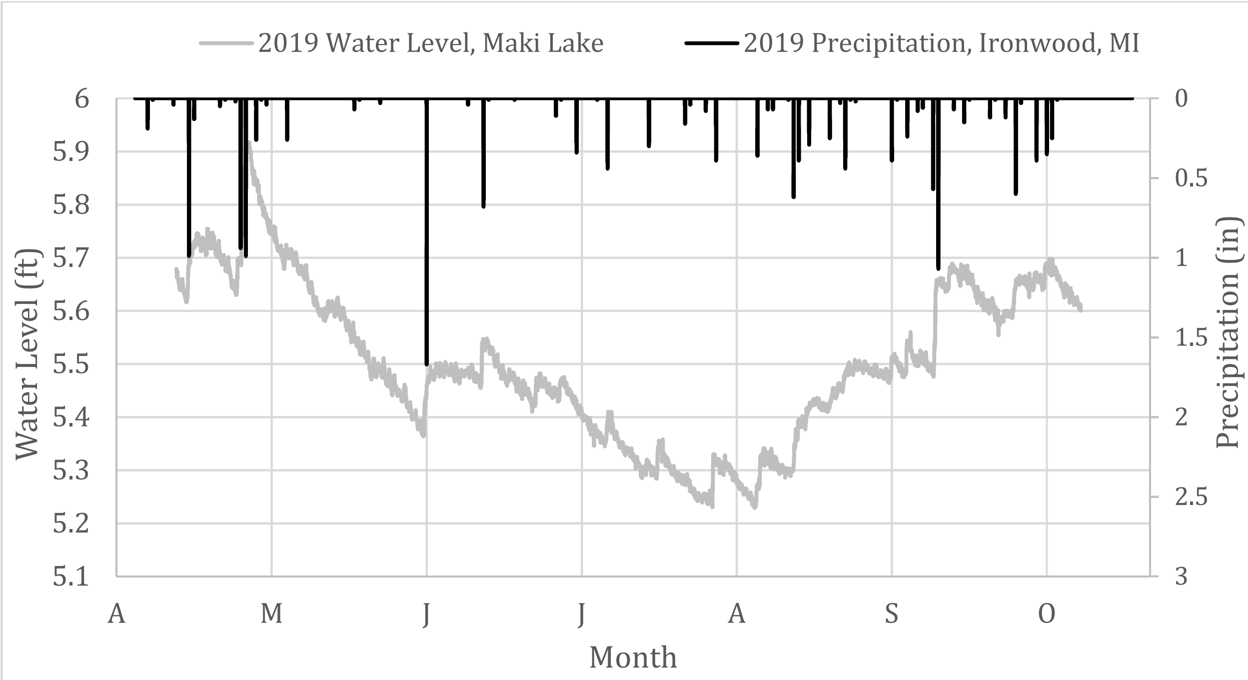

Figure E.15. 2019 water level record for Maki Lake with the 2019 precipitation record from Ironwood, MI, overlaid.

Figure E.16. Example of a beaver dam backing up water in the Penokee Lakes (Caroline Lake outlet, June 2020).

Appendix F – Dragonfly Larvae as Bio-Sentinels for Mercury on Inland Lakes in Northern Wisconsin

Senior Capstone thesis report completed by Emma Holtan, Mary Griggs Burke Center for Freshwater Innovation, Northland College, February 2021

Dragonfly Larvae as Bio-Sentinels for Mercury on Inland Lakes in Northern Wisconsin

Emma Holtan
Mary Griggs Burke Center for Freshwater Innovation
Northland College

February 2021

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Thank you to the Mary Griggs Burke Center for Freshwater Innovation, which granted me the opportunity to take on this project. I am lucky to have had the chance to work for the Burke Center all my years at Northland. Thank you to all of my bosses and coworkers who have shared kindness, support, and teachings in and out of the context of this project.

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A special thank you to Matt Hudson for helping facilitate this project and connecting me to it. I could not have completed this capstone without your help.

I would like to acknowledge the great privilege I feel to have studied in such an ecologically and culturally important region as the Penokee Lakes.

Lastly, I want to acknowledge the impact of taking living beings out of this ecosystem for the benefit of my research. It is my hope that our research can provide support for sustaining the health of the Penokee Lakes ecosystem so that many more dragonflies are able to thrive there long into the future.

Introduction

Mercury is a naturally occurring element with sources such as volcanic eruptions and oceanic emissions, but it also enters the environment via anthropogenic emissions. The largest anthropogenic emissions come from gold mining operations, coal burning power plants, and nonferrous metal production (UNEP, 2002). Since the industrial revolution, there has been a global increase in mercury deposition by a factor of three, and even in remote locations large fractions of mercury depositions are anthropogenic mercury (Lindberg *et al.*, 2007). Within the Lake Superior basin, the greatest anthropogenic source of mercury emissions to air and water is mining and metals production (LAMP, 2012).

In areas of northern Wisconsin over 95% of mercury input into lakes comes from direct precipitation (Fitzgerald and Watras, 1989). Once in lakes, mercury is largely impacted by climate variability, such as temperature and precipitation change (Watras *et al.*, 2019). Mercury enters aquatic systems in the inorganic form and quickly binds to sediment (Stopford and Goldwater, 1975). The bioaccumulation of mercury happens only after mercury is methylated into an organic form, becoming methylmercury. Although there is uncertainty about the specifics of the methylation process, it is generally accepted that it is through the work of microorganisms, namely sulphate reducing bacteria and iron reducing bacteria, that mercury is methylated (Sparling, 2009). Methylmercury is then released into the water column where it binds to microorganisms, suspended sediment, and organic detritus, which then is taken up by larger organisms through biomagnification, concentrating in muscle tissue (Stopford and Goldwater, 1975; Biggam *et al.*, 2005). Because of its long half-life, methylmercury concentration increases as it biomagnifies across trophic levels. (Stopford and Goldwater, 1975).

Methylmercury is a known neurotoxin. In lower trophic levels it causes decreases in growth and survival rates (Stopford and Goldwater, 1975). It is also detrimental to human health. Eating fish contaminated with methylmercury is the primary human exposure pathway and has led to negative health effects in humans, such as weakening muscles, hearing loss, slurred speech, tunnel vision, and abnormal behavior (*Biggam et al.*, 2005). It is especially dangerous to children and pregnant women. Adolescent brains and nervous systems are more vulnerable to the effects of methylmercury. Children exposed in the womb are at risk of impacts to their cognitive thinking, motor skills, memory, attention, language, and visual spatial skills (US EPA, 2019). The Environmental Protection Agency has set a general criterion of 0.3 mg methylmercury/kg fish based on a total fish and shellfish consumption-weighted rate of 0.0175 kg fish/day (US EPA, 2001). Methylmercury concentrations in fish vary widely between water bodies, so consumption advisories can vary widely as well and rely on data from individual waterbodies to be set appropriately.

With this in mind, the National Park Service (NPS) has collaborated with The United States Geologic Survey (USGS) to create the Dragonfly Mercury Project (DMP). The DMP looks at mercury concentrations in national parks as a citizen science project and study. The project uses dragonfly larvae as bio-sentinels for total mercury concentrations within aquatic ecosystems (here, the term “bio-sentinels” is used as any biological indicators of toxins integrated into the ecosystem). Typically, fish are used for mercury analysis, but recent work has shown the benefit of using dragonfly larvae due to greater ease in sampling, widespread abundance, responsiveness to localized changes in methylmercury availability and cycling, and the ability to sample for mercury in ecosystems without fish (Pritz *et al.*, 2014). Total concentrations of mercury in dragonfly larvae have been shown to be correlated with concentrations from water, fish, and other biota sampled and have illustrated fine scale differences between mercury concentrations within systems (Haro *et al.*, 2013; Pritz *et al.*, 2014; Jeremiason *et al.*, 2016).

Looking to the DMP as a guide and with an awareness of the potentially detrimental effects of mercury to ecosystems, the Mary Griggs Burke Center for Freshwater Innovation (MGBCFI) at Northland College determined that the inclusion of mercury analysis was an important addition to its inland lake monitoring. During the field season of 2019, the MGBCFI adopted DMP procedures to conduct a study of total mercury concentrations in a series of lakes in the Penokee iron range, in northern Wisconsin. The objective of this study is to establish sampling and analysis procedures for monitoring mercury within these Penokee lakes using dragonfly larvae and establishing a baseline to compare mercury concentrations within and between these systems over time. With the analysis of this first sampling effort, we hope to answer the question: how do mercury concentrations in dragonfly larvae compare between lakes in the study area in 2019?

Study Area: Penokee Lakes

Geology

The Penokee iron range is a segment of the Gogebic iron range, an 80-mile stretch of Paleoproterozoic strata that runs from Lake Gogebic in the Upper Peninsula of Michigan into Northern Wisconsin (Cannon *et al.*, 2008). The most recent deglaciation of this landscape, occurring around 13,200 years ago left behind an abundance of lakes and waterways, including the eleven which are the focus of this study (Ullman *et al.*, 2015; Figure 1). Spanning from Upson, Wisconsin to Mineral Lake, Wisconsin (Marsden, 1978), the Penokee range covers 21 miles. The study area, which straddles the iron formation, is mostly embedded in a mix of undivided volcanic rock and metamorphosed diabase and gabbro bedrock (Cannon, *et al.*, 1996). One of the lakes of interest is within the Tyler Formation, made up of quartz-rich graywacke and argillite (Cannon, *et al.*, 1996). Overlaying the bedrock is Copper Falls Formation glacial till, which moved in from the North (Clayton, 1984).

Figure 1. Penokee Lakes Study Area. The eleven Penokee Lakes are shown as well as the connecting tributaries. All the tributaries run into the Bad River. The location of the Penokee Iron Range is marked. It extends along the arrows past the extent of this map. The smaller map shows the location of the Penokee Lakes within the state of Wisconsin.

Hydrology

The eleven lakes of interest have been deemed “the Penokee Lakes” for the purposes of this study and further inland lake monitoring through the MGBCFI. The lakes, as aforementioned, are remnants of the last deglaciation to occur in the region.

Water from all eleven lakes eventually drains into the Bad River and empties into the Bad River/Kakagon Sloughs of Lake Superior (Figure 2). The sloughs hold the largest wild rice beds in the Great Lakes Basin and are a culturally important resource to the Bad River Band of Lake Superior Chippewa (Wisconsin Wetland Association, 2015). Despite all ending in the same place, only six of the eleven lakes are connected year-round via a Bad River tributary called Minnow Creek. The rest flow into other tributaries, with the exception for Caroline Lake, which is the headwaters for the Bad River (Figure 1).

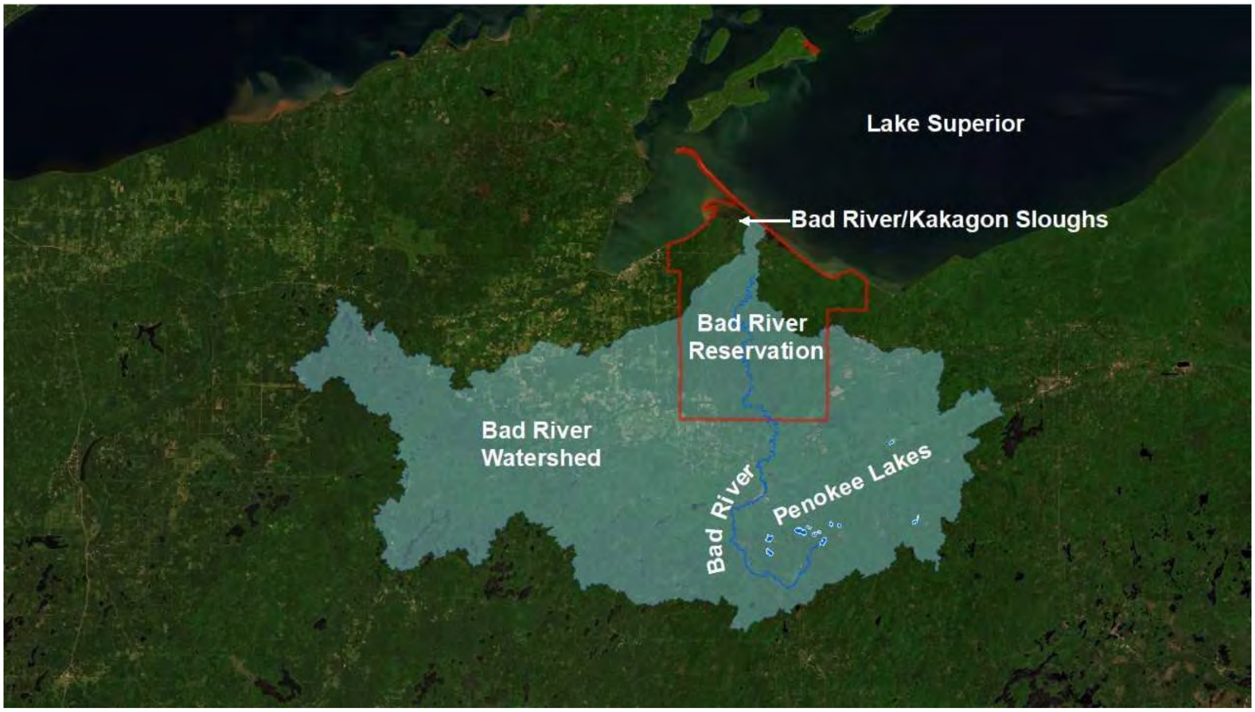

Figure 2. The Bad River watershed. The eleven Penokee Lakes are shown in relation to the entire Bad River Watershed, the Bad River Reservation, the Bad River/Kakagon Sloughs and Lake Superior.

Ecology

Historically, the Penokee Lakes area was covered predominately by hemlock, white spruce, balsam fir, tamarack, white cedar, sugar maple, white and yellow birch, white and red pine, and aspen (WDNR, 2015). Now, the land is dominated mostly by forested wetland, broad leafed deciduous forest, and some coniferous forest (WDNR, 2015). Some of the original species have grown back as second-growth after widespread logging, such as maple, birch, hemlock, and pine, but currently the area is mostly covered with successional species like aspen, poplar, and jack pine (Durand, Loyal and Bertrand, 1935).

Human History and Industry

The Penokee Lakes area is part of the ancestral, traditional, and contemporary lands of the Ojibwe people, ceded by the 1842 Treaty of La Pointe (GLIFWC, 2008). The Ojibwe migration story tells that groups of the Ojibwe people followed the Megis shell to this area sometime in the 1500's from the East Coast. Eventually it led them to *Mooningwanekaaning*, now known as Madeline Island, the place where food grows on water. This food was *manoomin*, wild rice, which continues to be a sacred food for the Ojibwe people who live in this area. European contact occurred sometime in 1600's and the area then became a center for the fur trade.

After the land was colonized, it was heavily deforested during the late 1800s. Logging activity peaked between 1890 and 1910 in what is referred to as the "cutover" (Durand, Loyal and Bertrand, 1935). Logging was not the only industry that found its way to the region. The first mining operations occurred in 1884, and within four years annual shipments of iron ore exceeded one million tons (Cannon *et al.*, 2008). It is estimated that there are still more than three billion metric tons of taconite iron reserves within the Gogebic Range that runs through Wisconsin (Marsden, 1978). These impressive numbers drew in a proposal for the largest open-pit iron ore mine in the world from the Gogebic Taconite Company in 2011. The company withdrew their application in 2015 and the mine never came to fruition.

Mary Griggs Burke Center for Freshwater Innovation

The MGBCFI at Northland College researches freshwater resources around Northern Wisconsin and works to engage the community and greater public in communication about their findings and other emerging freshwater resource issues. As a result of the mining proposal and lack of baseline data on potentially affected water resources, the MGBCFI began a monitoring project of the Penokee Lakes near Mellen, Wisconsin (Figure 1). The eleven lakes have been studied over a period of five years. The lakes were studied in two-year phases from spring 2015 to fall 2018, and in 2019 all eleven lakes were studied simultaneously from spring to fall. The monitoring consists of biweekly visits from May to August, and once a month visits during the remaining ice-free periods. During each visit, water samples are taken and analyzed for phosphorus and chlorophyll-a. In 2019, this water quality analysis was expanded to include measurements of nitrogen, alkalinity, total hardness, calcium, magnesium, sulfate, iron, and color. Sampling visits also include taking depth profiles of the lakes at their deepest point using a sonde instrument. At every meter from surface to bottom, temperature, dissolved oxygen, pH, and specific conductance were recorded. Beginning in 2019, depth profile measurements were expanded to include measurements of photosynthetically active radiation, colored dissolved organic matter, chlorophyll-a, and turbidity. In addition to water quality measurements, a habitat assessment, coarse woody debris survey, and aquatic plant survey were performed on each lake once over the study period. In 2019 MGBCFI added dragonfly larvae collection for total mercury analysis to the monitoring procedures, adopting the procedure and methods of the DMP.

Methods

The primary Penokee Lakes dragonfly larvae sampling occurred over the month of August in 2019. Crews of two to five students went out on each lake, traveled around via boat and sampled likely larval dragonfly habitat; typically vegetated bank margins, snags and logs, aquatic vegetation and decaying organic matter, and silt/sand/gravel substrate (Nelson *et al.*, 2018). Ten sites were selected around each lake with location information marked using handheld global positioning system (GPS) units.

The sampling goal for each lake was 10 individuals of two different families, Aeshnidae and Corduliidae (Figure 3). After the initial sampling, supplementary sampling occurred over the months of October and November 2019. Samples of both families were collected in every lake, with the sampling goal of 10 individuals met for at least one family in all the lakes except Galilee. Sampling targets for both families were unachievable in 45% of the lakes (Table 1).

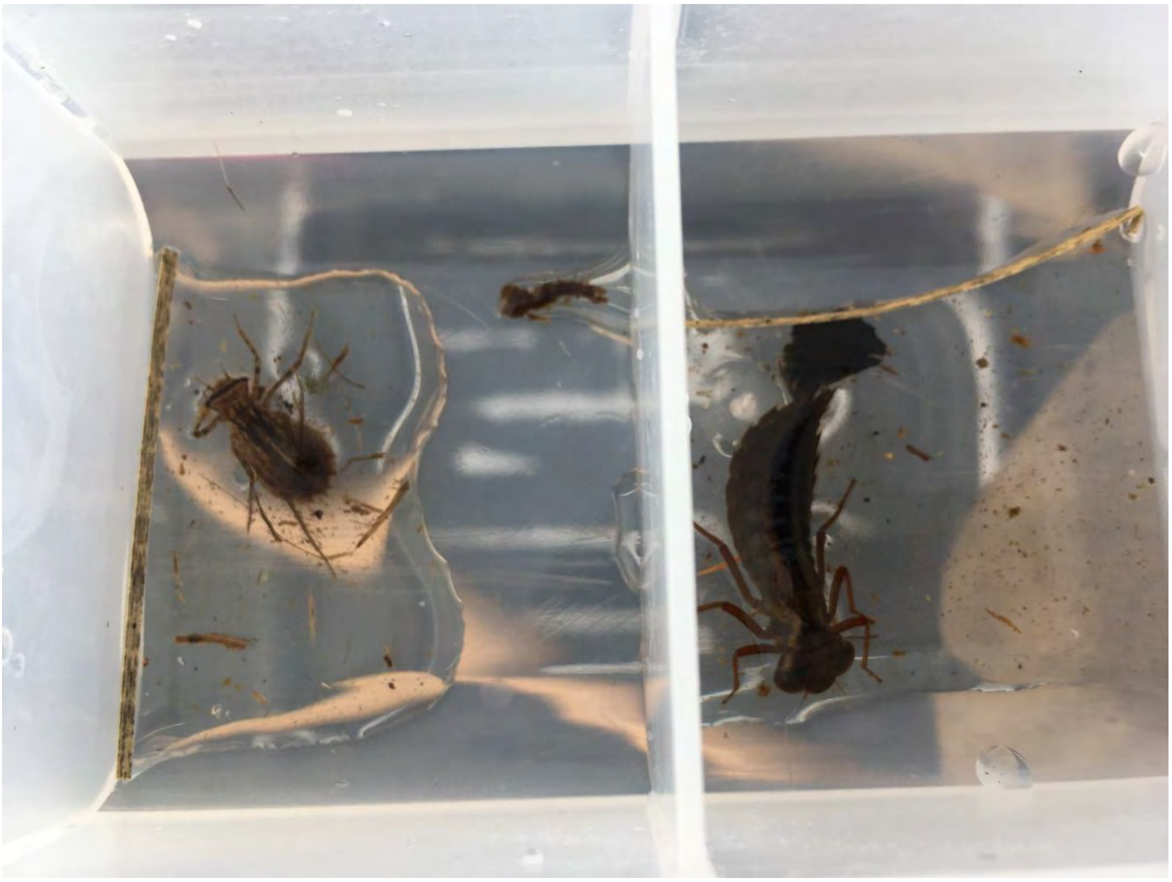

Figure 3. Dragonfly larvae collected. Corduliidae larvae is shown on the left. Aeshnidae larvae is shown on the right.

Lake	Dragonfly Larvae Family	
	Aeshnidae	Corduliidae
Caroline	10	10
East Twin	2	10
West Twin	5	10
Eureka	10	10
Galilee	8	7
Long	10	10
Maki	5	10
McCarthy	10	10
Meder	8	10
O'Brien	10	10
Upson	10	10

Table 1. Counts of dragonfly larvae collected by family from each of the Penokee Lakes.

Samples were collected using dip-nets and plastic spoons. Larvae were not touched due to potential mercury contamination. Sampling consisted of sweeping dip-nets through each chosen habitat (Figure 4). The net was then brought to the surface and the contents were examined for larvae. The larvae were measured, identified by family, and bagged before being put into a cooler and eventually frozen for preservation prior to mercury analysis.

Figure 4. Dragonfly larvae sampling on East Twin Lake. Student researchers collected dragonfly larvae along the shoreline of the lake with dip-nets.

Confirmation of species identification was performed on each individual before being placed in a vial and packaged to be sent off to the USGS Forest and Rangeland Ecosystem Science Center (Corvallis, OR) for total mercury analysis. There the samples were dried at 50 degrees Celsius in a laboratory oven. Each dried individual was thermally and chemically decomposed within a decomposition furnace. The products were then sent via flowing oxygen into a catalytic section of the furnace. There, oxidation was completed, trapping excess halogens and nitrogen/sulfur oxides. The remainder of the sample was moved to an amalgamator that traps mercury. Finally, the system was flushed with oxygen, removing remaining gases of detritus and the mercury vapor through two absorbance cells at two different sensitivities that were positioned to hit the pathway of light of a single wavelength atomic absorption spectrophotometer. The lab measured absorbance at 253.7 nanometers (nm) as a function of mercury concentration. The detection limit for the instrument was 0.1 nanograms (ng) of total mercury (US EPA, 2007). The final total mercury concentrations were reported in parts per billion (ppb).

Results and sample statistics were analyzed using Microsoft Excel. Mean and geometric mean total mercury concentrations as well as standard error were calculated for all individuals, for individuals by family, individuals by lake, and individuals by family and lake. Regression analyses were then run, comparing these concentrations to dragonfly length as well as different water quality and environmental variables observed to have effects over the bioaccumulation of mercury.

Results and Discussion

Total mercury (THg) concentrations in the dragonfly larvae ranged from 49 ppb to 672 ppb. The mean THg concentration for all individual dragonfly larvae was 200 ppb and the geometric mean THg concentration for all the individual dragonfly larvae was 180 ppb (Figure 5). The majority of the eleven lakes had THg geometric mean concentrations for both total individuals and by family between 150 and 250 ppb with the exception of three outliers: Eureka, Meder, and Galilee (Figure 6). Eureka Lake had the highest total geometric mean THg, 380 ppb (S.E. +/- 23), as well as highest by family, Aeshnidae: 391 ppb (S.E. +/- 26) and Corduliidae: 369 ppb (S.E. +/- 39). All of these values were at least 100 ppb over the geometric mean THg concentrations from the other ten lakes. The THg concentration of Eureka Lake falls within the top five highest concentrations of parks studied through the DMP (Eagles-Smith *et al.*, 2020; Figure 7). Meder Lake had the lowest geometric mean THg concentrations for all individuals, 80 ppb (S.E. +/- 23), and by family, Aeshnidae: 94 ppb (S.E. +/- 7) and Corduliidae: 70 ppb (S.E. +/- 5). The geometric mean THg concentrations for Meder Lake were at least 100 ppb lower than all the other lakes besides Galilee.

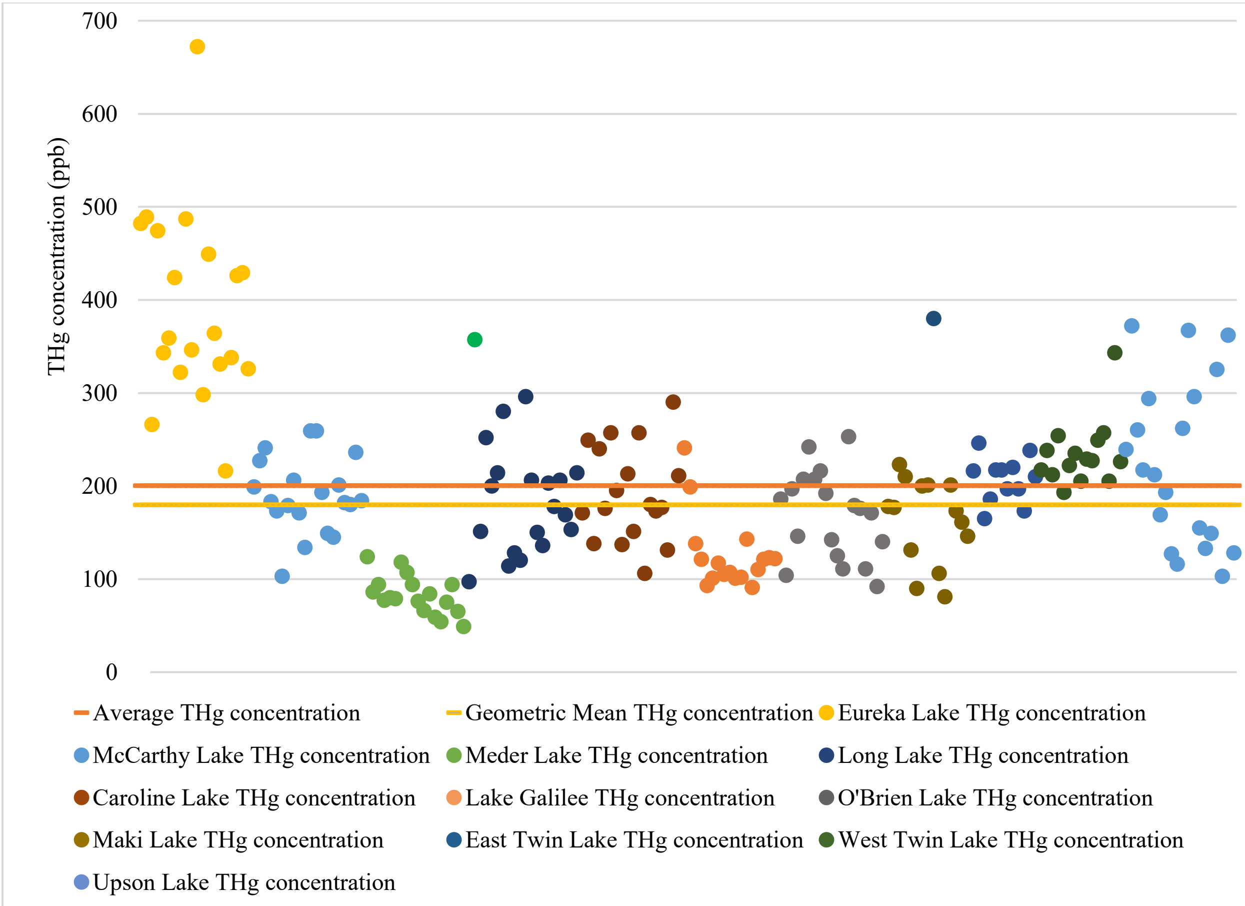

Figure 5. Individual dragonfly larvae total mercury (THg) concentrations from eleven Penokee Lakes with mean (dark orange) and geometric mean (light orange) THg concentration from all lakes combined shown.

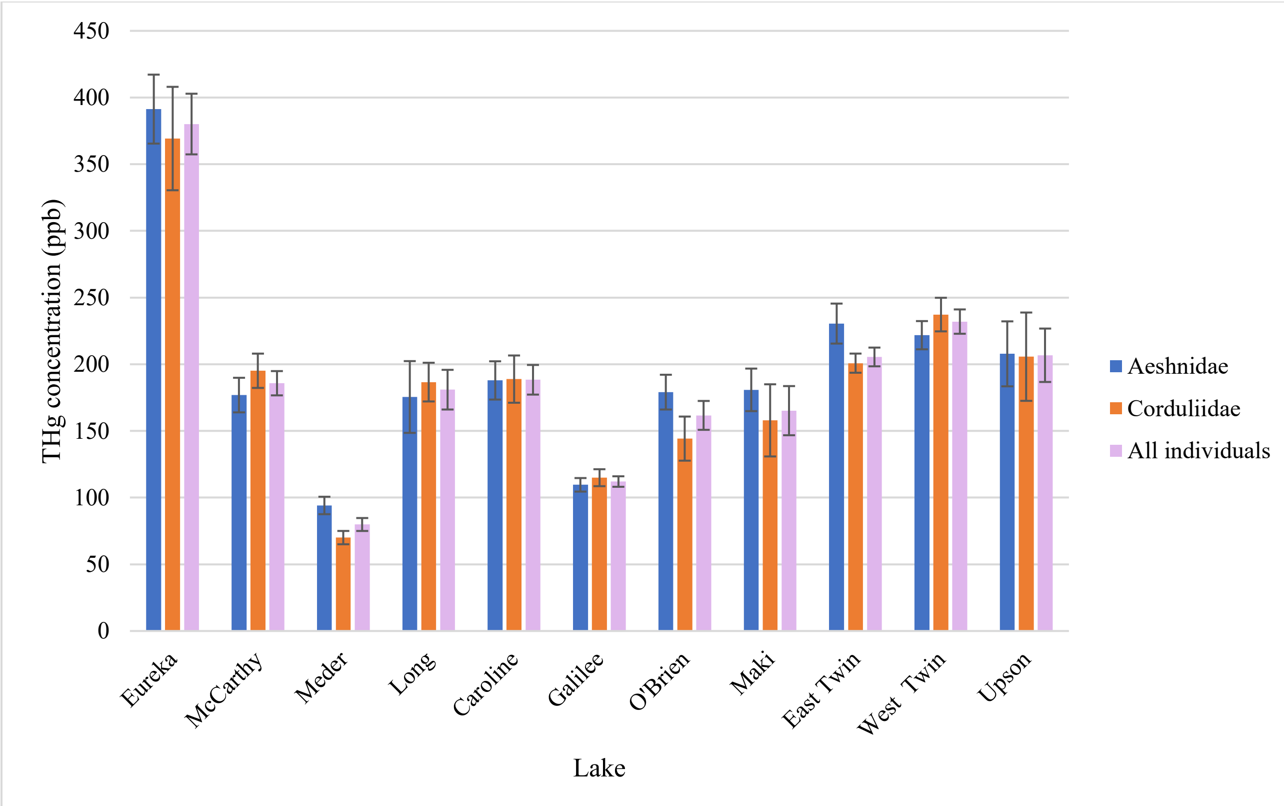

Figure 6. Geometric mean total mercury (THg) concentration by lake and by family. Error bars indicate standard error.

In seven out of the eleven lakes, the geometric mean concentration of total mercury was higher in the Aeshnidae family than in the Corduliidae family (Figure 6). In all eleven lakes, the difference of geometric mean THg concentrations between the two families did not exceed 35 ppb. O'Brien Lake had the largest difference in geometric means between families. The family geometric means varied the least in Caroline Lake, where there was only a difference of about 1 ppb between Aeshnidae and Corduliidae geometric mean concentrations.

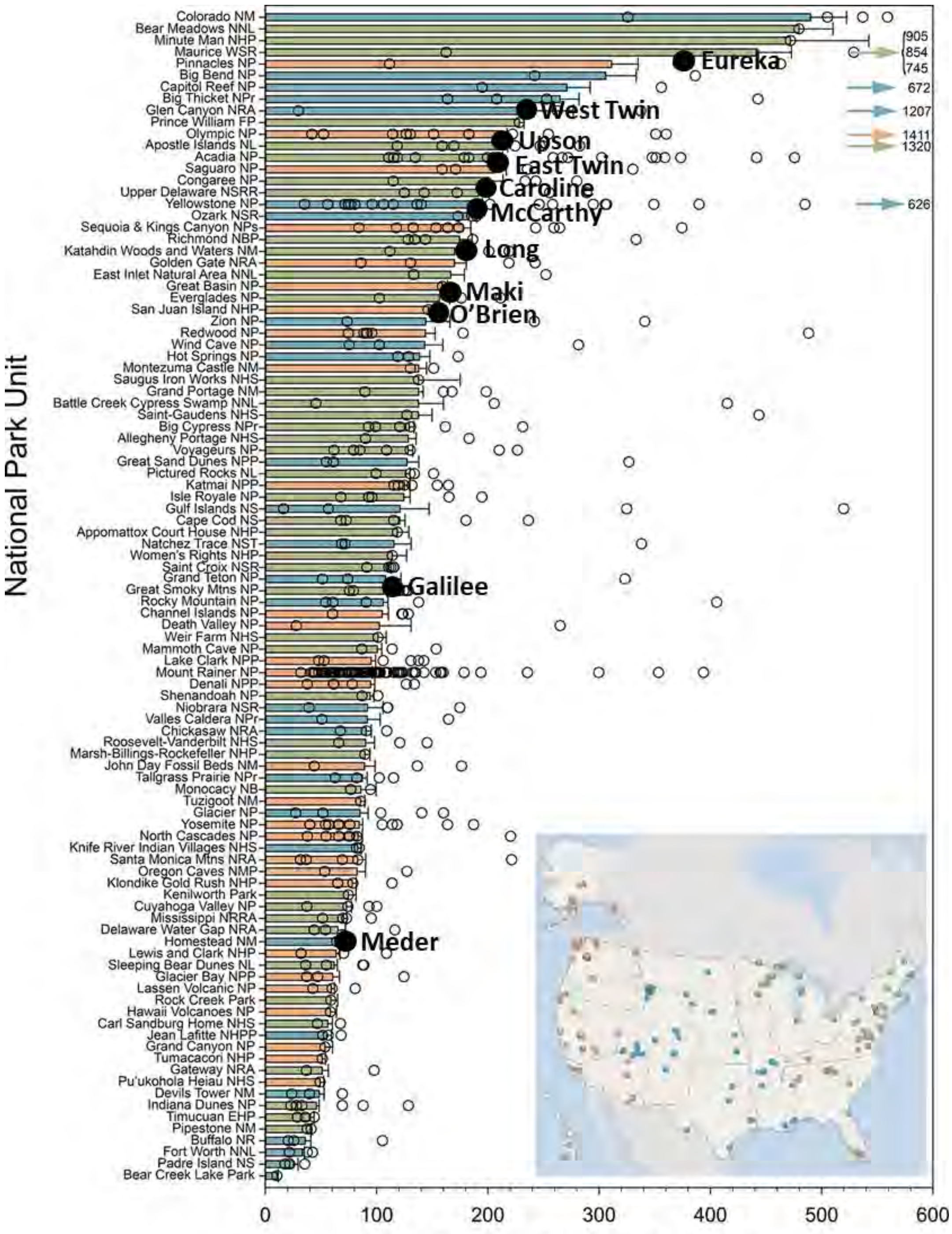

Figure 7. Base graph and map are Figure 1 from the paper, "A National-Scale Assessment of Mercury Bioaccumulation in United States National Parks Using Dragonfly Larvae as Biosentinels through a Citizen-Science Framework" (Eagles-Smith *et al*., 2020), showing geometric mean THg concentrations in dragonfly larvae collected from National Parks units. The black dots show geometric mean THg concentration for each Penokee lake based on dragonfly larvae in comparison to DMP results.

A series of plots were generated to search for variables that might explain differences in THg concentrations between the lakes. The first plots included THg concentrations and larval dragonfly body length. The relationship between length and THg for all individuals had a low r-squared value of 0.16 (Figure 8), although it did show statistical significance ($\alpha = 0.05$). Body length and THg were also compared within each family by lake, excluding the Aeshnidae family in East Twin, which consisted of only two individuals. The r-squared of these comparisons ranged from 0.00 to 0.69. The Aeshnidae family in Galilee had the strongest correlation, but the relationship showed no statistical significance ($\alpha = 0.05$). With these results, this study affirms the findings of the DMP that, dragonfly length has a weak relationship to THg concentration and is insufficient to explain differences in THg in dragonfly larvae (Eagles-Smith *et al.*, 2020). THg concentrations were compared with other water quality and environmental variables shown to have an effect on THg concentration in biota to investigate the explanatory powers they might have for THg concentration in the Penokee Lakes.

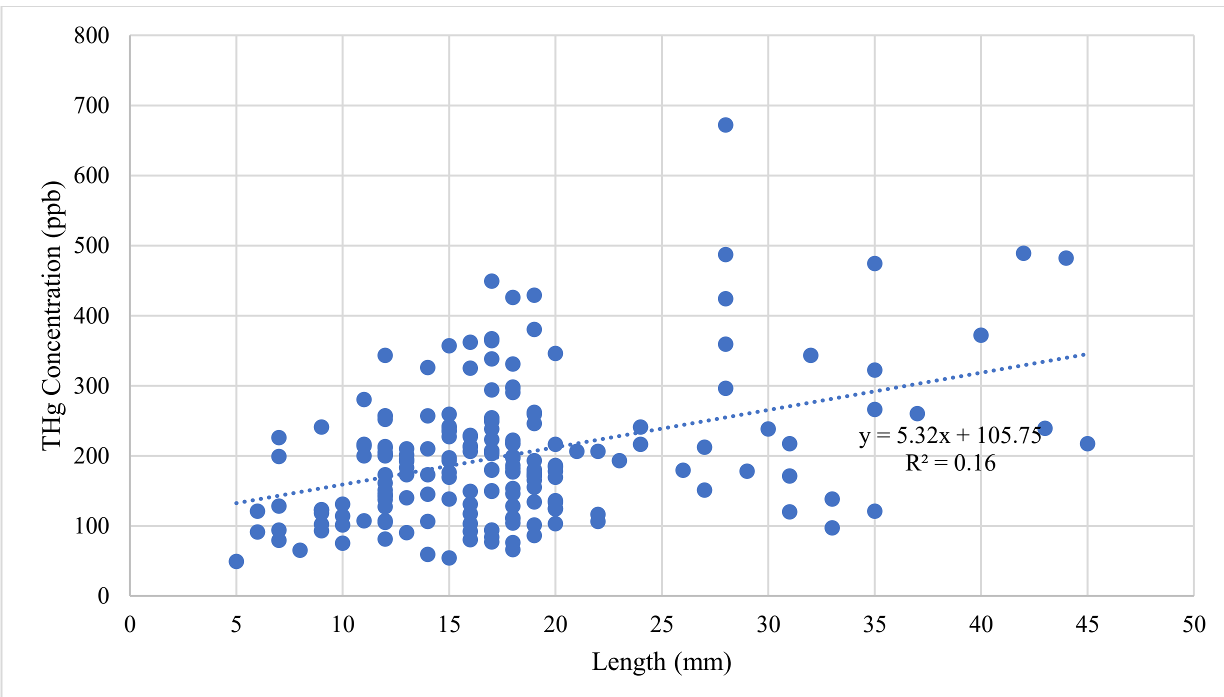

Figure 8. Relationship between total mercury (THg) concentration and length of dragonfly larvae (in millimeters) collected from eleven Penokee Lakes.

A connection to wetlands has been shown to influence its THg concentration and increase methylmercury (MeHg) production in waterbodies (Selvendiran *et al.*, 2008; Haro *et al.*, 2013; Watras *et al.*, 2019; Eagles-Smith *et al.*, 2020). The DMP found that areas in habitats with wetland connections have on average 35% higher THg concentrations than those without (Eagles-Smith *et al.*, 2020). Wetlands act as sinks for Hg due to their physical and chemical characteristics. They also have an active presence of sulfate reducing bacteria, which are an important component for MeHg production (Selvendiran *et al.*, 2008). Forested wetlands are a prevalent landscape in the study region. The percentage of wetland area within each lake's watershed was calculated in GIS using Wisconsin Department of Natural Resources WISCLAND data and graphed against mean lake THg concentration (Figure 9). The resulting relationship was a weak and negative correlated with an r-squared value of 0.11. The relationship was not statistically significant ($\alpha = 0.05$).

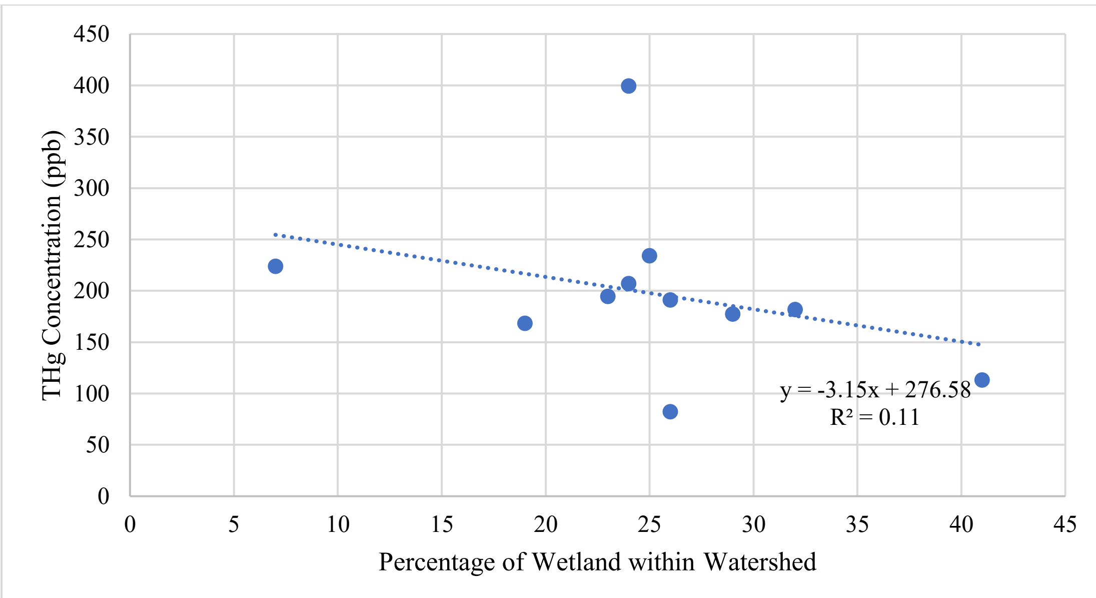

Figure 9. Relationship between the mean total mercury (THg) concentration in dragonfly larvae from the eleven Penokee Lakes and the percentage of wetland area within each lake's watershed.

Wetlands have high concentrations of Dissolved Organic Carbon (DOC), which has been shown in previous studies to have a positively correlated relationship with THg concentrations in the water column (Watras *et al.*, 1995, 2019; Driscoll *et al.*, 2007; Blackwell *et al.*, 2014; Jeremiason *et al.*, 2016; Eagles-Smith *et al.*, 2020). DOC is the organic matter, often from detritus, that exists in the water column and can pass through a filter. DOC forms complexes with Hg, acting as a carrier from upstream sites into lakes, it also promotes speciation into MeHg (Gorski *et al.*, 2008; Driscoll *et al.*, 2013; Eagles-Smith *et al.*, 2020). In order to approximate water column DOC and compare it to THg in the dragonfly larvae, Colored Dissolved Organic Matter (CDOM) measurements from each Penokee lake were compared to THg concentrations. The MGBCFI uses an *in situ* fluorometer with ultraviolet (UV) excitation for CDOM detection. These data are collected as part of regular vertical sonde profiles collected from the deepest part of each lake. CDOM data collected over the 2019 season were averaged for each lake. Mean CDOM concentration was graphed against mean THg concentration in dragonfly larvae from each lake (Figure 10). There was no correlation between CDOM and THg and the relationship was not statistically significant ($\alpha = 0.05$). Variability associated with using the *in situ* CDOM measurements to approximate DOC may have confounded any potential relationships between THg and DOC, so a more direct measurement of DOC to compare with THg in dragonfly larvae has the potential to yield different results.

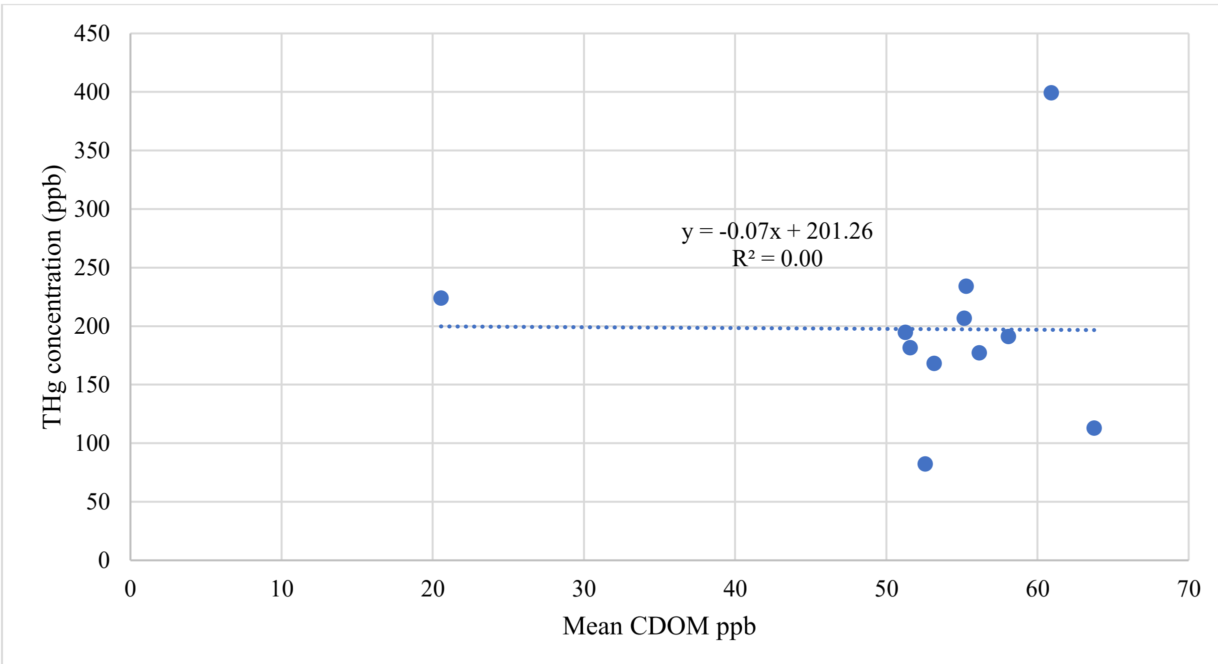

Figure 10. Relationship between mean total mercury (THg) concentration in dragonfly larvae and mean colored dissolved organic matter (CDOM) concentration in water for each of the eleven Penokee Lakes.

It has also been shown that high DOC accompanied by low pH has had an explanatory relationship with THg concentrations (Watras *et al.*, 1995, 2019) and, to a lesser extent, that pH alone has a negatively correlated relationship with THg (Hrabik and Watras, 2002). Mean pH was graphed against mean dragonfly larvae THg concentration from each lake (Figure 11). The resulting relationship had a slightly negative slope but virtually no correlation and no statistical significance ($\alpha = 0.05$) with an r-squared value of 0.04.

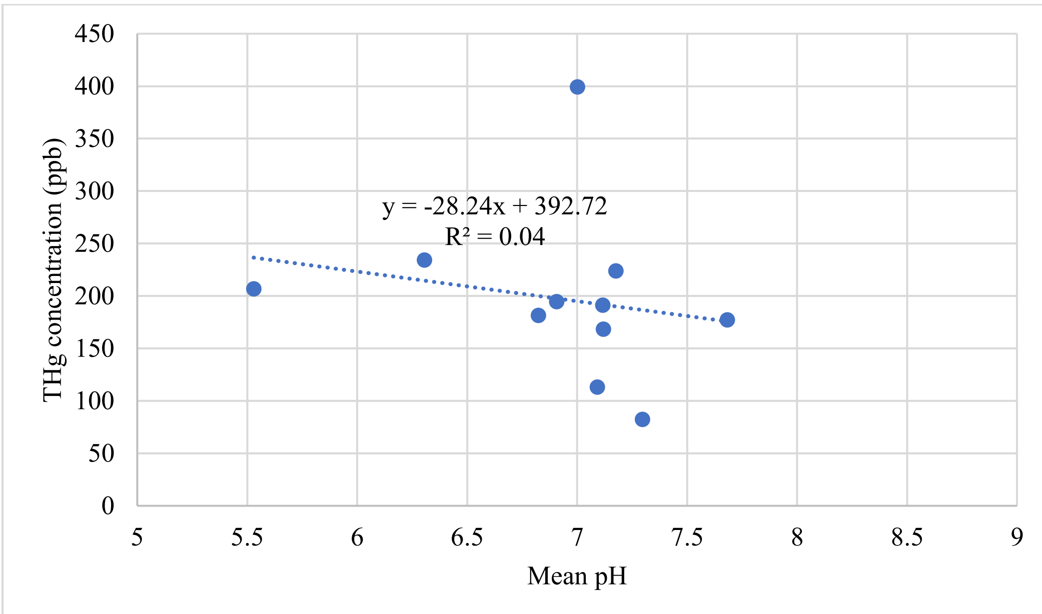

Figure 11. Relationship between mean total mercury (THg) concentration in dragonfly larvae and mean pH measurement for each of the eleven Penokee Lakes.

MeHg concentrations have been shown to follow water level oscillations in Northern Wisconsin lakes (Watras *et al.*, 2019). Frequent water level changes can increase mercury methylation and bioaccumulation, and dragonfly larvae found in seasonal wetlands had significantly higher THg concentrations than those who were found in permanent wetlands (Eagles-Smith *et al.*, 2020). The increase in methylation is likely due to mobilization of legacy mercury, redox cycle of sulfur, DOC input from decomposing flooded vegetation, and changes in sulfate and mercury concentrations in methylation zones (Watras *et al.*, 2019). Continuous water level measurements in many of the Penokee Lakes have been collected during ice-free periods since 2015. Mean and standard deviation of the water level data were calculated for each of the eleven lakes. The standard deviation from the mean water level was assumed to be a measure of the water level variance in each lake, meaning lakes with a greater standard deviation from the mean water level were more likely to have greater water level fluctuations. The standard deviation from the mean water level was compared to the lakes' mean larval dragonfly THg concentrations (Figure 12). There was relatively no relationship between the two variables, with a weak r-squared value of 0.12 and the relationship showed no statistical significance ($\alpha = 0.05$).

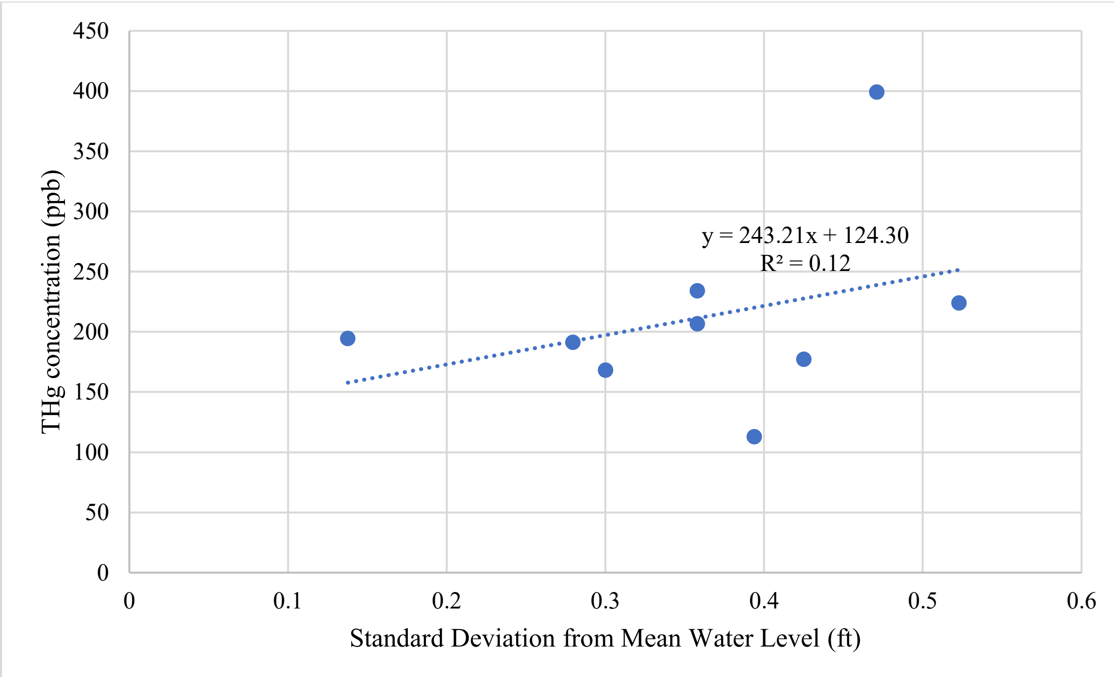

Figure 12. Relationship between mean total mercury THg concentration and mean water level difference over the years for which data has been collected.

Using their collected data, researchers with the DMP have generated an integrated impairment index to estimate the severity of potential risk of dragonfly THg concentrations to fish, wildlife, and humans through fish consumption using an Aeshnid-equivalent linear regression (Eagles-Smith *et al.*, 2020). These Aeshnid-equivalents transform all of the collected dragonfly family THg concentrations to concentrations that are consistent with those of the Aeshnidae dragonfly family THg concentrations, allowing for more uniform comparison across time, space, and family (Eagles-Smith *et al.*, 2020). Based on the magnitude of THg and the number of fish guilds, other wildlife, and human life impaired, the integrated impairment index is broken into five categories (Table 2).

Integrated Impairment Index	Aeshnid-equivalent THg Concentration (ppb dry weight)	Health Risk
Sub-impairment	<60	Piscivorous fish pose a low health risk to piscivorous predators
Low-hazard	60-100	Piscivorous fish pose a low health risk to bird predators; sunfish pose a low health risk to other fish predators
Moderate-hazard	100-300	Piscivorous fish are at moderate health risk and exceed US EPA MeHg criterion for human consumption; piscivorous fish and sunfish pose a moderate health risk to bird predators; dragonfly larvae, forage fish, and salmonids pose a low health risk to fish predators
High-hazard	300-700	Piscivorous fish and sunfish are at moderate health risk and pose a high health risk to bird predators; sunfish exceed US EPA MeHg criterion for human consumption; dragonfly larvae, forage fish, and salmonids pose a low health risk to bird predators
Severe-impairment	>700	Piscivores and sunfish are at high health risk and pose a high health risk to bird predators, salmonids exceed US EPA MeHg criterion for human consumption, salmonids, forage fish, and dragonfly larvae pose a moderate health risk to fish and bird predators, and salmonids and forage fish are at moderate health risk.

Table 2. Integrated Impairment Index using Aeshnid-equivalent total mercury (THg) concentrations with associated health risks (Eagles-Smith *et al.*, 2020).

For a more representative comparison of the dragonfly larvae THg concentrations within the Penokee Lakes were compared to the DMP integrated impairment index. Corduliidae THg concentrations were converted to Aeshnid-equivalent THg concentrations using the formula 0.931 x Corduliidae THg concentration + 0.556 = Aeshnid-equivalent (Eagles-Smith *et al.*, 2020). Geometric mean Aeshnid-equivalent THg concentrations were calculated for each lake and were compared along with Aeshnidae geometric mean THg concentrations to the DMP integrated impairment index (Figure 13). All eleven lakes besides Meder and Eureka fell within the moderate-hazard integrated impairment index. Meder fell within the low-hazard integrated impairment index. Eureka fell within the high-hazard integrated impairment index.

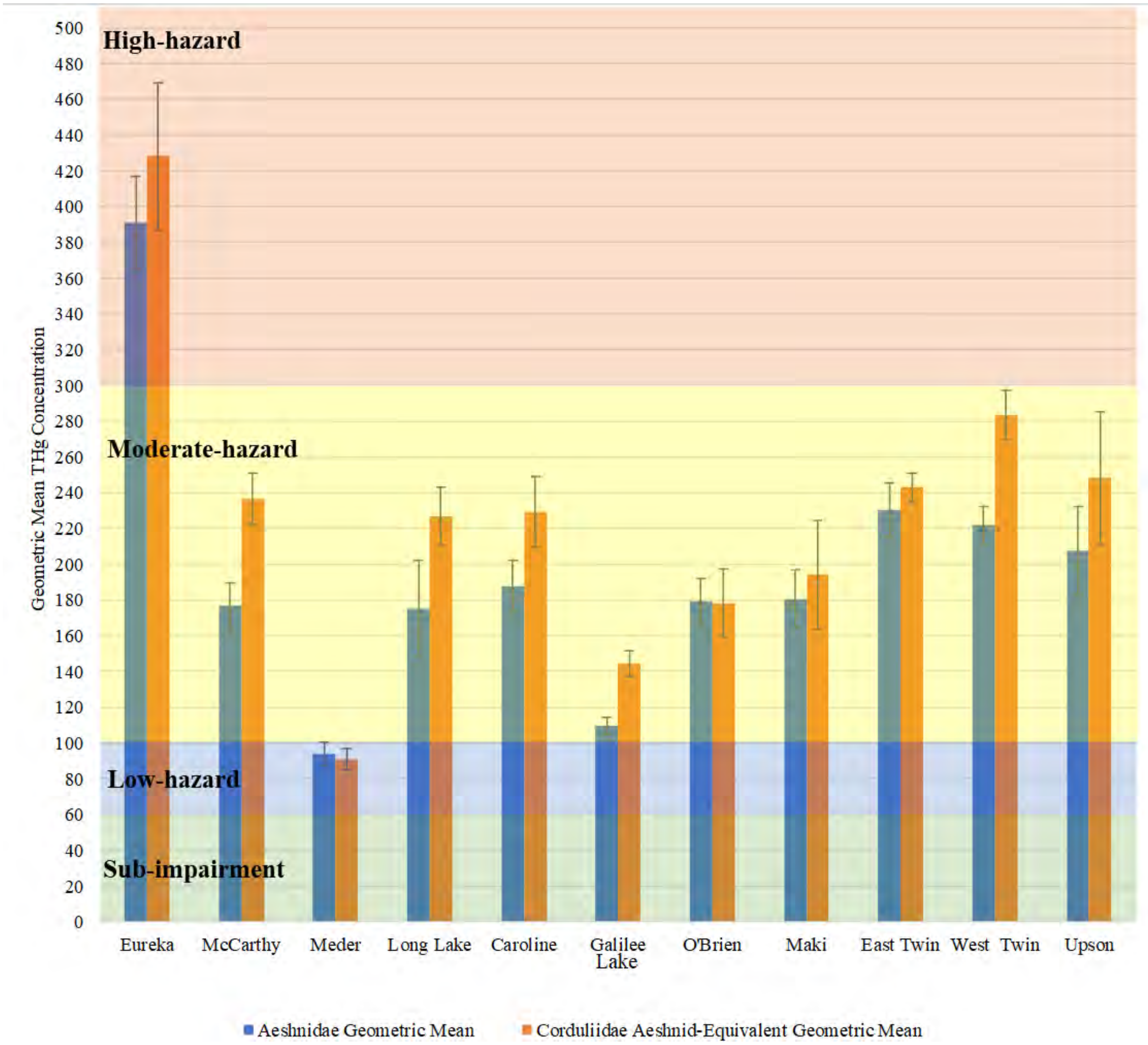

Figure 13. Aeshnidae geometric mean total mercury (THg) concentration, geometric mean Aeshnid-equivalent THg concentration, and Corduliidae Aeshnid-equivalent THg geometric mean concentration for each lake (bars) compared to the DMP's integrated impairment index values (shaded areas).

Conclusion

The consistency of THg concentrations between the Aeshnidae and Corduliidae larvae within each lake demonstrates the success of using dragonfly larvae as biosentinels for THg comparison among the Penokee lakes. The THg concentrations for both families show Eureka, Meder, and Galilee Lakes as potential outliers; Eureka on the high end, and Meder and Galilee on the low end. The cause for the extreme differences in THg concentrations between these outliers and the rest of the lakes is still unknown. Explanatory variables from previous studies examining THg concentrations in aquatic habitats and biota (wetland density, DOC, pH, and water level fluctuations) all had weak or non-existent relationships to THg concentration in the Penokee Lakes, even with the removal of outliers, showing no explanatory power in this study.

Further investigation of explanatory variables, especially those which explain the large variance between the Eureka, Meder, Galilee and the rest of the Penokee Lakes, is important. Given that this study looked primarily into environmental and water quality variables, there should be a study examining potential differences between food webs in the Penokee Lakes. Differences within a food web can affect the biomagnification of mercury and other contaminants, therefore potentially explaining observed differences between THg concentrations. A deeper examination into the potential relationship between DOC and THg should be considered as well. Through numerous studies, DOC plays a highly influential role in THg concentrations and future studies should consider taking lab measurements of DOC to compare with THg in lakes. If neither of these variables provide explanation, it is still possible that larger ecosystem factors could explain differences in THg concentrations. Forest type and cover within the watershed as well as climactic changes could have influence over THg concentrations within the lakes *(*Blackwell *et al.*, 2014; Watras *et al*., 2019) and should also be considered as potential future subjects of study.

The higher concentration of THg in Eureka puts the lake within the high-hazard integrated impairment index. Due to the potential risk to the ecosystem and human health, follow-up testing for total mercury concentrations of the fish population in Eureka Lake is advised. This testing would confirm whether fish exceed the EPA's MeHg criterion for human consumption so that mercury advisories for Eureka can be updated if necessary. It may be beneficial for fish within the lakes that fall within the moderate-hazard integrated impairment index to be tested for total mercury levels as well, due to potential risk to wildlife.

While the differences between the lakes in the Penokee system remain unexplained, the use of dragonfly larvae as a means of comparison was successful. Due to this success, and the potential risks of mercury within the ecosystem, especially within Eureka Lake, it should be added to the annual sampling routine of the MGBCFI. Using the DMP model there is also potential to involve citizens in the collection and identification process of dragonfly larvae from these lakes. With the use of citizen science, sampling dragonfly larvae for mercury can be a means of education of toxicity in the environment as well as a means of connection to and stewardship of place for the people who call the Penokee Lakes home.

References Cited

Biggam, G., Henry, B., and Bessinger, B., 2005, Mercury - A Tale of Two Toxins: Natural Resources & Environment, v. 19, p. 26–30.

Blackwell, B.D., Driscoll, C.T., Maxwell, J.A., and Holsen, T.M., 2014, Changing climate alters inputs and pathways of mercury deposition to forested ecosystems: Biogeochemistry, v. 119, p. 215–228, doi:10.1007/s10533-014-9961-6.

Cannon, W.F., LaBerge, G.L., Klasner, J.S., and Schulz, K.J., 2008, The Gogebic iron range - A sample of the northern margin of the Penokean fold and thrust belt: US Geological Survey Professional Paper, doi:10.3133/pp1730.

Driscoll, C.T., Han, Y.-J., Chen, C.Y., Evers, D.C., Lambert, K.F., Holsen, T.M., Kamman, N.C., and Munson, R.K., 2007, Mercury Contamination in Forest and Freshwater Ecosystems in the Northeastern United States: BioScience, v. 57, p. 17–28, doi:10.1641/b570106.

Driscoll, C.T., Mason, R.P., Chan, H.M., Jacob, D.J., and Pirrone, N., 2013, Mercury as a global pollutant: Sources, pathways, and effects: Environmental Science and Technology, v. 47, p. 4967–4983, doi:10.1021/es305071v.

Durand, Loyal, J., and Bertrand, K., 1935, The Forest and Woodland Regions of Wisconsin /209601: Geographical Review, v. 25, p. 264–271.

Eagles-Smith, C.A., Willacker, J.J., Nelson, S.J., Flanagan, C.M., Krabbenhoft, D.P., Chen, C.Y., Ackerman, J.T., Campbell, E.H., and Pilliod, D.S., 2020, A National-Scale Assessment of Mercury Bioaccumulation in US National Parks Using Dragonfly Larvae as Biosentinels Through a Citizen Science Framework: Environmental Science and Technology, p. 1–40.

Eagles-Smith, C.A., Willacker, J.J., Nelson, S.J., Flanagan Pritz, C.M., Krabbenhoft, D.P., Chen, C.Y., Ackerman, J.T., Grant, E.H.C., and Pilliod, D.S., 2020, A National-Scale Assessment of Mercury Bioaccumulation in United States National Parks Using Dragonfly Larvae As Biosentinels through a Citizen-Science Framework: Environmental Science and Technology, p. 8779–8790, doi:10.1021/acs.est.0c01255.

Fitzgerald, W.F., and Watras, C.J., 1989, Mercury in surficial waters of rural Wisconsin lakes: Science of the Total Environment, The, v. 87–88, p. 223–232, doi:10.1016/0048-9697(89)90237-4.

Gorski, P.R., Armstrong, D.E., Hurley, J.P., and Krabbenhoft, D.P., 2008, Influence of natural dissolved organic carbon on the bioavailability of mercury to a freshwater alga: Environmental Pollution, v. 154, p. 116–123, doi:10.1016/j.envpol.2007.12.004.

Haro, R.J., Bailey, S.W., Northwick, R.M., Rolfhus, K.R., Sandheinrich, M.B., and Wiener, J.G., 2013, Burrowing dragonfly larvae as biosentinels of methylmercury in freshwater food webs: Environmental Science and Technology, v. 47, p. 8148–8156, doi:10.1021/es401027m.

Hrabik, T.R., and Watras, C.J., 2002, Recent declines in mercury concentration in a freshwater fishery: Isolating the effects of de-acidification and decreased atmospheric mercury deposition in Little Rock Lake: Science of the Total Environment, v. 297, p. 229–237, doi:10.1016/S0048-9697(02)00138-9.

Jeremiason, J.D., Reiser, T.K., Weitz, R.A., Berndt, M.E., and Aiken, G.R., 2016, Aeshnid dragonfly larvae as bioindicators of methylmercury contamination in aquatic systems impacted by elevated sulfate loading: Ecotoxicology, v. 25, p. 456–468, doi:10.1007/s10646-015-1603-9.

Lindberg, S. *et al.*, 2007, A Synthesis of Progress and Uncertainties in Attributing the Sources of Mercury in Deposition: Ambio, v. 36, p. 19–32.

Marsden, R.W., 1978, Iron Ore Reserves of Wisconsin- A Mineral Availability System Report, *in* Duluth, Minnesota, p. 24–1 to 24–28.

Nelson, S.J., Eagles-Smith, C.A., Flanagan Pritz, C., Klemmer, A.J., Willacker, J.J., Blakesley, A., and Hess, M.C., 2018, Dragonfly Mercury Project: Sampling Guide for the Collection of Dragonfly Larvae: , p. 1–21.

Pritz, C.F., Eagles-Smith, C., and Krabbenhoft, D., 2014, Mercury in the National Parks: The George Wright Forum, v. 31, p. 168–180.

Selvendiran, P., Driscoll, C.T., Bushey, J.T., and Montesdeoca, M.R., 2008, Wetland influence on mercury fate and transport in a temperate forested watershed: Environmental Pollution, v. 154, p. 46–55, doi:10.1016/j.envpol.2007.12.005.

Sparling, R., 2009, Mercury methylation made easy: Nature Geoscience, v. 2, p. 92–94, doi:10.1029/2007PA001513.

Stopford, W., and Goldwater, L.J., 1975, Methylmercury in the environment: a review of current understanding: Environmental Health Perspectives, v. Vol.12, p. 115–118.

UNEP, 2002, Global Mercury assessment:, http://www.unep.org/gc/gc22/Document/UNEP-GC22-INF3.pdf.

US EPA, 2007, Mercury total (organic and 7439-97-6 inorganic): , p. 1–17, https://www.epa.gov/sites/production/files/2015-07/documents/epa-7473.pdf.

USEPA, 2001, Water Quality Criterion for the Protection of Human Health : Methylmercury Final.:

Watras, C.J., Grande, D., Latzka, A.W., and Tate, L.S., 2019, Mercury trends and cycling in northern Wisconsin related to atmospheric and hydrologic processes: Canadian Journal of Fisheries and Aquatic Sciences, v. 76, p. 831–846, doi:10.1139/cjfas-2018-0157.

Watras, C.J., Morrison, K.A., Host, J.S., Bloom, N.S., and Geosciences, F., 1995, Concentration of Mercury Species in Relationship to Other Site-Specific Factors in the Surface Waters of Northern Wisconsin Lakes Author (s): Carl J . Watras , Kenneth A . Morrison , Jodi S . Host and Nicolas S . Bloom Stable URL : https://www.jstor.org: Limnology and Oceanography, v. 40, p. 556–565.

Appendix G – Summary of Management Plan Comments and Responses

Section 3 of the management plan describes the overall process for stakeholder engagement, gathering information on uses and values of the Penokee Lakes, and gathering/addressing comments about the plan. Further detail on comments received on draft versions of the management plan are described here.

Conversations between Dawn White and John Coleman from the Great Lakes Indian Fish and Wildlife Commission, Edith Leoso, Tribal Historic Preservation Officer for the Mashkiiziibii Natural Resources Department, and Burke Center staff in March and April 2021, led to the “Cultural Uses and Values” section described in Section 3.1. The contribution of the text for this section from Dawn White, John Coleman, and Edith Leoso was a critical component of formally weaving Ojibwe lifeways into the management plan and acknowledging the cultural uses and values of the Penokee Lakes as an overarching goal for the management plan.

Following the effort to incorporate cultural uses and values into the draft management plan goals, a virtual meeting was held by Burke Center staff on May 21, 2021 that was mainly focused on a discussion with the broader stakeholder group about proposed management goals and implementation strategies. During the meeting, participants expressed strong support for maintaining and enhancing water quality in the Penokee Lakes and identifying concrete action items following monitoring efforts. Participants were given the option to provide verbal input during the meeting and respond to an online survey after the meeting. All responses were compiled and used to update the draft management plan goals, as well as develop a series of implementation strategies for each of the goals.

The updated goals and implementation strategies were shared with the stakeholder group, along with an Executive Summary of the management plan on November 2, 2021 for a 30-day comment period. In the interim period, a draft of the main body of the management plan was completed, additional comments addressed, and the draft management plan minus appendices was sent out to stakeholders on December 22, 2021. Comments on this draft were addressed and incorporated into the management plan, the appendices were completed, and the final draft was submitted for approval on June 24, 2022. Final approval of the plan and grant deliverables was completed by WDNR staff on 7/25/2022.

The following table includes the individual comments that were received by Burke Center staff from various stakeholders regarding the draft management plan. All comments were incorporated into the plan unless noted *in italics within the comment*.

Name	Affiliation	Date	Comment
MaryJo Gingras	Ashland County Land and Water Conservation Dept.	5/20/2021	Mgmt Goal 1. Agree with this goal. This goal is supported by the Ashland County Land & Water Conservation Dept. as Goal 1 in the revised Ashland Co. Land & Water Resource Mgt Plan is to Maintain & Enhance Ashland Co.'s Surface Water. Also develop a long-term surface water monitoring plan. Develop planning strategies which account for increased precipitation related to climate change in Ashland County. Mgmt Goal 2. Agree with this goal. This would provide opportunity to work with shoreland owners on shoreline habitat restoration and erosion control which is a practice that is cost-sharable through the Ashland County LWCD. We can provide technical and financial assistance. Mgmt Goal 3. Agree with this goal. This would provide opportunity to work with shoreland owners on shoreline habitat restoration and erosion control which is a practice that is cost-sharable through the Ashland County LWCD. We can provide technical and financial assistance. Mgmt Goal 4. Agree with this goal. May need to consider adaptation strategies for any lakes without inlet or outlet as seepage lakes may be more impacted by increased precipitation (Pigeon Lake; Bayfield County) as an example). Mgmt Goal 5. Agree with this goal. Diversity provides for the greatest habitat protection and greatest potential to keep invasive species. Diversity also reduces devastating impact of pest/insect invasion (Dutch elm, etc). Also promote native plant diversity AND account for species transition related to climate change (i.e. Climate Change Projections for Individual Tree Species) www.forestadaptation.org - https://forestadaptation.org/sites/default/files/212J_ Southern%20Superior%20Uplands%201-21.pdf) https://forestadaptation.org/learn/resource-finder/ tree-species-projections-ecological-sections-northern-Wisconsin Mgmt Goal 6. Agree with this goal. Agree with importance; don't have knowledge about the species to comment. Don't know enough about the

Name	Affiliation	Date	Comment
			species to provide specific recommendations other than to consider species transition if water temps increase by the end of the century. Mgmt Goal 7. Agree with this goal. Mgmt Goal 8. Agree with goal. Mgmt Goal 9. Neutral on this goal. I'm not sure about current levels of use for all lakes, so I cannot comment on them. Mgmt Goal 10. Agree with this goal.
Matt Dallman	The Nature Conservancy	5/20/2021	Mgmt Goal 1. Agree with this goal. However, if there are property level, or watershed level activities we can promote with land owners we should pursue those efforts. Mgmt Goal 2. Agree with this goal. There's never enough money or willing sellers (or state or non-profit staff capacity) to do this all, so focusing on a targeted small list of land owners that can have the greatest impact will be key. Finding people open to conservation/land protection that know landowners on the targeted list to make introductions will be important. Maybe members of this Penokee Lakes group can use their networks to find friends of these owners. The Nature Conservancy would like a natural partner to intro us to the owner of the north end of Caroline Lake. Mgmt Goal 3. Agree with this goal. Especially on lakes where development has occurred. Will need an outreach plan to make landowners aware of programs that are available. Mgmt Goal 4. Somewhat agree with this goal. However, given climate change driven intensive storm events, this may be a goal that's difficult to achieve. For water levels, I wouldn't want to see control structures placed only to achieve this goal. For hydro processes, maintaining forests and wetlands. carefully planning road project (ditching/culverts/road-stream crossings) and keep this landscape from bring open pit mined will be key.

Name	Affiliation	Date	Comment
			Mgmt Goal 5. Agree with this goal. Not sure if this is only focused on aquatic vegetation or watershed/landscape vegetation. I'd suggest we look at the landscape. Forests are a big driver of the hydrologic process across this watershed. Diversity in tree species will serve as a buffer against climate change, since we do not exactly know what species will be winners and losers. Promoting management based on this document would be useful. https://forestadaptation.org/field-guide-northern-wisconsin Mgmt Goal 6. Agree with this goal. Eventually climate impacts may complicate the maintenance of any coldwater fisheries, but given the topography and proximity to Lake Superior there may be opportunities to life-boat coldwater fishes. Given the most of these lakes are bass-panfish-northern, lakes this goal should be achievable over the long run. Mgmt Goal 7. Agree with this goal. Mgmt Goal 8. Agree with this goal. Mgmt Goal 9. Somewhat agree with this goal. May need to better plan ORV/ATV/UTV use and better control/enforce use of these vehicles in non-permitted areas (especially in Iron Co). While I'd like to see greater limits on where these vehicles can operate, I'm also conscience of the economic impact of recreational vehicle use to the region. We need to maintain a place for use of these vehicles, but we should also monitor impacts from a water quality, spread of invasives, habitat disturbance/destruction perspective. Non-motorized, hiking, biking, (mountain biking), skiing could be promoted with limited environment impact if planned right. For motor and non-motor use on the lakes themselves - we all know boat landings are the primary entry point of invasives. Monitoring and control needs to be part of this goal. Mgmt Goal 10. Agree with this goal.
Jessica Strand	Mashkiiziibii Natural	5/20/2021	Mgmt Goal 1. Agree with this goal. I agree that the water quality at the lakes should be protected as one of the highest goals, but I would like to ensure that the lakes

Name	Affiliation	Date	Comment
	Resources Dept.		experiencing WQ concerns would be addressed to. I like the wording that Mary Jo shared: "Maintain and enhance water quality conditions". Also landowner outreach regarding the use of fertilizers and maintaining appropriate shoreline buffers. Periodic monitoring to ensure WQ is being maintained. Possible zoning requirements or protective easements for land use around the lakes. Mgmt Goal 2. Agree with this goal. Shoreline and nearshore habitat is very important because it is critical to a healthy functioning ecosystem for the lakes. Appropriate setbacks and buffers for future development and restoration for areas currently developed that need to be restored. Possible Slow, No Wake ordinances for lakes where motorized traffic is allowed to minimize degradation due to wake disturbance, especially for those lakes where manoomin is growing. Mgmt Goal 3. Agree with this goal. Restoration of the shorelines could provide so many tangible benefits to the lake. Work on repealing legislation that inhibits local and counties setting more restrictive shoreline zoning rules by working with outside partners. I also like Heather's suggestion about the tax break for the shoreline buffer program, if feasible. Mgmt Goal 4. Somewhat agree with this goal. I do not know if there are any of these lakes that are impaired due to manmade structures artificially altering the hydraulic regime of the lake, if so, I think an analysis would be needed about whether the health of the lake would benefit from this artificial alteration being removed. I think this USGS work would be a good base to start with additional models rather than starting from scratch: https://www.researchgate.net/publication/284550407_Groundwatersurface-water_interactions_in_the_Bad_River_Watershed_Wisconsin Mgmt Goal 5. A diverse native plant community will increase resiliency to climate change, hopefully. Also ensure that timber harvests in the watersheds for these lakes follow BMPs for forest health and climate resiliency by working with partners, local agencies, and land owners. Also, complete monitoring for invasive species frequently and post

Name	Affiliation	Date	Comment
			educational signage at any public access points (terrestrial and aquatic) for invasive species. Mgmt Goal 6. Agree with this goal. Mgmt Goal 7. Agree with this goal. Mgmt Goal 8. Agree with this goal. Mgmt Goal 9. Neutral on this goal. I'm not sure about current levels of use for all lakes, so I cannot comment on them. Mgmt Goal 10. Agree with this goal.
Bobbi Rongstad	Private Landowner, O'Brien Lake	5/20/2021	Mgmt Goal 1. Agree with this goal. We should maintain and even improve water quality in these lakes. Continuous (citizen science?) monitoring should help to engage the public and keep the focus. Proper maintenance of septic systems, stormwater management, ongoing education for landowners. Mgmt Goal 2. Agree with this goal. Add education. *NOTE: Added to Goal 3 (instead of Goal 2 as suggested here) as a need specifically for shoreland habitat protection program for landowners.* Mgmt Goal 3. Agree with this goal. Add funding and design assistance. Mgmt Goal 4. Agree with this goal. Climate change, development and forest management practices have the potential to change lake levels. Not sure how much of that we, as a group, can have control over. Also education, opportunities to provide input on forest management plan in the areas surrounding these lakes

Name	Affiliation	Date	Comment
			Mgmt Goal 5. Agree with this goal. There are so few places left with diverse native plant communities. Seems like it is our responsibility to protect them. Mgmt Goal 6. Agree with this goal. The health of the fish populations is likely tied directly to the water quality. They need to be considered together. Mgmt Goal 7. Agree with this goal. These lakes are in the ceded territory and within the Bad River Watershed which flows through the reservation, effecting the Bad River Band in so many ways. It is only right to work with them on this effort. Continue consulting with the tribes and GLIFWC. Mgmt Goal 8. Agree with this goal. One of the first times I visited Lake O'Brien, about 25 years ago, there were a couple of clear cuts scarring the landscape along the road on the way in. I commented once we arrived at the lake that someday, people would likely pay admission to see what a natural forest on a woodland lake looked like. The natural beauty of the place is so very important. Also forest management, water quality measures and all the other things discussed above. Mgmt Goal 9. Agree with this goal. The beauty and peaceful atmosphere of the lake is destroyed by the sound of a motor, the oil sheen from a motor, disruption of the waterfowl, threat of invasive species being introduced. If it were up to me, I'd lobby to close the boat landing, too. I can't speak for the other lakes where I'm not familiar. Mgmt Goal 10. Agree with this goal. Always good to have a roadmap. Other comment: I really appreciate all the monitoring and background data that has been collected to get to this point and I look forward to the next steps.
Dan Scudder	Private Landowner, Lake Galilee	6/16/2021	Mgmt Goal 1. Agree with this goal. The lake activities we enjoy - swimming, fishing, wild life viewing and the native plants - depend on maintaining the current water quality conditions.

Name	Affiliation	Date	Comment
			Also Manage invasive species, manage shoreland runoff, manage septic/wastewater inputs. Mgmt Goal 2. Agree with this goal. Part of the value my family places on the lakes relates to the native plants and wildlife. Natural habitat is critical to that. Also Outreach, education & resources for property owners, education & enforcement of shoreland zoning regulations, county oversight of lake properties that are routinely rented-out to vacationers to ensure that wastewater loads are not exceeding the design capacity of the septic system (such as 10-12 people renting a dwelling with a septic system sized for a family of 4-6). *NOTE: Education, outreach, and resources for landowners added to Goal 3 (instead of Goal 2 as suggested here) as a need specifically for shoreland habitat protection program for landowners.* Mgmt Goal 3. Agree with this goal. To maintain the natural setting and facilitate habitat for native species. This will be a difficult goal because restoration can be expensive, and may require local fundraising for specific restoration projects. Projects/activities should be selected based on individual lake needs. Tree falls and shoreline brush may be beneficial in some lakes. Mgmt Goal 4. Agree with this goal. If these aren't maintained it will be difficult to maintain water quality and habitat. Gain a better understanding of the watersheds and aquifers/groundwater contributing to the lakes, for any lakes with a control structure at its outlet work with DNR to establish the optimum outlet level. Mgmt Goal 5. Somewhat agree with this goal. I would say, "maintain plant communities native to the lake/watershed." I wouldn't advocate introducing additional native plants (that may never have been present) to a watershed. *Noted but decided to leave this goal title as is because the word "maintain" implies keeping current conditions.* A biologic survey of the lakes and their watersheds to establish a blueprint for going forward.

Name	Affiliation	Date	Comment
			Mgmt Goal 6. Somewhat agree with this goal. Again, I would modify the goal to read, "maintain native fish populations." *Noted but decided to leave this goal title as is because the word "maintain" implies keeping current conditions.* Over the years DNR and others have introduced additional native fish species, such as northerns, into lakes that never had them. In hindsight most, including DNR, don't think it was very beneficial. Fish and lake surveys, which DNR has done on a few lakes, to understand what's currently in each lake. Then work with DNR & others to develop a plan to support and sustain desirable species. Mgmt Goal 7. Agree with this goal. The tribes may be a critical ally in efforts to maintain water quality and habitat. Any plan should recognize their interests and goals for the ceded territory. Consult and partner with interested tribes. Mgmt Goal 8. Neutral on this goal. "Scenic beauty" is in the eye of the beholder. Sometimes natural systems can be a bit messy, or even ugly. I'd rather have a truly natural system than one that's beautiful but not natural. Foster, support and maintain the natural ecosystems occurring around the Penokee Lakes. Mgmt Goal 9. Agree with this goal. To get the broadest support for our goals I think we need to recognize that many people enjoy the lakes with various types and uses of motorized watercraft. However, the Penokee Lakes are not large and cannot sustain high volumes of motorized boating. Trying to maintain current, or near current, levels is probably the best we can aim for. Work with DNR and the towns to identify necessary and appropriate restrictions. Outreach to water users regarding courtesy for multiple use activities. Mgmt Goal 10. Agree with this goal.

Name	Affiliation	Date	Comment
			Other comment: This is a good set of goals, with maybe a few "tweaks" needed. If these goals are worked on and mostly achieved we'll be able to preserve and enjoy the Penokee Lakes for a while longer.
Jim and Maria Minikel	Private Landowner, McCarthy Lake	6/17/2021	Mgmt Goal 1. Agree with this goal. Water quality of McCarthy Lake has always seemed to be good and your studies have documented that. Keep what is good! 1.Maintaining outflow of the lake. This is a recent concern McCarthy lake because the beaver dams are more numerous than ever! 2. Forbid use of gasoline motors on smaller lakes like McCarthy. 3. Limit public access points on smaller lakes to walk-in only Mgmt Goal 2. Somewhat agree with this goal. Protecting this area ultimately protects the lake itself. 1.Control/removal of invasive species on the shore and near shore areas. Mgmt Goal 3. Somewhat agree with this goal. Natural shorelines and near shore areas have a positive impact on lake life and water quality. On our lake, nature has done an impressive job of restoring the natural lakeshore habitat: huge riprap rocks are hidden by plants and downed trees. A concern is the change in lake levels over the years due mainly to beaver activity. In our short stay on McCarthy Lake (27 years) the lake level and therefore the location of the lake shore has varied at least 4 feet. Mgmt Goal 4. Neutral on this goal. Water levels are changing due to beaver activity. Beaver have been removed in the past and it clearly changed the lake. Is this a good thing that should be repeated? We don't know. Mgmt Goal 5. Agree with this goal. Native plants are most likely to thrive and produce the benefits of beauty, food, protection, etc. to the lake residents. Educate landowners about native plant communities and how to support them. Mgmt Goal 6. Agree with this goal. Diversity is protective of a thriving fishery.

Name	Affiliation	Date	Comment
			Mgmt Goal 7. Agree with this goal. It's way past time we non-native communities lived up to the treaties we ignored for too long. Specific recommendations for this goal should be developed collaboratively with the Ojibwe community. Mgmt Goal 8. Agree with this goal. Natural environments are healing in so many ways that are needed more and more. Mgmt Goal 9. Neutral on this goal. We don't know the level of motorized use on these 11 lakes. Gasoline engine use seems contraindicated on all these lakes because gas and oil always get into the water. Regulations on gasoline engines on these lakes. Mgmt Goal 10. Agree with this goal. Overall, we agree with these broad goals, understanding that this plan is not a one-size -fits-all plan; i.e. not all goals will be applied in the same way to all lakes.
Zach Lawson	Wisconsin DNR	8/10/2021	Sorry for the delayed response – I knew it'd be a while till I was able to get to this, but finally got to take a peek. Looks really good, you've got a mountain of data to deal with here, and I was able to make heads/tails of it, so nice work! If you want to discuss these items below, feel free to give me a call. Otherwise, see my thoughts, here: 1. I included a few quick general comments (attached) 2. I also attached the Meder lake survey summary (in case you wish to include those data) 3. May want to include the stocking histories for these fisheries? Let me know if I didn't' send those and you want them, I can pull those for you. 4. Regarding discussion/management recommendation: a. Are you planning on discussion/management recommendations/discussions for other species? b. Regarding walleye management recommendations/discussion, given the scope of the project here, I think it makes sense stick to simple inference from the data presented. I see a few main points

Name	Affiliation	Date	Comment
			i. Galilee and Meder have both shown that they have the capacity to produce walleye populations with quality size structures. ii. Both Galilee and Meder currently support low-density walleye fisheries, although have supported higher density adult populations in the past. iii. While walleye populations in both Galilee and Meder lakes have been supplemented with periodic stocking efforts, each system has also shown the capacity to produce natural year classes. iv. While both of these systems contain limited walleye spawning habitat, and exhibit characteristics of struggling/transitional walleye fisheries, regionally (see Raabe et al. 2020), recent data suggest that these systems may indeed support a low-moderate density walleye fishery. v. Given the recruitment histories of these lakes, I think a reasonable goal would be to document consistent natural reproduction, and maybe surpass regional recruitment benchmarks on at least a consistent basis. vi. Of course, to do so may require promoting favorable walleye habitats, protecting limited spawning habitats, promoting a conducive fish community for walleye dominance, and maintaining a native biotic community. vii. Continued monitoring of adult/juvenile walleyes, as well as overall fish community structure will be important for adaptive management strategies going forward.
Kevin Gauthier	Wisconsin DNR	10/28/2021	Mgmt Goal 4. A. Add stormwater management, so a. would read - Implement shoreline habitat restoration and stormwater management program focusing on areas with greatest restoration potential highlighted in shoreline habitat surveys. Realize more details are coming with the larger plan, but in goal 4. – Usually folks need someone (or they do this on their own) to come to their property and design a habitat restoration and/or stormwater plan – not sure if this would be its own thing (i.e., letter C) or embedded within the existing bullets A and B. I could probably think of a few more things to add under some of the existing goals/strategies – more like suggested actions to implement those. Thinking you will be developing those more within the bigger plan, so I can watch for those then and

Name	Affiliation	Date	Comment
			send along more thoughts at that time.
Bobbi Rongstad	Private Landowner, Lake O'Brien	11/4/2021	Chinese mystery snails are also present in Lake O'Brien. In fact, during a high school summer camp a few years ago, the teachers (Ron Nemec and Annie ??) grilled them and some kids tasted them. Ugh! Their numbers may be down in recent years because I don't recall seeing any this year, but we used to find them both on the 'beach' where you launch the canoe and along the dock. I suspected Racoons ate them because, at times, a stash of empty shells would pile up together at the shore. Regarding the blue-green algae… I probably mentioned this before but Joan identified a patch of it while we were kayaking around the shoreline a few years before you started monitoring. If you think there is any chance at all that failing septic systems or any other man-made concern is the cause, I'd like to be sure the owners are aware. I think I asked you this before but just wanted to check again.
Dawn White	Great Lakes Indian Fish and Wildlife Commission	12/1/2021	I do not have comments on the executive summary, other than it outlines the conditions of lakes and recommendations very nicely. Thank you for pulling all of this together.
Catherine Hein	Wisconsin DNR	12/10/2021	Overall, I like your recommendations. You got me thinking about a couple of items. 1. You've listed so many partners – I wonder if this project will recruit volunteers for long-term monitoring? I agree with your recommendation for continued monitoring. Trophic state, early detection AIS monitoring, and lake level monitoring could all be volunteer efforts. Perhaps in the detailed part of the report, you can list information on how to get involved. 2. I wonder if it would be worth putting a long-term monitoring plan suggestion in there for the dragonfly mercury monitoring. This might be hard to do because you leveraged your relationship with the park service for this initial sampling. I'm not sure if that can continue. It seems like an effort that would be nice to repeat every 5-10 years, similar to the plant point intercept survey.

Name	Affiliation	Date	Comment
			3. As you point out, this study was initially motivated by the proposed mine and lack of baseline data. I wonder if there is more to say here for mine preparedness besides the hydrologic study you recommend to better understand surface and groundwater interactions? Maybe also something more on the human side – simply being aware of mining prospects and getting involved in the planning process should another mine be proposed? *NOTE: This is an intriguing idea but we were not able to find a good way to incorporate it within a lake management planning context.*
Jim Brennan	Private Landowner, Lake Galilee	12/10/2021	Thank you for many years of your work on this project. I appreciate the product which will serve as a touchstone for our lake planning going forward.
Connie and John Franke	Private Landowners, Twin Lakes	12/13/2022	Great job Matt very thorough report!
Zach Lawson	Wisconsin DNR	1/26/2022	You bet – more than happy to help. Thanks for looping me in on this. I'd say it looks really good, this is quite a ball of wax to put together, but it looks like you did a fantastic job piecing everything together. I had a few very minor comments on page 95 – and am having some difficulty with Drive (probably internal IT issues…). In any event, to cut down on bulk, I screenshot my comments in the attachment here (again, very minor), but that's all I had on the fisheries section in the plan. Feel free to ship me the appendix when it's ready, I can take a look at that as well.
Kevin Gauthier	Wisconsin DNR	1/27/2022	What about adding more about uses of the lake other than human – i.e., in-lake biota, out of lake biota… not sure I have my head wrapped around this completely – there is mention of the cultural importance, but what about the importance of these lakes to plants, animals, ecology… that ultimately determines the quality of human uses. Thinking this could maybe be a section of sorts in the plan, could maybe even be woven into existing goals, or perhaps have another goal or 2 put in. *NOTE: This is an interesting idea and we felt like the addition of the cultural use and values kind of gets at the idea of protecting uses for non-human beings who use the lakes because of how interwoven tribal lifeways are with beings who use the lakes.* Coarse Wood survey is Coarse Woody Habitat (not debris….)

Name	Affiliation	Date	Comment
			High Diversity plant areas from PI surveys could be areas of focus for protection also – slow-no wake, shoreland rest/stormwater mgmt. (if needed), shoreland protection, education of the high habitat value and the importance of this diversity and to not lose it… In goals, “protect” is used, without what measure(s) could be used to protect – for instance, the wild rice goal.
Ashley Beranek	Wisconsin DNR	1/27/2022 and 2/3/2022	The Dropbox wouldn’t let me save documents to it so here are my edits. I focused most on the classification portion but there are a couple of other areas where I made edits. The attached spreadsheet has my Lillie-Lathrop calculations and a comparison of WDNR’s data to your recommendations. Please let me know if you have questions on any of my notes. *Follow-up comment received 2/3/2022 after addressing 1/27 comments:* Glad I can help! In looking through the spreadsheet I noticed on tabs EURKL and MAKI the formulas don’t use the last data point – don’t know if that was on purpose or not. Other than that it looks good.
Zach Lawson	Wisconsin DNR	7/13/2022	Sorry again, but went through the appendix here again and just clarified a few points and tried to: 1) Differentiate between relative abundance and absolute density estimates 2) Clarify a few of the regional standards/benchmarks I put everything in track changes here, but let me know if you have any questions/clarifications on things. Otherwise kudos to you, there are a lot of different types of data collected there on a lot of different lakes and I’d say she looks pretty darn good considering the mess of data you had to polish!

Name	Affiliation	Date	Comment
			I'll take a look at the complete draft too now, but wanted to get you these comments as these were the major things I meant to get you before this made it to Kevin et al. *Additional comment received 7/13/2022:* After going through the final draft, looks like the GLIFWC bios must have had a lot of the same comments - not much to change in the final version…. Looks good so I passed along the thumbs up in our internal review.