Chapter 1 Outline

A REVIEW OF MANAGEMENT-RELATED CONDITION SHIFTS IN SHALLOW LAKES
CAUSES, CASE STUDIES, COST, AND CLIMATE CHANGE

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Intended submission for Fish and Fisheries

[A]Purpose

This literature review aims to compile a summary on ecosystem shifts, the importance and causes of those shifts, trophic cascades, and the impact of introduced species in shallow lakes. It will then examine case-studies of management-linked shifts and explain current shift theory. Next, it will review cost analyses of maintaining a stable condition in both cost versus profit and usability terms. Finally, it will discuss historic shift frequency and expected outcome of climate change on shallow lakes.

[A]Shallow Lakes, Ecosystem Condition Shifts, and the Event of Trophic Cascades

A lake's ecosystem condition exists within a gradient between a clear and turbid condition (each having their own characteristics) and can often shift towards one end of the spectrum due to trophic cascades (i.e. top-down or bottom-up controls).

Shallow lakes are the most abundant lake types within the globe and are unique in size and characteristics.

A lakes food chain consists of multiple trophic levels including phytoplankton, zooplankton, fish, and plants.

Lakes currently in a clear, macrophyte-dominated condition will display different characteristics than those of a turbid, algal-dominated condition.

The change in condition will affect all trophic levels in a trophic cascade as a positive feedback loop.

[A]Causes of Condition Shifts within Shallow Lakes

One of the most common reasons a lake's condition shifts is due to phosphorous particles.

[B]Natural Causes

Phosphorous is a natural particle that is cycled into different forms and undergoes the process of sedimentation within shallow lakes.

Although phosphorous may not be added in large amounts, historic loads magnify the effect of additional phosphorous, also known as internal loading conditions.

Physical phenomena such as a fire or flooding can exaggerate the amount of phosphorous reaching that shallow lake.

[B]Anthropogenic Causes

A major source of phosphorous input from humans comes from agricultural sources in the form of fertilizer and manure.

Sewage system overflows are another potential source of excess phosphorous in the system due to organic matter.

Direct dumping is an illegal act decreed by the Environmental Protection Agency that used to be a common practice and may still occur.

[A]Species Introduction Effects on Shallow Lakes Condition

Introduced or invasive species are notorious for causing issues within a system for a variety of reasons.

Introduction of Common Carp (Cyprinus carpio) is known to direct a lake into a turbid condition due to bioturbation.

Rusty Crayfish (Orconectes rusticus) introduction leads shallow lakes towards a turbid condition due to influenced fish communities and a decrease in vegetation.

Zebra Mussels (Dreissena polymorpha) have been known to increase water clarity and encourage a clear, macrophyte-dominated condition.

Eurasian Watermilfoil (Myriophyllum spicatum) is one of the most troublesome plants in North America.

[A]Case Studies of Documented Shifts in Shallow Lakes

Although long-term documentation of these shifts is rare, there have been a few case studies in which the condition of a lake was studied in perspective of a condition shift.

Lake Shaokatan, located in Southwestern Minnesota, is a shallow lake that underwent a steady shift towards a clear condition from management action in the early 21st century.

Lake Christina is a shallow lake also located in Western Minnesota that has continuously shifted back towards a clear condition in congruence with biomanipulations of fish by management agencies.

Lake Krankesjön and Lake Tåkern are two Southern Sweden lakes that have repeatedly shifted and are of international waterfowl importance (Hargeby and Blindow, 2007).

[A]Shift Theory – Resilience and Switch Points

Although the causes of shifts in lake conditions are previously explained, the requirements or precipice at which a shift occurs are less known.

[A]Cost Analysis of Management for Shallow Lakes- Human Benefit vs. Ecosystem Health

Decision-makers in management positions must weigh or regard anthropogenic concerns and benefits against ecosystem function and health in accordance with each condition.

[B]Ecosystem Impacts of Shifts

Ecosystem health and biodiversity is greatly affected by condition shifts as well as the specific condition the lake resides.

Management-induced shifts will impact genetic diversity, adaptation to condition changes, and resistance towards invasive species.

Many areas of research in reference to ecosystem shifts could be vastly improved upon.

A meta-analysis was conducted by Hilt and colleagues (2017) on the consequences of regime (condition) shifts for landscape carbon processing.

Information from this meta-analysis on the impact of condition shifts on greenhouses gases is also conflicting (Hilt et al., 2017).

[B]Anthropogenic Decision Factors

Management must weigh importance of recreational swimming and drinking-quality against wishes of anglers and boat-users.

Management decisions must also look at revenue from agricultural or industrial activity nearby to the cost of maintenance for the preferred lake condition.

[A]Frequency of Shifts Pre-Industrialization and Expected Outcomes of Climate Change

The actions of civilization have caused great change to the environment and the impact humans have on world systems.

Frequency of condition shifts prior to industrialization can be determined through sediment core analyses.

Climate change will have a great impact on shallow lakes moving forward and may cause shifts toward a turbid, algal-dominated state more common.

[A]Conclusions

[A]References

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Chapter 2

IMPLICATIONS OF MANAGEMENT ACTIONS (LAND-USE CHANGES AND VEGETATION REMOVAL) ON CONDITION SHIFTS DUE TO TROPHIC CASCADES.

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[A]Abstract

Management actions have been known to lead to condition shifts within lakes, and shallow lakes are especially vulnerable to these shifts. Ecosystem conditions exist as a continuum between turbid, algal-dominated and clear, macrophyte-dominated conditions. Lake Shaokatan, a shallow Southwestern Minnesota lake, has undergone a shift throughout the early 21st century towards a clear condition in correspondence with land-use changes. These land-use changes were accomplished through the rehabilitation of three feedlots, four wetland areas, and shoreline septic systems. A recent fluctuation in the summer of 2019, suggesting a shift towards a turbid condition, may have been initiated by the chemical removal of about 15 percent of vegetation within the lake basin. The primary objective of this study examined the long-term trends of water quality, percent phytoplankton composition, zooplankton and fish relative biomass, as well as percent coverage of the littoral area by plants on Lake Shaokatan. Fish biomass was subdivided into piscivores and non-piscivores by the most prominent diet item in each species' adult stage. This study also documented how two management actions (land-use changes and chemical removal of vegetation) had a role in ecosystem shifts. The final objective investigated whether patterns of dissolved oxygen, water temperature, and phosphorus concentrations correlated with trophic level changes and/or served as indicators, along with

taxon of plants or phytoplankton, of an oncoming shift in the ecosystem. Results of this proposed study would aid management agencies to make deliberate decisions and inform them of triggers for a condition shift.

[A]Introduction

Aquatic ecosystems around the world (i.e. coral reefs, shallow lakes) alternate within a continuum between a turbid, algal-dominated condition and a clear, macrophyte-dominated condition (also termed as stable states) due to human-induced and/or natural causes (Scheffer et al., 2001). Scheffer and his colleagues (2001) stated these two conditions may transition in a smooth, continuous shift or inertly from perturbation, especially in smaller basins. When a historically turbid and algal-dominated lake shifts to a clear condition (and vice versa) for an extended period, it is known as a stable condition shift (Hobbs et al., 2012). Shallow lakes are especially vulnerable to eutrophication and shifts due to their small size and depth, which provide the most important wildlife habitat of all lakes (MN DNR, 2019). Decreased water column depth allows sunlight to sometimes reach the lake bottom during clear water quality, encouraging vegetation growth throughout the entire lake (Scheffer, 1998).

Human-induced eutrophication leading to the loss of transparency and vegetation in shallow lakes is one of the best-studied and most dramatic stable ecosystem shifts (Scheffer et al., 2001), however, natural disturbances also occur. Natural disturbances can include high winds increasing wave energy and resuspending nutrient-filled sediments (Havens et al., 2012; Scheffer, 1998) and wildfires reducing shoreline vegetation resulting in increased runoff and erosion (Paige & Zygmunt, 2013), which encourage a turbid condition. However, droughts leading to lower water levels induce a shift towards a clear condition as shallow depths allow sunlight to sometimes penetrate farther (McGowan et al., 2005). Considered as a natural or human action, the introductions of invasive species that bottom-feed, such as Carp (Cyprinidae family) and Bullhead (*Ameiurus* spp.), resuspend nutrient-filled sediment to the water column while looking for food, decreasing the stability of a clear condition as well (RMBEL, 2013; Scheffer, 1998). Anthropogenic encouragement towards a turbid condition also include the addition of phosphorous and organic litter through direct waste dumping of citizens and industries (pre-Clean Water Act in 1977 published by Hall in 1978), construction of dams at outflows of lakes increasing retention, agricultural runoff during rain events, and combined sewage system overflows. Excluding natural fluctuations, to attain a long-term clear ecosystem once disturbed, anthropogenic nutrient runoff must be dramatically reduced to recover (Hobbs et al., 2012).

Once a stable clear condition reaches a threshold of excess nutrients, the lake will shift from a macrophyte-dominated to an algal-dominated ecosystem, causing a trophic cascade of changes in biomass. Overabundant nutrients increase algal biomass leading to reduced light penetration, which limits macrophyte distributions and growth (Schallenberg & Sorrell, 2009; Hobbs et al., 2012). Lack of macrophyte roots to retain sediments allows resuspension into the water column with their attached nutrients. These nutrients fuel greater phytoplankton abundance and encourages *Bosmina* spp. to outcompete large-bodied *Daphnia* spp., as fish prey on the larger species (DeMott and Kerfoot, 1982), which results in a higher fish biomass favoring planktivores and benthivores over piscivores (Hobbs et al., 2012). Reducing fish biomass creates a top-down control as Scheffer et al. (2001) stated in a review article that in the absence of plants, fish control *Daphnia* spp. and are central to maintaining a turbid state. Therefore, Hobbs et al. (2012) stated a management action, such as biomanipulations (i.e. fish kills on Lake Christina, MN), temporarily return turbid systems to clear ecosystems (5-10 years) and exemplify changes in plant community structure associated with improved water clarity (Hansel-Welch et al., 2003).

A shift towards a stable clear, macrophyte-dominated condition is harder to achieve and is therefore uncommon, especially when the lake experiences human-related nutrient addition. A reduction in planktivorous fish biomass leads to reduced phytoplankton biomass through increased *Daphnia* spp. grazing (Brönmark and Hansson, 2005). This reduction in phytoplankton allows sunlight to reach the plant beds below. Brönmark and Hansson (2005) also stated a reduction in benthivorous fishes decreases macrophyte uprooting and sediment resuspension. This decrease in turbidity of the water column and greater succession of macrophytes leads toward a more stable clear condition. However, to ensure stability in this new condition, nutrient input must remain well below the threshold for a shift to turbid conditions (Scheffer et al., 2001). McGowan et al. (2005) suggested drawdowns in water level by management also induce a shift towards a clear condition due to greater light penetration.

Although the large-scale results of reducing fish biomass have been documented, the proof of indicators and long-term data analyses on the change of trophic levels' biomass during a shift are rare. Therefore, a primary objective of this study is to analyze long-term trends of water quality, phytoplankton, zooplankton, and fish biomass, as well as percent cover of the littoral area by plants in Lake Shaokatan, which has undergone a stable shift and a recent condition fluctuation. A secondary objective is to document how two management actions (land-use changes and chemical removal of vegetation) had a role in ecosystem shifts. A tertiary objective is to investigate whether patterns of dissolved oxygen, water temperature, and phosphorus concentrations correlate with trophic level changes and/or serve as indicators, along with taxon of plants or phytoplankton, of an oncoming shift in ecosystem condition. Results of this study would aid management agencies to make deliberate decisions and inform them of triggers for a condition shift.

[A]Methods

This study is designed as a case study of Shaokatan Lake, MN. Lake Shaokatan is a shallow lake that was declared impaired in 2002 (MPCA, 2002). It was involved in several nutrient management and monitoring programs to boost waterfowl use and the walleye fishery. Rehabilitating wetland areas, animal feedlots, and shoreline septic systems during the early 21st century led to a shift towards a clear, macrophyte-dominated condition. However, chemical removal of 15% of vegetation in the summer of 2019 may be reversing this shift. To meet the objectives of this study, the following methods were utilized in collection and processing of each trophic level.

[B]Fish

Fish populations were sampled following MN DNR (2019) procedures using 3 experimental, multifilament gill nets 76.2 meters long, divided into five 15.2-meter panels of 19.1 mm, 25.4 mm, 31.7 mm, 38.1 mm, and 50.8 mm bar mesh according to a standardized lake survey protocol (MDNR 1993). This mesh is extended 1.5 meters vertically through the water column at three of six predetermined site locations (chosen based on wind and weather patterns as well as previous years' sample placement) on the first week of August each year. On each end, the net is held to the bottom of the lake by an anchor attached to the lead line and a buoy attached to the float line brings the top side of the net towards the surface. Gill nets fish overnight, during which fish attempt to swim through and become entangled by their gills, fin spines, and sometimes teeth. The net is pulled after approximately 24 hours and captured fish (separated by mesh size) were identified, counted, and measured by total length (mm). Weights were taken for Northern Pike and Walleye, as well as for Yellow Perch and Bluegill that had aging structures removed for another project. Relative biomass was then calculated for each species weighed and a weight length regression was used for those who only had length taken. Biomass was then combined into two groups (piscivore and non-piscivore) based on most frequent prey during adult stage stated in literature (Appendix A). Non-piscivorous fish were classified as Black Bullhead, Bluegill, Bluntnose Minnow, Brook Stickleback, Common Carp, Fathead Minnow, Golden Shiner, Green Sunfish, Johnny Darter, Orange-spotted Sunfish, Pumpkinseed, Sunfish hybrid, and White Sucker. Piscivorous fish were classified as Black Crappie, Northern Pike, Yellow Perch, and Walleye.

[B]Phytoplankton

Phytoplankton samples were annually collected once a month from May to October at the surface of the lake's site of maximum depth using a 2 m polyvinyl chloride (PVC) integrated tube with a diameter of 1.25 inches (MN DNR, 2016). Samples were stored on ice and in the absence of light until they were decanted into a dark plastic bottle (usually 250 mL in volume) and preserved with Lugol's Solution (glutaraldehyde post-2017 due to preservation preference) for later analysis. In the lab, a membrane filter (25-mm diameter Pall, Metricel, GN-6, 0.45 µm pore size) was placed on a filter tower (Phycotech 2014 webpage: phycotech.com/technical; adapted from Crumpton 1987). The water sample was homogenized by shaking 100 times before a 5 mL sample was removed using a calibrated Eppendorf macropipet. This sample was added to the tower and vacuumed until the water disappeared. This filter was placed face down on a cover slip (# 1.5 thickness, 0.17 mm thickness; 25 mm x 25 mm) and inserted into a drying oven at 60 ºC for 1 hour. The slide was then placed filter side down on a microscope slide and using a compound microscope at 500x magnification, the percent abundance by biovolume was estimated for each algal taxon or type. Chlorophyll *a* concentration represented the relative biomass of phytoplankton within the sample and was averaged across the year.

Chlorophyll a Calculation

$$Chlorophyll\ a, \frac{mg}{L} = \frac{26.7 \times (664_{abs} - 665_{abs}) \times EV}{SV \times L}$$

Where: EV= volume of extract, L (0.020 typically)

SV= volume of whole water sample filtered, L (0.2 typically)

L= optimal pathlength of cuvette, cm (5)

[B]Zooplankton

Zooplankton samples were collected by a vertical tow monthly from May to October using a 30 cm mouth, 80 µm mesh simple zooplankton net (MN DNR, 2016a). Each net was set within 0.5 m of the bottom and hauled approximately 0.5 meter per second. The net was then rinsed into sample bottles topped with 100% reagent alcohol and later analyzed by MN DNR personnel. Each sample was adjusted to a known volume by rinsing specimens into a graduated beaker from an 80 µm mesh net and adding water to a volume that provided 150 organisms or more per 5 mL aliquot. A 5 mL aliquot was withdrawn using a bulb pipette and transferred to a counting wheel for each sample. Organisms were identified by species, counted, and measured to within 0.01 mL using a dissecting microscope and an image analysis system. Relative biomass estimates (µg/L) for each taxonomic group were calculated using length/weight regression coefficients based on dry weight, obtained from Culver et al. (1985) and Dumont et. al (1975).

These values were summed then averaged across all months to provide a single value for annual comparisons.

[B]Plants

Plant surveying was performed annually on Lake Shaokatan using the lakewide point intercept survey method, as explained by the MN DNR (2016b), to estimate abundance of frequently occurring taxa and percent of the littoral zone containing vegetation. Surveyors navigated to within five meters of 304 (2019) predetermined sites using GPS units on boats without anchoring. In the depth zone from shore to 1.5 m were spaced 65 meters apart, while those in greater depths were spaced 195 meters apart. These were chosen based on desired number of sample sites within each zone. Sampling occurred on a designated side of the boat and consisted of a square meter at that location. Record was kept of the greatest depth consistently sampled with vegetation present sites. A reason for not sampling (i.e. possible destruction of emergent plants, site location on shore, limited access, etc.) was recorded if a site was not sampled. At each site, water depth was measured to the nearest foot in depths less than 2.5 meters and to the quarter foot in depths less than 0.305 meters. Plants within the square meter were sampled visually and with a rake sampler by tossing it once and dragging it within 3 to 5 meters. Total plant abundance was described as not detected, sparse (one or few fragments), common (neither sparse nor matted), and abundant (matted at or near surface). Taxa were identified to species level if possible or as “unknown” if insufficient plant material exists. If unfamiliar with the plant, preservation of the specimen for later identification included labeling, pressing, and drying of plant. Percent coverage of the littoral zone was then calculated. The equation from the MN DNR (2016b) was used to calculate error value for each year (Appendix B).

[B]Water Quality Characteristics

Water quality data was collected through the Sentinel Lakes program (MN DNR, 2019) and the MPCA. Water temperature was collected every hour within the water column through data sensors year-round. Dissolved Oxygen (DO) was collected before 9 am and summarized as daily maximums and minimums in open-water months (April through November) according to water quality assessment standards (MPCA, 2016). Following those same standards, total phosphorous was collected at a single site and compared to the standard (seasonal average from June to September).

[B]Statistical Analyses

Statistical analyses were adapted from MN DNR (2016a) and were completed using program R.

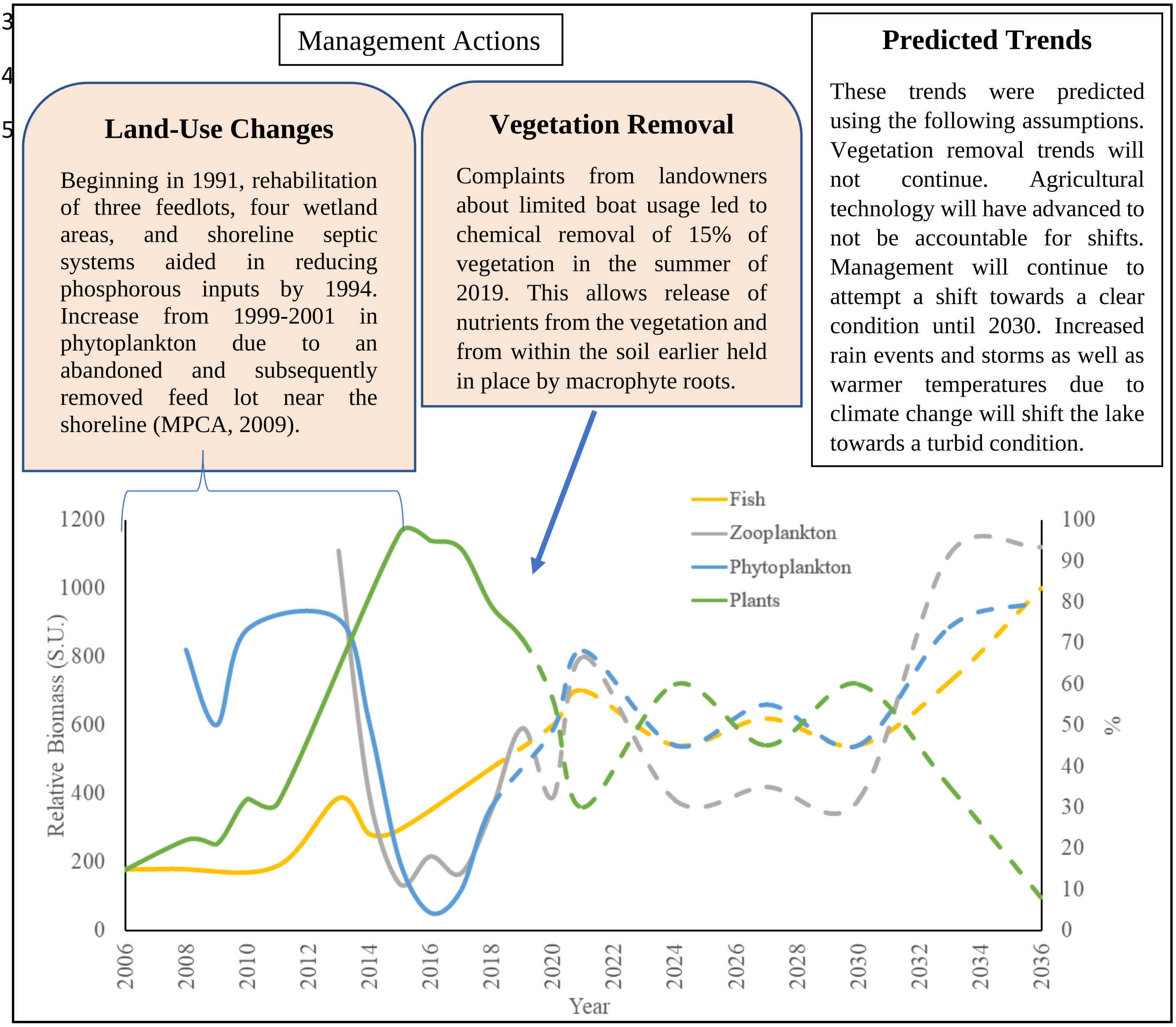
To determine whether fish species richness significantly differed over time, a one-way analysis of variance (ANOVA) was performed. Significant differences ($p < 0.05$) suggest a lake condition shift has occurred.

To determine which (if any) years of Shaokatan Lake showed significant differences in fish community structure, analysis of similarity (ANOSIM) tests were performed. The produced R statistic shows a comparative measure of the degree of separation between years (Clarke and Warwick 2001). R typically falls between 0 and 1, with values near zero suggesting similar assemblages and representing the null hypothesis of no differences between years. Greater assemblage differences lead to an R-value closer to 1.

To examine similarities and dissimilarities in community structures in Shaokatan Lake by year based on both phytoplankton and zooplankton, non-metric multidimensional scaling (MDS) analysis (Clarke 1993). Years proximally graphed exhibit similar community assemblages while those farther apart display less similarity. Accuracy of the relationship is indicated with a stress value, which is acceptable if below 0.2 (Clarke 1993).

To determine which, if any, of the physicochemical parameters best explained the zooplankton community structure, the BIOENV procedure was performed (Clarke and Gorley, 2006). The rank correlation (ρ) of BIOENV ranges from -1 to 1 comparing biotic and environmental similarity matrices (Clarke and Ainsworth 1993) with values near +1 showing a strong positive relationship and values near zero showing no relationship.

To examine relationships between phytoplankton, zooplankton, plant, and fish communities as well as chemical lake characteristics, Spearman Rank Order Correlations were performed. Spearman's correlation coefficient (ρ) ranges from -1 to +1, with values close to -1 indicating a strong inverse relationship. Coefficient values near +1 show a strong positive relationship while values near zero suggest no relationship.



Management Actions

Land-Use Changes

Beginning in 1991, rehabilitation of three feedlots, four wetland areas, and shoreline septic systems aided in reducing phosphorous inputs by 1994. Increase from 1999-2001 in phytoplankton due to an abandoned and subsequently removed feed lot near the shoreline (MPCA, 2009).

Vegetation Removal

Complaints from landowners about limited boat usage led to chemical removal of 15% of vegetation in the summer of 2019. This allows release of nutrients from the vegetation and from within the soil earlier held in place by macrophyte roots.

Predicted Trends

These trends were predicted using the following assumptions. Vegetation removal trends will not continue. Agricultural technology will have advanced to not be accountable for shifts. Management will continue to attempt a shift towards a clear condition until 2030. Increased rain events and storms as well as warmer temperatures due to climate change will shift the lake towards a turbid condition.

Figure 1. Relative biomass of zooplankton (µg/L) and fish (kg/m^2), percent cover of plants, and percent composition of Cyanophyta with associated management actions over time. Right vertical axis represents percent cover of littoral acres by plants and percent composition of Cyanophyta, while the left vertical axis shows units for biomass select trophic levels. Dotted lines within the graph show expected trends if vegetation removal does not continue and management continues to attempt a manipulated shift towards a macrophyte-dominated condition.

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[A]Appendices

[A]Appendix A

Table A1. Diet and classification of diet group for fish in Lake Shaokatan. For the purpose of this study, fish were labeled non-piscivorous (NP) and piscivorous (P) based on whether fish was their main diet as an adult. Those assigned a group with red text represent fish that may be assigned differently in other studies were finalized using EPA protocol classification (Barbour et al., 1999).

Fish Species	Diet (in order of most frequent)	Assigned Group
Black Bullhead (*Ameiurus melas*)	Insects, debris, fish, crustaceans (Kutkuhn, 1955)	NP
Black Crappie (*Pomoxis nigromaculatus*)	Invertebrates, fish, crustaceans, debris (Liao et al, 2002; Kutkuhn, 1955)	P
Bluegill (*Lepomis macrochirus*)	Small soft-bodied invertebrates, crustaceans (Werner and Hall, 1981; Olson et al., 2003).	NP
Bluntnose Minnow (*Pimephales notatus*)	Detritus, algae, invertebrates, plankton (Moyle, 1973)	NP
Brook Stickleback (*Culaea inconstans*)	Zooplankton, invertebrates (Held and Peterka, 1974)	NP
Common Carp (*Cyprinus carpio*)	Detritus, invertebrates, debris (Garcia-Berthou, 2001)	NP
Fathead Minnow (*Pimephales promelas*)	Zooplankton, invertebrates (Held and Peterka, 1974)	NP
Golden Shiner (*Notemigonus crysoleucas*)	Zooplankton, insects, benthos (Harnois et al., 1992; Reebs, 2002)	NP
Green Sunfish (*Lepomis cyanellus*)	Invertebrates, fish, plant detritus (Lemley, 1985)	NP
Johnny Darter (*Etheostoma nigrum*)	Zooplankton, insects, benthos (Reebs, 2002)	NP
Northern Pike (*Esox Lucius*)	Fish, invertebrates (Liao et al., 2002)	P
Orange-spotted Sunfish (*Lepomis humilis*)	Insects, crustaceans (Kutkhun, 1955)	NP
Pumpkinseed (*Lepomis gibbosus*)	Insects, zooplankton, crustaceans, plant material (Rezsu and Specziár, 2006)	NP
Sunfish hybrid (*Lepomis spp.*)	most likely eats mainly insects and sometimes smaller fish	NP
Yellow Perch (*Perca flavescens*)	Invertebrates, fish, crustaceans (Liao et al., 2002; Kutkuhn, 1955)	P

Walleye (*Stizostedion vitreum*)	Fish, insects, crustaceans (Kutkuhn, 1955)	P
White Sucker (*Catostomas commersoni*)	Zooplankton, zoobenthos (Saint-Jacques et al., 2000)	NP

[B]References

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[A]Appendix B

The grid used in the lakewide point intercept survey method is suggested to have a minimum of 225 sample sites to have a 95% confidence within ± 20% of true value. There should be a minimum of 75 sites within the 0-5 ft and 6-10 ft depth classifications. The default spacing for each stratum is 65m (1 point per acre) but may be 40 m on small lakes. A minimum of 30 m spacing is recommended. The appropriate number of sample sites are found through the following equation.

Number of sample sites

$$N = (\frac{t}{D})^2 \times \frac{(1-p)}{p}$$

Where:

N = required sample size

t = appropriate value from t distribution table (1.96 for 95% confidence interval)

p = estimate of frequency of occurrence

D = error as a fraction of p (i.e. 0.1 to estimate p within 10% of true value)

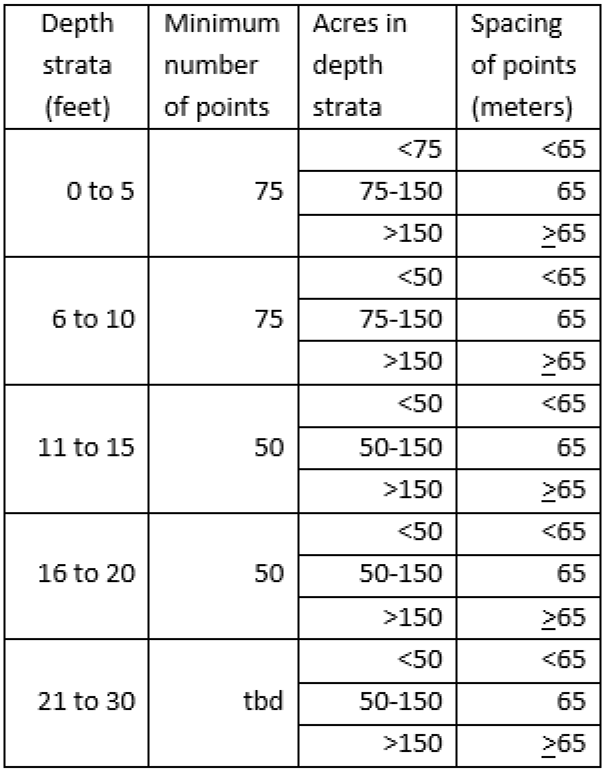
Example of Frequency of Occurrence

$$D = t\sqrt{\frac{(1-p)\times p}{N}}$$

Within the shore to 20 feet depth zone, plants occurred in 30% of the 1 m^2 sample sites (N=250). There is 95% confidence that this value is within 6% of the estimated value (24-36%).

$$\text{Error} = 1.96\sqrt{\frac{(0.7-0.3)\times 0.3}{250}} = 0.06 = 6\%$$

Table B1. Recommended minimum sample number by depth strata for Minnesota lakewide point intercept surveys (Table 5-2, MN DNR, 2016b).



Depth strata (feet)	Minimum number of points	Acres in depth strata	Spacing of points (meters)
0 to 5	75	<75	<65
		75-150	65
		>150	≥65
6 to 10	75	<50	<65
		75-150	65
		>150	≥65
11 to 15	50	<50	<65
		50-150	65
		>150	≥65
16 to 20	50	<50	<65
		50-150	65
		>150	≥65
21 to 30	tbd	<50	<65
		50-150	65
		>150	≥65

[A]Appendix C

[B]Fish IBI Program

Fish Index of Biotic Integrity (IBI) was used to assess whether the aquatic community is being supported by the lake (MPCA, 2016). Developed by the MN DNR with assistance from the MPCA, it uses multiple attributes, called “metrics”, to assess the health and diversity within a complex biological system. This program targets nearshore fish using a combination of back pack electrofishing and 50 ft. beach seines (DNR, 2019). For backpack electrofishing, an electrofishing unit is carried on the back of a crew member. Wearing waders to protect from the electrical current, the crew members walk in the shallow water (0-3 ft) along the sample site shoreline and net the fish momentarily stunned by the electrical pulse emitted by the unit. For seine hauls, the 50-foot length of mesh netting is mounted on each end to a 5-foot pole. Two crew members wearing waders stand a set distance in the lake in the 0-3 ft depth and dragged the seine towards the shoreline. Abundance by species of fish were found for both methods in number per unit effort (i.e. electrofishing- number caught per unit of time and seine hauls- number caught per net. IBI surveys were completed in ‘08, ‘11, ‘13, ‘14, and ‘15 showing similar results. However, this appendix will look at functional groups in those years based on fish biomass grouping methods of piscivorous and non-piscivorous.