Stressor identification – Lakes

February 2021

Snake River Watershed Stressor Identification Report—Lakes

A study of local stressors limiting the fish community health in lakes within the Snake River Watershed, with a focus on Pokegama Lake. Pokegama Lake is impaired based on the Fish Index of Biotic Integrity.

Report prepared by Minnesota Department of Natural Resources staff, for the Minnesota Pollution Control Agency.

DEPARTMENT OF NATURAL RESOURCES

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CLEAN WATER LAND & LEGACY AMENDMENT

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Cover photos: Four Shoreline Images taken during a June 2019 Pokegama Lake Fish Survey. Images show two undeveloped shorelines and two highly developed shorelines with egregious clearing of vegetation observed, photos taken during a 2019 FIBI survey.

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Key terms and abbreviations

APM	Aquatic Plant Management
AMA	Aquatic Management Area
Contributing watershed	All upstream areas bounded peripherally by a divide that ultimately drain into a particular watercourse or water body
DO	Dissolved oxygen
DOW	Division of Waters number; in this report, a unique identification number for water basins in Minnesota. Numbering follows the format of XX-YYYY-ZZ where XX is a county code, YYYY is the basin number in that county, and ZZ is the sub-basin identifier

EPA	United States Environmental Protection Agency
FIBI	Fish-based lake index of biological integrity; an index developed by the MNDNR that compares the types and numbers of fish observed in a lake to what is expected for a healthy lake (range from 0–100). More information can be found at the MNDNR Lake Index of Biological Integrity website
HUC	Hydrologic Unit Code
Insectivorous species	A species that predominantly eats insects
Intolerant species	A species whose presence and/or abundance decreases as human disturbance increases
Littoral acres	In this report, the acres of a lake that are 15 feet deep or less
MDA	Minnesota Department of Agriculture
MNDNR	Minnesota Department of Natural Resources
MPARS	Minnesota Department of Natural Resources Permitting and Reporting System
MPCA	Minnesota Pollution Control Agency
Nearshore survey	In this report, a fisheries survey conducted at evenly spaced, but random sites along the shoreline utilizing 1/8 inch mesh seines and backpack electrofishing to characterize primarily the nongame fish community of a lake
NLCD	National Land Cover Database developed by the U.S. Geological Survey to provide spatially explicit information on the land cover and land cover change in the U.S.
Small benthic dwelling Species	A species that is small and predominantly lives in close proximity to the bottom
SSTS	Sewage treatment systems
StS	Score the Shore survey; a survey designed by the MNDNR to be able to rapidly assess the quantity and integrity of lakeshore habitat so as to assess differences between lakes and detect changes over time
TMDL	Total Maximum Daily Load
Tolerant species	A species whose presence or absence does not decrease, or may even increase, as human disturbance increases
TP	Total phosphorus; measurement of all forms of phosphorus combined
Vegetative dwelling species	A species that has a life cycle dependent upon vegetated habitats
Weight of evidence Approach	A method of using multiple sources or pieces of information to classify a waterbody as impaired

Executive summary

The Minnesota Pollution Control Agency (MPCA) in coordination with the Minnesota Department of Natural Resources (MNDNR) uses biological monitoring and assessment as a means to determine and report the condition of the state's lakes and inform restoration and protection strategies and projects. This approach examines fish communities and related habitat conditions at multiple lakes throughout major watersheds. Fish communities are sampled using a combination of trap nets, gill nets, beach seines, and backpack electrofishing. From these data, a fish-based index of biological integrity (FIBI) score can be developed, which provides a measure of overall fish community health. More information about the sampling and assessment process can be found at the MNDNR lake index of biological integrity website. If biological impairments are found, stressors to the aquatic community must be identified.

Stressor identification (SID) is a formal and rigorous process that identifies stressors causing biological impairment of aquatic ecosystems and provides a structure for organizing the scientific evidence supporting the conclusions (Cormier et al. 2000). In simpler terms, it is the process of identifying the major factors causing harm to aquatic life. SID is a key component of the major watershed restoration and protection projects supported by Minnesota's Clean Water Legacy Act.

This report summarizes SID work related to lakes in the Snake River Watershed. The Snake River Watershed encompasses about 1,006 square miles and is predominantly as a mix of forested, wetland, and agricultural land, and includes the cities of Mora and Pine City. The Snake River Watershed also contains several lakes, rivers, streams, and wetland complexes.

Of the lakes within the Snake River Watershed, five were sampled and assessed using the FIBI to evaluate biological health. Of the lakes that were sampled, all appear impacted by human activities in the watershed and on the shorelines. Pokegama Lake was assessed as not supporting aquatic life use based on FIBI scores that were below the impairment threshold established for similar lakes. The remaining lakes were assess as fully supporting, but Cross Lake scored near the impairment threshold.

After examining many candidate causes for the biological impairments, eutrophication and physical habitat alteration were identified as probable causes of stress to aquatic life within Pokegama Lake. Altered interspecific competition was identified as a possible, but inconclusive cause. This SID report follows a format to first summarize candidate causes of stress to the biological communities at watershed scale. Within Section 3 there is information about how each stressor relates broadly to the Snake River Watershed, water quality standards, and general effects on biology. Section 4 focuses on Pokegama Lake. Section 5 contains conclusions and recommendations for the lakes assessed, with a focus on Pokegama Lake. Each section discusses the available data and relationships to the fish communities in more detail.

1. Introduction

1.1. Monitoring and assessment of lakes

The approach used to identify biological impairments in lakes includes the assessment of fish communities present in lakes throughout a major watershed. The fish-based lake index of biological integrity (FIBI) utilizes fish community data collected from a combination of trap nets, gill nets, beach seines, and backpack electrofishing. From this data, an FIBI score is calculated for each lake survey. The FIBI score provides a measure of overall fish community health based on species diversity and composition. The MNDNR has developed four FIBI tools to assess different types of lakes throughout the state (Table 1; Table 3). More information on the FIBI tools and assessments based on the FIBI is available at the MNDNR lake index of biological integrity website. Although an FIBI score may indicate that a lake's fish community is impaired, a weight of evidence approach is still used during the assessment process that factors in considerations such as sampling effort, sampling efficiency, tool applicability, location in the watershed, and any other unique circumstances to validate the FIBI score.

A common source of confusion regarding assessment decisions based on the FIBI is that if a lake supports a quality gamefish population (e.g., high abundance or desirable size structure of a popular gamefish species), that lake is considered completely healthy. This is not necessarily true because both game-and nongame fish species must be considered when holistically evaluating fish community health. Oftentimes, the smaller nongame fishes serve ecologically important roles in aquatic ecosystems and are generally the most sensitive to human-induced stress. Likewise, high abundance or quality size structure of gamefish populations will not disproportionately affect the FIBI score because multiple metrics are used to evaluate different components of the fish community and each contributes equal weight to the total FIBI score.

Table 1. Summary of lake characteristics and metrics for FIBI tools.

Lake characteristics	FIBI 2	FIBI 4	FIBI 5	FIBI 7
Generally deep (many areas greater than 15' deep)	X	X		
Generally shallow (most areas less than 15' deep)			X	X
Generally with complex shape (presence of bays, points, islands)	X		X	
Generally with simpler shape (lack of bays, points, and islands)		X		
Species richness metrics				
Number of native species captured in all gear	X			
Number of intolerant species captured in all gear	X	X	X	
Number of tolerant species captured in all gear	X	X	X	X
Number of insectivore species captured in all gear	X			X
Number of omnivore species captured in all gear	X	X	X	
Number of cyprinid species captured in all gear	X			
Number of small benthic dwelling species captured in all gear	X	X		X
Number of vegetative dwelling species captured in all gear	X	X		X
Community composition metrics				
Relative abundance of intolerant species in nearshore sampling	X		X	
Relative abundance of small benthic dwelling species in nearshore sampling	X	X		

Lake characteristics	FIBI 2	FIBI 4	FIBI 5	FIBI 7
Relative abundance of vegetative dwelling species in nearshore sampling				X
Proportion of biomass in trap nets from insectivore species	X	X	X	X
Proportion of biomass in trap nets from omnivore species	X	X	X	
Proportion of biomass in trap nets from tolerant species	X	X	X	X
Proportion of biomass in gill nets from top carnivore species	X	X	X	X
Presence/absence of Intolerant species captured in gill nets	X	X		
Total number of metrics used to calculate FIBI	**15**	**11**	**8**	**8**

1.2. Stressor identification process

Stressor Identification (SID) is a formal and rigorous process that identifies stressors causing biological impairment of aquatic ecosystems. The process provides a structure for organizing scientific evidence to support conclusions (Cormier et al. 2000). In simpler terms, it is the process of identifying the major factors causing harm to aquatic life. Stressor identification is a key component of the major watershed restoration and protection strategy (WRAPS) projects funded by Minnesota's Clean Water Legacy Act.

1.3. Summary of lake stressors

The MNDNR has developed a separate document that describes the various stressors of biological communities in lakes, including where they are likely to occur, their mechanism of harmful effect, Minnesota's standards for those stressors where applicable, and the types of data available that can be used to evaluate each stressor (MNDNR 2018a;

Table 2). Many literature references are cited, providing additional sources of information. The document is entitled "Stressors to Biological Communities in Minnesota's Lakes" and can be found on the MNDNR lake index of biological integrity website. Additionally, the United States Environmental Protection Agency (EPA) has information, conceptual diagrams of sources and causal pathways, and publication references for numerous stressors to aquatic ecosystems on their CADDIS website.

Table 2. Summary of potential stressors of biological communities in Minnesota lakes.

Stressor	Examples of anthropogenic sources	Examples of links to aquatic biology
Eutrophication	Inputs of excessive nutrients from agricultural runoff, animal waste, fertilizer, industrial and municipal wastewater facility discharges, non-compliant septic system effluents, and urban storm water runoff	Detrimental changes to aquatic plant diversity and abundance, restructuring of plankton communities, detrimental effects to vegetative dwelling and sight-feeding predatory fishes
Physical habitat alteration	Riparian lakeshore development, aquatic plant removal, non-native species introductions, water level management, impediments to connectivity, sedimentation	Detrimental changes to aquatic plant diversity and abundance, reduced diversity and abundance of habitat specialists, reductions in spawning success
Altered interspecific competition	Unauthorized bait bucket introductions or unintentional transport, introductory and supplemental stocking activities by management agencies or private parties, angler harvest	Detrimental changes to energy flow, reductions in native species diversity and abundance through predation or competition for resources

Stressor	Examples of anthropogenic sources	Examples of links to aquatic biology
Temperature regime changes	Climate change resulting from emission of greenhouse gases	Physiological stress and reduced survival, particularly for intolerant coldwater fishes, increases in aquatic plant biomass and distribution
Decreased dissolved oxygen	Inputs of excessive nutrients, climate change resulting from emission of greenhouse gases	Suffocation, detrimental effects to locomotion, growth, and reproduction of intolerant fishes
Increased ionic strength	Road salt and de-icing product applications, industrial runoff and discharges, urban storm water and agricultural drainage, wastewater treatment plant effluent	Detrimental effects to intolerant fishes and other aquatic organisms
Pesticide application	Herbicide applications to aquatic plant communities, runoff and drift from herbicide and insecticide applications to agricultural, suburban, and urban areas	Reduced aquatic plant biomass, reduced abundance and diversity of vegetative dwelling fishes
Metal contamination	Runoff and leaching from mining operations, industrial sites, firing ranges, urban areas, landfills, and junkyards	Reduced survival, growth, and reproduction of fishes
Unspecified toxic chemical contamination	Runoff and leaching from industrial sites, agricultural areas, mining, logging, urban and residential activities, and landfills, spills, illegal dumping, and discharges from industries, municipal treatment facilities, and animal husbandry operations	Altered food web dynamics, reduced fitness of fishes from chronic exposure

2. Overview of Snake River Watershed Lakes

2.1. Background

The Snake River Watershed encompasses approximately 1,006 square miles characterized predominantly as a mix of forested, wetland, and agricultural land, with more forested and wetland land in the northern part of the watershed, and a higher portion of agricultural land in the southern portion of the watershed (Figure 1.). Approximately 25% of the watershed is in public ownership with several state forests and wildlife management areas, mostly in the upper portions of the watershed. Most of the watershed is rural, with Mora and Pine City as the largest population centers. The Snake River Watershed also contains many rivers, streams, and wetland complexes and several lakes. The Snake River Watershed falls within the North Central Hardwood Forest and Northern Lakes and Forests ecoregions.

2.2. Monitoring and summary of biological impairments

The FIBI was used to assess five lakes in the Snake River Watershed (Figure 1. ; Table 4). Four lakes with FIBI scores at or above the impairment threshold for their respective FIBI tool were assessed as fully supporting aquatic life use (Table 3; Table 4). These lakes include Knife, Fish, Ann, and Cross Lakes. Pokegama Lake was assessed as not supporting aquatic life use because the FIBI scores were below the impairment threshold (Table 4). The focus of this document is to review stressor information for Pokegama Lake, although sections 3 and 5 will briefly discuss stressors relevant to all lakes in the watershed.

Table 3. Lake FIBI tools with respective number of lakes assessed in the Snake, FIBI impairment thresholds, and lower/upper 90% confidence limits (CL) around the impairment threshold.

Lake FIBI tool	Number of Snake River WS lakes assessed	FIBI impairment threshold	Lower CL	Upper CL
Tool 2	2	45	36	54
Tool 5	1	24	9	39
Tool 7	2	36	27	45

The five lakes sampled and assessed with the FIBI in the Snake River Watershed had fairly high species richness, likely due to the strong connections with several streams and rivers, including the Snake River in some cases. Several riverine species not commonly sampled in Minnesota lakes were sampled during FIBI surveys, including Chestnut Lamprey, Lake Sturgeon, and several redhorse species. In the lakes assessed in the Snake River Watershed, relatively few vegetative dwelling species or intolerant species were sampled.

Figure 1. Snake River Watershed land cover classes with lakes sampled and assessed with Fish IBI protocols (2016 National Land Cover Database land use data. Land use categories as described in Jin et al. (2019)).

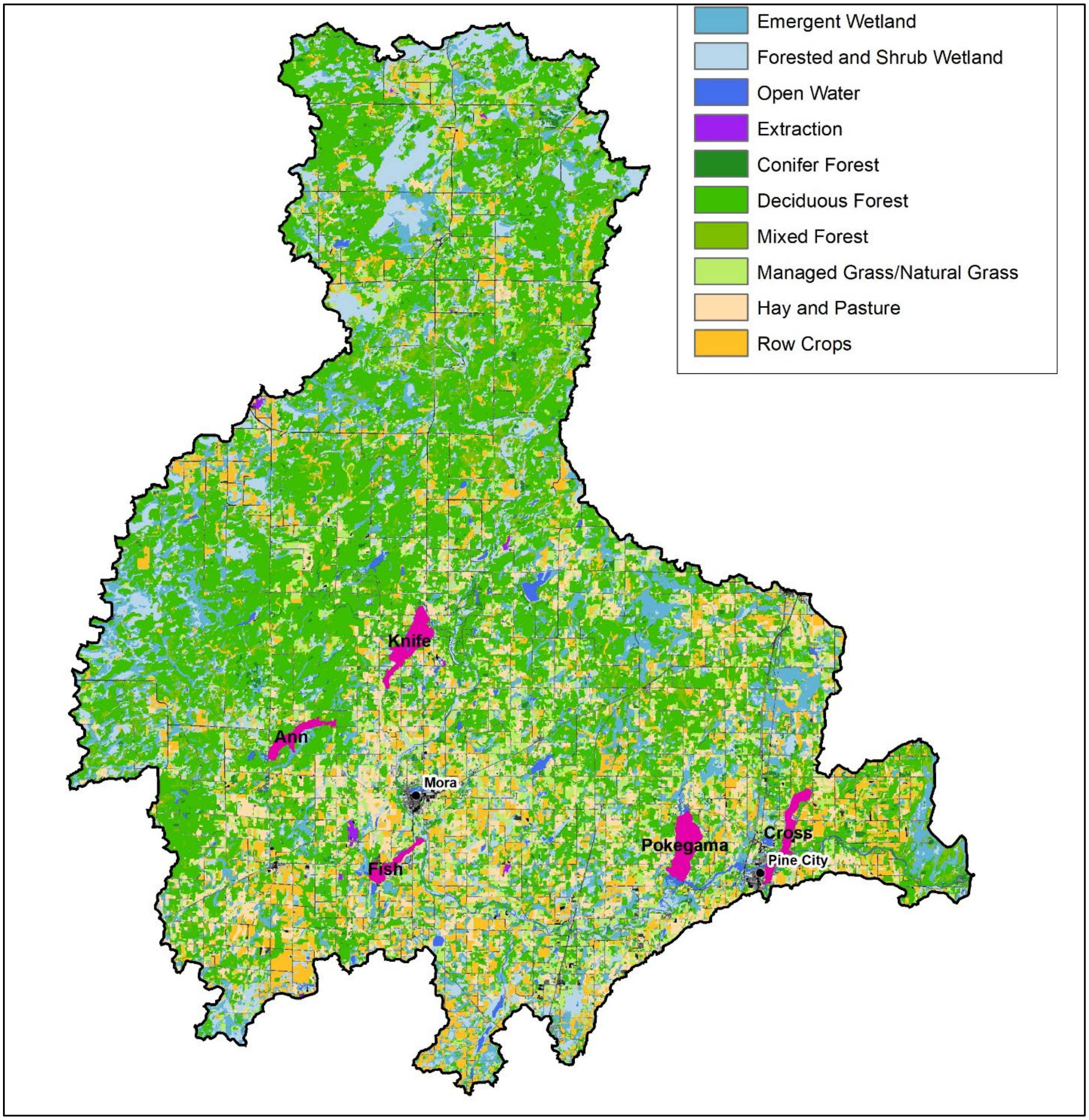


Table 4. Summary of lakes in the Snake River Watershed assessed with FIBI tools.

DOW	Lake name	County	FIBI survey	Survey Notes	DNR GIS acres	FIBI tool	% littoral[1]	FIBI scores	Impairment Threshold for tool	FIBI Aquatic Life Assessment status[2]
33-0028-00	Knife	Kanabec	2015, 2011		1,259	7	100	46, 47	36	FS
33-0036-00	Fish	Kanabec	2017		506	7	100	56, 52	36	FS
33-0040-00	Ann	Kanabec	7/2015, 6/2015		653	5	92	52, 28	24	FS
58-0119-00	Cross	Pine	2018, 2014	water level high in 2014	925	2	55	52, 48	45	FS
58-0142-00	Pokegama	Pine	2019, 2014	water level high in 2014	1,521	2	59	33, 35	45	NS
≤ lower CL			> lower CL & ≤ threshold		> threshold & ≤ upper CL				> upper CL	

[1] % littoral is the percentage of the lake that is less than 15 feet deep calculated using MNDNR GIS data.
[2] "FS" indicates fully supporting aquatic life use based on the Fish IBI, "NS" indicates not supporting aquatic life use based on the Fish IBI

Table 5. Fish species sampled in the Snake River Watershed with FIBI tolerance, feeding, and habitat guild assignments, and indications of which have been sampled[1] historically in Pokegama Lake, and in recent FIBI surveys (2019, 2018, 2014) in Pokegama Lake.

Species Sampled in the Snake River Watershed	Tolerance, feeding, and/or habitat guild[1]	Historically Sampled in Pokegama Lake	Sampled in recent FIBI survey in Pokegama Lake
Bigmouth Buffalo	Nat, Tol, Ins	X	X
Black Bullhead	Nat, Tol, Omn	X	X
Black Crappie	Nat, TC	X	X
Blackchin Shiner	Nat, Int, Ins, Veg, Cyp		Not Sampled
Blacknose Shiner	Nat, Int, Ins, Veg, Cyp		Not Sampled
Bluegill	Nat, Ins	X	X
Bluntnose Minnow	Nat, Omn, Cyp		Not Sampled
Bowfin	Nat, TC, Veg	X	X
Brook Silverside	Nat, Ins	X (1995)	Not Sampled
Brown Bullhead	Nat, Omn	X (multiple surveys)	Not Sampled
Burbot	Nat, Int, TC	X	X
Central Mudminnow	Nat, Ins, Veg		Not Sampled
Channel Catfish	Nat, TC	X	X
Chestnut Lamprey	Nat, TC	X	X

Species Sampled in the Snake River Watershed	Tolerance, feeding, and/or habitat guild[1]	Historically Sampled in Pokegama Lake	Sampled in recent FIBI survey in Pokegama Lake
Common Carp	Tol, Omn	X	X
Common Shiner	Nat, Ins, Cyp	X	X
Fathead Minnow	Nat, Tol, Omn, Cyp	X	X
Freshwater Drum	Nat, Ins	X	X
Golden Redhorse	Nat, Ins	X	X
Golden Shiner	Nat, Ins, Cyp	X	X
Greater Redhorse	Nat, Int, Ins	X (2000)	Not Sampled
Green Sunfish	Nat, Tol, Ins		Not Sampled
Hornyhead Chub	Nat, Ins, Cyp		Not Sampled
Iowa Darter	Nat, Int, Ins, Smb, Veg		Not Sampled
Johnny Darter	Nat, Ins, Smb	X	X
Lake Sturgeon	Nat, Int, Ins	X	X
Largemouth Bass	Nat, TC	X	X
Logperch	Nat, Int, Ins, Smb	X	X
Mimic Shiner	Nat, Int, Ins, Veg, Cyp		Not Sampled
Muskellunge	Nat, Int, TC, Veg	X[2] (1987, 2010)	
Northern Pike	Nat, TC, Veg	X	X
Northern Redbelly Dace	Nat, Veg, Cyp		Not Sampled
Pumpkinseed	Nat, Ins	X	X
Quillback	Nat, Omn	X	X
River Redhorse	Nat, Ins	X	X
Rock Bass	Nat, Int, TC	X	X
Shorthead Redhorse	Nat, Ins	X	X
Silver Redhorse	Nat, Ins	X	X
Smallmouth Bass	Nat, Int, TC	X (1995)	Not Sampled
Spotfin Shiner	Nat, Ins, Cyp	X	X
Spottail Shiner	Nat, Ins, Cyp	X (1995, 2000)	Not Sampled

Species Sampled in the Snake River Watershed	Tolerance, feeding, and/or habitat guild[1]	Historically Sampled in Pokegama Lake	Sampled in recent FIBI survey in Pokegama Lake
Tadpole Madtom	Nat, Ins, Smb, Veg	X	X
Walleye	Nat, TC	X	X
White Bass	Nat, TC	X	X
White Crappie	Nat, TC	X	X
White Sucker	Nat, Omn	X	X
Yellow Bullhead	Nat, Omn	X	X
Yellow Perch	Nat, Ins	X	X

[1] Tolerance, feeding, and habitat guilds are abbreviated as follows: Nat=Native, Int=Intolerant, Tol=Tolerant, Ins=Insectivore, Omn=Omnivore, TC=Top Carnivore, Smb=Small Benthic Dweller, Veg=Vegetative Dweller, and Cyp=Cyprinid. Guild abbreviations colored red contribute negatively to the FIBI score whereas those colored blue contribute positively to the FIBI score.
[2] Stocked into connected lake (Cross)

3. Possible Stressors to Lake Fish Communities in the Snake River Watershed

3.1. Candidate causes

Eutrophication

Land use disturbance and the resulting excess nutrients such as total phosphorus (TP) have been identified as causes of eutrophication in lakes. Water quality measurements taken in the five Snake River Watershed lakes assessed for aquatic life use indicate that TP averages 113 parts per billion (ppb) and varies from 75 ppb in Ann Lake to 203 ppb in Cross Lake (Table 6). Similarly, land use disturbance (i.e., cropland, pasture, urban, and/or mining), in the upstream watersheds averages 24% and varies from 11% in Ann Lake to 34% in Pokegama Lake (Table 6). Cross and Jacobson (2013) found that TP levels are typically significantly elevated when land use in the contributing watershed approaches 40%, with higher rates of TP elevation in shallow lakes and in watersheds with agricultural land use disturbance. All lakes assessed have agriculture in their contributing watersheds and are subject to mixing and resuspension of TP. All five lakes in this report were assessed by MPCA for aquatic recreation as impaired based on MPCA's nutrient water quality standards (Minn. R. Ch. 7050). The standards require that TP and either chlorophyll-a or transparency need to exceed an established threshold to be listed as impaired. MPCA's nutrient water quality standards have been established for aquatic recreation use; however, fish communities may exhibit responses at different threshold levels, and are also affected by connected waters and lake habitat characteristics. Climatic conditions can exacerbate eutrophication with increased heavy rainfall and increased temperatures worsening existing water quality problems. The Snake River watershed receives on average two additional inches of rain from the historical average (1895-2018) and climate scientists suggest that precipitation events are becoming more intense (MPCA 2020d). Given the above information, eutrophication will be evaluated further as a potential stressor within the Snake River Watershed in Section 4.

Table 6. Summary of watershed and shoreline stressor information for the Snake River Watershed lakes that were assessed using FIBI tools. Eutrophication, shoreline, and interspecific competition are addressed in the next several pages and refer back to Table 6.

DOW	Lake name	FIBI tool	FIBI Assessment status[1]	Percent contributing watershed landuse disturbance[2]	Total phosphorus (ppb)[3]	Dock density (#/mi)[4]	Score the Shore score[5]	Non-native fish and plant species[6]
33-0028-00	Knife	7	FS	20	103	17	71	CLP, EWM[7]
33-0036-00	Fish	7	FS	26	92	5	No data	Carp, CLP
33-0040-00	Ann	5	FS	11	75	4	83	Carp, CLP
58-0119-00	Cross	2	FS	29	203	16	69	Carp, CLP, EWM
58-0142-00	Pokegama	2	NS	34	94	22	67	Carp, CLP, EWM

[1] "FS" indicates fully supporting aquatic life use, "NS" indicates not supporting aquatic life use
[2] Percent watershed disturbance is calculated as the percentage of land in each lake's contributing watershed that was classified as developed, agricultural, or barren based on 2016 National Land Cover Database land use data. Land use categories as described in Jin et al. (2019). Calculations of watershed disturbance from Watershed Health Assessment Framework (MNDNR 2020d).
[3] Total phosphorus is calculated as the 10-year average of measurements taken June 1–September 30, MPCA data (4/2020)
[4] Dock density is estimated from counts of docks visible on Google Earth in 2015–2019.
[5] Score the Shore scores (Perleberg et al. 2019) assess the quantity and integrity of lakeshore habitat.
[6] Carp=Common Carp, CLP=curly-leaf pondweed, EWM=Eurasian water milfoil
[7] Common Carp have not been sampled in Knife Lake since the 1989 chemical reclamation.

Physical habitat alteration

There are a number of components of physical habitat including, but not limited to, substrate, aquatic and shoreline vegetation, and in-lake woody habitat. There are also numerous ways to measure physical habitat alteration; this section will discuss measures of shoreline disturbance, aquatic and shoreline plant alterations, hydrologic and connectivity alterations, and sedimentation.

Four of the five lakes discussed in this report have MNDNR Score the Shore (StS). Score The Shore is a natural resources survey to estimate the amount of habitat in shoreland, shoreline, and aquatic lakeshore zones. StS scoring process provides a simple method of ranking individual lake sites and the entire lake based on the amount of lakeshore remaining in natural condition surveys (Perleberg et al. 2019). The scores on the Snake River Watershed lakes suggest that lakes within the Snake River Watershed have a similar amount of riparian shoreline disturbance on average to lakes that have been surveyed statewide, although lakes surveyed statewide were not selected at random. The average StS score for lakes within the Snake River Watershed was 72, which is similar to the statewide average of 73 (Table 6. The average scores for developed and undeveloped sites in the Snake River Watershed were 61 and 94, respectively. Developed sites generally scored low and undeveloped sites generally scored high. "Low" StS scores are indicative of disturbed riparian lakeshore habitat with substantial removal of natural ground cover, shrubs, trees, and a lack of emergent and floating vegetation and woody habitat. "High" StS scores are indicative of relatively undisturbed riparian lakeshore habitat (Perleberg et al. 2019; Table 7**.**). These results, in particular the large difference in score between developed and undeveloped sites, indicate that habitat loss from riparian lakeshore development may be affecting the aquatic habitat for fishes.

Another measure of shoreline disturbance, dock density (based on Google imagery from 2015-2019), can also be used to evaluate the level of disturbance occurring along the shoreline of a lake. Dock densities exceeding approximately 16 docks per mile can significantly affect fish communities and habitat (Jacobson et al. 2016; Dustin and Vondracek 2017; MNDNR unpublished data). Of the five lakes in the Snake River Watershed that were assessed for aquatic life use, Knife, Cross, and Pokegama had dock densities exceeding 16 docks per mile (Table 6).

Table 7. Interpretation of Score the Shore survey data (From Perleberg et al. 2019).

Mean lakewide score	Mean shoreland score	Mean shoreline score	Mean aquatic score	Rating
85-100	28-33.3	28-33.3	28-33.3	High
66-84	22-27	22-27	22-27	Moderate
50-65	17-21.5	17-21.5	17-21.5	Low
<50	<17	<17	<17	Very Low

A review of MNDNR Permitting and Reporting System (MPARS) information indicates that permits have been and are currently issued to mechanically and chemically remove emergent, floating-leaf, and submerged plants and for shoreline alterations, including removal of native and non-native vegetation.

The permitting system does not capture all vegetation removal and shoreline alterations. Largescale removal of Curly-leaf Pondweed has been permitted on lakes within the watershed.

A review of non-native species that would have the potential to alter physical habitat, including aquatic plant community structure, indicates that several species: Common Carp, Curly-leaf Pondweed, and Eurasian Watermilfoil are present in a subset of lakes within the Snake River Watershed.

A GIS review of the DNR Minnesota inventory of dams indicates that there are approximately 25 dams and water control structures located within the Snake River Watershed; however, not all water control structures may be identified or included in this inventory. Minimal quantitative data is available describing fish habitat conditions prior to engaging in long-term water level management on lakes within the watershed and the effects of water level management on the FIBI score are unknown. Therefore, water level management is an inconclusive stressor due to a lack of data from which to draw conclusions.

A review of the MNDNR Watershed Health Assessment Framework (WHAF) Aquatic Connectivity Index tool indicates that the potential for aquatic disruption from culverts, bridges, and dams is lower than the statewide average (MNDNR 2020a). A lower Aquatic Connectivity Index score indicates higher potential for aquatic disruption, and the Snake River Watershed scores 62 out of a possible 100, whereas the statewide average is 53. Preliminary data from a MNDNR culvert inventory is also available for culverts that have been assessed to date. Of the 56 culverts that have been evaluated in the Snake River Watershed, mostly in the upper portion of the watershed, approximately 30 % create a possible barrier to fish passage at some flows due to their size, function, or design (MNDNR 2019).

A review of sedimentation data indicates that measures such as total suspended solids or substrate embeddedness are lacking for most lakes within the Snake River Watershed. Although sedimentation may contribute to lower than expected FIBI scores for certain lakes, the lack of high quality quantitative data and scientific research on the topic makes it challenging to draw conclusions for lakes within the watershed.

Given the shoreline development and other factors affecting physical habitat, physical habitat alterations will be evaluated as a potential stressor within the Snake River Watershed in Section 4.

Altered interspecific competition

A review of MNDNR survey data indicates that the Snake River Watershed is affected by non-native species that can directly compete with native fish species for resources (Table 6). Of the five FIBI assessed lakes, Common Carp were sampled in four lakes, including Pokegama Lake. Common Carp have the potential to directly compete with native fishes, as well as affect vegetated habitat by disrupting substrates and vegetation.

A review of gamefish management activities indicates that stocking and harvest regulations occur in lakes within the Snake River Watershed. While some gamefish management activities can result in changes to the fish community of a lake, in general, there is an overall lack of conclusive evidence linking these changes to FIBI scores. Fisheries managers determine stocking levels with ecological considerations and game fish are stocked at rates to increase opportunities for game fish harvest at a sustainable level. Altered interspecific competition is considered inconclusive as a potential stressor to the fish communities in the watershed and will be discussed further in Section 4.

3.2. Eliminated causes

Pesticide application

According to a USEPA report by Atwood and Paisley-Jones (2017), farmers in the United States account for 20% of global pesticide use. In 2017, the most commonly sold pesticides to Minnesota agricultural producers, ranked by weight, were glyphosate (herbicide), acetochlor (herbicide), metam sodium (fungicide), metolachlor (herbicide), atrazine (herbicide), and chlorpyrifos (insecticide; MDA 2020); however, these estimates do not include pesticide seed treatments. Seed treatments have recently become widely adopted, with a majority of row crop seeds treated with pesticides such as neonicotinoids prior to planting. Neonicotinoids, broad-spectrum systemic insecticides, are the fastest growing class of insecticides worldwide and are now registered for use on hundreds of field crops in over 120 different countries (Morrissey et al. 2015; Douglas and Tooker 2015). Coating seeds with insecticide as a method of pest management poses a particular risk to aquatic environments as most seed-applied neonicotinoids (80–98%) fail to enter treated plants and instead dissolve into soil water (Goulson 2014).

Pesticides can affect fish communities through several pathways. Direct effects to fish include nervous, metabolic, and endocrine system disruptions, as well as negative effects to ontogenetic development (Köhler and Triebskorn 2013). Chlorpyrifos, a commonly used insecticide, has been found to be highly toxic to fish (e.g., Bluegill Sunfish LC_{50} = 1.8 ppb) and aquatic invertebrates (e.g., Daphnia LC_{50} = 0.1 ppb) on an acute basis (Corbin and Flaherty 2009). Aquatic invertebrates, often more sensitive to agricultural pesticides than their terrestrial relatives (Krupke and Tooker 2020), mediate indirect negative effects on fish abundances and community structure (Yamamuro et al. 2019). For example, Yamamuro et al. (2019) observed a 91% reduction in average annual yields of Rainbow Smelt in a freshwater lake within a primarily agricultural watershed and attributed the reduction to neonicotinoid pesticide contamination resulting in a lack of invertebrate prey. As many waterbodies in Minnesota share similar agricultural watershed characteristics, it is plausible that pesticides are negatively affecting FIBI scores either through direct or indirect means in some cases. Indirect impacts are common with pesticide application, and often unrelated to the toxicity on the species ultimately affected. The indirect pathway by which pesticides can reduce the abundance of prey available for insectivorous fishes is a critical consideration for maintaining healthy aquatic ecosystems composed of appropriately balanced native fish communities, and is likely of greater concern than the direct effects to the fishes themselves.

A summary of monitoring data from the 2017 National Lakes Assessment (NLA) summarized pesticide levels detected in lakes statewide with no pesticides detected in far northern Minnesota lakes, and increasing numbers of pesticides detected in central and southern Minnesota, with a significantly higher number of pesticides and concentration of pesticides detected with higher amount of cropland (MDA 2019).

Pesticide application is unlikely to be occurring at a level that would contribute to impaired fish communities in the lakes in the watershed. The following three pieces of information were used to conclude that pesticide application as an unlikely stressor to FIBI impairments in lakes in the Snake River Watershed. Only about 10% of the land use in the Snake River Watershed is categorized as cultivated agricultural land (MNDNR 2020d). A review of Minnesota Department of Agriculture (MDA) incident reports indicated only one small spill and a few old emergency incidences within the watershed (MDA 2021a). And, there are no impairments in Minnesota Department of Agriculture (MDA) stations in and near the watershed (MDA 2021b).

Temperature regime changes

A review of research (MNDNR 2020c) indicates that mean air temperatures within the Snake River Watershed have increased by an average of 0.26°F per decade from 1895 – 2020. Increases in lake-specific air temperature have been shown to be correlated with increases in water temperature (Robertson and Ragotzkie 1990). Although modeling evidence suggests that water temperature has increased in lakes within the Snake River Watershed, limited research is available to demonstrate the magnitude of change needed to result in changes to the fish community as indicated by the FIBI. Further, none of the lakes assessed with the FIBI were assessed as deep lakes (lakes >40 feet) supporting cold water fisheries and therefore temperature regime changes is eliminated as a candidate cause for impairment.

Decreased dissolved oxygen

Data regarding DO concentrations in lakes is generally limited to discrete profiles collected during periodic MPCA and MNDNR surveys or is provided as anecdotal information when related to summer or winterkill events. As such, limited information exists to indicate whether DO concentrations are changing in a manner that might result in changes to fish communities in the Snake River Watershed. Knife, Ann, and Fish Lakes are shallow lakes and very susceptible to wind mixing events. Cross and Pokegama are deeper lakes but have a long fetch making them apt to periodic mixing and likely to not have a strong oxycline. Further, because the lakes assessed with the FIBI are not expected to support cold water species based on their morphometry, decreased dissolved oxygen will not be discussed further and is eliminated as a candidate cause.

Increased ionic strength

A review of MPCA's Impaired Waters List indicates that no lakes within the Snake River Watershed were assessed as impaired for aquatic life use based on the chronic standard for chloride (MPCA 2020a). Chloride concentrations that are toxic to fish and other aquatic organisms would need to exceed the aquatic life use standards. Therefore, standards and actions intended to address chloride impairments should provide adequate protection to eliminate chloride as a likely candidate cause for impaired fish communities.

Metal contamination

A review of MPCA's Impaired Waters List indicates that the Snake River Watershed contains lakes that have been identified as impaired for aquatic consumption based on mercury levels; however, MPCA and local partners have developed a statewide mercury reduction plan approved by the EPA to address these impairments (MPCA 2007). Mercury concentrations that are toxic to fish and other aquatic organisms would need to far exceed the aquatic consumption standards. Therefore, standards and actions intended to address aquatic consumption impairment should provide adequate protection to eliminate mercury as a likely candidate cause for impaired fish communities.

Unspecified toxic chemical contamination

A review of publicly accessible MPCA data indicated that most properties that generate hazardous waste were located around population centers (Mora, Pine City, Brook Park) including stores, gas stations, dumps, etc. Given their locations, they are not unlikely to be a significant stressor to fish communities in lakes within the watershed (MPCA 2020b).

4. Evaluation of candidate causes in Pokegama Lake (58-0142-00)

While all of the lakes within the Snake River Watershed are undoubtedly impacted by land use within their watersheds and on their shorelines, section 4 of this report will focus on evaluating the causes of stress to the fish community in Pokegama Lake, which was assessed as not supporting aquatic life use. All FIBI scores for Pokegama Lake were below the impairment threshold for similar lakes (Table 4).

Pokegama Lake is about 1,521 acres, with a maximum depth of 25 feet, and a littoral zone covering about 59% of the lake area. These characteristics put it into a group scored with FIBI Tool 2. Lakes scored with this tool are characterized as generally deep with complex shorelines (i.e., presence of bays, points, and islands), less than 80% littoral area, and high species richness (Table 1).

Eutrophication and physical habitat alteration have been identified as likely stressors to aquatic life use in Pokegama Lake and will be evaluated further. Altered interspecific competition and pesticide application have been identified as inconclusive stressors. A description of available data and current understanding of levels believed to affect fish communities is discussed in this report and summarized in Figure 4.

Biological community in Pokegama Lake

The biological integrity of the fish community in Pokegama Lake was evaluated using trap net, gill net, seining, and backpack electrofishing surveys. Survey data from 2014, 2018, and 2019 was used for assessment, with supporting information from an older survey completed in 2008. The two FIBI scores reported for assessment are generated from a survey conducted in June and July 2014 which included all components (gill net, trap net, seining, and backpack electrofishing), and a July 2018 gill net and trap net survey paired with a seining and backpack electrofishing survey in June 2019.

The FIBI uses fish community data to measure a lake's health, and the types of fish species present can help identify any stressors that may be negatively affecting the lake environment. The FIBI score, composed of fifteen fish community diversity and composition metrics for tool 2 lakes (Table 1), indicates the overall health of a lake by comparing it to what is expected for a healthy lake. The FIBI scores are 35 and 33 from 2014 and 2018/2019, respectively, which are both below the impairment threshold (45) and below the 90% confidence interval for Tool 2 FIBI scores (36-54). The score from the 2008 survey is similar (31; Table 3).

Twenty-five native fish species were sampled in Pokegama Lake in 2014, including many riverine species, because of its open connection with the Snake River. The overall FIBI score is most negatively impacted by the high biomass of tolerant species (Common Carp and Bigmouth Buffalo) in the trap net survey and a relatively low richness of intolerant, cyprinid, small benthic, and vegetation dwelling species as indicated by the respective FIBI metric scores. Channel Catfish were most abundant by biomass in the gill nets (47% of the biomass). Freshwater Drum and Common Carp dominated the biomass in the trap net survey, accounting for 32% and 21% of the biomass respectively. The nearshore survey catches were light, and were comprised primarily of Yellow Perch (41%) and Bluegill (35%).

The 2018/2019 survey sampled a similar number of species, with 27 native species, and metric scores were similar to 2014. The overall FIBI score is most negatively impacted by the high biomass of tolerant species (Common Carp) in the trap net survey and a relatively low richness of intolerant, cyprinid, and vegetation dwelling species, and a relatively high number of tolerant species sampled. Channel Catfish were most abundant by biomass in the gill nets (63% of the biomass). Common Carp and Freshwater Drum dominated the biomass in the trap net survey with Common Carp accounting for 35% of the biomass and Freshwater Drum 21%. The nearshore survey sampled 16 species, with Yellow Perch (66%) and Bluegill (18%) again most commonly sampled, followed by Black Crappie (18%) and Johnny Darter (4%).

Because this is the first time utilizing the FIBI protocols in the lake assessment process, historical surveys of similar rigor are unavailable to facilitate comparison of fish species assemblages through time, and to examine changes in the fish community related to changing lake conditions. However, historic data indicates that several additional species have been sampled in Pokegama Lake, including Brook Silverside (in 1995), Brown Bullhead (in several surveys, most recently in 2005), Greater Redhorse (in 2000), and Spottail Shiner (1995, 2000) but these species have not been observed in MNDNR surveys since that time (MNDNR 2020b). These historically sampled species may be represented by only one or two occurrences and identification confirmation cannot occur due to the lack of vouchered specimens. Note that Smallmouth Bass were not sampled in the FIBI gears, but were sampled in a separate nighttime electrofishing survey in May 2018. In addition, several species classified as intolerant of eutrophication and shoreline disturbance, including Blacknose Shiner, Iowa Darter, and Mimic Shiner have been sampled in other portions of the Snake River Watershed, and are common in other similar lakes in the major basin, but are absent from Pokegama Lake (Table 5).

Data analysis/Evaluation for each candidate and inconclusive cause

Eutrophication, Candidate Cause

Eutrophication is likely occurring at a level that would contribute to an impaired fish community in Pokegama Lake based on review of relevant water quality and watershed disturbance information. Pokegama Lake is listed as impaired for aquatic recreation based on high nutrient levels, and has had a history of water quality problems for decades or longer. Dense algae blooms were reported by Moyle in 1937 and Woodward and Olson in 1929 (MNDNR 2007).

Recent water quality data collected and summarized by MPCA indicates that mean TP is 94 ppb (N=22), chlorophyll-a is 38.4 ppb (N=23), and Secchi transparency is 0.9 meters (N=108) in Pokegama Lake. A TMDL reported on sources of nutrients to Pokegama Lake (see MPCA 2013). These parameters indicate that the lake is receiving inputs of excess nutrients that could negatively affect the fish community.

Of the approximately 52,000 acres within the contributing watershed, 35% is classified as unnatural land cover (i.e., 31% agricultural and 4% developed). The percentage of unnatural land cover is approaching a threshold identified by MNDNR Fisheries Research that often results in significantly elevated TP levels in Minnesota Lakes, especially in shallow lakes with agricultural land use (Cross and Jacobson 2013). Additionally, the quantity of land within the contributing watershed is high relative to the size of Pokegama Lake, as indicated by a watershed-to-lake ratio of 34:1. The combination of a large contributing watershed and the moderate percentage of unnatural land cover can contribute large inputs of nutrients into associated lakes and waterways. Approximately 6% of the agricultural land within Pokegama Lake's contributing watershed is cultivated whereas 25% is hay and pasture land. Additionally, 16 feedlots are located within the contributing watershed (MPCA 2020c). Surface runoff from agricultural land and feedlots can contribute excess nutrients into the lake if not properly managed. The Snake River Watershed TMDL identified watershed drainage sources as contributing 57% of the annual phosphorus budget for Pokegama Lake (MPCA 2013). Pokegama Creek which flows into Pokegama Lake is also impaired for aquatic life use.

While the shoreland owners on Pokegama Lake are connected to a city sewer, there are an unknown number of individual subsurface sewage treatment systems (SSTS) on parcels within the contributing watershed to the lake. However, failing SSTS were estimated to only contribute 2% of the annual total phosphorus budget for Pokegama Lake (MPCA 2013). There is a waste water treatment plant discharge downstream of Pokegama Lake therefore potential associated nutrients do not impact the lake.

Internal loading of phosphorus from lake sediments can also be a significant contributor to eutrophication on lakes. Internal loading was identified in the Snake River Watershed TMDL as a significant source of nutrients to Pokegama Lake, with 40% of the annual phosphorus budget attributed to internal loading (MPCA 2013). Common Carp are known to modify the structure and function of aquatic ecosystems (Huser et al. 2017). Carp dig in the bottom sediment with their mouths while searching for food, re-suspending sediment, increasing water turbidity, and uprooting aquatic plants. At great enough densities, Common Carp play a significant role in nitrogen and phosphorus transport from sediment to the water column as a result of both physical sediment disturbance and excretion. With the littoral zone of Pokegama Lake covering over half of the lake area, large Common Carp populations could intensify the effects of eutrophication. However, carp populations are not large originators of excess nutrients, but rather function as agents for nutrient re-suspension.

Residentially developed land within the contributing watershed is predominantly located along the shoreline of Pokegama Lake and in the small town of Brook Park. As discussed in the next section, shoreline development practices observed on Pokegama Lake during a survey of the shoreline documented substantial vegetation clearing in the shoreland and shoreline zones. Runoff from shoreline development and practices could be contributing excess nutrients into the lake.

Although a high percentage of land is classified as unnatural, undeveloped land includes numerous wetland and water features, privately owned forested land, and several WMAs and a portion of a state forest are present within the contributing watershed. Undeveloped lands, particularly parcels in public ownership that are protected from future development, play a critical role in collecting and filtering rainfall, recharging the groundwater supply, and reducing surface runoff that could otherwise be contributing sediment and nutrients into lakes and rivers.

Physical habitat alteration, Candidate Cause

Physical habitat alteration is likely occurring at a level that would contribute to an impaired fish community in Pokegama Lake based on review of information reflecting riparian lakeshore development, aquatic plant removal, non-native species presence, water level management, and sedimentation.

Shoreline alterations and vegetation removal can adversely affect the fish community and can occur via several pathways. It is difficult to quantify the total amount of habitat loss that has and is presently occurring around and within Pokegama Lake, but we can use survey and permit data to make inferences. In recent years, there have been several permits for removal of aquatic vegetation, shoreline excavation, sand blanket and riprap installation and other shoreline alteration permits. In addition, information about potential permitted and unpermitted plant removal activities (and other habitat alterations such as addition of sand blankets or riprap) within a lake can also be inferred from dock counts, and a review of aerial imagery indicates that approximately 22 docks per mile of shoreline are present on Pokegama Lake. Similar densities of docks have been linked to changes in fish community composition (Dustin and Vondracek 2017) and during FIBI development, several metrics were correlated with dock density, for example a reduced number of intolerant species was correlated with higher density of docks.

Riparian lakeshore habitat quality is highly impacted by shoreline development on Pokegama Lake, as indicated by a Score the Shore (StS) survey score of 67 on Pokegama Lake (Table 8). The average score at developed sites, 60, is categorized as a low score, and is significantly lower than the average score at undeveloped sites 96, which is a high score. A low score indicates that sites have a lower than expected amount of natural habitat. In this case, development has a large effect on all three habitat components, shoreland, shoreline, and aquatic, which indicates that replacement of trees, shrubs, and natural ground cover with open yards has most likely occurred and vegetation removal is common along with numerous docks in the lake. Replacement of riparian vegetation with open lawns oftentimes results in increased nutrient inputs from fertilizer and lawn clippings, reduced buffering capacity, destabilized shoreline, and elimination of future contributions of coarse woody habitat into the lake. During the FIBI survey, DNR surveyors noted several properties with egregious removal of shoreline vegetation, and severe erosion occurring (see cover photo). Removal of vegetation and coarse woody habitat in the lake detracts from available habitat for nearshore fishes.

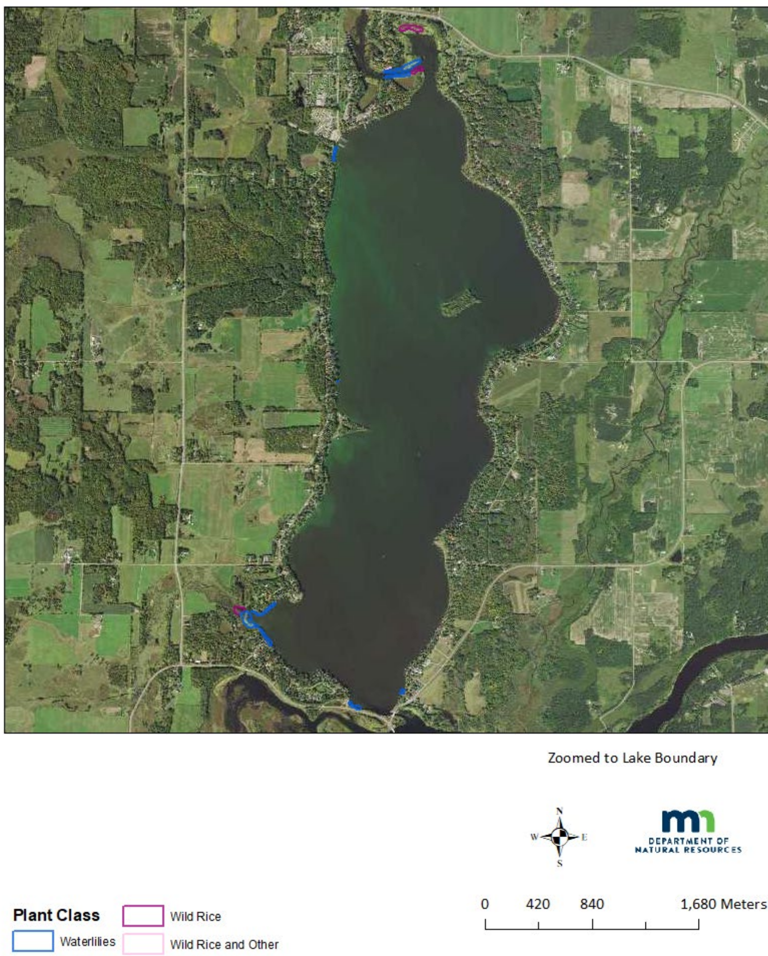
Table 8. Score the Shore survey data for Pokegama Lake, June 8, 2017.

Category	Number of Survey Sites	Shoreland Score (33.3)	Shoreline Score (33.3)	Aquatic Score (33.3)	Mean Score Std Error	Mean Site Score (100)
Lakewide	84	23.6	20.4	23.3	2.4	67.2
Undeveloped Total	17	33.3	32.5	29.8	1.3	95.7
Undeveloped Nonwetland	15	33.3	32.9	30.7	1.1	96.9
Undeveloped Wetland	2	33.3	30.0	23.3	0.0	86.7
Developed Total	67	21.1	17.3	21.6	2.2	60.0
Boat Access	1	18.3	30.0	23.3	0.0	71.7
Campsite	1	25.0	16.7	20.0	0.0	61.7
Roadway	3	16.7	15.6	26.7	17.9	58.9
Several Single-Family Residential Lots	39	20.3	14.9	20.9	2.8	56.1
Single-Family Residential Lots	23	23.0	21.0	22.2	3.7	66.2

Recent plant surveys suggest the plant community is impacted by poor water quality and/or shoreline activities. Aquatic plant surveys included a point intercept vegetation survey and a delineation of floating leaf and emergent aquatic vegetation; both were completed in 2017 by DNR Fisheries Hinckley

Area staff. During the point intercept survey, most of the vegetation was growing in 5 feet of water or less, likely due to poor water quality. Canada waterweed (Elodea canadensis) was the most commonly occurring species, occurring in 75% of sample points less than 8 feet in depth. Vegetation growth along most of the shoreline of the lake was sparse, with dense patches in the north and southwest bays. Eurasian watermilfoil was found at scattered locations throughout the lake. Floating leaf and emergent vegetation was extremely limited, with a total of 7.8 acres of floating leaf and 3.2 acres of emergent plants mapped, primarily in the north and southwest bays of the lake (Figure 2).

Figure 2. Floating leaf and emergent plants mapped in summer 2017, Pokegama Lake.

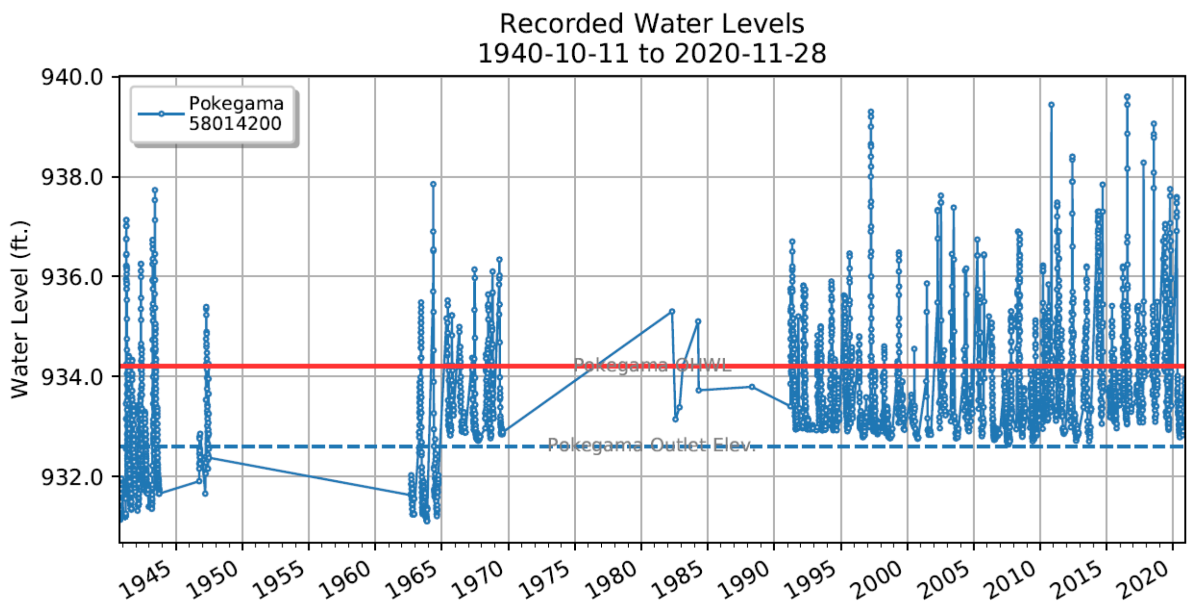


Based on the dock density estimate, plant and score the shore survey results, and aquatic plant and shoreline alteration permits, it is very likely that shoreline activities contributed to some physical habitat loss within the lake, which could result in changes to the fish community as evaluated by the FIBI.

Curly-leaf Pondweed, Eurasian Watermilfoil, and Common Carp, three non-native species, are present in Pokegama Lake. As noted above, Eurasian Watermilfoil is present in scattered locations. An early season June 2016 vegetation survey conducted by Wenck found curly-leaf widespread and dense in areas (Langer and Strom 2016). The Pokegama Lake Association currently conducts a weed harvesting program which targets dense areas of Curly-leaf Pondweed and Eurasian Watermilfoil growth with permits from MNDNR. Recent surveys indicate that Common Carp are sampled at a similar rate as other lakes in the same lake class; however, any potential effects of the species have not been evaluated or documented (MNDNR, unpublished data). Common Carp are known to modify the structure and function of aquatic ecosystems (Huser et al. 2017). They can reduce aquatic plant densities both directly and indirectly. Carp dig in the bottom sediment with their mouths while searching for food, re-suspending sediment, increasing water turbidity, and uprooting aquatic plants. In shallow lakes of homogeneous depth, light penetration can decrease when a threshold turbidity is exceeded, and submergent plants can disappear (Scheffer 1990). With the littoral zone of the Pokegama Lake covering approximately 59% of the lake area, abundant Common Carp populations could intensify the effects of eutrophication. Consequently, carp are likely contributing to physical habitat alterations that are inconclusive stressors to the fish community in Pokegama Lake.

There have been several dams that were constructed and operated at varying levels at the outlet of Cross Lake over the past approximately 170 years. The current dam level has been maintained since the mid-1960s. The varying water levels have undoubtedly impacted the shoreline habitat including sediment and vegetation. It is likely this has indirectly impacted the fish community. MNDNR Dam Safety hydrologists concluded that higher precipitation related to climate change had influenced recent high lake levels (personal communication, Heidi Lindgren, MNDNR, 2020). While the changing water levels have likely contributed to a dynamic fish community over the past nearly 200 years, currently fish can migrate in and out of the lake with an open connection with the Snake River.

Figure 3. Pokegama Lake hydrograph available at mndnr.gov. Note the significant gaps in the record prior to 1992 (elevations in NGVD 1929 datum).



Altered interspecific competition, Inconclusive Cause

Altered interspecific competition is identified as an inconclusive stressor. Altered interspecific competition is not likely occurring at a level that would contribute to the impaired fish community in Pokegama Lake based on review of non-native species occurrence, stocking activities, angling, and other harvest-related activities.

Curly-leaf Pondweed, Common Carp, and Eurasian Watermilfoil are present within Pokegama Lake. Direct competition of Eurasian Watermilfoil or Curly-leaf Pondweed with the fish community is unlikely.

However, the habitat provided by dense monocultures of Curly-leaf Pondweed and Eurasian Watermilfoil, while better than no vegetation, have lower habitat value for fish than a diverse native plant community (Valley et al., 2004).

Common Carp catch rates from recent surveys would indicate that they are occurring at similar or higher densities when compared to other lakes in the same lake class (MNDNR, unpublished data). At high densities, Common Carp have the potential to compete with native species for resources. Common Carp can induce bottom-up effects within aquatic ecosystems that increase total phosphorus and turbidity while decreasing chlorophyll-a biomass and macrophyte cover. This is known to decrease macroinvertebrate biomass and growth in juvenile Largemouth Bass and juvenile Bluegill (Wahl et al. 2011). These bottom-up effects can influence multiple trophic levels, thus modifying aquatic community structure and function. In 2014 and 2018 trap net surveys on Pokegama Lake, Common Carp made up 22% and 35% of fish biomass, respectively. Common Carp can shift how nutrients are cycled throughout the trophic system of Pokegama Lake, which may result in an alteration in interspecific competition. The impacts of Common Carp to physical habitat and water quality were also discussed in the eutrophication and physical habitat alterations sections.

According to a 2017 Lake Management Plan Amendment, MNDNR Fisheries currently stocks approximately 500 pounds of Walleye fingerlings every other year to assess the success of natural reproduction in the non-stocked years (MNDNR, unpublished data). Prior to 2017, Walleye fingerlings were stocked every year for several years. A walleye stocking analysis was conducted in 2016-2017 and suggested that there was potential of 83% of walleye resulting from natural reproduction, resulting in the change to every other year stocking. Relative abundance of adult Walleye in Pokegama Lake in the most recent survey (2018) was low with a gill net catch of 1.1 fish per net. Although this is well below the 25th percentile for the lake class and below the management goal of 4 fish per net, this is the same catch rate as the previous survey and is similar to historical catch rates. Given that there is a substantial portion of the population likely from natural reproduction and the numbers are low, it is unlikely stocking impacts the FIBI metrics and score. Further, no significant relationships between FIBI scores or metrics and the number of species stocked, relative abundance of stocked species, or Walleye stocking density have been observed in Minnesota lakes (Drake and Pereira 2002; J. Bacigalupi, MNDNR, unpublished data).

Angling and other harvest-related activities also have potential to alter interspecific competition but are unlikely stressors. Angler effort and harvest were most recently quantified for Pokegama in a 2013-2014 creel. The angling pressure was estimated at 22.6 hours/acre during the winter and 29.4 hours/acre during the 2014 open water season, with Black Crappie and Bluegill comprising most of the catch and harvest. Similarly, a 1997 creel estimated 24.6 angler hours per acre during the open water season with Black Crappie being harvest in largest numbers, a 1988 angler survey estimated fishing pressure at 14.2 angler hours per acre, and a 1983 recreational use survey estimated fishing pressure at 32.7 angler hours per acre during the open water season. The 2013-2014 creel report compared pressure on Pokegama to other Hinckley Area lakes and also to other lakes in Schupp Lake Class 22, finding that winter pressure was higher on Pokegama than other lakes in the comparison, and open water pressure was similar (MNDNR 2015). No special regulations are implemented that might reflect concerns about angler harvest affecting fish community diversity that would be reflected in the FIBI.

Commercial harvest of Common Carp and Freshwater Drum (and smaller numbers of other non-regulated species) has occurred on Pokegama Lake, with harvests occasionally exceeding 100,000 pounds years (personal communication, Leslie George, MNDNR January 2021). Commercial harvest has not been completed in recent years, therefore it is unlikely to have had much of an impact on the current fish community.

5. Conclusions and recommendations

Conclusions

All five lakes assessed with the FIBI in the Snake River Watershed are impacted by human activities in their watersheds and along their shorelines. All FIBI scores on Pokegama Lake were below an impairment threshold. The FIBI scores on the other four FIBI assessed lakes within the Snake River Watershed were above an impairment threshold, but two lakes (Cross and Ann) had scores within a confidence interval of the impairment threshold, and they should be monitored closely and considered for best management practices in local planning.

Although this report focused on the impairment, Table 9 presents a summary of the stressors associated with the lakes assessed within the Snake River Watershed. Eutrophication (excess nutrients) is likely adversely affecting the fish communities in all the assessed lakes. Pokegama, Cross, and Knife have significant physical habitat alterations from shoreline development activities. All of the five lakes assessed with the Fish IBI have one or more non-native fish and/or plant species present.

Table 9. Summary of the conclusions related to stressors associated with the FIBI assessed lakes in the Snake River Watershed.

		Candidate Causes[1]		
Lake Name	**DOW**	**Eutrophication (excess nutrients)**	**Physical habitat alteration**	**Altered interspecific competition**
Knife	33-0028-00	*	*	0
Fish	33-0036-00	*	0	0
Ann	33-0040-00	*	0	0
Cross	58-0119-00	*	*	0
Pokegama	58-0142-00	*	*	0

[1] "*" supports the case for the candidate cause as a stressor, "0" indicates that evidence is inconclusive as to whether the candidate cause is a stressor.

Recommendations

The recommended actions listed below will help to reduce the influence or better understand the stressors that are limiting the fish communities of the Snake River Watershed lakes, particularly on Pokegama Lake. Collaboration among agencies, watershed districts, and local government units will be imperative for successful planning and implementation of these recommendations within the watershed. There are numerous examples of past collaborative successes in the Snake River Watershed including waste water treatment improvements, nutrient reduction projects and numerous best management practices (BMPs) to help improve and protect water quality throughout the watershed, and a dam modification project allowing fish passage at the outlet from Cross Lake. These examples involved numerous project, organizational, and funding partners that were critical to their success. However, additional projects are needed to continue the work of removing impairments to the lakes and streams in the watershed.

Eutrophication (excess nutrients)

Best management practices should be used to reduce inputs of nutrients into biologically impaired or lakes that may be vulnerable to future impairment. In agricultural areas, such practices may include applying correct fertilizer types at appropriate rates and times depending on soil type and other factors (e.g., weather), using no till or minimum tillage practices, planting cover crops, maintaining riparian buffer zones around lakes, rivers, and ditches, and using grass waterways and constructed wetlands to filter nutrients from surface waters. In residential areas, practices may include minimizing application of lawn fertilizer, reestablishing or maintaining shoreline buffer zones, and ensuring individual sewage treatment systems are compliant with state regulations (Minnesota Rules Chapter 7080) and local government ordinances.

Where applicable, recommendations outlined in lake eutrophication TMDLs should also be followed to minimize potential nutrient inputs from surrounding water bodies.

Land acquisition may also be a viable option to protect lakes from eutrophication and other negative effects of development. Undeveloped forested or wetland areas can provide numerous benefits to the surrounding ecosystem including filtering surface runoff and thereby reducing eutrophication and sedimentation, recharging the groundwater supply, and removing carbon dioxide from the atmosphere.

Physical habitat alteration

Restoration of developed shorelines with natural shoreline buffers should be prioritized when physical habitat alteration has been identified as a candidate cause of stress to a lake. Shoreland owners can significantly improve shoreline habitat by choosing to reestablish or maintain native plants along their property. Natural shorelines provide overhead cover to fish and wildlife species, contribute important coarse woody habitat into the lake, and provide a buffer for nutrient runoff from lawns and impervious surfaces. While shoreline restoration projects vary in scope and size, all can be completed in ways that are visually appealing and that maintain a view of the lake. Once completed, these projects have potential to provide many ecosystem benefits that a more traditional developed shoreline (e.g., mowed lawn and sand beach) could not offer. The MNDNR maintains an interactive Restore Your Shore webpage that provides guidance for shoreland owners and professionals to use in implementing shoreland restoration projects. Protection and restoration of floating-leaf and emergent aquatic vegetation should also be prioritized, especially where aquatic habitat is limited. Shoreland owners should be aware of and adhere to current laws that regulate shoreline and aquatic plant control and shoreline alterations.

Oftentimes lakeshore parcels are privately owned and developed; however, in some situations land acquisition can be a viable option to protect existing natural shoreline and aquatic habitat. Future acquisitions aimed at increasing the percentages of protected shoreline and protected watershed area should be a priority where appropriate.

Recommendations related to other physical habitat alteration concerns should be considered where appropriate. Floating-leaf and emergent vegetation mapping surveys should be completed to document existing plant stands in lakes where these data are lacking. Upstream and downstream connections should be restored when crossings (i.e., dams, culverts, and bridges) have been identified as barriers to fish passage and unevaluated crossings should be inspected for potential concerns. Non-native species should continue to be monitored in lakes where they are present. Additionally, efforts to reduce the spread of non-native species, including those that are absent from the Snake River Watershed should continue to be encouraged.

Altered interspecific competition

Altered interspecific competition was identified as an inconclusive cause of stress. Nonetheless, monitoring efforts to further understand densities and potential effects of species such as Common Carp could be considered. Monitoring of stocking and harvest-related activities should also continue as these data can help inform future changes within biologically impaired or vulnerable lakes. Historic efforts to reduce densities of Common Carp via trapping and barriers have been controversial and generally unsuccessful within Minnesota.

Summary of Pokegama Lake Fish Community and Stressors Based on the FIBI

A summary of the fish and stressor data is illustrated in a handout on the next page (Figure 4)

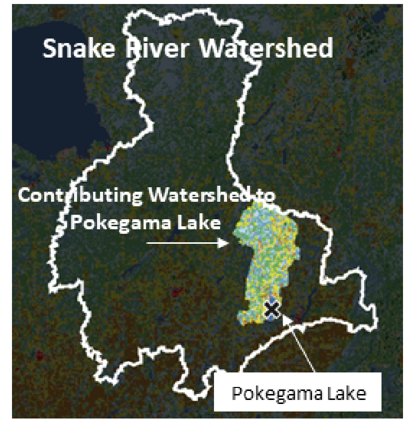
Figure 4. Pokegama Lake (58-0138-00) fish community and stressors summary and handout; based on fish index of biological integrity (FIBI) results.

Summary: Pokegama Lake (58-0138-00) Fish Community and Stressors based on the Fish-based Index of Biotic Integrity (FIBI)

Fish Community:

- Three Fish IBI surveys score well below the impairment threshold (45) for FIBI: The scores from recent surveys are 33 (2019) and 35 (2014). An older survey had a score of 31 (2008).
- The FIBI scores are most negatively influenced by a relatively low number of intolerant and vegetation-dwelling species compared to similar lakes, and relatively high proportion of biomass of tolerant and omnivorous species (primarily Common Carp and White Sucker).
- The fish community in Pokegama Lake is highly influenced by its connection to the Snake River with several riverine species sampled during each survey.
- Fish Species sampled that negatively affect the FIBI score: Black Bullhead, Common Carp, Fathead Minnow, Quillback, White Sucker ,Yellow Bullhead
- Fish Species sampled that positively affect the FIBI score: Black Crappie, Bluegill, Bowfin, Burbot, Channel Catfish, Common Shiner, Freshwater Drum, Golden Redhorse, Golden Shiner, Johnny Darter, Lake Sturgeon, Largemouth Bass, Logperch, Northern Pike, Pumpkinseed, River Redhorse, Rock Bass, Shorthead Redhorse, Silver Redhorse, Spotfin Shiner, Tadpole Madtom, Walleye, White Bass, White Crappie, Yellow Perch
- Other fish species previously sampled in Pokegama Lake but not sampled in recent FIBI surveys include: Banded Killifish, Iowa Darter, Smallmouth Bass

Candidate Stressors



- Eutrophication: Pokegama Lake is nutrient impaired with water quality problems and nuisance algae blooms reported since at least the 1920s. See the TMDL for detailed information about nutrient sources (primarily from animal agriculture via Pokegama Creek and other watershed sources and from internal loading). Pokegama lake has a large contributing watershed with approximately 34.5% watershed disturbance (residential (3.5%), agriculture (31%)). During the most recent assessment, the average Total Phosphorus for summer samples was 94 ppb.
- Physical habitat alteration, shoreline: Pokegama Lake has high shoreline development with ~14 docks per km/shoreline, a Score the Shore survey measured poor shoreline habitat at developed sites and good shoreline habitat at undeveloped sites, with an overall score of 67. Emergent and floating leaf vegetation is very limited. Common Carp are present and could be impacting aquatic vegetation habitat. The aquatic vegetation community is dominated by non native plants including Curly-leaf Pondweed and Eurasian Water-milfoil.
- Physical habitat alteration, hydrology: Pokegama Lake water levels have varied dramatically for over 150 years, with several dams and varied run-out elevations which have likely influenced water quality and habitat, and shaped the fish community. In recent years, the lake has experienced large water level fluctuations due to rainfall and spring melt which may impact the habitat for aquatic plants and some fish species.

Inconclusive stressors

- Altered interspecific competition: Common Carp may impact habitat in areas. Walleye stocking is unlikely to have an impact on the fish community assemblage, survey data suggests that the most significant contributions of Walleye are from natural reproduction.

Recommendations:

- Continue to implement or promote agricultural BMP's within the watershed to reduce nutrient and sediment inputs from the watershed, per the TMDL report recommendations.
- Continue to research internal phosphorus loading within the lake and its sources, following the TMDL recommendations.
- Promote and maintain vegetated riparian areas with shoreline buffers and shoreline restoration projects.
- Limit removal of native shoreland, shoreline, and aquatic plant communities.

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CLEAN WATER LAND & LEGACY AMENDMENT

DEPARTMENT OF NATURAL RESOURCES

References

Atwood, D., and C. Paisley-Jones. 2017. Pesticides industry sales and usage: 2008–2012 market estimates. USEPA, Washington, D.C.

Cormier, S., S. Norton, G. Suter, and D. Reed-Judkins. 2000. Stressor identification guidance document. U.S. Environmental Protection Agency, Washington D.C., EPA/822/B-00/025. Available: https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=20685. (March 2019).

Cross, T. K., and P. C. Jacobson. 2013. Landscape factors influencing lake phosphorus concentrations across Minnesota. Lake and Reservoir Management 29:1–12.

Douglas, M. R., and J. F. Tooker. 2015. Large-scale deployment of seed treatments has driven rapid increase in use of neonicotinoid insecticides and preemptive pest management in US field crops. Environmental Science and Technology, 49:5088–5097.

Drake, M. T., and D. L. Pereira. 2002. Development of a fish-based index of biotic integrity for small inland lakes in central Minnesota. North American Journal of Fisheries Management 22:1105–1123.

Dustin, D. L., and B. Vondracek. 2017. Nearshore habitat and fish assemblages along a gradient of shoreline development. North American Journal of Fisheries Management 37:432–444.

Goulson, D. 2014. Pesticides linked to bird declines. Nature 511:295–296.

Huser, B. J., Bajer, P. G., Chizinski, C. J., and Sorensen, P. W. 2016. Effects of common carp (Cyprinus carpio) on sediment mixing depth and mobile phosphorus mass in the active sediment layer of a shallow lake. Hydrobiologia, 763(1), 23-33.

Jacobson, P. C., T. K. Cross, D. L. Dustin, and M. Duval. 2016. A fish habitat conservation framework for Minnesota lakes. Fisheries 41:302–317.

Jin, S., C. Homer, L. Yang, P. Danielson, J. Dewitz, C. Li, Z. Zhu, G. Xian, and D. Howard. 2019. Overall methodology design for the United States National Landcover Database 2016 products. Remote Sensing 11 (24): 2971.

Köhler, H. R., and R. Triebskorn. 2013. Wildlife ecotoxicology of pesticides: can we track effects to the population level and beyond? Science 341:759–765.

Krupke, C. H. and J. F. Tooker. 2020. Beyond the headlines: the influence of insurance pest management on an unseen, silent entomological majority. Frontiers in Sustainable Food Systems 4:595855.

Langer, R. and J. Strom. 2016. Wenck Associates Technical Memo: June 2016 Vegetation Community Assessment on Pokegama Lake.

MDA (Minnesota Department of Agriculture). 2019. Pesticides in Minnesota lakes. MDA, St. Paul, Minnesota. Available: https://wrl.mnpals.net/islandora/object/WRLrepository%3A3462/datastream/PDF/view. (January 2021).

MDA. 2020. Pesticide sales database. MDA, St. Paul, Minnesota. Available: https://www.mda.state.mn.us/minnesota-pesticide-sales-information. (December 2020).

MDA 2021a. What's in my neighborhood? Agricultural interactive mapping. MDA, St. Paul, Minnesota. Available: https://app.gisdata.mn.gov/mda-agchem/. (January 2021).

MDA 2021b. Surface Water Pesticide Water Quality Monitoring. MDA, St. Paul, Minnesota. Available: https://www.mda.state.mn.us/pesticide-fertilizer/surface-water-pesticide-water-quality-monitoring (January 2021).

MNDNR (Minnesota Department of Natural resources) 1999. 1837 Ceded Territory Lakes Investigations. Part 1: Creel surveys of lakes during winter season 1996-97 and summer 1997. MNDNR, Hinckley, Minnesota.

MNDNR 2007. Pokegama Lake, Fisheries Lake Management Plan. MNDNR, Hinckley, Minnesota.

MNDNR 2015. Creel Surveys of Cross Lake (58-0119-00) and Pokegama Lake (58-0142-00) during the ice and open water angling seasons, 2013-2014.

MNDNR 2018. Stressors to biological communities in Minnesota's lakes. MNDNR, Brainerd, Minnesota.

MNDNR. 2019. Shapefile: MNDNR Culvert Inventory Suite. MNDNR, St. Paul, Minnesota. Available: https://www.dnr.state.mn.us/watersheds/culvert_inventory/index.html (December 2020).

MNDNR. 2020a. Watershed health assessment framework. MNDNR, St. Paul, Minnesota. Available: http://www.dnr.state.mn.us/whaf/index.html. (May 2020).

MNDNR. 2020b. Fishes of Minnesota mapper. MNDNR, St. Paul, Minnesota. Available: https://www.dnr.state.mn.us/maps/fom/mapper.html. (May 2020).

MNDNR. 2020c. Minnesota Climate trends. MNDNR, St. Paul, Minnesota. Available: https://arcgis.dnr.state.mn.us/ewr/climatetrends/ (June 2020).

MNDNR, 2020d. Watershed Health Assessment Framework. MNDNR, St. Paul MN Available: https://www.dnr.state.mn.us/whaf/index.html (June 2020).

Morrissey, C. A., P. Mineau, J. H. Devries, F. Sanchez-Bayoe, M. Liess, M. C. Cavallaro, and K. Liber. 2015. Neonicotinoid contamination of global surface waters and associated risk to aquatic invertebrates: a review. Environment International, 74:291–303.

MPCA (Minnesota Pollution Control Agency). 2007. Minnesota statewide mercury total maximum daily load. MPCA, St. Paul, Minnesota.

MPCA. 2013. Snake River Watershed TMDL. MPCA, St. Paul, Minnesota. Available: https://www.pca.state.mn.us/water/tmdl/snake-river-watershed-restoration-and-protection-strategy-tmdl-project (May 2020).

MPCA. 2020a. Minnesota's impaired waters list. MPCA, St. Paul, Minnesota. Available: https://www.pca.state.mn.us/water/minnesotas-impaired-waters-list. (December 2020).

MPCA. 2020b. Shapefile: what's in my neighborhood (WIMN). MPCA, St. Paul, Minnesota. Available: https://www.pca.state.mn.us/document/env-my-neighborhood. (December 2020).

MPCA. 2020c. Shapefile: feedlots in Minnesota. MPCA, St. Paul, Minnesota. Available: https://gisdata.mn.gov/dataset/env-feedlots. (June 2020).

MPCA 2020d. Snake River Watershed Water Assessment and Trends Update. St. Paul, Minnesota. (Draft June 2020).

Minnesota Rules Chapter 7050. Standards for the Protection of the Quality and Purity of the Waters of the State. Revisor of Statutes and Minnesota Pollution Control Agency, St. Paul, Minnesota. Available: https://www.revisor.mn.gov/rules/7050/ (May 2020).

Minnesota Rules Chapter 7080. Individual Subsurface Sewage Treatment Systems. Revisor of Statutes and Minnesota Pollution Control Agency, St. Paul, Minnesota. Available: https://www.revisor.mn.gov/rules/7080/ (November 2019).

Perleberg, D., P. Radomski, S. Simon, K. Carlson, C. Millaway, J. Knopik, and B. Holbrook. 2019. Minnesota lake plant survey manual, version 3, for use by Fisheries Section, EWR Lake Unit, and EWR Minnesota Biological Survey Unit. MNDNR, Ecological and Water Resources Division, Brainerd, Minnesota.

Robertson, D. M., and R. A. Ragotzkie. 1990. Changes in the thermal structure of moderate to large sized lakes in response to changes in air temperature. Aquatic Sciences 54:360–380.

Scheffer, M. 1990. Multiplicity of stable states in freshwater systems. Hydrobiologia 200/201: 475–486.

Valley, R. D., T. K. Cross, and P. Radomski. 2004. The role of submersed aquatic vegetation as habitat for fish in Minnesota lakes, including the implications of non-native plant invasions and their management. Minnesota Department of Natural Resources Special Publication No. 160, St. Paul.

Yamamuro, M., T. Komuro, H. Kamiya, T. Kato, H. Hasegawa, and Y. Kameda. 2019. Neonicotinoids disrupt aquatic food webs and decrease fishery yields. Science 366:620–623.