MINNEHAHA CREEK WATERSHED DISTRICT

QUALITY OF WATER QUALITY OF LIFE

SIX MILE CREEK - HALSTED BAY HABITAT RESTORATION

A technical report on restoration efforts through common carp management.

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December 2024

EXECUTIVE SUMMARY

From 2014-2023, the Minnehaha Creek Watershed District (MCWD) and its partners conducted one of the region's largest habitat and water quality restoration programs in the Six Mile Creek – Halsted Bay (SMCHB) Subwatershed. Several lakes in the Subwatershed, which is Lake Minnetonka's largest tributary, are impaired for excess nutrients and have degraded aquatic plant communities. **The program's goals were to restore and enhance ecological conditions and water quality throughout the Subwatershed's system.**

Common carp are abundant in the region and a known driver of poor ecological conditions, so beginning in 2014, MCWD conducted a 3-year carp assessment in partnership with the Minnesota Aquatic Invasive Species Research Center (MAISRC), to evaluate carp abundance, recruitment, and movement in the SMCHB Subwatershed. This assessment informed a holistic carp management approach that included a data-driven, three-pronged strategy.

1) **Adult Removal:** reduce carp biomass through direct removal
2) **Barrier Installation:** prevent movement between waterbodies
3) **Aeration of Shallow Lakes:** prevent successful carp reproduction

Following this strategy's implementation, MCWD analyzed monitoring data to determine whether carp populations decreased and if reduced carp biomass improved water quality and submerged aquatic vegetation.

MCWD successfully reduced carp to or near biomass goals in the majority of the SMCHB Subwatershed lakes. However, the data revealed complex relationships between carp density, water quality, and vegetation health that indicate successful carp management alone may not restore ecological conditions.

Carp removal did not result in consistent vegetation and water quality improvements systemwide. A lake's initial carp biomass, as well as its magnitude of degradation, morphology, depth, and legacy nutrient impairments, impacted the effectiveness of carp management as a lake restoration strategy.

These nuanced findings indicate removing one driver of poor conditions does not guarantee immediate or predictable recovery. Following carp removal, many of the SMCHB Subwatershed lakes continued to experience poor water quality and lacked diverse vegetation cover, indicating other drivers may continue to degrade a system even after successful carp removal. Because of this, **comprehensive lake restoration requires a multifaceted approach to support resilient, diverse aquatic ecosystems.**

PARTNER ACKNOWLEDGEMENTS

As part of a comprehensive effort to restore habitat and water quality throughout the 27-square mile Six Mile Creek – Halsted Bay Subwatershed, which drains to Lake Minnetonka, the Minnehaha Creek Watershed District (MCWD) worked with leading University of Minnesota researchers within the Minnesota Aquatic Invasive Species Center (MAISRC) to develop a data-driven management strategy drawing on an understanding of carp abundance, movement patterns, and spawning areas.

Working in partnership with the Lessard-Sams Outdoor Heritage Council in the form of a $567,000 grant, local communities, county agencies, and Three Rivers Park District, MCWD implemented a management strategy to reduce common carp populations, improve water quality and habitat, and inform the ongoing science of carp management as one of many watershed restoration tools.

City of St. Bonifacius

Laketown Township

City of Victoria

Wassermann Lake Association

City of Minnetrista

Waconia

Carver County Minnesota

Hennepin County Minnesota

Carver Soil & Water Conservation District

Clean Water Land & Legacy Amendment

mn Department of Natural Resources

University of Minnesota

Three Rivers Park District

Partners also include the Area Partnership for Pierson Lake Enhancement (A.P. P. L. E.)

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1. BACKGROUND AND INTRODUCTION

1.1 PURPOSE AND OUTCOMES

The aim of this assessment is to offer an overview of the execution of the carp management program in the Six Mile Creek - Halsted Bay (SMCHB) Subwatershed. This includes an examination of the advancements made toward achieving our objectives of restoring and enhancing ecological conditions and water quality. We strive to provide an evaluation of the management strategies used, outline future management activities needed to meet our goals, and provide guidance and direction on MCWD's carp management strategy districtwide.

1.2 WATERSHED OVERVIEW

The SMCHB Subwatershed is located in the western portion of the Minnehaha Creek Watershed, in Carver County. The subwatershed covers 26.6 square miles, including parts of Victoria, Laketown Township, St. Bonifacius, and Minnetrista, and represents the largest tributary to Lake Minnetonka (Figure 1-1).

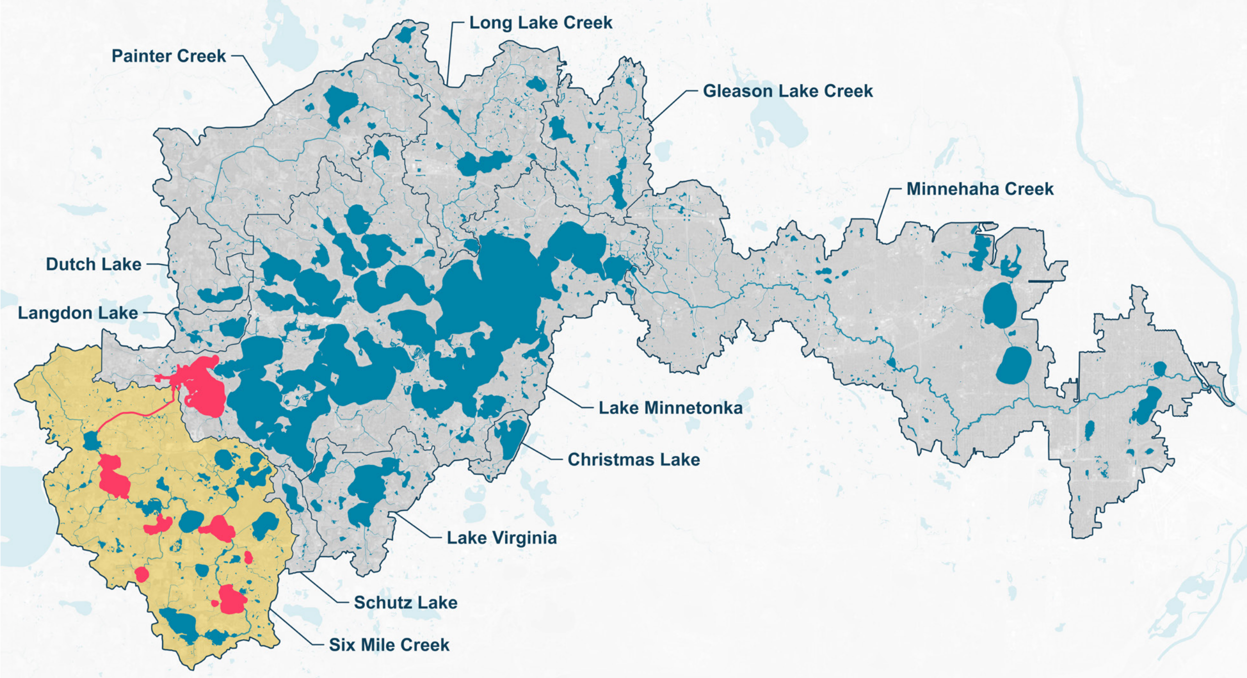


Figure 1-1. The Minnehaha Creek Watershed District spans 178 square miles and includes 11 subwatersheds. The SMCHB Subwatershed is the headwaters of the watershed and is highlighted in yellow, with its impaired waterbodies highlighted in red.

The Carver Park Reserve, owned and operated by Three Rivers Park District, also covers a large portion of the subwatershed, including the areas draining to Stone, Zumbra, Steiger, East and West Auburn, and North and South Lundsten Lakes. The subwatershed is relatively flat and is dominated by hydric soils and low-lying wetland areas. The subwatershed is highly altered with development in parts of the subwatershed and drained agricultural lands throughout. Many of the wetlands are highly ditched and the channels themselves indicate alterations, such as straightening for drainage improvements. It is composed of several deep and shallow lakes, has numerous wetlands, and eventually flows into Halsted Bay on Lake Minnetonka.

1.3 DIAGNOSTIC ASSESSMENTS

1.3.1 WATER QUALITY AND VEGETATION ASSESSMENT (SMC DIAGNOSTIC STUDY)

Several lakes in this subwatershed are impaired for excess nutrients (Figure 1-2). They can be characterized as generally turbid with poor water clarity and degraded aquatic plant communities that provide poor habitat for fish and waterfowl (Wenck, 2013). Common carp *(Cyprinus carpio)* are abundant in the subwatershed (Figure 1-3) and are a known driver of poor ecological conditions (Wenck, 2013; Koch et al., 2016). Common carp are one of the world's most widely introduced and invasive fish species and dominate the fish biomass of many shallow lakes, rivers, and wetlands in North America, including in central and southern Minnesota.

Carp can degrade water quality and decrease waterfowl, fish, and amphibian habitat by rooting in the lake bottom while searching for food, primarily plant seeds and benthic macroinvertebrates that live in lake sediments (Parkos et al., 2003). While foraging, carp burrow into lake sediments and in the process, they uproot aquatic vegetation, increasing water turbidity and releasing sediment-bound nutrients, which can cause algal blooms (Huser et al., 2022). The University of Minnesota's Aquatic Invasive Species Center (MAISRC) estimates over 70% of lakes in southern Minnesota have lost their plant cover and suffer from algal blooms due to carp's foraging behavior. Because of this, common carp have impacted much of Minnesota's waterfowl habitat (Bajer et al., 2009; Haas et al., 2007).

Managing carp is a top priority for the SMCHB Subwatershed's management and restoration and is part of a broader plan in MCWD's 2017 Comprehensive Plan to improve water quality and ecological conditions across the entire system.

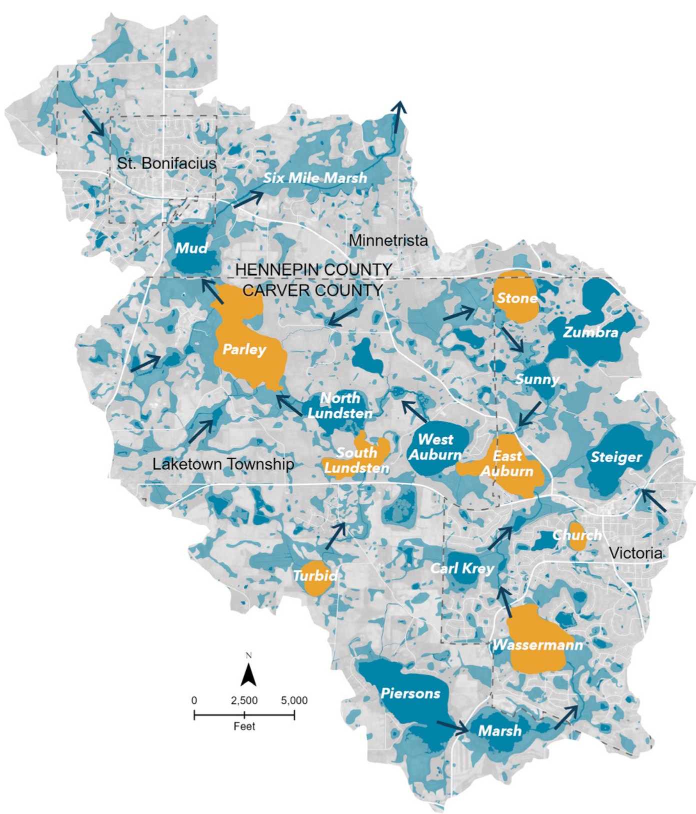


Figure 1-2. The SMCHB Subwatershed contains 14 lakes, seven of which were impaired (orange).

1.3.2 CARP BIOMASS ASSESSMENT (UMN CARP ASSESSMENT)

In 2014, MCWD partnered with the University of Minnesota (UMN) to complete a 3-year assessment of common carp in the SMCHB Subwatershed (Koch et al., 2016). Its purpose was to determine carp abundance, recruitment patterns, and seasonal movements, to enable the development of carp control strategies for restoration of the SMCHB Subwatershed. The study found that adult carp biomass in 12 of the subwatershed's lakes exceeded 100 kg/ha (89 lbs/acre), a threshold where ecological damage can occur (Figure 1-3, Koch et al., 2016; Bajer, 2009).

Juvenile carp were found in very low numbers at five sites within the subwatershed; South Lundsten Lake and Crown College Pond had extremely high numbers.

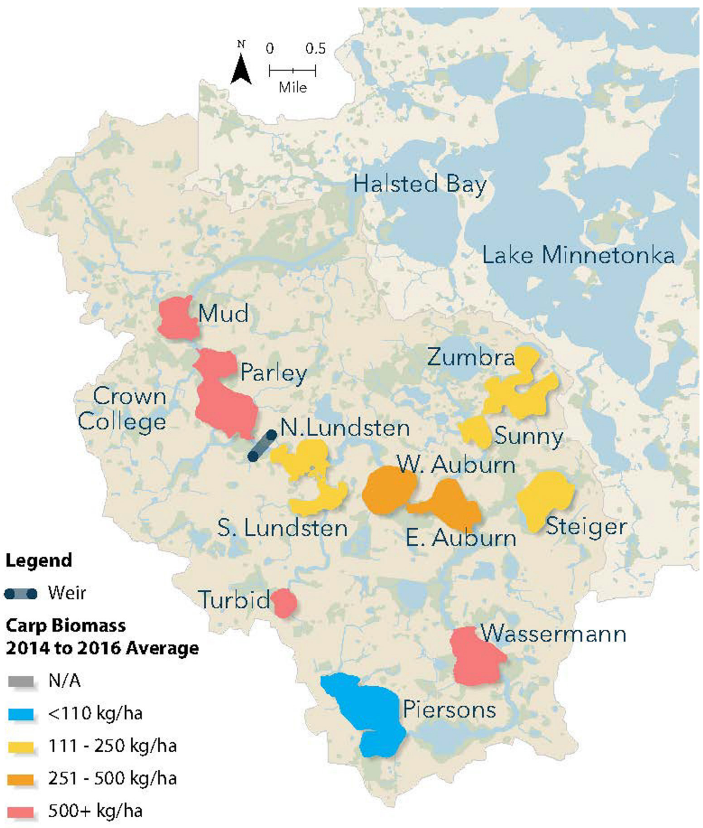


Figure 1-3. Mud, Parley, Turbid, and Wassermann Lakes had the highest average carp biomass from 2014-2016 in the SMCHB Subwatershed.

South Lundsten was found to be a top management priority, contributing high abundances of juvenile common carp to several lakes in the subwatershed, including upstream to Auburn Lake, downstream to Parley Lake, and even as far as Wassermann Lake.

Other potential carp nurseries were identified (Marsh, Wassermann Pond West, North Lundsten, South Lundsten, Turbid, Crown College Pond, Big SOB, Mud, Sunny, and Shady Pond). Although some have not produced juvenile carp in many years, they could provide successful carp recruitment during drought years or in harsh winter conditions that allow winterkill of bluegill sunfish (Koch, 2016).

Movement data of common carp identified four distinct populations in the subwatershed, which can be managed separately with barriers (Koch, 2016).

The following are the movement zones for this system (Figure 1-4):

1) Pierson-Marsh-Wassermann
2) Auburn-Lundsten-Turbid
3) Zumbra-Steiger
4) Parley-Mud
5) Halsted Bay

Figure 1-4. Carp movement zones informed recommended barrier placement throughout the SMCHB Subwatershed.

1.4 COMMON CARP MANAGEMENT

In September 2017, the Lessard Sams Outdoor Heritage Council (LSOHC) awarded MCWD $567,000 for the SMCHB Habitat Restoration Program. The program took a holistic and comprehensive approach to manage common carp in the SMCHB Subwatershed, with the goal of not exceeding the 100 kg/ha carp biomass threshold in each waterbody. This approach consisted of three management strategies:

1. Adult biomass removal
2. Barriers to prevent carp movement between waterbodies and assist with removal
3. Aeration of shallow lakes to prevent successful carp reproduction

ADULT BIOMASS REMOVAL

MCWD deployed a variety of tactics over the past five years to remove carp across the SMCHB Subwatershed. These methods included stream trapping utilizing permanent and temporary barriers, baited box net trapping, and commercial winter seining (Appendix D).

To date, across the 14-lake system, MCWD has removed approximately 30,000 carp totaling 276,647 pounds. In addition to direct removal, barriers and aeration were strategically deployed to cut off and isolate spawning locations.

CARP BARRIER CONSTRUCTION

Three barriers have been in place since March 2019 — between the Crown College Pond and Parley Lake, at Highland Road between Mud Lake and Halsted Bay, and at the outlet of Wassermann Lake — and have proved effective at preventing carp from moving through major migratory corridors. In Fall 2020, MCWD completed minor retrofits on the largest of the three barriers, the Highland Road Barrier, to improve its performance.

A fourth and final barrier was constructed in February 2021 at the outlet of West Auburn Lake in the Carver Park Reserve.

Installation of the Wassermann Lake outlet barrier in 2019 after the spring migration of carp out of the lake was one of this management strategy's key success points. This allowed MCWD to quickly meet biomass goals for that lake and narrow removal efforts to the downstream lakes.

SHALLOW LAKE AERATION

Aeration is an important strategy for preserving adequate oxygen levels in lakes in which carp are known to spawn, thereby maintaining populations of bluegill and sunfish — fish that predate carp eggs — and preventing successful carp recruitment.

Utilities have been installed at three locations to operate aeration systems in South Lundsten, North Lundsten, and Mud Lakes.

Throughout the implementation of the SMCHB Habitat Restoration Program, MCWD deployed an adaptive management strategy that utilized a variety of monitoring approaches and evaluation techniques (MCWD, 2017). These actions included quantifying removal biomass relative to original removal targets for each lake, monitoring surveys that update carp population estimates with boat electrofishing, and documenting in-lake habitat response as carp densities are reduced.

These actions enabled MCWD to refine its system understanding, track ecosystem responses to reduced carp densities, and guide the development of a long-term monitoring and maintenance plan that will sustain program achievements beyond the LSOHC funding period (Appendix A).

Wassermann Lake, located in the City of Victoria, had one of the highest carp populations in the SMCHB Subwatershed prior to the carp management program. After implementing the program's three-pronged management plan, the lake's carp biomass fell below the 100 kg/ha threshold.

2. EFFECTIVENESS ASSESSMENT

2.1 THEORY AND APPROACH

Common carp contribute to the degradation of water quality and habitat in lake systems. Carp primarily consume plant material and insect larvae residing in the lake bottom (Garcia-Berthou, 2001). While searching for food, they uproot aquatic plants and stir up lake sediments, which can increase turbidity and release nutrients into the water (Figure 2-1, Parkos et al. 2003; Bajer et al. 2009; Weber & Brown 2009; Vilizzi et al. 2015; Bajer et al. 2016).

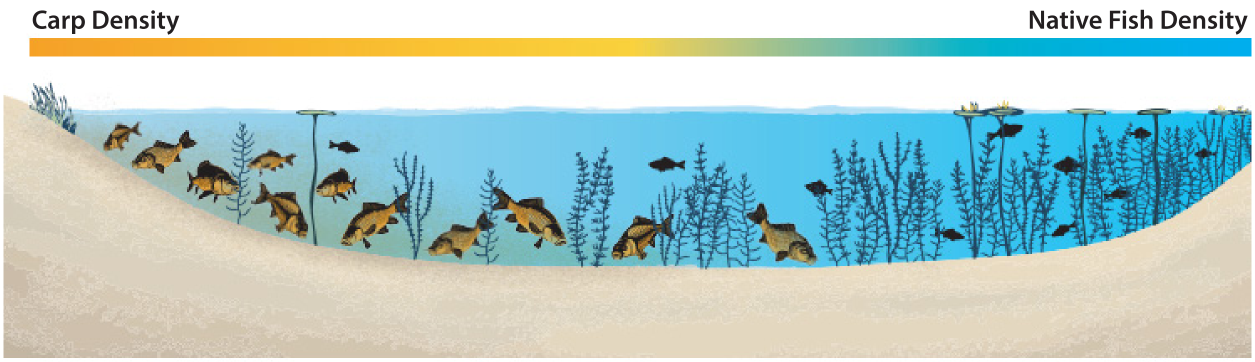


Figure 2-1. As bottom feeders, carp uproot native vegetation and stir up sediment, which reduces water clarity and degrades habitat for native fish species.

This impact is greatest in shallow lakes with a large amount of littoral area that can be affected by carp feeding behavior. A threshold was developed in 2009 stating a 50% reduction in a shallow lake's vegetative cover will occur at carp biomasses above 100 kg/ha (Figure 2-2, Bajer et al, 2009).

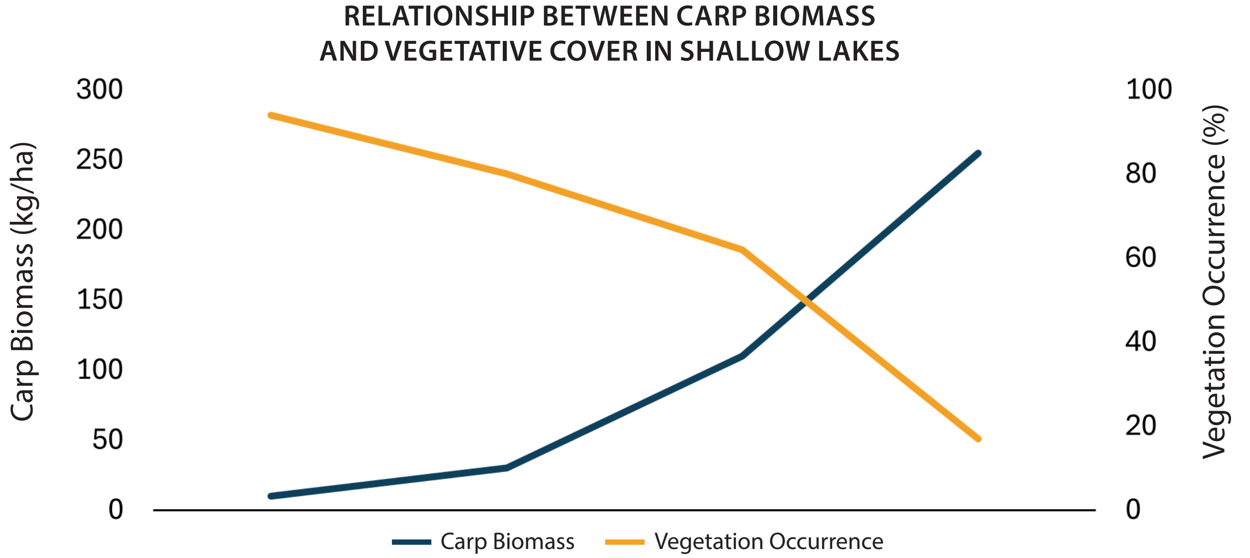


Figure 2-2. In general, an increase in carp biomass will lead to a decrease in vegetative cover. Shallow lakes with a carp biomass above 100 kg/ha are expected to experience a sharp decline in vegetative cover. Bajer et al, 2009.

Bajer et al. 2016 suggests a carp biomass of 200 kg/ha or higher causes a 90% reduction in vegetation in Midwest lakes. In deeper, thermally-stratifying lakes, large decreases in water clarity and reductions in submersed aquatic plant growth in littoral zones have also been observed; however, the impacts of carp on nutrient cycling are less straightforward (Bajer & Sorensen 2015).

It is also important to consider the two theoretical pathways through which carp can degrade a lake's vegetation; 1) uprooting plants directly while foraging and 2) stirring up sediments while foraging, which then decreases a plant's ability to receive light and grow (Figure 2-3).

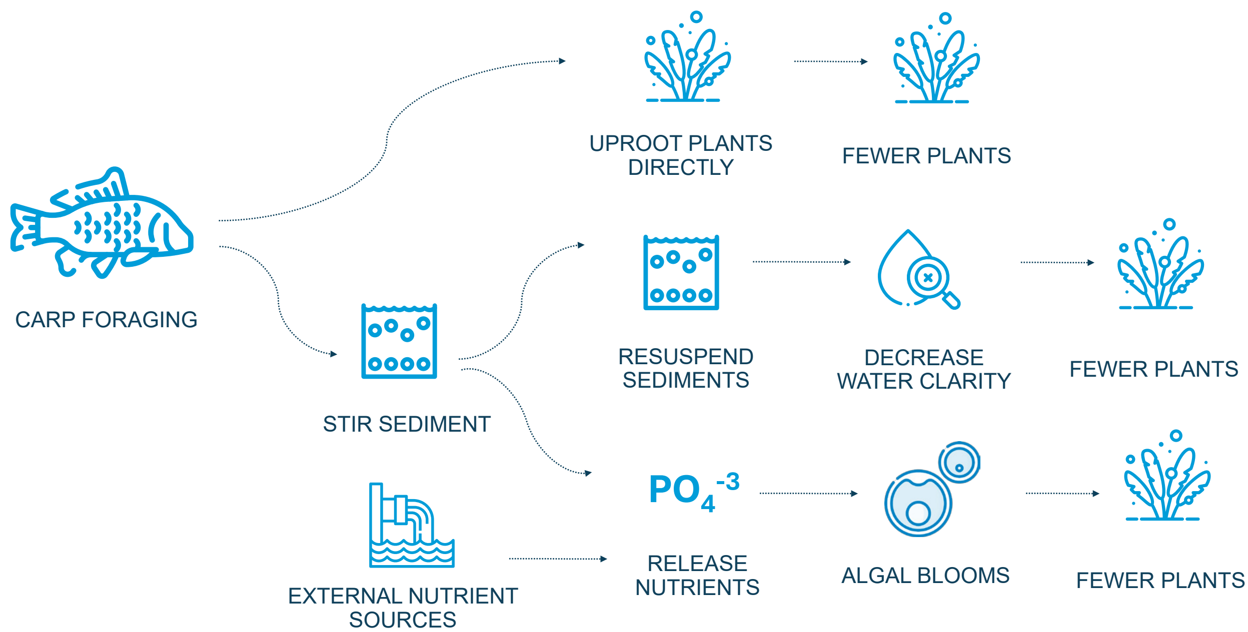


Figure 2-3. Carp have the potential to degrade a lake's vegetation by stirring up sediment, which can lead to uprooted plants and/or decreased water clarity. In addition to carp, external nutrient sources can also impact a lake's water clarity and vegetation.

Therefore, the data was analyzed to:

1) characterize the biomass to confirm carp populations have decreased;
2) characterize the impact reduced biomass has on water quality and submerged aquatic vegetation (SAV);
3) and begin to tease apart the dynamic between common carp, SAV, and water clarity.

2.2 FIELD METHODS

2.2.1 SUBMERGED AQUATIC VEGETATION (SAV)

Point Intercept Surveys

Aquatic plants are beneficial to lake ecosystems, providing spawning and cover for fish, habitat for macroinvertebrates, refuge for prey, and sediment stabilization.

To assess the presence, abundance, and health of the SAV community, MCWD has been conducting point intercept surveys in spring and summer before, during, and after carp management activities (Table 2-1). Late summer surveys provide the greatest assessment of SAV health, abundance, and spatial distribution, while spring surveys assess the abundance of invasive curlyleaf pondweed.

Point intercept surveys are designed to assess the distribution of plants across a lake and assess changes in frequently occurring taxa from year to year (Perleberg et al., 2015). Sampling is conducted primarily from a boat and GPS units are used to navigate to each sample point.

A sample rake is used to sample SAV. Depth, damp biomass of vegetation on the rake, and estimated biomass of each species on the rake is recorded.

At each sample point, a sample rake is tossed out 1-2 meters away from the boat, allowed to sink to the lake bottom, and pulled in at a steady pace. At each point, the depth, the damp biomass of all the vegetation on the rake, and the estimated percentage of biomass for each species present on the rake is recorded.

In conjunction with MCWD's point intercept surveys, biobase sonar logs were taken to assess the aquatic plant biovolume and create extrapolated plant cover maps for each lake.

Biobase sonar logs are taken by recording a sonar log from the boat's depth finder as the point intercept survey is conducted, ensuring sufficient coverage of the lake. The logs are then uploaded to CiBiobase's proprietary software for processing.

Table 2-1 **Available Point Intercept Survey Data in the SMCHB Subwatershed**		
Lake	**Spring Survey**	**Summer Survey**
Church	2013	2013
East Auburn	2012, 2016, 2019, 2022	2015, 2017, 2018, 2022, 2024
Halsted Bay	2013, 2017, 2019	2013, 2018
Kelzer's Pond		2013
North Lundsten	2016, 2018, 2019	2018
Marsh	2018	
Mud	2017, 2019, 2022, 2023, 2024	2017, 2018, 2020, 2022, 2023, 2024
Parley	2016, 2018, 2019, 2022, 2023, 2024	2015, 2018, 2020-2024
Piersons	2014, 2022, 2024	2015, 2022, 2024
South Lundsten	2016, 2018, 2019	2018
Steiger	2014, 2022	2015, 2018, 2020, 2023
Stone		2015
Sunny	2016	2015, 2018
Turbid	2013, 2017, 2019	2013, 2018, 2019
Wassermann	2015, 2017-2024	2015, 2017-2024
West Auburn	2016, 2019, 2022	2011, 2015, 2018, 2022, 2024
Zumbra (TRPD)	2011, 2016, 2022, 2023, 2024	2011, 2015, 2018, 2022, 2023, 2024

Point intercept dataset details are located in Appendix B.

2.2.2 CARP BIOMASS

Electrofishing Surveys

Throughout the SMCHB Habitat Restoration Program's implementation, MCWD deployed an adaptive management strategy that utilized a variety of monitoring approaches and evaluation techniques. These actions included conducting boat electrofishing surveys, following sampling protocols outlined in Bajer & Sorenson 2012*, to assess the adult carp population estimates and compare to original removal targets for each lake (Table 2-2). All common carp were netted, counted, and measured for total length (weight was extrapolated from length using a regression model) prior to being released.

** Bajer, P.G. and P.W. Sorensen. 2012. Using Boat Electrofishing to Estimate the Abundance of Invasive Common Carp in Small Midwestern Lakes. North American Journal of Fisheries Management 32: 817-822.*

This information, along with the amount of time spent electrofishing, was used in linear regression models developed by Bajer and Sorensen 2012, to estimate the current population size and density within each lake (Equation 2-1).

Equation 2-1. Carp Biomass Calculation

$$\text{Carp Biomass} = \text{Avg. carp weight}\ (4.74\ (\frac{\text{\# of carp}}{\text{shock time}}) + 3.04)$$

Nets are used to collect carp during a boat electrofishing survey. Electrofishing involves using electricity to temporarily stun a fish before netting, couting, and measuring it prior to release.

Table 2-2 **Available Electrofishing Survey Data in the SMCHB Subwatershed**	
Lake	**Years Monitored**
East Auburn	2014-2016, 2019, 2021, 2022, 2024
Halsted Bay	2014-2016, 2019
Kelzer's Pond	2014-2016
North Lundsten	2014-2016, 2020
Mud	2014-2016, 2019-2021, 2023
Parley	2014-2016, 2019-2024
Piersons	2014-2016, 2019, 2021-2024
South Lundsten	2014-2016
Steiger	2014-2016, 2019, 2021-2024
Stone	2014-2016
Sunny	2014-2016
Turbid	2014-2016, 2019, 2020
North Lundsten	2014-2016, 2020
Wassermann	2014-2016, 2018-2021, 2024
West Auburn	2014-2016, 2019, 2019-2024

Electrofishing dataset details are located in Appendix C.

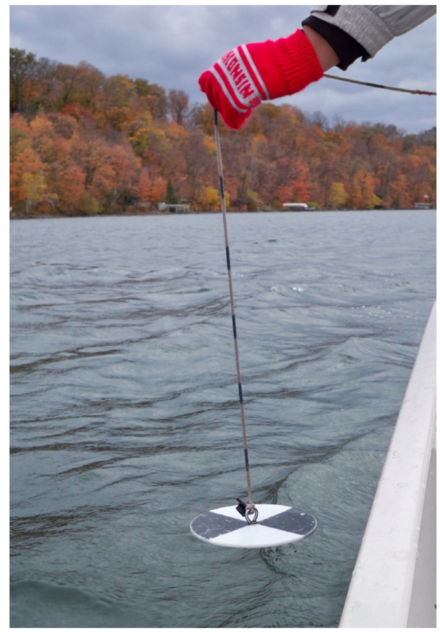
2.2.3 WATER QUALITY

Field Sampling

Water quality sampling was conducted throughout the management period and followed standardized protocols to ensure consistency and reliability of the data (Table 2-3). Samples were collected at the lake's deepest location using a calibrated multiparameter sonde, which measured parameters such as temperature, dissolved oxygen, pH, and specific conductivity directly in situ.

For nutrient analysis, water samples were collected at the surface using a 2-meter composite tube and from the lake bottom using a Van Dorn. Samples were placed into a clean sampling bottle, preserved as required, and stored in a cooler on ice for transport to a certified laboratory for analysis. Relevant parameters analyzed in the lab included total phosphorus and chlorophyll-a.

Secchi depth was also measured at each sampling location using a black-and-white Secchi disk to assess water clarity. All measurements and observations were recorded in Survey123 field logs to support quality assurance and data interpretation.



A Secchi disk is used to measure water clarity. Secchi depth measures water clarity by lowering a black-and-white Secchi disk until it can longer be seen from the surface.

Table 2-3
Available Lake Monitoring Data in the SMCHB Subwatershed

Lake	Site ID	Years Monitored
Carl Krey	LCK01	2006-2005, 2012-2015
Church	LCU01	2006-2008, 2012-2016
East Auburn	LAU03	2006-2016, 2019, 2022, 2024
Halsted Bay	LHL01	2006-2024
Kelzer's Pond	LKZ01	2009-2016
North Lundsten	LLU03	2006-2016, 2019
Marsh	LMS01	2010-2016
Mud	LMD01	2006-2008, 2012-2016, 2019-2021
Parley	LPR01	2006-2024
Piersons	LPI01	2006-2016, 2022
South Lundsten	LLU02	2012-2016, 2019

Table 2-3
Available Lake Monitoring Data in the SMCHB Subwatershed

Lake	Site ID	Years Monitored
Steiger	TRPD	2008, 2010-2019, 2021, 2024
Stone	TRPD	2008, 2010-2015
Sunny	LSY01	2013-2015, 2019
Turbid	LTU01	2006-2008, 2010-2016, 2019
Wassermann	LWS01	2006-2024
West Auburn	TRPD	2008-2019, 2021, 2023, 2024
Zumbra	TRPD	2008-2013, 2015-2018, 2021, 2023, 2024

Water quality dataset details are located in Appendix E.

2.3 DATA ANALYSIS METHODS

Data analysis has focused on three primary components — carp biomass, submerged aquatic plant (SAV) quantity and quality, and water quality — and the interactions between them.

Carp populations in lakes were analyzed using two primary metrics: biomass and the number of individual carp. Biomass, which refers to the total weight of carp in the lake, provides an indication of the species' overall impact on the ecosystem. The number of individual carp offers insights into population growth or decline trends. These metrics were monitored before, during, and after management efforts and removals, to assess the effectiveness of the work and progress made toward achieving the initial goal of 100 kg/ha biomass in each lake.

SAV health in the lakes was assessed using two main indicators: plant quantity and plant quality. Plant quantity was measured through frequency of occurrence and overall coverage, while plant quality was evaluated using species richness. Carp negatively impact SAV by uprooting and damaging plants, and growth is further limited by light availability in the littoral zone. In healthy lakes within MCWD's ecoregion, vegetation should occupy 90-100% of the littoral area. Seasonal vegetation surveys were conducted to evaluate SAV coverage at different times of the year. The spring survey, conducted in May and June, focused on the peak presence of invasive curlyleaf pondweed. The summer survey, conducted in August and September, captured the peak growth of native vegetation. These surveys provided a snapshot of both native and invasive plant coverage throughout the growing season.

Following carp removal and other management actions, an increase in SAV coverage and species richness is typically expected as plant communities recover. However, sensitive native species may take longer to rebound, especially if disturbances like external nutrient loading persist. The Minnesota DNR's Floristic Quality Index (FQI) was used to assess the biological health of SAV communities. This index scores plant species based on their tolerance to disturbance, with higher scores reflecting less tolerant, native species and lower scores associated with invasive plants. Therefore, higher FQI scores indicate diverse native plant communities with abundant growth across the littoral area, while lower scores signal declining lake health, characterized by reduced diversity, increased presence of invasive species, monodominance, and shallower depth of growth (Table 2-4).

Table 2-4
Lake Plant IBI Thresholds Found within the NCHEF (2B) Ecoregion

Classification	FQI - Biodiversity		FQI - Habitat		Narrative Description
	Deep	Shallow	Deep	Shallow	
Exceptional	>32.4	>26.0	>32.4	>26.0	High species diversity often comprised of intolerant native species. The community is near reference communities.
Good	18.7 - 32.4	17.9 - 26.0	18.7 - 32.4	17.9 - 26. 0	The community is beginning to show signs of anthropogenic disturbance. Moderate species diversity and a mixed assemblage of tolerant and intolerant species.
Poor	13.0 - 18.6	7.6 - 17.8	13.0 - 18.6	7.6 - 17.8	The community shows obvious signs of anthropogenic disturbance. Low species diversity with a community often comprised of non-native and/or intolerant species.
Degraded	≤13	≤7.5	≤13	≤7.5	Very low species diversity with a community comprised of non-native and/or intolerant species. Most disturbed communities.

Note: Deep lakes are classified with a maximum depth of 15 feet; shallow lakes are classified with a maximum depth of < 15 feet.

Water quality in the lakes was assessed using three closely related parameters: total phosphorus, chlorophyll-a, and Secchi depth. Total phosphorus is often the limiting nutrient in Minnesota lakes, meaning algal growth increases as phosphorus levels rise. In some cases, however, lakes may become limited by nitrogen or light availability instead. Chlorophyll-a, the primary pigment in algae, is directly correlated with algal biomass and serves as another indicator of water quality. Secchi depth, a physical measurement of water clarity, is determined by the depth at which a black-and-white disk becomes invisible when lowered into the water. Higher Secchi depths reflect better water clarity and fewer light-refracting particulates in the water column. Lower Secchi depths reflect high concentrations of total phosphorus and chlorophyll-a, which are indicative of poor water quality and reduced clarity.

These three parameters — carp biomass, SAV quantity and quality, and water quality — were analyzed collectively to provide a comprehensive evaluation of water quality and to track improvements that resulted from carp removal and SAV recovery efforts.

3. RESULTS

3.1 CARP BIOMASS

Biomass reduction through removals, aeration, and barriers is the first metric to understand if the management actions have resulted in a reduction of carp biomass below 100 kg/ha. Assessing the carp biomass in each lake can confirm the three-pronged strategy has been successful and there is not an unknown source of common carp to the system.

Through the carp management program, MCWD successfully reduced carp biomass to at or near the 100 kg/ha threshold in the majority of the subwatershed's lakes, with Parley, Mud, and Wassermann Lakes having the largest reductions (Figures 3-2 and 3-3). Parley and Mud Lakes are not yet meeting their biomass goal but will continue to be targeted for future removals.

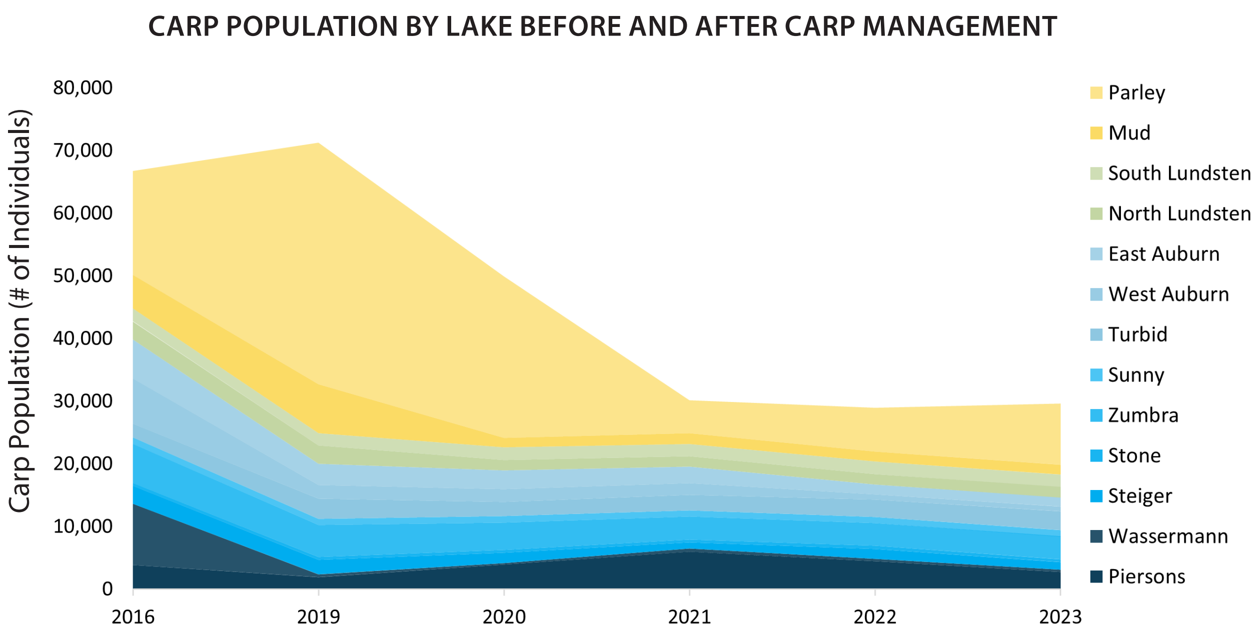


Figure 3-2. Cumulative carp population estimates by number of individuals in the SMCHB Subwatershed. Parley Lake saw the largest decrease in the total number of estimated carp before and after management efforts.

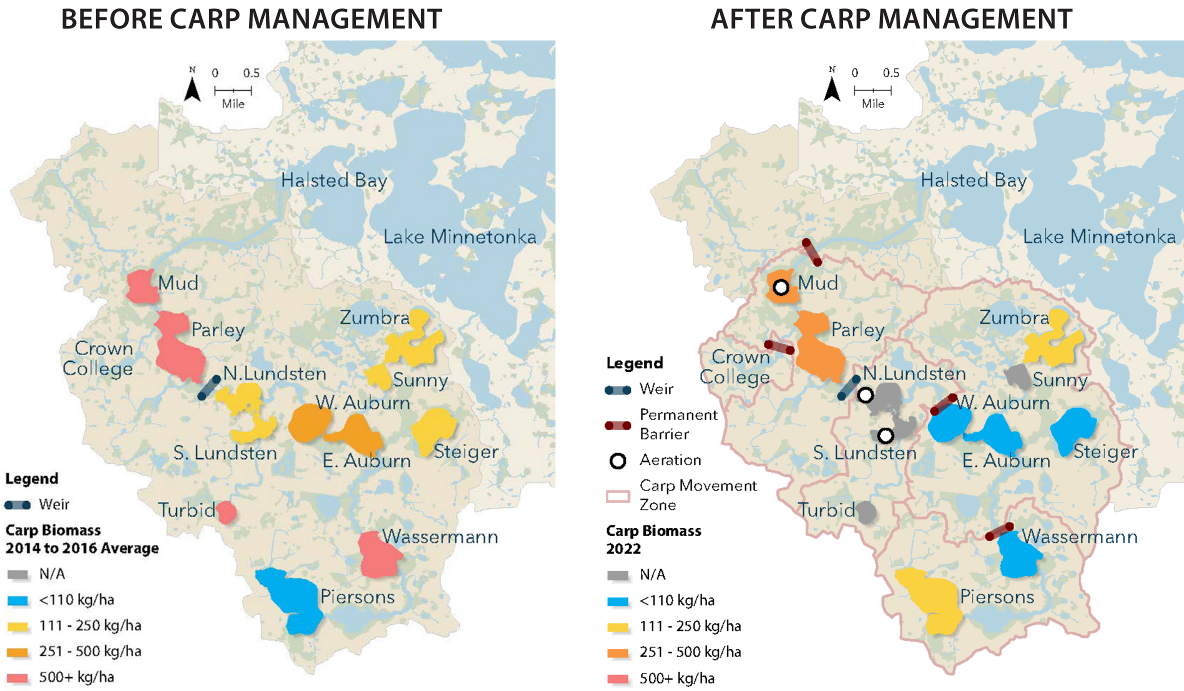


Figure 3-3. Carp biomass estimates for Six Mile Creek - Halsted Bay (SMCHB) Subwatershed lakes before (left) and after (right) carp management. Most of the subwatershed's lakes experienced a decrease in carp biomass.

3.1.1 ZUMBRA-STEIGER MOVEMENT ZONE

Zumbra, Sunny, Stone, and Steiger Lakes are separate subpopulations from the rest of the SMCHB lakes and, therefore, were recommended to be managed separately (Koch, 2016). From 2014-2016, no radio-tagged carp were observed moving in or out of this unit to the adjacent Auburn-Turbid-Lundsten management unit (Koch, 2016). Additionally, the carp in each of those systems were observed to be significantly larger and older than those in the rest of the SMCHB Subwatershed (Koch, 2016).

Zumbra and Steiger Lakes had limited success with removal efforts (box-netting and seining), but they were determined to not need future removals due to consistently having a carp biomass under 200 kg/ha, an FQI vegetation score of "good", and meeting water quality standards. Therefore, further carp removal in these lakes may cause more harm than benefit, as seining activity can damage vegetation, and a minimal biomass reduction may not improve vegetation or water quality. These lakes will be closely monitored for either an increase in carp biomass or declines in the response metrics.

A weighted box net is placed in the water with cracked corn as bait to attract and remove carp.

3.1.2 PIERSONS-MARSH-WASSERMANN MOVEMENT ZONE

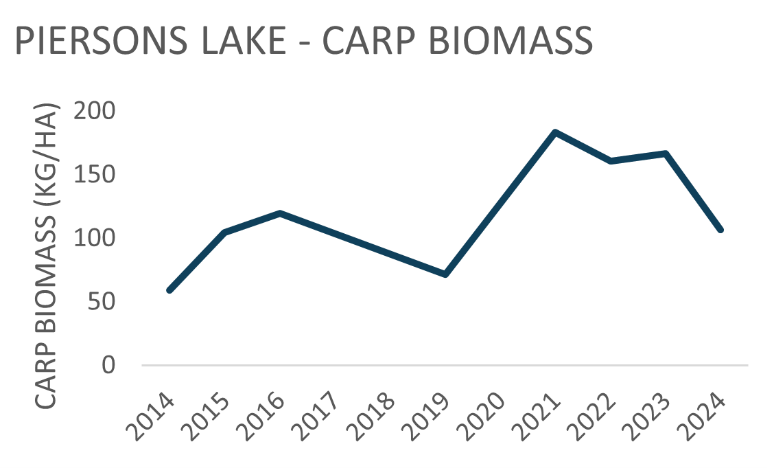


Figure 3-1. Piersons Lake carp biomass estimates over time.

Piersons Lake met its <100 kg/ha biomass goal in 2017, thanks to extensive removal efforts by the Piersons Lake Association. However, in 2020, carp successfully spawned and surpassed the threshold (Figure 3-1). Future plans include continued carp removal and monitoring for impacts on aquatic plants and water quality. Recruitment from the nearby Marsh Lake carp nursery seems intermittent. As aerating or installing a permanent barrier into Marsh Lake is not feasible at this time, the current strategy focuses on monitoring Piersons Lake outlet water levels. If downstream carp migration is possible, a temporary barrier should be installed to prevent movement and aid in stream trapping, to reduce carp numbers as was done successfully in 2023.

Wassermann Lake met its <100 kg/ha goal in 2018 through winter seining, box-netting, and installation of the permanent barrier at the lake's outlet after a large number of the carp had migrated out of the lake to spawn.

3.1.3 AUBURN-TURBID-LUNDSTEN MOVEMENT ZONE

East and West Auburn Lakes began with a moderately high carp biomass (250-315 kg/ha) and are closely connected to South Lundsten Lake, which was identified as the most productive carp nursery in the SMCHB Subwatershed (Koch, 2016). A carp barrier was constructed at the outlet of West Auburn Lake to prevent access to this nursery. Removals of the adult carp in East and West Auburn Lakes were done mainly through box-netting and stream trapping, which lowered the carp biomass to fluctuate around 50-150 kg/ha.

A barrier at the outlet of West Auburn Lake prevents carp migration from a productive nursery.

Utilities were installed at North and South Lundsten so that surface water aeration can be conducted in the Lundsten basins to prevent carp recruitment. The lakes have been aerated, when feasible, since 2019 in cooperation with Three Rivers Park District. Trap-net surveys have been conducted in the spring and fall each year to assess for bluegill presence (success of aeration) and young-of-year (YOY) carp recruitment. Small numbers of YOY carp were found in Fall 2023 and suspected one-year-old carp were found Spring 2024. Low water levels (as observed in 2022 and 2023), regardless of aeration, seem to allow for some carp recruitment. More assessment of dissolved oxygen conditions and recruitment success at different water levels should be conducted.

MCWD staff determined Turbid Lake is typically isolated from the rest of the SMCHB Subwatershed under normal water conditions (excluding high water years). Only 5% of carp caught in Lundsten and Auburn Lakes matched the genetic signature of carp from Turbid Lake (Koch, 2016). Monitoring efforts found Turbid Lake has a cyclical carp population that reaches high biomass states but also winterkills frequently, during which, the lake has large-scale carp and native fish die-offs (Koch, 2016). No management efforts have occurred at this time. Turbid Lake will need to be managed holistically to address the poor water quality and fish kills before a stable fish community can be supported. Additionally, any changes to the Turbid-Lundsten Corridor should take into account carp passage connectivity.

3.1.4 PARLEY-MUD MOVEMENT ZONE


Commericial winter seining was conducted on Parley Lake in 2020.

A large number of carp removals have occurred in Parley Lake, which has resulted in carp biomass decreasing from 588 kg/ha in 2016 to 322 kg/ha in 2023. Removals were chiefly accomplished through commercial winter seining and box-netting.

Although initial removal goals set based on biomass estimates from the UMN in 2014-2016 were met, biomass estimates from subsequent electrofishing CPUE surveys have remained higher than 100 kg/ha. For example, 21,730 individual carp were removed from Parley Lake, which is larger than the original estimated population of 21,315 individuals. This leads us to believe additional carp have re-entered the management unit since the initial estimate was made. It is likely some number of carp from the upstream lakes have made their way down into Parley Lake. Small numbers of YOY carp have also been observed during electrofishing surveys on Parley Lake, which could indicate low levels of in-lake recruitment have occurred in either Parley or Mud Lakes. This system will continue to be targeted for carp removals, chiefly through commercial winter seines. In addition, a mark-recapture study would improve understanding of the carp population in the lake.

MCWD staff have aerated Mud Lake, when feasible, since 2019. Drought conditions in 2022 and 2023 saw water levels in Mud Lake drop to only 2 feet deep. Operating surface water aerators in too shallow of water can cause resuspension of sediments and is not recommended.

3.2 AQUATIC VEGETATION

Six lakes within the SMCHB Subwatershed have pre- and post-carp removal aquatic plant datasets that can be used to characterize whether SAV coverage has increased following a reduction in carp biomass (Figures 3-4 and 3-5). The most notable changes have occurred in lakes that began as the most degraded, with carp biomass above 300 kg/ha and degraded aquatic communities, such as Wassermann, Parley, and Mud Lakes. Lakes that started with lower carp biomass (between 100 and 300 kg/ha), as well as limited plant coverage and low diversity, have seen limited increases in SAV coverage.

The improvements in Wassermann, Parley, and Mud Lakes could be chiefly due to removing the mechanism of carp uprooting plants, but SAV occurrence has only increased a small amount because poor water clarity still limits growth. East and West Auburn Lakes had no observable change, which may mean water clarity limits vegetation occurrence more than carp uprooting plants. Steiger Lake's littoral occurrence decreased, while carp populations have consistently hovered around the 100 kg/ha threshold since 2020 (Figures 3-4 and 3-5).

A comparison of native to invasive species in the summer shows less dominance by invasives compared to the spring. Since summer invasive species are composed mainly of Eurasian watermilfoil, one potential hypothesis is invasive milfoil has not formed a monodominance over natives during the summer or is also limited by poor water clarity in the summer.

Invasive Eurasian watermilfoil

Spring vegetation surveys assessed the abundance of invasive curleyleaf pondweed. A few lakes displayed an increase in spring vegetation coverage following successful carp removal; however, this was primarily due to growth in invasvie curleyleaf pondweed.

3.2.1 SPRING PLANT COVERAGE

In the spring, all lakes except for Wassermann showed no substantial change in plant occurrences before and after carp removals (Figure 3-4). However, Wassermann Lake's increases are primarily due to expanded growth of curlyleaf pondweed, which increased from 17.7% in 2015 to 84.5% in 2024. Steiger Lake had only a small amount of curlyleaf pondweed present in 2014 (0.56%), which greatly expanded to 60.8% in 2022, leading to a small increase in the overall spring vegetation occurrence.

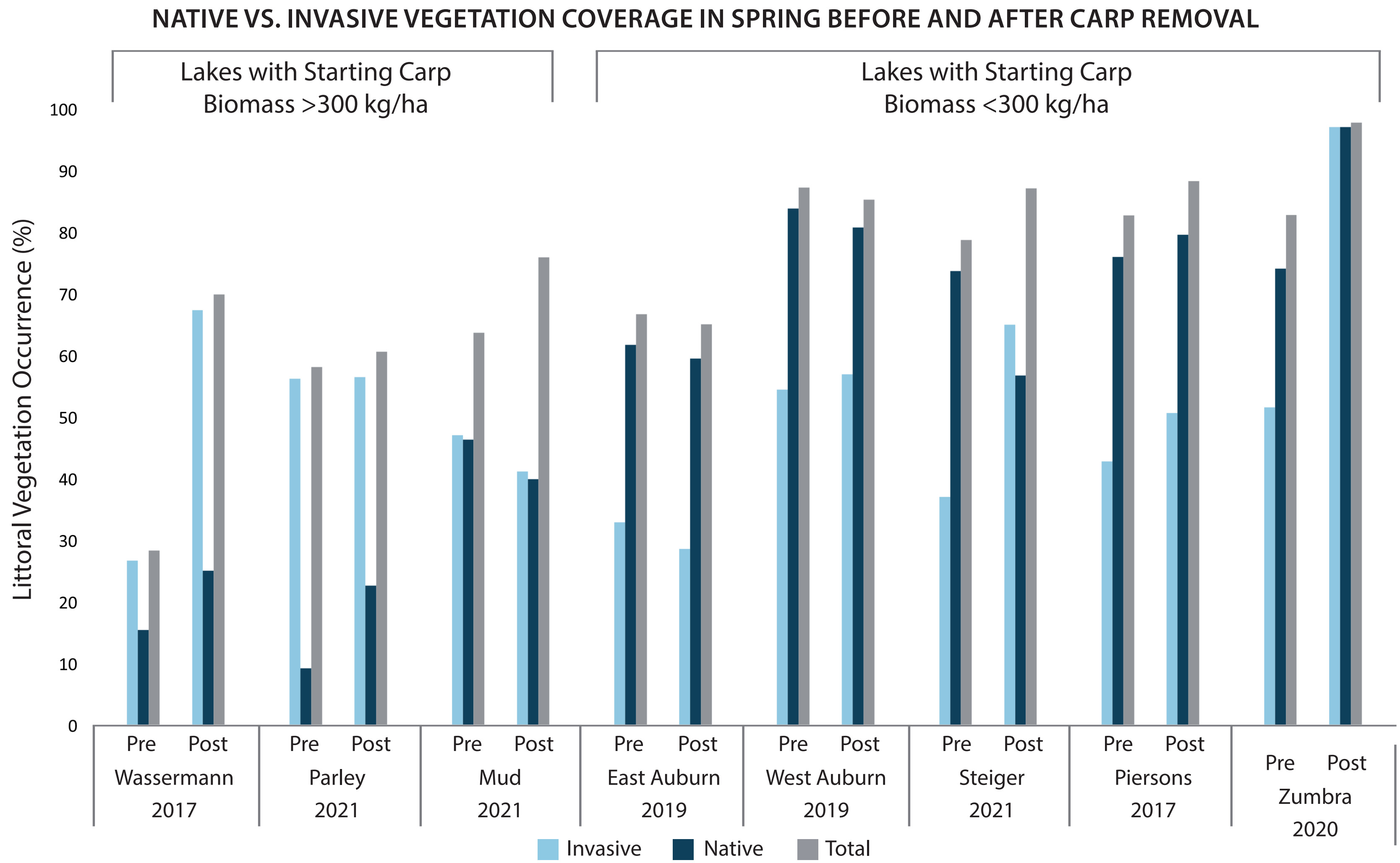


Figure 3-4. Average spring aquatic vegetation for years before and after carp management. The year carp biomass decreased in each lake is indicated below the lake name and is the breakpoint for which the years before and after were averaged. The lakes that began with the highest carp biomass (above 300 kg/ha) showed the largest increases in SAV coverage.

3.2.2 SUMMER PLANT COVERAGE

In the summer, Parley, Wassermann, and Mud Lakes have shown increases in littoral SAV occurrence, but total occurrence is still less than the desired coverage (Figure 3-5). East Auburn, West Auburn, and Steiger Lakes have either decreased slightly or not changed.

NATIVE VS. INVASIVE VEGETATION COVERAGE IN SUMMER BEFORE AND AFTER CARP REMOVAL

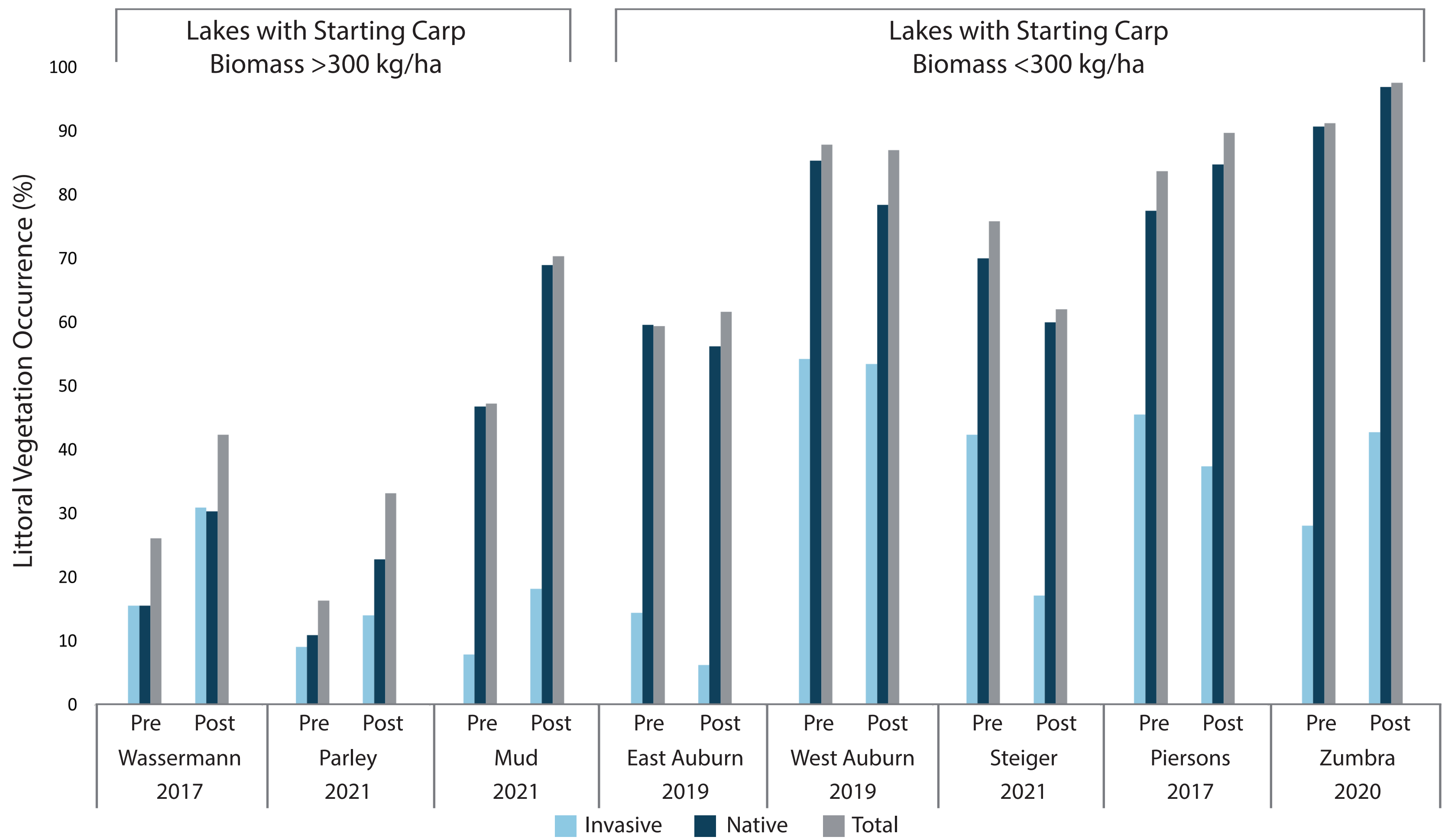


Figure 3-5. Average summer aquatic vegetation for years before and after carp management. The year carp biomass decreased in each lake is indicated below the lake name and is the breakpoint for which the years before and after were averaged. The lakes that began with the highest carp biomass (above 300 kg/ha) showed the largest increases in SAV coverage.

3.2.3 PLANT DIVERSITY

Thus far, only minor improvements in FQI scores were seen following carp management (Figure 3-6). The three lakes with the most extensive carp removals (Wassermann, Parley, and Mud) did see a 2-3 point increase in FQI scores, which equates to roughly one or two additional plant species found on those lakes. The average conservation values for the plant species that were gained in these lakes indicate only species tolerant to poor conditions and disturbance are able to grow.

Additionally, the abundance of each species does not factor into the FQI score, and most native species other than coontail continue to have low abundance. However, the fact that additional species are being found, even in low amounts, indicates a trend toward improving conditions in these lakes.

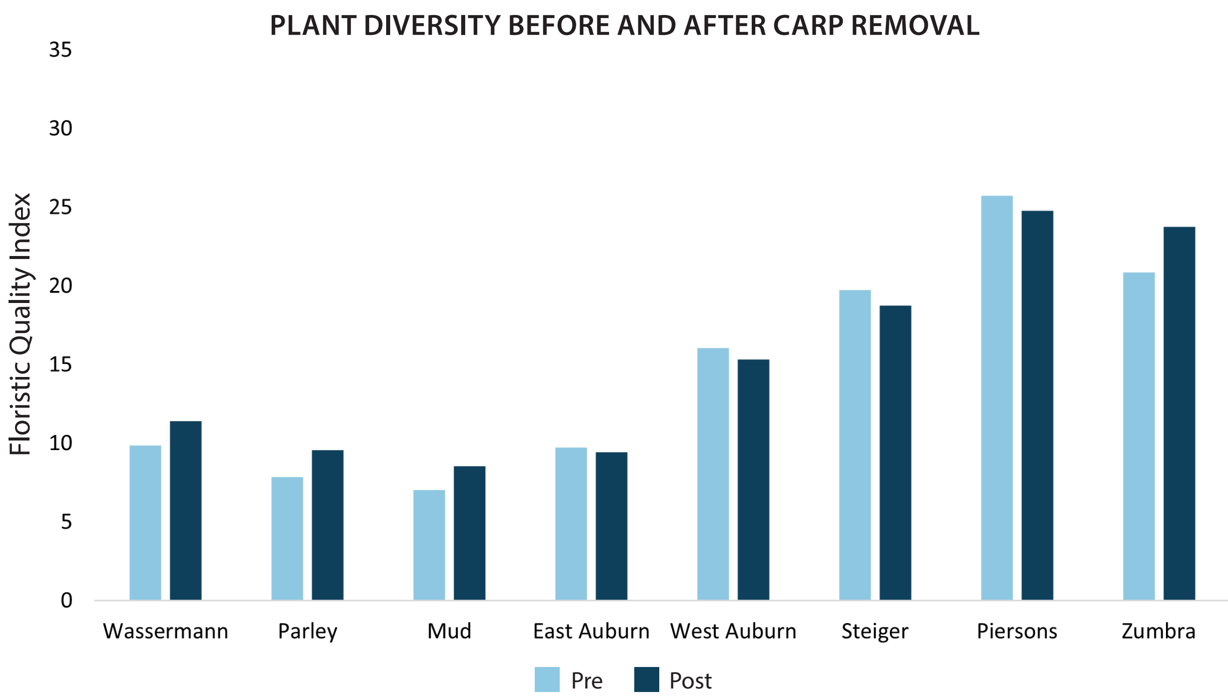


Figure 3-6. FQI scores before (light blue) and after (dark blue) carp removal. None of the lakes have experienced an improvement that caused them to shift to a new IBI threshold.

3.3 WATER QUALITY

Water clarity will be the primary measure of the potential water quality response to carp management, since it characterizes both ways carp can impact lake water quality, including:

1) Increasing phosphate efflux from sediments due to common carp bioturbation and sediment resuspension. The increased efflux from sediments could hypothetically lead to increased algae and lower water clarity.
2) Carp bioturbation of sediments that causes sediment resuspension could result in greater suspended solids in each lake, which would result in lower water clarity.

Within the SMCHB Subwatershed, eight lakes (Table 2-3) have field-collected water clarity measurements that occur before, during, and after carp management. Of those eight lakes, four have successfully met reduction goals identified for improving vegetation, which were not intended to be thresholds for water quality improvements. However, there have been a small number of studies that have linked reductions in common carp biomass with improvements in water clarity (Bajer & Sorensen, 2015; Huser et al, 2022). The goal of this section is to determine if lakes within the SMCHB Subwatershed that have had substantial reductions in carp biomass have also had observable water clarity improvement.

3.3.1 WATER CLARITY

No improvements in water clarity have been observed, with the exception of Wassermann Lake (Figure 3-7).

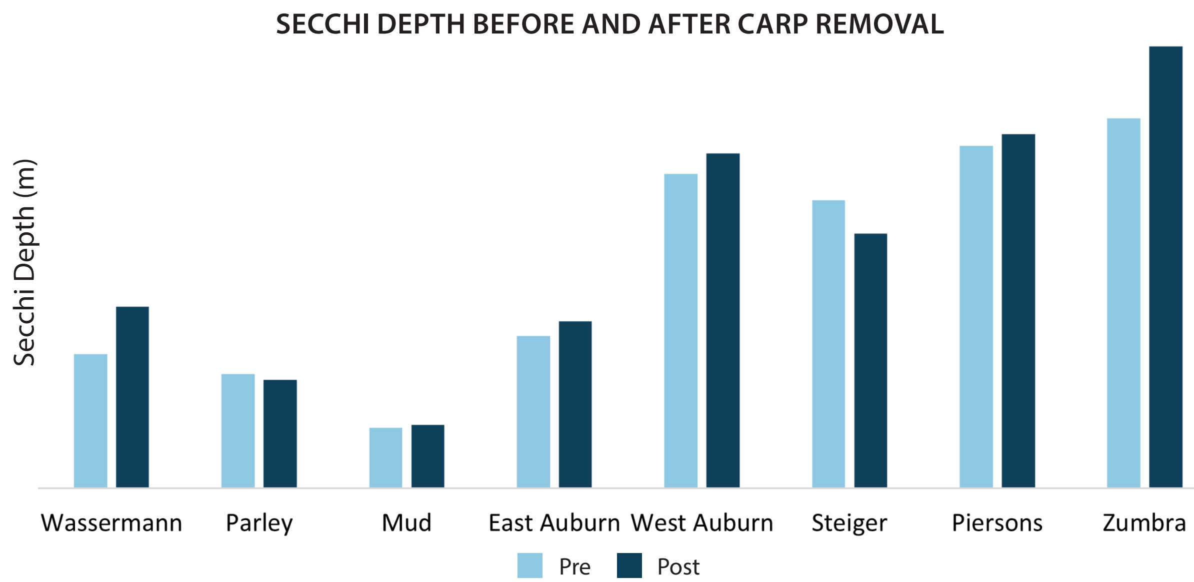


Figure 3-7. Annual mean Secchi depth before (light blue) and after (dark blue) biomass goals were met for each lake in the SMCHB Subwatershed.

Further investigation of the timing indicates the majority of Wassermann Lake's carp biomass reduction occurred in 2018, which is several years before water clarity conditions began to improve (Figure 3-8). The primary driver of water clarity in Wassermann Lake appears to be alum treatment, since clarity after alum treatments in 2021 and 2022 represents the lake's best water clarity conditions in the past decade (Figure 3-8).

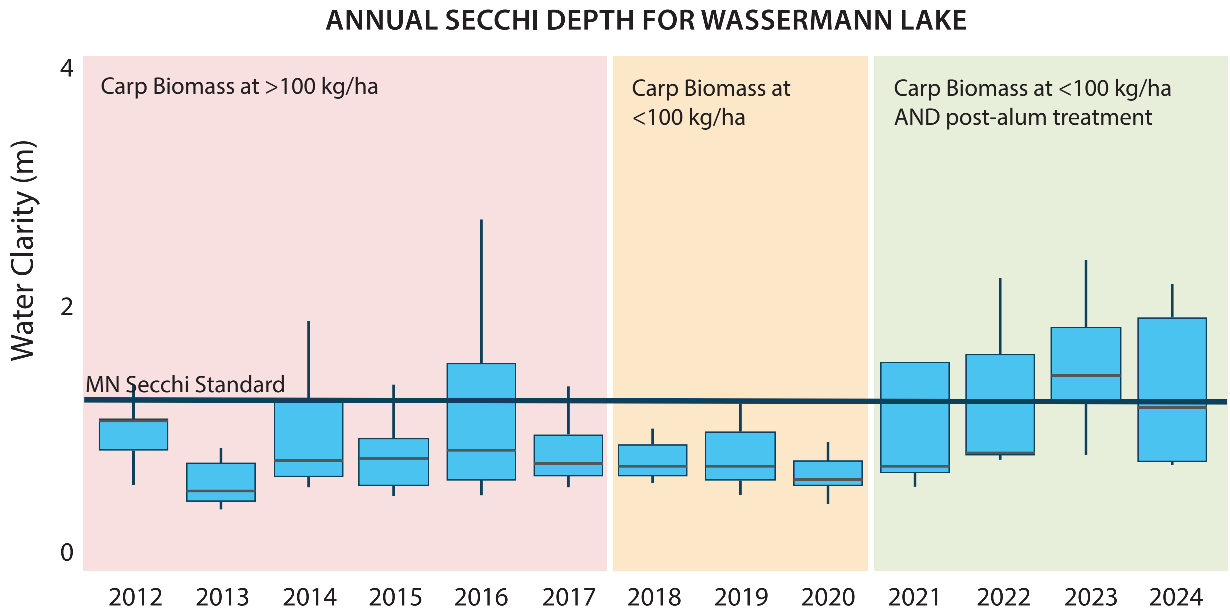


Figure 3-8. Water clarity in Wassermann Lake did not significantly improve after carp removal. However; water clarity did improve following alum treatments in 2021 and 2022, after which, the lake saw its best water clarity conditions in over 10 years.

3.3.2 TOTAL PHOSPHORUS

All of the lakes within the SMCHB Subwatershed demonstrated lower average phosphorus concentrations after biomass removals met management targets (Figure 3-9). These data were somewhat surprising, since water clarity, which is typically the variable impacted most by carp management, did not appear to change in most lakes.

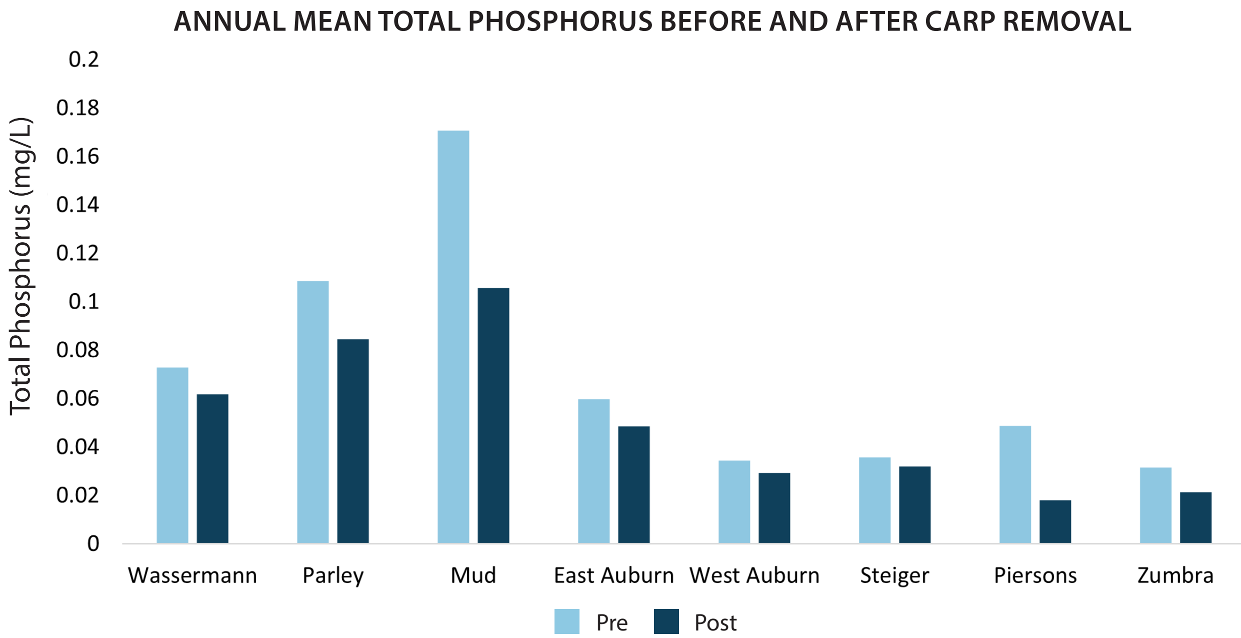


Figure 3-9. While water clarity did not improve in most lakes after biomass goals were met, all of the SMCHB Subwatershed lakes experienced lower average phosphorus concentrations after carp removal.

3.3.3 CHLOROPHYLL-A

Total phosphorus is typically the limiting nutrient in Minnesota's lakes, meaning algal growth will increase due to increases in phosphorus concentration. Chlorophyll-a is the primary pigment in aquatic algae and has been shown to have a direct correlation with algal biomass. Chlorophyll-a data from the SMCHB Subwatershed lakes largely confirms changes in total phosphorus are driving changes in chlorophyll-a (Figure 3-10).

However, there were a few lakes, such as Parley and East Auburn, where the changes in chlorophyll-a concentrations were dissimilar to changes in phosphorus concentrations after carp removal had occurred (Figure 3-10). These data suggest most of the lakes appear to have phosphorus-driven algal biomass; however, a few lakes may have factors in addition to phosphorus that are impacting algal biomass.

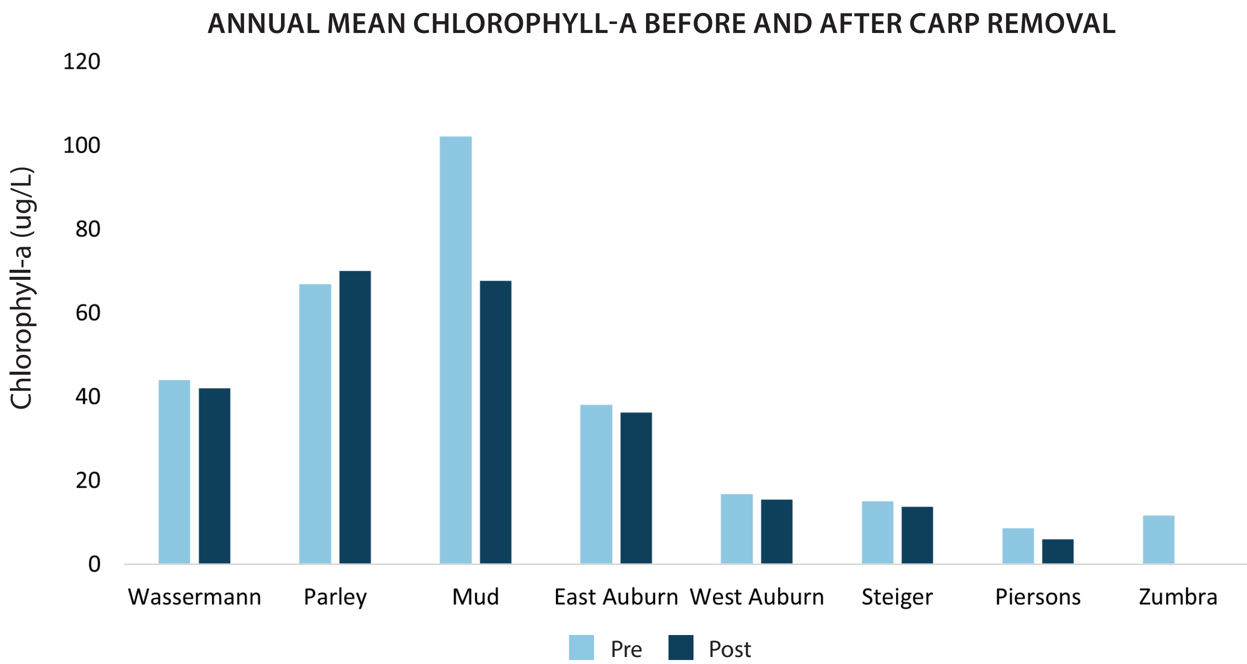


Figure 3-10. Chlorophyll-a concentrations were similar to total phosphorus in most of the lakes after meeting biomass goals, with the exceptions of a few lakes, such as Parley and East Auburn.

3.4 INTERSECTION OF CARP, VEGETATION, AND WATER QUALITY

Early attempts to evaluate the effects of reducing carp biomass on aquatic vegetation and water quality yielded mixed outcomes, even in lakes that achieved biomass targets. However, it is important to recognize ecological systems rarely respond to a single management intervention with predictable outcomes.

Lake ecosystems are shaped by complex interactions among a variety of physical, chemical, and biological factors. Physical factors such as climate, underlying geology, and surrounding land use influence the amount of water flowing in streams and discharging to lakes, as well as the types of materials and nutrients found in the water. These physical and chemical factors support a community of biological organisms, which in turn respond to and shape the lake ecosystem. Therefore, restoring lake ecosystems is a challenging endeavor, since each element affects the others, creating a dynamic web that typically requires an integrated approach addressing multiple elements of the ecosystem.

Researchers have quantified the threshold of carp biomass (100 kg/ha) that begins to affect vegetation in shallow lake systems (Bajer et al, 2009), to support lake managers' decision-making processes surrounding carp management. However, the complexity of interactions in an ecosystem complicates management efforts, as submerged aquatic vegetation is influenced by both common carp and water clarity, with carp biomass densities also impacting water clarity itself. Therefore, characterizing the effects of both carp density and baseline water clarity is essential for understanding SAV outcomes.

While characterizing carp density and water clarity provides insight into their effects on SAV, other lake-specific factors further shape these interactions. The presence of a pelagic (open water) zone in deeper lakes can provide some buffer against the impacts carp have in the littoral (nearshore) zone. Thus, in these lakes, the specific threshold at which carp biomass begins to degrade plant communities remains uncertain, as factors like water depth, the lake's unique morphology, and other ecological dynamics may help mitigate some of carp's disruptive effects.

In the SMCHB Subwatershed lakes, the health and diversity of aquatic vegetation hinges on two key factors — carp abundance and water clarity — and findings highlight a complex interplay, revealing reducing carp biomass alone may not immediately or fully restore plant health. The results demonstrate carp, when present in large numbers (over 300-400 kg/ha), disrupt lake ecosystems and limit plant growth (Figure 3-11). However, lakes with carp biomass levels under 300 kg/ha showed varying vegetation quality based on water clarity, demonstrating water quality remains a crucial factor (Figure 3-11).

Lakes meeting state water clarity standards display more diverse vegetation, whereas those failing to meet these standards continue to show degraded plant communities, regardless of carp management efforts (Figure 3-11).

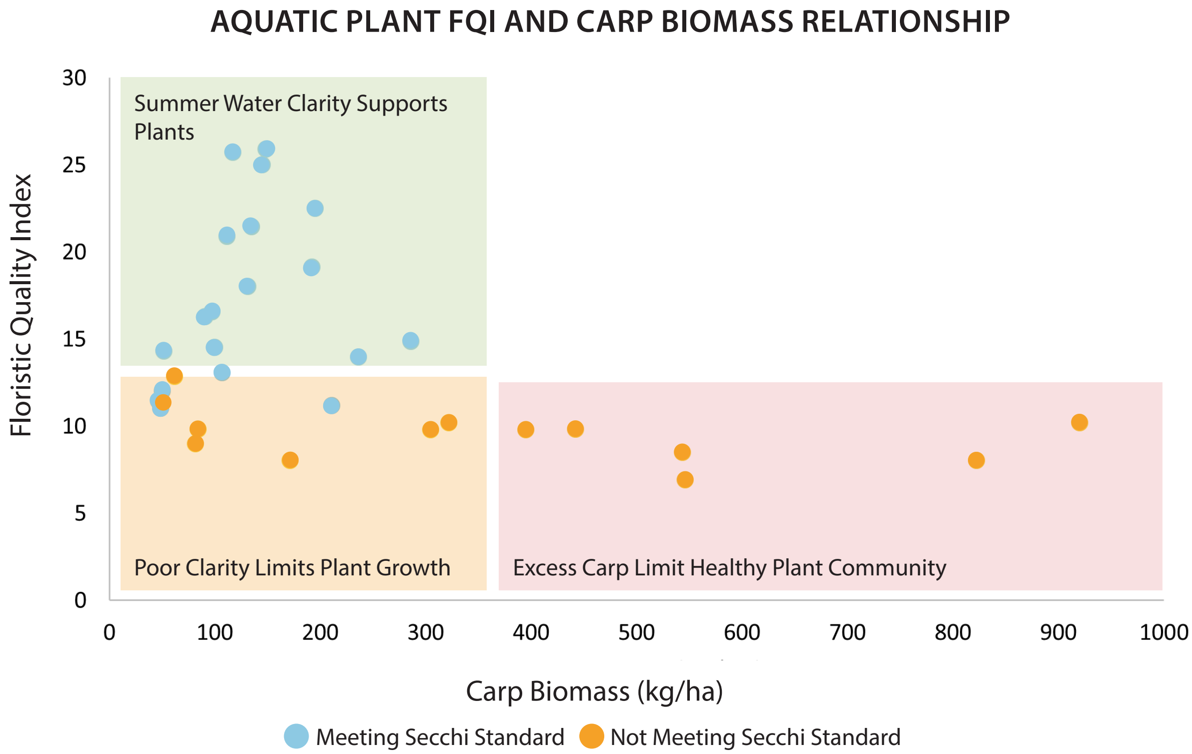


Figure 3-11. The SMCHB Subwatershed lakes demonstrated removing carp biomass alone may not restore a lake's plant health because low carp biomass did not lead to a high FQI for each lake. A lake's existing water clarity also impacted its FQI.

One example to highlight this interplay is Wassermann Lake. The lake achieved its carp biomass reduction goals in 2017 and moved from a very high to a very low carp population. Monitoring completed directly after the removals showed no change in water clarity conditions. Additionally, vegetation coverage increased in the spring (mainly invasive curlyleaf pondweed) but showed no obvious improvement in the summer (Figure 3-13).

Wassermann Lake follows a pattern common to lakes with internal loading issues: it has clearer water in early spring but becomes turbid in summer as anoxic conditions develop, releasing phosphorus from the lake sediments (Figure 3-12).

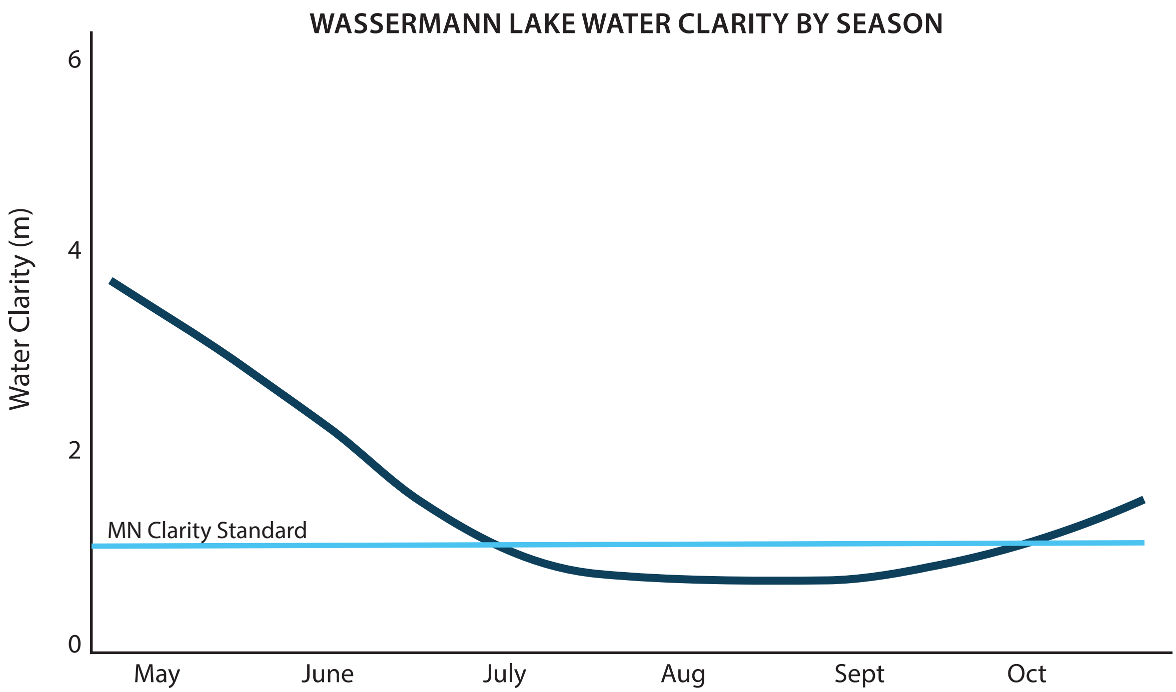


Figure 3-12. Throughout the 2022 open water season, Wassermann Lake experienced clearer water in early Spring but became turbid in Summer, which is a pattern commonly found in lakes with internal loading issues.

Therefore, removing the impact of carp allowed plants to grow during clear conditions in the spring, but growth continued to be limited during the summer.

In 2021 and 2022, the lake was treated with alum to manage internal phosphorus loading. Following the treatment, clarity has improved on the lake and is tracking toward meeting state clarity standards, and the summer vegetation coverage is beginning to increase (Figure 3-13).

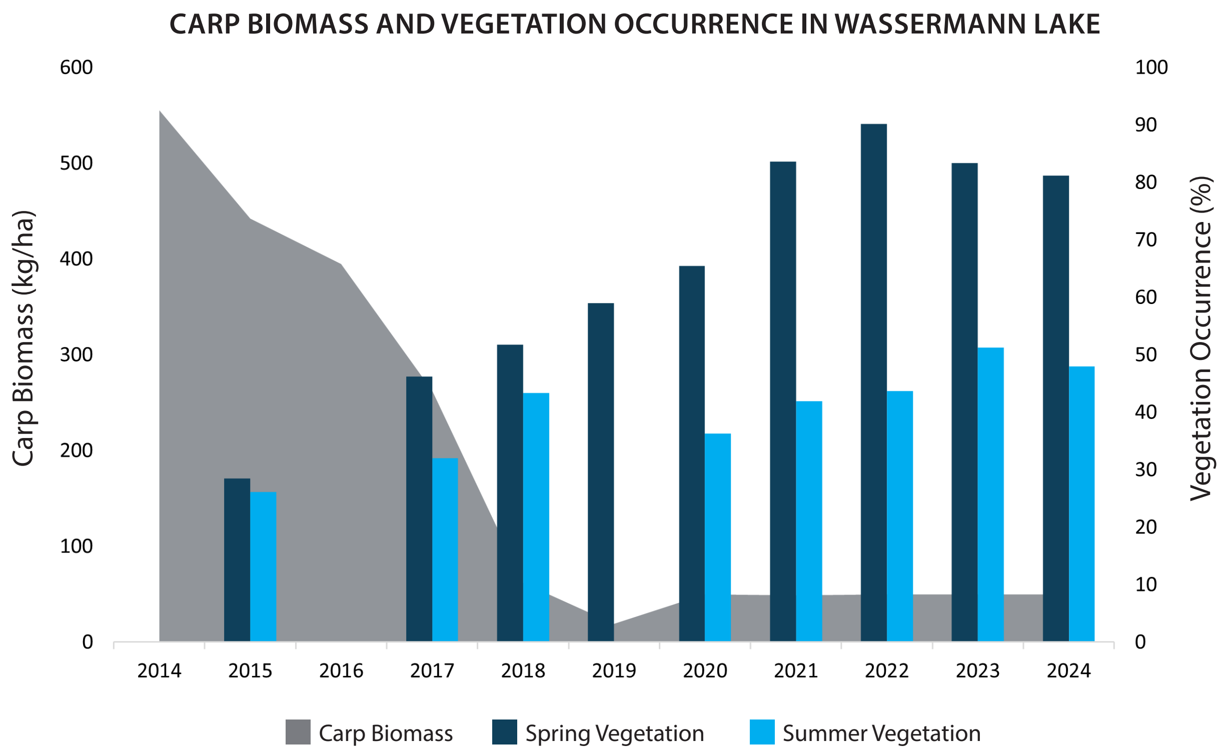


Figure 3-12. Wassermann Lake saw improvements in water clarity and summer vegetation coverage following alum treatments to manage internal phosphorus loading.

4. CONCLUSION

The SMCHB Subwatershed Habitat Restoration Program dramatically reduced common carp biomass and made progress toward restoring the Subwatershed's lake ecosystems. Through the combination of carp removal, barrier installation, and aeration strategies, the majority of targeted lakes have achieved or are nearing their reduction goals. These efforts led to SAV improvements in several lakes, particularly those with the highest initial carp densities.

However, the complex relationships between carp density, water quality, and vegetation health suggest carp management alone may not restore ecological conditions. In many lakes, the effects of nutrient loading and poor water clarity continue to limit aquatic vegetation recovery, underscoring the need for integrated management approaches. For example, while Wassermann Lake achieved considerable carp reductions, vegetation displayed limited improvements until additional restoration strategies were implemented.

This points to an important reality in lake restoration: removing a stressor does not guarantee immediate or predictable recovery. The path to restoration is often longer and more complicated than the process of degradation, as ecosystems settle into degraded states that require significant time and a suite of management strategies to reverse. As seen with the SMCHB Subwatershed lakes, reducing high carp populations can be an important restoration step but is not always sufficient on its own. Conversely, in lakes with stable and low or moderate carp populations, nutrient management may be more critical for vegetation restoration.

Comprehensive lake restoration demands a multifaceted approach to support resilient, diverse aquatic ecosystems. These findings suggest both carp and nutrient management strategies will be essential for sustaining and enhancing the SMCHB Subwatershed's ecological health. Continued monitoring and adaptive management are recommended to refine these strategies, particularly in lakes where carp biomass remains low or where internal nutrient cycling continues to impact water quality.

These nuanced results suggest a need to continue analyzing the factors that influence carp management effectiveness in lake systems statewide.

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APPENDICES

APPENDIX A

SIX MILE CREEK CARP MANAGEMENT
OPERATIONS AND MAINTENANCE PLAN

Six Mile Creek Carp Management

Operations and Maintenance Plan

January 2023

EXECUTIVE SUMMARY

The Six Mile – Halsted Bay Subwatershed is located in the western portion of the Minnehaha Creek Watershed District, in Carver County. It is composed of several deep and shallow lakes, has numerous wetlands, and eventually flows into Halsted Bay of Lake Minnetonka. Several lakes in this subwatershed are impaired for excess nutrients, and can be characterized as generally turbid with poor water clarity and degraded aquatic plant communities that provide poor habitat for fish and waterfowl (Wenck, 2013). Common carp (*Cyprinus carpio*) are abundant in the Six Mile – Halsted Bay Subwatershed, and are a known driver of poor ecological conditions (Wenck, 2013; Koch et al., 2016). Managing carp is a top priority for management and restoration of this subwatershed, and is part of a broader plan in the District's 2017 Comprehensive Plan to improve water quality and ecological conditions across that entire system (MCWD, 2018).

In 2014, the Minnehaha Creek Watershed District (MCWD) partnered with the University of Minnesota (U of M) to complete a 3-year assessment of common carp in the Six Mile – Halsted Bay Subwatershed (Koch et al., 2016). Its purpose was to determine the abundance, recruitment patterns, and seasonal movements of carp to enable the development of carp control strategies for restoration of the Six Mile – Halsted Bay Subwatershed. Adult carp biomass in 12 of the 15 lakes was found to exceed 100 kg/ha (89 lbs/acre), a threshold where ecological damage can occur (Koch et al., 2016; Bajer, 2009).

In September 2017, the Lessard Sams Outdoor Heritage Council awarded the Minnehaha Creek Watershed District (MCWD or District) $567,000 for the Six Mile Creek-Halsted Bay (SMCHB) Habitat Restoration Project. The program took a holistic and comprehensive approach to manage common carp in the SMCHB Subwatershed to ultimately reach the goal of not exceeding the 100 kg/ha carp biomass threshold for each waterbody. This approach consisted of three management strategies:

- Adult biomass removal
- Barriers to prevent carp movement between waterbodies and assist with removal
- Aeration of shallow lakes to prevent successful carp reproduction

Throughout the implementation of the SMCHB Habitat Restoration Program, the District deployed an adaptive management strategy that utilized a variety of monitoring approaches and evaluation techniques. These actions included quantifying removal biomass relative to original removal targets for each lake, monitoring surveys that update carp population estimates with boat electrofishing, and documenting in-lake habitat response as carp densities are reduced. These actions have enabled us to refine our system understanding, minimize uncertainty and risks by removing carp, track ecosystem responses to reduced carp densities, and guide the development of a long-term monitoring and maintenance plan that will sustain program achievements beyond the LSOHC funding period.

The District deployed a variety of tactics over the past five years to remove carp across the Six Mile Creek-Halsted Bay Subwatershed. These methods included stream trapping utilizing permanent and temporary barriers, baited box net trapping, and commercial winter seining. To date, across the 14-lake system, MCWD has removed approximately 30,000 carp totaling 276,647 pounds. Most waterbodies are either at or near the 100 kg/ha carp biomass goal. In addition to direct removal, barriers and aeration were strategically deployed to cut off and mitigate spawning locations.

Various elements of this project require long-term maintenance to sustain their function. To ensure that maintenance roles and responsibilities are clear, the Minnehaha Creek Watershed District has prepared this Operations and Maintenance (O&M) plan. An additional cooperative agreement has been developed (Appendix A) that describes aspects of operation and maintenance that are a joint effort between MCWD and Three Rivers Park District (TRPD) to aerate North and South Lundsten Lake and maintain the Auburn carp barrier.

This Operations and Maintenance (O&M) Plan is organized into the following sections:

I. Introduction
II. Project Elements Requiring Maintenance
III. Site Boundaries and Posting Protected Areas
IV. Law Enforcement and Site Protection and Safety
V. Conclusion

I. Introduction

The Lessards Sams Grant requires an O&M plan that will cover the three main components of the management strategy.

1. Maintenance of Adult Carp Biomass

The most critical component of the Six Mile Creek Habitat Restoration program was reducing carp densities in the 13 major lakes in the subwatershed to at or below the 100 kg/ha threshold of ecological degradation developed by the U of M. MCWD met this goal on the majority of the lakes using removal techniques developed over the past five years. MCWD worked with the Minnesota Department of Natural Resources (MN DNR) to permit these activities and should consider modifying the biomass goals for lakes that are already meeting water quality and vegetation standards where the MN DNR had concerns that carp removal activities could cause more harm than good. It is important to continue monitoring carp populations to ensure we continue to meet our biomass goals while simultaneously conducting effectiveness monitoring of these management actions.

2. Carp Barriers

Carp barrier installations are an important piece of the management strategy to prevent carp from moving through major migratory corridors and to aid in stream trapping removals. Four barriers were constructed between 2019 and 2021 and have proved effective at preventing carp migration. Each barrier is designed in such a way as to not impede flow but block adult carp and their known migration behavior of jumping and digging around obstacles. They are also designed to have a gate that allows the barrier to be opened and closed at different times of the year and facilitate cleaning of debris. The most critical barrier was installed at Highland Road in Minnetrista to block carp movement into the Six Mile Halsted Bay Subwatershed from areas that still have high carp densities including Lake Minnetonka and other connected subwatersheds. The other three barriers divide the subwatershed into separate management units and cut off major carp nurseries. Routine maintenance and monitoring of the barriers occurs throughout the open water season and consists of cleaning debris to prevent clogging and inspection to ensure the barriers are functioning as desired. MCWD staff have noted frequent issues of vegetation and floating cattail bogs clogging barriers during high flow that may lead to localized flooding if maintenance doesn't occur at a regular frequency throughout the open water season. A refined operations plan to inform when barriers can be opened with minimal risk of carp movement should be developed to facilitate native fish passage and decrease maintenance needs throughout the year.

3. Shallow Lake Aeration

Aeration is a strategy for maintaining oxygen levels in lakes in which carp are known to reproduce, thereby maintaining populations of bluegill and sunfish - fish that predate carp eggs - and preventing successful carp spawning. Utilities were installed in 2019 at three locations to operate aeration units. The aeration program began in 2019 and has been operated annually since. Only one of the three aeration sites are operated solely by MCWD. The two most critical in preventing carp recruitment, North and South Lundsten, are jointly operated by TRPD and MCWD. A cooperative agreement with TRPD should be preserved to ensure this task continues to occur as desired. Further refinement of this operations plan should take place in the future to improve our understanding of oxygen dynamics, fish kills, and recruitment, which will reduce the energy costs and staff time spent on aeration operation.

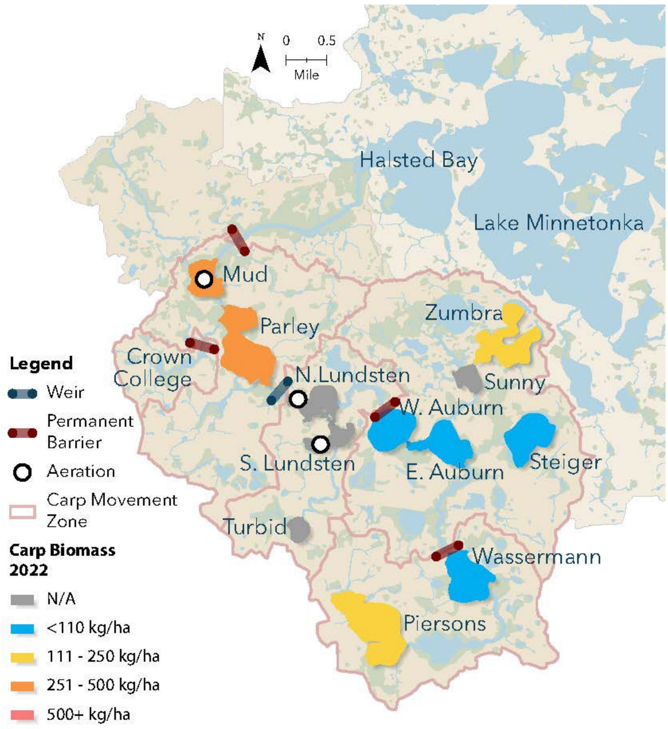

Figure 1. SMCHB Subwatershed with carp biomass estimates from 2022 and aerator and barrier locations.

II. Project Elements Requiring Maintenance

This O&M plan will provide a quick reference to specific maintenance needs, the frequency at which maintenance should occur, the responsible party, and any coordination that must occur to perform maintenance. All maintenance and other activities will be performed in a manner that reasonably minimizes impact on the surrounding natural environment and on any prior-constructed improvements.

Regular safety inspections and associated maintenance of these facilities will be performed to reduce the risk of hazards. An inspection record (Appendix B) should be completed during each inspection and follow-up maintenance should be documented. The timing and inspection frequency for items listed below are based on a consideration of potential hazards, the benefits of early identification of maintenance and repair needs, and staff/contractor costs.

Overall Operations and Maintenance Tasks and Responsibilities for the Six Mile Carp Management Program

Table 1 lists the major project elements of the Six Mile Carp Management program that require maintenance and whether work will be done jointly with TRPD (Appendix A for the cooperative agreement between TRPD and MCWD for carp management within the Carver Park Reserve).

Table 1. Overall operations and maintenance tasks for carp biomass maintenance (blue), carp barrier operation (green) and aeration operation (purple)

Task/Unit	**Responsible Organization**	**Responsible MCWD Program**
Monitoring of carp biomass & recruitment	MCWD	R&M
Conducting small scale removal events	MCWD	R&M
Coordination of removal events with consultants	MCWD	R&M
Highland Road Carp Barrier	MCWD	R&M/PMLM
Wassermann Lake Outlet Carp Barrier	MCWD	R&M/PMLM
Lake Auburn Outlet Carp Barrier	MCWD & TRPD	R&M/PMLM
Crown College Carp Barrier	MCWD	R&M/PMLM
Aeration Utility Maintenance on Mud Lake	MCWD	R&M/PMLM
Aeration Utility Maintenance on North Lundsten Lake	MCWD & TRPD	R&M/PMLM
Aeration Utility Maintenance on South Lundsten Lake	MCWD & TRPD	R&M/PMLM
Aeration Operation on Mud Lake	MCWD	R&M/PMLM
Aeration Operation on Lundsten Lakes	MCWD & TRPD	R&M/PMLM

Adult Carp Biomass Maintenance

A critical aspect in the maintenance phase of the carp management program will be maintaining the carp populations at or near our target thresholds for ecological improvement. This involves monitoring the adult carp biomass to identify recruitment or migration events that could potentially cause an increase in carp populations and then implementing or coordinating the removal efforts when necessary. Resources to support carp removal decision-making and execution include:

- Table 2, **Adult Carp Biomass Maintenance Task Overview,** details the specific tasks required.
- Appendix C, **Carp Population Monitoring Frequency Framework,** provides a basis for determining the frequency of carp population monitoring, and

- Appendix D, **Decision Matrix for Carp Removal,** provides a guide for determining when removals should occur.
- Appendix E, **Lake-by-Lake Removal History** provides details of removal events including an example contract structure and what removal techniques have been attempted successfully or unsuccessfully on the various lakes.

Table 2. Adult Carp Biomass Maintenance Task Overview

Operation or Maintenance Activity	**Description**	**Frequency**	**Comments/Responsible Party**
DNR Permitting	DNR permits needed for electrofishing surveys, trap-netting, temporary barrier installation, and any removal activities	As needed	R&M
Carp Biomass Monitoring	Electrofishing CPUE surveys (Electrofishing Boat- control box, generator, live well, motor, booms General equipment- nets, etc)	Each lake 2-3 times yearly, every other year, or every 3-5 years depending on risk level (see monitoring schedule)	R&M
Conducting small scale removal events	Maintaining equipment needed (temporary barriers/traps, nets, backpack electrofishing unit, etc)	As needed	R&M
Coordinating of removal events with consultants	Contract development, assistance with aspects of removal (monitoring, day of coordination, etc.)	As needed	R&M

Barrier Operation and Maintenance Tasks

A major feature of the project that will require coordinated maintenance is the continual operation of the four carp barriers that block carp movement (Figure 1). This includes frequent and consistent cleaning throughout the open water season as well as keeping the structures themselves maintained in a safe, working order. MCWD Research & Monitoring staff currently maintain the barriers by incorporating cleaning tasks into its routine stream monitoring as well as a considerable amount of time and specifically dedicated visits during moderate to high flow conditions. At this present time, the ability to predict time periods of low of carp movement is not refined enough to mitigate the risk of a reintroduction of carp, therefore the barriers are always closed. This current strategy is presumably also blocking some level native fish passage, which could negatively impact the ecological health of Six Mile Creek Lakes (MnDNR, 2015).

- Table 3, **Site Specific Barrier Information**, includes pertinent information for each barrier.

- Table 4, **Barrier Operation and Maintenance Tasks**, details specific activities required to operate and maintain the barriers that are solely under MCWD's control.
- Appendix A, **Operations & Maintenance Plan for Carp Management within the Carver Park Reserve**, contains information on the cooperative agreement between MCWD and TRPD as it pertains to the Auburn Lake carp barrier.

Table 3. Site Specific Barrier Information

	Highland Road	**Wassermann Lake Outlet**	**Crown College**	**Auburn Lake Outlet**
Location	44.901459, -93.733080	44.846120, -93.679480	44.885007, -93.738748	44.871539, -93.695532
Purpose	Separates the Six Mile Subwatershed from Lake Minnetonka	Separates the Wassermann-Piersons Management Unit from the lower subwatershed	Prevents carp movement into the Crown College Pond nursery	Separates the Carver Park Management Unit and prevents carp movement into the Lundsten Lake nursery
Build Date	Mar, 2019	Mar, 2019	Mar, 2019	Feb, 2021
Site Specific Issues	-Large cattail bogs -Vegetation build-up -Vandalism -Gates occasionally get jammed and require physical lifting (1 gate is wedged shut)	-Vegetation build-up -Vandalism -Winch post is pulling out of the ground	-Jammed gate that requires physical lifting	-Erosion of streambed filling in around the gate and not allowing the barrier gate to sit flush
Retrofit Date	Sept, 2020	Dec, 2020		
Retrofit Description	Replaced chain-link section with vertical bars and added streambank riprap	Added riprap and streambank stabilization to fix erosion issues		

Table 4. Barrier Operation and Maintenance Tasks

Maintenance or Inspection Activity	**Description**	**Frequency**	**Comments/Responsible Party**
Debris cleaning	Clean out debris (aquatic plants, floating bogs, etc.) to ensure barriers are not impeding flow	Approximately twice a week (more if flood conditions, less if drought). The Crown College barrier receives low flow and only requires cleaning quarterly.	R&M/PMLM
Barrier grates/steel pilings	Ensure proper functionality of grates to prevent carp movement. Water pressure, debris build-up, or vandalism can cause damage.	Bi-Annually in spring and fall	R&M/PMLM
Concrete footings	Frost and water freezing can cause concrete abutments to become askew, causing lift gates to get stuck	Bi-Annually in spring and fall	R&M/PMLM
Riprap/ Bank Erosion	Confirm riprap is in place and protecting the stream bank from eroding around or under the barrier	Bi-Annually in spring and fall	R&M/PMLM
Winch system- winch, crank, cables, pulleys	Rusting, grinding, fraying can occur and make the winch system inoperable	Bi-Annually in spring and fall	R&M/PMLM
Barrier lift gates	Lift gates should raise and lower and sit squarely in the grooves	Bi-Annually in spring and fall	R&M/PMLM
Locks	Locks and keys should open and close, salt damage may cause corrosion	Bi-Annually in spring and fall	R&M/PMLM
Streambanks	Ensure downstream and upstream banks are in good condition	Bi-Annually in spring and fall	R&M/PMLM
Signage if applicable	Confirm present and in good condition (none currently)	Bi-Annually in spring and fall	R&M/PMLM
Surveillance camera	A cellular security camera can be used to aid in monitoring the barriers. Maintain battery and charge.	As needed	R&M/PMLM

Aeration Operation and Maintenance Tasks

Another feature of the project is the annual operation of aeration units on carp nursery lakes to prevent carp recruitment. Currently, the aerators operated by MCWD on Mud Lake are installed in mid-January and operated until ice-off and require a high level of MCWD staff time and a specific skill set. Using a contractor may be desirable in the future.

- Table 5, **Aeration Operation and Maintenance Tasks,** details specific activities to operate the aerators solely under MCWD's responsibility (Mud Lake).
- Appendix F, **Aeration SOP**, is a standard operating procedure (SOP) for aeration that describes the process for installing, monitoring, troubleshooting issues, and uninstalling.
- Appendix A, **Operations & Maintenance Plan for Carp Management within the Carver Park Reserve**, contains information on the cooperative agreement between MCWD and TRPD as it pertains to the aeration of North and South Lundsten.

Table 5: Aeration Operation and Maintenance Tasks

Operation or Maintenance Activity	Description	Frequency	Comments/Responsible Party
DNR Permitting	Re-apply annually, pay application fee, coordinate public notice with TRPD	Annually in fall	R&M/PMLM
Homeowner Communication for Site Access	Give homeowner, Kent Tangren (952-270-7533), at least 30 minutes advance notice via text message when accessing the site.	As needed	R&M/PMLM
Motor	Oil/grease bearings. If issues arose during winter-use note any need for maintenance or replacement. Replacement motors will need to be wired by an electrician.	Annually in spring or fall	R&M/PMLM
Float	Ensure no cracks or punctures. Should have appropriate nuts and bolts for the motor attachment	Annually in spring or fall	R&M/PMLM
Anchors/anchor lines	Ensure correct number of anchors/anchor lines for installation	Annually in fall	R&M/PMLM
Power cables	Check for knicks or damage to the cables or connectors	Annually in spring	R&M/PMLM
Utility boxes	Keep clear access around the box and maintenance access doors	Annually in fall	R&M/PMLM
Thin ice/Warning signs	Ensure appropriate number of signs and sign placement following the DNR permit	Annually in spring or fall	R&M/PMLM
Installation equipment	Sleds, augers (batteries, blades), ice saws, ice chisels in working condition	Annually in fall	R&M/PMLM

Storage	Ensure adequate indoor storage is available	Annually in fall	R&M/PMLM
Surveillance camera	A cellular security camera can be used to aid in monitoring the aeration site. Maintain battery and charge.	As needed	R&M/PMLM
Utility payment	Xcel Energy Bill	Monthly	Operations

III. Site Photos

Figure 2. Highland Road Carp Barrier

Figure 3. Wassermann Lake Outlet Carp Barrier

Figure 4. Auburn Lake Outlet Carp Barrier

Figure 5. Crown College Carp Barrier

Figure 6. Aeration on Mud Lake

APPENDIX A - Operations & Maintenance Plan for Carp Management within the Carver Park Reserve

APPENDIX B – Inspection Record (TBD)

APPENDIX C – Framework for Frequency of Carp Population Monitoring

APPENDIX D – Decision Matrix for Carp Removal

APPENDIX E – Six Mile Creek Carp Removal History

APPENDIX F – Aeration SOP

Operations & Maintenance Plan for Carp Management within the Carver Park Reserve

Partnership Between:
Minnehaha Creek Watershed District (MCWD) & Three Rivers Park District (TRPD)
Date:

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Terms of this operations and maintenance plan may be modified only by agreement between MCWD and TRPD.

Project overview

MCWD and its partners are engaging in one of the Twin Cities metro's largest habitat restoration and water quality enhancement projects: the restoration of 2,488 acres of in-lake habitat across 14 connected deep and shallow lakes and the creation of corridors of restored wetland and uplands in the Six Mile Creek – Halsted Bay Subwatershed (SMCHB), one of the largest tributaries to Lake Minnetonka.

The SMCHB is one of MCWD's focal geographies. With our partners, we'll be working to align priorities and investments across agencies to accomplish large-scale habitat, corridor, and water resource restoration objectives, including larger-scale wetland restorations, additional rough fish management, in-lake and watershed phosphorus reduction, or others.

In September 2017, the Lessard Sams Outdoor Heritage Council awarded the Minnehaha Creek Watershed District (MCWD) $567,000 for the Six Mile Creek-Halsted Bay (SMCHB) Habitat Restoration Project. The program takes a holistic and comprehensive approach to managing common carp in the SMCHB Subwatershed, consisting primarily of three management strategies:

- Adult biomass removal
- Barriers to prevent carp movement between waterbodies and assist with removal
- Aeration of shallow lakes to prevent successful carp reproduction

The District has deployed a variety of tactics over the past year to remove carp across the Six Mile Creek-Halsted Bay Subwatershed. These methods have included stream trapping utilizing permanent and temporary barriers, baited box net trapping, and commercial winter seining. To date, across the 14 lake system, MCWD has removed approximately 30,000 carp totaling 275,346 pounds. We have been able to strategically install 4 barriers to direct much of the remaining carp population into just a few waterbodies and prevent carp from moving into carp nursery lakes where they are able to recruit successfully. Power utilities have also been installed at 3 sites to allow for winter aeration of carp nursery lakes.

With the TRPD's Carver Park Reserve in the heart of SMCHB, TRPD is a vital partner to MCWD. Carver Park Reserve is a 3,700 acre park that contains six lakes and numerous marshes, including North and South Lundsten Lake, which are the focus of winter aeration, and Lake

Auburn, of which the lake outlet and stream is a major junction point and is the location of a permanent carp barrier.

Winter Aeration

A 3-year carp assessment conducted by the University of Minnesota identified North and South Lundsten as carp nurseries. North and South Lundsten Lakes are both shallow lakes that can frequently winter kill. Winter kill can decimate the bluegill population in these lakes, which are effective predators of carp eggs. Maintaining a healthy bluegill population is the primary goal of winter aeration. Bluegills provide effective predation of carp eggs as carp spawn in the spring, eliminating carp recruitment to the system. Winter aeration is a vital component of the SMCHB Habitat Restoration project.

Winter Aeration Operating Plan

MCWD and TRPD have entered into an agreement that allows MCWD to partner in operation of aeration units on TRPD property.

Timeline – Aeration units will be installed annually once ice is safe enough to traverse on foot. At least 6 inches of solid, consistent ice is desired. Installation of units will likely occur early to mid-January in most seasons. Aeration units will stay in place until ice thaws enough where a canoe or small watercraft can be launched to retrieve the aeration unit. Thin ice signage will be placed in accordance with DNR permit requirements and retrieved in the spring.

Roles and Responsibilities

MCWD is responsible for the following:

- **Permits** - All permitting related to operating winter aeration units.
- **Maintenance** - Maintenance of aeration units, which include disruption of service due to failure of the units, cords, motor control, or anything that requires the assistance of a professional contractor will be secured by the District. (See "maintenance assistance" below).
- **Replacement** - Replacement of aeration units, cords, motor control, utility boxes, or any other equipment necessary for the operations of the aeration system, or parts therein, if and when needed.
- **Utilities** - Utility costs to operate aeration units, and maintenance of electrical source to lakes.

TRPD is responsible for the following:

- **Maintaining clear access to electric boxes** - TRPD will keep the route to the electrical boxes clear of trees and shrubbery that would impede access to the lakeshore of South Lundsten and North Lundsten electric sites.
- **Electrical maintenance** - TRPD will provide electrical services, including wiring motors for aeration units and assistance troubleshooting electrical issues as they may arise.

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- **Install** - Installation of aeration units and related appurtenances, including placing thin ice signage on the lake in accordance with DNR permits. Installation will be conducted according to the timeline above.
- **Signage**- TRPD will construct and install thin ice signs around the open water area and warning signs near trail access locations. Signage will be installed in accordance with the specifications required by the DNR permit.
- **Monitoring and Observations** – TRPD will conduct bi-weekly observations of aeration systems on North and South Lundsten Lake while they are being operated. TRPD will notify MCWD immediately if issues are observed.
- **Maintenance Assistance** – TRPD will conduct maintenance on the units and related appurtenances if it is able. Maintenance requiring specialty assistance, including the hiring of a contractor or acquisition of new materials, or that which is beyond the capacity of TRPD staff, will be the responsibility of MCWD.
- **Aeration Failure Response** – If feasible, TRPD will attempt to retrieve the failed aeration unit from the lake, troubleshoot the issue, and reinstall. TRPD will notify MCWD if they observe an aeration unit fail and inform MCWD of the response actions and whether any maintenance or replacement of equipment is needed.
- **Removal** – TRPD will remove aeration units and related appurtenance and signage in the spring.
- **Storage** – TRPD will store the aeration units on its own property, and will be responsible for transportation of the units between the storage facility and aeration sites. TRPD will store the thin ice and warning signs while they are not in use on the lake.

Carp Barriers

A 3-year carp assessment conducted by the University of Minnesota identified North and South Lundsten as carp nurseries. A permanent carp barrier was installed in March 2021 at the outlet of Lake Auburn to prevent adult carp from moving into North and South Lundsten to spawn. Preventing or controlling carp migration is a vital component of the SMCHB Habitat Restoration project. Temporary barriers may also be installed along various stream reaches within Carver Park to assist in stream trapping removals.

Auburn Carp Barrier Operating Plan

MCWD and TRPD have entered into an agreement that allows MCWD to partner in operation of a carp barrier on TRPD property. The carp barrier will be operated during the open water season. MCWD will dictate and communicate whether the barrier gate should be left raised or lowered depending on the time of year and/or to aid in carp removal attempts. Currently the barrier is 'unlocked' but requires use of a removable handle to use the winch system. The handle should be removed after every use to mitigate ability of the general public to raise or lower the barrier lift gate. If at any point TRPD or MCWD deems it necessary to add a locking mechanism, both parties will be informed and the combination or key will be shared with staff from both organizations.

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Roles and Responsibilities

MCWD is responsible for the following:

- **Permits** - All permitting related to the carp barrier.
- **Maintenance** - Maintenance of barrier which include disruption of service due to failure of the lift gate, winch mechanism and cables, erosion around the barrier, or anything that requires the assistance of a professional contractor will be secured by the District. (See "maintenance assistance" below).

TRPD is responsible for the following:

- **Monitoring and Cleaning** – TRPD will conduct weekly observations of the barrier and clean out debris when needed. TRPD will notify MCWD immediately if issues are observed. If the frequency of cleaning becomes an issue, TRPD will notify MCWD and MCWD will work to resolve the issue or adjust the operating plan.
- **Maintenance Assistance** – TRPD will conduct maintenance on the barrier if it is able. Maintenance requiring specialty assistance, including the hiring of a contractor or acquisition of new materials, or that which is beyond the capacity of TRPD staff, will be the responsibility of MCWD.

Temporary Carp Barrier Operating Plan

Temporary carp barriers will be installed by MCWD as needed to for carp removal stream trapping.

MCWD is Responsible for the Following:

- DNR permits for temporary barrier and removal of common carp.
- Installation and removal of temporary barriers.
- All maintenance of barriers, including debris removal. MCWD will inspect barriers once/week.
- Carp removal
- Storage of barrier materials.
- Requesting TRPD permit to drive on trails with pickup truck to install and maintain barriers to trap and remove carp.
- MCWD agrees to use discretion when driving on trails, and will avoid muddy or too wet of conditions.

TRPD is Responsible for the Following:

- Permitting MCWD to access carp barrier location with pickup truck for the installation, maintenance and trapping and removal of carp.
- Notifying MCWD if any activities or management actions are planned in the vicinity that could impact the barriers or MCWD's access to the barriers.

Access for Monitoring and Carp Management

In addition to the specific activities listed in this plan, MCWD will also be accessing lakes and stream locations throughout the year within Carver Park Reserve for monitoring and additional

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carp management work. MCWD will utilize the public boat access locations when available, and access lakes without a public access via TRPD trails. Lakes that will be accessed via trails include North and South Lundsten and Sunny Lake.

Notification Process for Planned Activities

- For scheduled work, MCWD will provide five business days' notice and, on TRPD request, will conform to reasonable travel, parking and staging conditions.
- For unscheduled work, MCWD will endeavor to provide as much advanced notice as possible, if less than five days.
- MCWD will notify the contacts below:
  Pete Hill/Park Supervisor/Pete.Hill@threeriversparks.org
  Tom Ruschmeier/Maintenance/ Tom.Ruchmeier@threeriversparks.org
  Brian Vlach/Senior Water Resources Manager/Brian.Vlach@threeriversparks.org

Contacts
Minnehaha Creek Watershed District

Three Rivers Park District

Signatures

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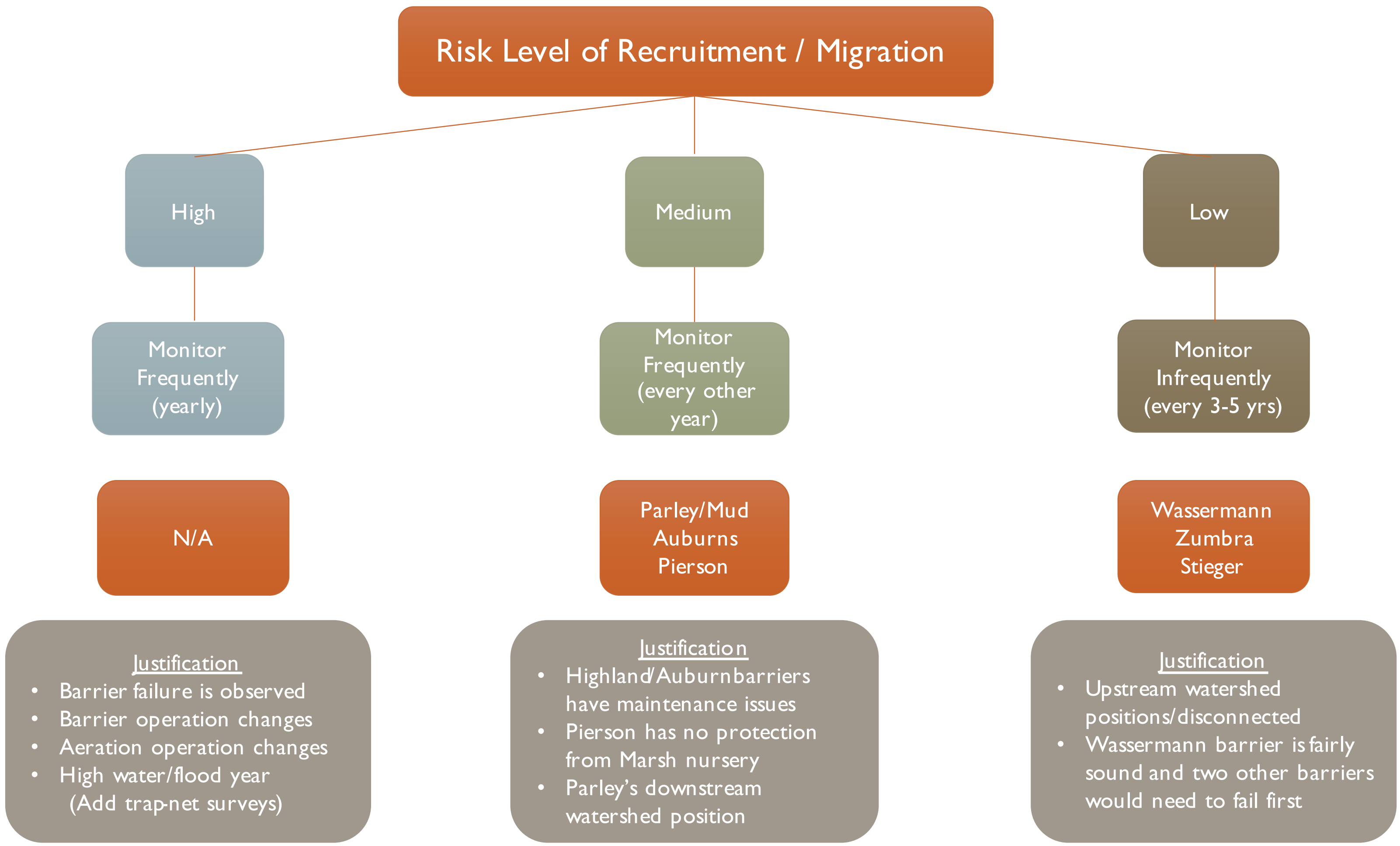
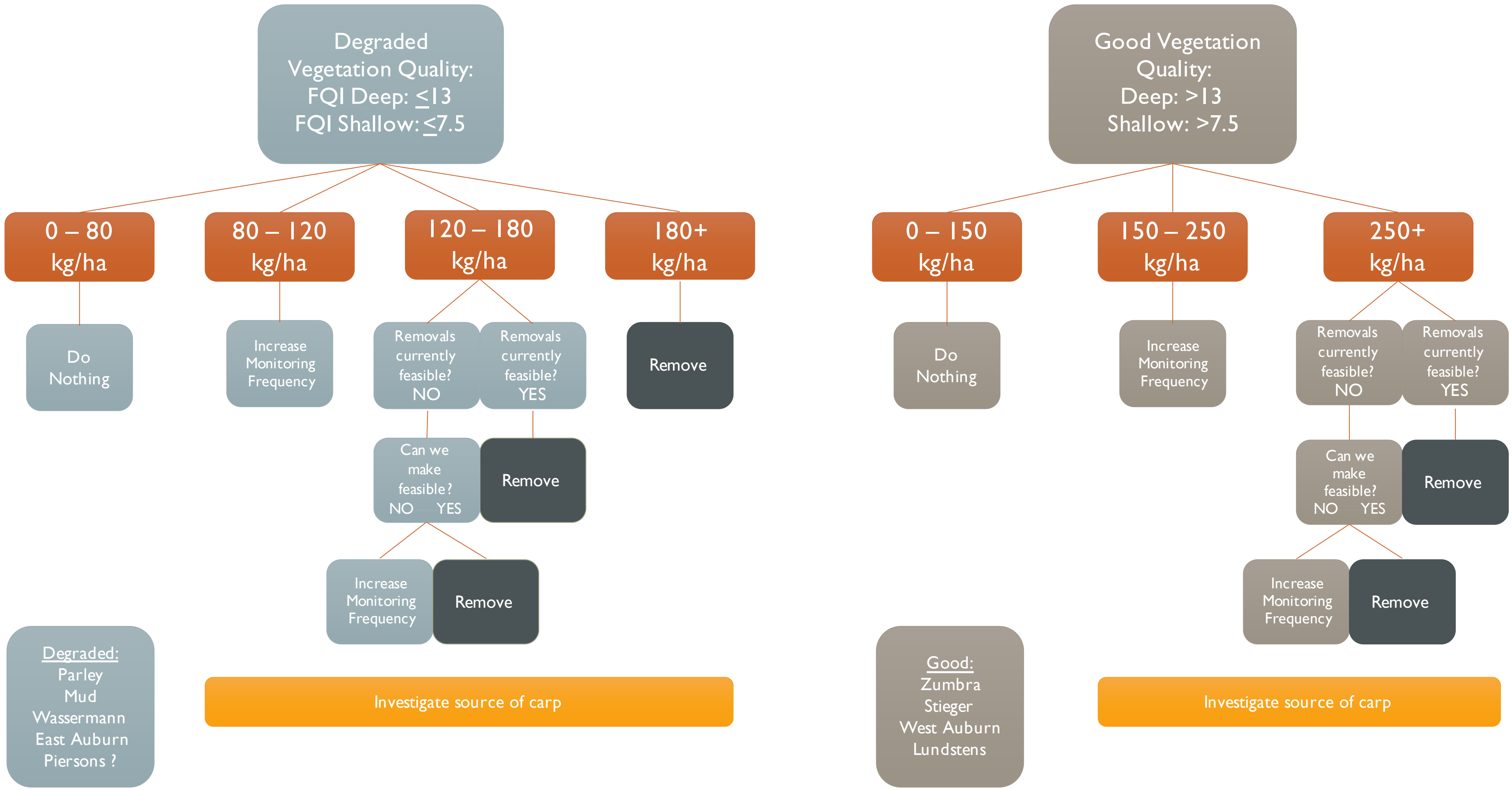
Appendix C

Framework for Frequency of Carp Population Monitoring



Appendix D

Decision Matrix for Carp Removals



Floristic Quality Index (FQI), a Minnesota aquatic macrophyte integretiy index. A lake with a degraded FQI has a very low species diversity with a community comprised of non-native and/or intolerant species.

Appendix E

Six Mile Creek Carp Removal History

Piersons:

2012 – A large number of carp were removed via stream trapping at the lake outlet by the Piersons Lake Association. Cost: $0

2022 – Stream-trapping was pursued but was not feasible due to low water levels. Cost: $3,340 (stream trapping materials kept for future use)

2022 - Box-netting was completed by WSB in September. 68 carp (516 lbs) removed in 4 removal events across 2 nets that were baited by MCWD and volunteers. Bait consumption was limited. Cost: $11,191.

2023 – Stream-trapping was completed in May of 2023 in two events removing 600 carp (7,472 lbs). No cost—MCWD staff time, Lake Association assistance, and some material purchasing.

Recommendation for future removals: Stream-trapping has the most potential for success on Piersons.

Wassermann:

2017 – A winter seine was completed by Geyer on 1/23/2017. 2,450 carp (18,584 lbs) were removed. The net was landed in SW corner of the lake. MCWD and UMN did assist with radio tag tracking. Cost: $0 (was done on own schedule/interest/permit of Geyer's crew).

2018 – A winter seine was completed by Geyer on 2/7/2018. 1,000 carp (9,041 lbs) were removed. The net was landed in SW corner of the lake. The net did get hung up in mud and also caught an aggregation of panfish (returned to the lake). MCWD completed radio tag tracking. Cost: $3,000 directly to Geyer (no contract).

2018 – Box-Netting was completed by Carp Solutions on 9/25/18. Only 2 carp were removed in 2 events across 3 nets that were baited by MCWD. Cost: $12,000 (approximately)

Future CPUE electrofishing surveys confirmed <100 kg/ha of carp in the lake. We suspect an emmigration of carp occurred in the spring of 2018 and then were blocked to return to the lake by temporary barrier at the outlet and the permanent barrier installation in March, 2019.

Recommendation for future removals: Wassermann should be protected by the carp barrier at the outlet but if carp were to be re-introduced, a commercial seine is the best option.

Auburns (East and West):

2018 – Box-netting was completed by Carp Solutions in September. 1,708 carp (10,167 lbs) were removed in 3 events across 4 nets (2 on East and 2 on West) that were baited by MCWD. Cost: $12,000 (approximately)

2018 - Stream-trapping was conducted in May by MCWD staff at a trail crossing downstream of Auburn. 12 carp were removed. The site consisted of a drop culvert upstream and a temporary barrier installed approximately 50 ft downstream. We used backpack shocking for one effort and subsequently observed the temporary barrier fail. Cost: MCWD staff time

2019 – Stream-trapping was conducted in May by MCWD staff at a trail crossing downstream of Auburn. 940 carp (4,545 lbs) were removed. The site consisted of a drop culvert upstream and a temporary barrier installed approximately 100 ft downstream. We used backpack shocking and a variety of small seine nets over 4 efforts to catch carp. Cost: MCWD staff time

2019 – Box-netting was completed by Carp Solutions in September. 119 carp (785 lbs) were removed in 3 events across 4 nets (2 on East and 2 on West) that were baited by MCWD. Cost: $25,000

2021 – A winter seine was attempted by Reiderman's crew in Jan/Feb on East Auburn. Prior to ice on, WSB and Reidermann scoped out the lake for suitable seining locations as this lake had never been seined. Carp were tracked by MWCD and were aggregated in a suitable location in the western corner of the lake (in front of the shallow channel area to West Auburn). Reiderman's completed pre-lining and we suspect due to noise on the ice, carp were scared north. The MUM technique (underwater speakers) was attempted by WSB to move the carp back but no luck and the seine was called off. Cost: $7,000 (plus $5,095 in recon of seine feasibility)

2022 – Stream-trapping was conducted by MWCD and WSB in May (some labor assistance from Stantec as well). 1,119 carp (5,922 lbs) were removed. The site consisted of the permanent barrier at the West Auburn outlet and a temporary barrier and push trap approximately 200 ft downstream. The permanent barrier was opened and the downstream barrier was monitored for carp to stack up. A variety of methods to remove the carp from the stream reach were attempted including setting a box-net up in-stream but the most effective was backpack shocking and hand netting. Volunteers also did a day of bow-fishing/spearing in the stream. Cost: $16,360

2022 – Hoop-netting was attempted by MCWD and WSB in August. This adapted fyke net was placed along the shoreline in East Auburn and was baited by MCWD with corn and hemp products. No carp were caught or observed (nor bait consumption) during the 10 days the net was set. A small amount of native fish mortality was observed so the net was removed. Cost: $2,260

Recommendation for future removals: Stream-trapping. Further winter seines could be attempted on East Auburn but should take care to deal with more skittish carp.

Stieger:

2018 – Box-netting was conducted by Carp Solutions in September. 296 carp (6,723 lbs) were removed in 2 removal events across 3 nets. MCWD did the baiting. Nets were extremely hard to work up due to unconsolidated/mucky substrate. The lake was determined not to be ideal for box-netting. Cost: $12,000 (approximately)

2021 – An open-water bait & seine was attempted by WSB in October. MCWD baited an area of the lake with a firmer lake bottom that was feasible to land the net. No consumption of the bait was observed so the seine was not pursued. Cost: $3,300

Recommendation for future removals: Stieger is meeting standards for water quality and vegetation so even though carp are above 100 kg/ha, further removals are not necessary.

Zumbra:

2019 – Box-netting was conducted by Carp Solutions in September. 195 carp (1,432 lbs) were removed in 2 removal events across 3 nets that were baited by MCWD. Bait consumption was limited. Cost: $15,000

2020 – A winter seine was conducted in February by WSB/Reiderman. Only 9 carp (69 lbs) were removed. The carp aggregation in the NW bay was determined to be too deep for traditional seining. Cost: $14,000

2021 – A winter seine was partially attempted in February by WSB/Reiderman with MUM guidance to a more suitable seining location. Fisherman were onsite with sonar during the MUM application but the carp never moved out of the NW bay. Cost: $3,912.

Recommendation for future removals: Zumbra is meeting standards for water quality and vegetation so even though carp are above 100 kg/ha, further removals are not necessary.

Parley:

2019 – Box-netting was conducted by Carp Solutions in August - October. 2,333 carp (23,754 lbs) were removed in 6 events across 4 nets. MCWD and Carp Solutions baited. A net was installed in Mud but was immediately crushed by a floating cattail bog so it was relocated to Parley. Cost: $37,200.

2020 – Winter seines were conducted by WSB/Geyer's Crew in February. 2,922 carp (30,906 lbs) were removed in 3 seines hauls (3 different locations). MCWD conducted radio tag tracking. Cost: $16,000.

2020 – Box-netting was conducted by Carp Solutions and UMN in July – September. 3,567 carp (39,510 lbs) were removed in 3 removal events across ~4 nets. Approximately 300 carp were PIT tagged prior to the netting as part of a UMN research project to study carp feeding behavior. MCWD did not do any baiting. Cost: $41,181

2021 - Winter seines were conducted by WSB/Geyer's Crew in February. 5,522 carp (51,100 lbs) were removed in 3 seines hauls (3 different locations). MCWD conducted radio tag tracking and paid $17,714.

2021 – Box-netting was conducted by Carp Solutions and UMN in July – September. 1,249 carp (11,978 lbs) were removed in 4 removal events across ~5 nets. MCWD conducted radio tag tracking. Cost: $32,143.

2022 – A winter seine was conducted by WSB/Geyer's Crew 1/16/2022. 6,237 carp (61,600 lbs) were removed in 1 seine haul landing the net at the Crown College beach. MCWD conducted radio tag tracking. Cost: $16,430.

2024 - A winter seine was approved but due to a mild winter and poor ice condition it was not able to proceed.

2025 – A winter seine occurred on 2/22/2025 in 1 seine haul landing the net at the Crown College beach. 3,129 carp (22,839 lbs) were removed. An additional 253 (936 lbs) were PIT/RFT tagged and released. Cost: ~$25,000 (tbd)

Recommendation for future removals: Winter seining

Halsted:

2019 – Box-netting was conducted by Carp Solutions and UMN in September and October. 1,787 carp (11,121 lbs) were removed in 3 events across 3-4 nets. This was also part of the UMN's research project. MCWD assisted in implanting 300 PIT tags. Cost: $18,690 (approximately)

Recommendation for future removals: No removals recommended due to connection to greater Lake Minnetonka.

Misc:

A variety of other removal methods were tried at various locations.

Used side-scan sonar with WSB on West Auburn, Stieger, and Zumbra to search for early spring aggregations within the lake.

Various stream sites were monitored for spring migrations and/or had attempted removals with little/no success – Wassermann outlet, Parley dam (Lundsten outlet), and Highland Road.

Appendix F: Aeration SOP

Aeration units are operated on select shallow lakes as part of carp management.

Equipment Needed:

- Aire-O2 Series II Unifloat and U-float Horizontal Aerator (bring a spare with during installation)
  - Pontoon float
  - Aerator motor
- Ice Augers (4 in and 6 in)
- Charged spare batteries for power drill
- Cords (10 gauge with heavy duty weather-proof plug ends)
- 2 or 4 Cement block anchors/unit
- Floating nylon rope/carabiners
- Depth pole or weighted measuring rope
- Ice chippers
- Ice saws – (Fish's Sporting Toys) – Store in a plastic gun case
- Sleds
- Small snow shovel
- Ice scoop (with ruler)
- Thin ice signs (approximately 20/lake)
- Access warning signs (place one at every access/trail to the lake)
- Tool box
  - Zip ties/Reusable zip ties
  - Gorilla tape
  - Socket set & wrenches
  - Hammer
  - Spare bolts
  - Pliers/nippers
  - Electric volt tester
- Handheld propane torch (for ice melting)
- Ice safety equipment
  - PFDs
  - Ice picks
  - Throw rope

Aeration Installation: As soon as DO monitoring determines oxygen levels have dropped below 5 mg/L at 1 meter depth, schedule a day to install aerator. **Note: If the DO stays above/at 5 through mid-February, fish will most likely survive even if the DO starts dropping in March.**

Four staff people are ideal for installation. See map/document/GPS points for the location of the power box and when the aerator should be placed.

- Stretch cord out from electric plug-in location to desired aerator placement location on the ice but leave the cord unplugged for now. Bring aerator unit and other equipment out to that location.
- Place the pontoon where you want it on the ice, imagining how you would ideally aim the water current generated by the aerator's propeller. Mark shape of pontoon's outline on ice/snow, then move it out of the way.
- Using ice auger, drill 4 holes at the corners, more holes if desired, then saw ice between holes. Push ice square(s) below and away with ice chipper bars.
- Place aerator motor onto pontoon/bracket. Attach bolts to secure motor to the bracket and determine which angle you want. Plug motor's cord into long extension cord and stand back; have someone on shore briefly plug cord's other end into outlet to test motor, make sure system is working. Then unplug.
- Tape connection from motor cord to extension cord to ensure no water will get in. Zip tie cord connection UP near top of motor somewhere it won't interfere with moving parts, plenty high enough to keep away from ice and snow.
- Move the other equipment back to shore in preparation for turning motor on. **Wait to actually turn it on until staff have completed the thin ice sign installation, just to be safe.**

Thin Ice Sign Installation:

- Place thin ice signs around where open water is expected (300' x 500' rectangle around aerator), using 4" hand auger to make holes for signs in ice. **Be careful not to drill too close to shore as the blades will dull if they touch mud or rock.**
- If close to shore, consider zip-tying signs into trees or brush somehow. Make sure signs form a rectangular shape (square, rectangle, or L-shape) and signs are facing outward with no more than 100 feet (~30 paces) between signs.
- To make thin ice signs/warning signs: Order signs from ______. Bolt the signs to wooden post---10 ft 2x4 (cut 18" off one end to make a cross piece which sits on the ice after you drill the 4" hole to stick it in)

Completing Aeration Installation:

- Attach cement anchor ropes to the 4 corners of the pontoon and stretch out. Allow for enough rope to reach the lake bottom and to be diagonally out from each corner (~15-20 ft).
- If there is a lot of ice and cold weather predicted, auger a few holes out in front of the aerator to encourage it to open up the ice in the right direction.
- Push aerator into water so it's floating (if it doesn't float, you're in trouble- retrieve and use different pontoon).
- Plug cord in and make sure aerator is now running.

Aerator Monitoring:

- Go back the day after installation, if possible, to make sure things are still looking good.
- Follow up by checking the aeration set-up from shore weekly and recording your visits.
- **Checklist:**
    - Motor is running
    - No alarming sounds from motor
    - The aerator is pointed the direction you left it (if not, it may mean the anchor rope may have been chewed by muskrats)
    - Some open water is visible
    - Thin ice signs are where you left them
    - Open water has not exceeded thin ice sign area
- If you need to go out on the ice to fix/check/inspect the motor, go with a buddy, wear safety gear, and slide yourself out there in the canoe or sled. Ice could be thin in weird places.
    - Unplug power before going out.
    - If there is ice buildup on the pontoons, it SHOULD absolutely be chipped off. The motors can sink because of ice buildup. Just don't chip through anything important, like the cord insulation or the anchor ropes, etc.
    - **SAFETY NOTE: Do not attempt if deemed unsafe. If you choose to attempt, make sure to have at least one other person (Notify staff in office), and all winter safety equipment (ice picks, throw rope, blankets, dry clothes/boots). Most locations where aerators are installed are quite shallow, but that doesn't mean staff won't get wet. If the situation is unsafe, contact fire department/ice rescue; they may want to use as a training opportunity.**

If motor needs to be fixed or replaced, take it to Andrew at Elroy's Electric Service, at 7333 Argenta Trail, Inver Grove Heights, MN 55077, (651) 454-5672, or other more local location TBD

If new pontoons are needed, buy one from AireO2.

If 6 inch K-drill auger blades need to be sharpened, take or mail them to K-drill/AWC Distributing at 6667 West Old Shakopee Rd, Suite 102, Bloomington, MN 55438.

APPENDIX B

SUBMERGED AQUATIC VEGETATION SURVEYS

Spring: May-June Surveys													
Lake	Date	Total Points	Points Sampled	Whole Lake Occurrence (%)	Total Littoral Points (<15 ft depth)	Littoral Occurrence (%)	Max Depth of Plant Growth	Mean Depth of Plant Growth	# of Taxa	FQI	Mean C	Native Occurrence (%)	Invasive Occurrence (%)
Big SOB	6/1/2015	69	67	38.8	66	39.4	7.4	3.7	4	6	3	33.3	3
Crown College	6/1/2015	50	49	98	49	98	3.1	2.5	4	8	4	98	0
East Auburn	5/12/2012	116	77	67.5	77	67.5	8.5	5.1	7	11.6	4.4	62.3	49.4
East Auburn	5/12/2016	116	111	49.5	83	66.3	7.8	3.6	3	5.2	3	61.4	16.9
East Auburn	6/13/2019	116	111	55	81	74.1	13.5	5.2	6	11	4.5	66.7	42
East Auburn	6/9/2022	116	108	40.7	77	57.1	9.3	4.8	5	9.4	4.2	54.5	20.8
Halsted Bay	6/7/2017	464	430	28.8	302	40.7	12.5	4.7	7	10.8	4.1	22.8	34.8
Halsted Bay	6/19/2019	351	320	22.5	217	33.2	8	4.6	9	15	5	22.6	25.3
Marsh	6/27/2018	96	73	100	73	100	4.5	3.6	13	20.9	5.8	100	12.3
Mud	5/26/2017	72	72	55.6	72	55.6	5.6	4.4	6	9.1	3.7	30.6	41.7
Mud	6/14/2019	72	72	72.2	72	72.2	5.5	3.7	5	8	3.6	63.9	54.2
Mud	6/3/2022	72	72	61.1	72	61.1	4.7	3.1	5	8.5	3.8	26.4	43.1
Mud	6/2/2023	72	72	70.8	72	70.8	4.3	3.2	6	8.6	3.5	54.2	40.3
Mud	6/12/2024	71	71	97.2	71	97.2	6.8	5.4	7	10.6	4	95.8	70.4
North Lundsten	6/8/2016	44	41	97.6	41	97.6	7.1	3.7	7	11.6	4.4	97.6	26.8
North Lundsten	6/15/2018	96	77	100	77	100	7.4	3.2	9	14.7	4.9	100	28.6
North Lundsten	6/10/2019	96	89	98.9	89	98.9	8	3.7	10	15.2	4.8	97.8	28.1
Parley	5/18/2016	252	252	49.2	219	56.6	10.2	4.6	5	8	3.6	4.6	54.3
Parley	6/12/2018	252	252	49.6	211	59.2	10.6	4.9	5	8.5	3.8	13.3	57.8
Parley	6/14/2019	252	252	47.6	203	59.1	11.6	5.6	5	8	3.6	10.3	56.2
Parley	6/14/2022	166	165	47.9	141	56	7.4	4.5	5	8	3.6	27	48.9
Parley	6/1/2023	164	163	50.3	137	59.9	11.4	5	7	10.6	4	18.2	56.2
Parley	6/12/2024	166	163	50.9	125	66.4	11.7	6.5	6	9.1	3.7	23.2	64.8
Piersons	5/29/2014	251	215	74.4	193	82.9	13	4.9	16	22	5.5	74.1	43
Piersons	5/27/2022	244	226	70.4	199	79.4	13.8	5	16	23.6	5.9	64.8	43.7
Piersons	6/10/2024	251	190	84.7	160	97.5	14.7	6.1	21	27	5.9	98.1	59.4
South Lundsten	6/8/2016	27	27	77.8	27	77.8	5.2	2.3	7	10.8	4.1	74.1	29.6
South Lundsten	6/22/2018	71	48	85.4	48	85.4	6.7	2.9	9	14.4	4.8	77.1	45.8
South Lundsten	6/10/2019	71	67	89.6	67	89.6	6	2.8	9	12.9	4.3	76.1	34.3
Stieger	5/9/2014	236	226	62.8	180	78.9	14.5	4.9	14	22.1	5.9	73.9	37.2
Stieger	6/3/2022	235	233	67.8	181	87.3	14.2	5.9	13	20.9	5.8	56.9	65.2
Sunny	6/7/2016	75	73	82.2	65	92.3	11.3	3.9	7	11.4	4.3	92.3	7.7

Spring: May-June Surveys													
Lake	**Date**	**Total Points**	**Points Sampled**	**Whole Lake Occurrence (%)**	**Total Littoral Points (<15 ft depth)**	**Littoral Occurrence (%)**	**Max Depth of Plant Growth**	**Mean Depth of Plant Growth**	**# of Taxa**	**FQI**	**Mean C**	**Native Occurrence (%)**	**Invasive Occurrence (%)**
Turbid	6/19/2013	73	73	65.8	57	84.2	11	5.4	5	10.3	4.6	84.2	10.5
Turbid	6/27/2017	65	65	53.8	41	85.4	10	4.6	4	8	4	70.7	53.7
Turbid	6/7/2019	65	65	53.8	41	85.4	11.5	5	5	8.9	4	51.2	73.2
Wass. Pond West	6/21/2018	66	66	51.5	47	72.3	7	3.8	5	8.5	3.8	72.3	29.8
Wassermann	5/30/2017	258	254	31.1	171	46.2	8.2	4.9	4	8	4	23.4	40.4
Wassermann	5/27/2020	258	203	54.2	162	67.9	12.2	7	4	7.6	3.8	14.8	67.3
Wassermann	5/6/2021	173	172	73.3	165	76.4	14.2	6	4	7.6	3.8	15.8	74.5
Wassermann	5/28/2021	210	209	70.8	164	89.6	14.7	7.5	5	9.4	4.2	13.4	89.6
Wassermann	5/19/2022	198	198	78.3	167	92.8	14.2	7.2	5	9.4	4.2	18.6	88.6
Wassermann	5/25/2023	219	218	67.9	167	88.6	14.5	7.4	6	11	4.5	27.5	82
Wassermann	5/29/2024	225	224	74.6	160	98.1	14.9	8	8	13	4.6	38.1	97.5
Wassermann	6/19/2015	258	189	28	186	28.5	5.8	3.1	5	9.4	4.2	15.6	26.9
Wassermann	6/6/2018	258	257	35	174	51.7	9.8	5	7	11.6	4.4	31	45.4
Wassermann	6/17/2019	258	258	39.5	173	59	9.6	5.4	5	9.4	4.2	30.1	55.5
Wassermann	6/22/2020	258	178	58.4	165	63	10.5	5.9	6	9.8	4	21.2	61.2
Wassermann	6/16/2021	201	201	72.6	172	84.9	14.4	6.8	7	11.4	4.3	24.4	82.6
Wassermann	6/20/2022	205	204	73	169	87.6	14.2	7.3	5	9.4	4.2	19.5	85.2
Wassermann	6/16/2023	220	219	61.6	173	78	11.7	6.2	7	11.6	4.4	32.9	69.9
Wassermann	6/27/2024	216	216	47.2	159	64.2	11.2	6.5	10	13.3	4.2	46.5	44
West Auburn	5/10/2016	119	119	87.4	119	87.4	12.9	4.6	9	15	5	84	54.6
West Auburn	5/31/2019	119	117	82.1	116	82.8	11.1	5.4	11	16.9	5.1	81.9	51.7
West Auburn	6/8/2022	119	117	88	117	88	13.8	5.6	8	14.1	5	82.1	64.1
Zumbra	5/16/2016	169	169	75.7	136	91.9	15	7.3	17	24.3	5.9	77.9	75.7
Zumbra	6/6/2011	169	169	74	169	74	5.6	2.2	16	22.4	5.6	72.2	27.2
Zumbra	6/14/2022	169	168	90.5	145	97.2	14.8	6	19	25.3	5.8	102.8	77.9

Summer: July-September Surveys													
Lake	Date	Total Points	Points Sampled	Whole Lake Occurrence (%)	Total Littoral Points (<15 ft depth)	Littoral Occurrence (%)	Max Depth of Plant Growth	Mean Depth of Plant Growth	# of Taxa	FQI	Mean C	Native Occurrence (%)	Invasive Occurrence (%)
East Auburn	8/30/2017	116	104	44.2	76	60.5	7.4	3.9	5	8.9	4	60.5	13.2
East Auburn	8/11/2022	116	107	42.1	80	56.2	8.3	4.1	4	9	4.5	56.2	6.2
East Auburn	8/26/2024	116	107	48.6	78	66.7	9.8	5.4	5	9.8	4.4	66.7	46.2
East Auburn	9/15/2015	116	105	46.7	80	61.3	12.5	4.3	5	11.2	5	58.8	15
East Auburn	9/6/2018	105	105	44.8	79	59.5	7.3	3.8	4	9	4.5	59.5	15.2
Halsted Bay	8/29/2018	351	324	21	236	28.8	9	3.6	8	15.8	5.6	25	9.7
Mud	7/27/2017	72	72	59.7	72	59.7	4.6	2.7	6	7.8	3.2	59.7	15.3
Mud	7/23/2020	72	72	18.1	72	18.1	3.3	2.1	3	5.2	3	15.3	2.8
Mud	8/7/2018	72	72	63.9	72	63.9	3.5	2.2	5	8	3.6	63.9	5.6
Mud	8/4/2022	72	69	44.9	69	44.9	3.9	2.7	5	6.7	3	43.5	5.8
Mud	9/18/2023	72	72	95.8	72	95.8	3.5	2.1	7	9.5	3.6	94.4	30.6
Mud	9/9/2024	72	72	97.2	72	97.2	5.7	4.2	7	9.5	3.6	97.2	23.6
North Lundsten	9/6/2018	96	59	98.3	59	98.3	7.1	3.7	7	13.2	5	98.3	0
Parley	7/27/2020	166	126	16.7	123	17.1	6.4	3.8	5	8	3.6	8.9	10.6
Parley	7/29/2022	166	164	31.7	144	36.1	6.6	3.4	6	9.8	4	31.2	14.6
Parley	8/13/2018	252	251	13.5	225	15.1	4	2.5	5	8.5	3.8	12	8.4
Parley	8/5/2021	166	164	15.9	144	18.1	3.8	2.6	5	8	3.6	11.8	13.2
Parley	8/19/2024	166	164	26.2	135	31.9	6.5	4.3	7	10.3	3.9	31.1	8.9
Parley	9/9/2015	252	248	13.3	220	15	3.8	2.6	3	6.9	4	11.4	7.7
Parley	9/5/2023	166	163	28.2	146	31.5	6.4	3	7	10.3	3.9	25.3	14.4
Piersons	8/24/2022	189	177	80.2	155	91.6	13.4	4.3	19	25.7	5.9	86.5	39.4
Piersons	8/30/2024	208	199	75.9	172	87.8	14.4	5.6	19	23.5	5.4	83.1	35.5
Piersons	9/10/2015	251	196	76	178	83.7	13.5	4.2	20	25.9	5.8	77.5	45.5
South Lundsten	9/6/2018	71	31	74.2	31	74.2	7	4.1	7	10.6	4	71	16.1
Stieger	7/30/2018	236	221	60.2	177	75.1	11.5	4.4	14	21.3	5.7	74.6	36.7
Stieger	8/4/2022	235	214	45.3	167	58.1	11.7	3.6	11	16.6	5	56.9	14.4
Stieger	8/31/2023	224	210	54.8	175	65.7	11.9	3.8	15	20.9	5.4	63.4	20
Stieger	9/8/2015	236	218	60.1	171	76.6	13	5.3	10	18	5.7	65.5	48
Stone	9/18/2015	90	81	100	81	100	12	4	8	13	4.6	98.8	42
Sunny	8/30/2018	75	66	89.4	63	93.7	13	4.9	7	13	4.9	93.7	1.6
Sunny	9/14/2015	75	75	88	67	98.5	12.5	4.7	7	14	5.3	98.5	1.5
Turbid	8/6/2020	65	65	29.2	42	45.2	4.3	2	3	5.2	3	42.9	2.4

Summer: July-September Surveys													
Lake	Date	Total Points	Points Sampled	Whole Lake Occurrence (%)	Total Littoral Points (<15 ft depth)	Littoral Occurrence (%)	Max Depth of Plant Growth	Mean Depth of Plant Growth	# of Taxa	FQI	Mean C	Native Occurrence (%)	Invasive Occurrence (%)
Turbid	9/11/2013	105	99	49.5	59	83.1	10.3	4.7	3	7.4	4.3	83.1	0
Turbid	9/12/2018	65	61	27.9	36	47.2	7.4	3.9	2	7.1	5	47.2	0
Wass. Pond West	9/7/2018	66	62	50	46	67.4	7.4	3.7	4	8.4	4.2	67.4	0
Wassermann	7/16/2020	258	142	32.4	138	33.3	9.1	4	7	11.4	4.3	28.3	13.8
Wassermann	7/9/2021	214	214	37.9	177	45.8	11.7	5.3	6	11	4.5	27.7	34.5
Wassermann	7/14/2022	206	205	31.2	183	35	8.7	4.1	7	11.4	4.3	29	20.2
Wassermann	7/14/2023	220	219	37	177	45.8	8.2	3.9	8	11.9	4.2	37.3	32.8
Wassermann	7/31/2023	218	217	41.9	183	49.7	9.4	4.1	7	11.4	4.3	42.6	38.8
Wassermann	7/18/2024	224	224	37.1	167	49.7	10.5	5.8	6	11.5	4.7	44.3	27.5
Wassermann	8/28/2015	258	248	19	180	26.1	7.4	3.6	5	9.8	4.4	21.1	15.6
Wassermann	8/29/2017	258	255	22.4	178	32	5.9	3.8	6	9.8	4	29.2	26.4
Wassermann	8/30/2018	258	166	43.4	166	43.4	8.6	4.1	8	14.4	5.1	41	28.9
Wassermann	8/3/2020	258	159	28.9	155	29.7	6.3	3.9	6	9.8	4	21.3	14.2
Wassermann	8/31/2020	258	143	35.7	143	35.7	6.7	4.2	4	7.6	3.8	28	18.9
Wassermann	8/3/2021	211	211	30.8	181	35.9	8.7	4.2	8	11.6	4.1	21	30.9
Wassermann	8/30/2021	199	198	37.9	182	41.2	8.2	4.5	7	11.4	4.3	24.7	31.9
Wassermann	8/9/2022	209	208	36.5	185	41.1	7.7	3.7	7	11.4	4.3	30.3	28.6
Wassermann	8/25/2023	222	221	44.3	184	53.3	9.9	4.2	8	11.9	4.2	40.2	39.7
Wassermann	8/9/2024	226	225	34.2	168	45.8	9.1	5.6	7	11.6	4.4	40.5	21.4
Wassermann	9/21/2020	258	148	45.9	146	46.6	7.5	4.9	3	5.2	3	21.2	39
Wassermann	9/21/2021	187	187	40.6	172	44.2	8.2	4.4	7	11.4	4.3	22.1	36
Wassermann	9/2/2022	209	208	40.9	184	46.2	7.4	3.9	7	11.4	4.3	32.6	32.1
Wassermann	9/19/2022	209	208	46.2	184	52.2	8	4.2	7	11.4	4.3	32.1	41.8
Wassermann	9/27/2023	219	218	45.9	178	56.2	8.9	4.4	8	11.6	4.1	42.1	39.3
Wassermann	9/16/2024	237	236	40.3	171	55	9.3	5.2	7	11.6	4.4	45.6	32.2
West Auburn	7/8/2011	119	119	95.8	118	96.6	13.7	4.9	14	18.7	5	89	83.9
West Auburn	7/31/2018	119	115	84.3	115	84.3	12.6	3.9	10	14.5	4.6	83.5	47
West Auburn	8/10/2011	119	119	92.4	116	94.8	11.5	4.3	12	17.3	5	94.8	75.9
West Auburn	8/11/2022	119	116	82.8	116	82.8	10.7	4	9	14.4	4.8	78.4	53.4
West Auburn	8/23/2024	118	116	90.5	115	91.3	13.4	5.4	11	16.3	4.9	90.4	65.2
West Auburn	9/15/2015	119	116	83.6	116	83.6	12.3	4.2	10	14.9	4.7	83.6	31.9

Summer: July-September Surveys													
Lake	Date	Total Points	Points Sampled	Whole Lake Occurrence (%)	Total Littoral Points (<15 ft depth)	Littoral Occurrence (%)	Max Depth of Plant Growth	Mean Depth of Plant Growth	# of Taxa	FQI	Mean C	Native Occurrence (%)	Invasive Occurrence (%)
Zumbra	8/14/2018	169	157	80.3	127	92.9	14.7	7.2	16	22.4	5.6	98.4	29.1
Zumbra	8/12/2022	169	159	93.7	141	97.9	14.8	5.7	18	25	5.9	105	43.3
Zumbra	9/9/2011	169	169	73.4	139	88.5	14.2	5.7	17	22.7	5.5	89.2	18.7
Zumbra	9/14/2015	169	156	76.3	129	92.2	14.5	7.1	13	19.1	5.3	91.5	36.4

APPENDIX C

CARP POPULATIONS

Lake	Size (Hectare)	Surveyor	Date	Shock Time (hour)	Number of Carp	Average Length (cm)	Average Weight (kg)	CPUE	Estimated Density (carp/ha)	Biomass mean (kg/ha)	Estimated Population Size
East Auburn	59.9	U of MN	2014	1.0	NA	NA	1.8	31.6	151.7	323	8,237
Halsted Bay	223.4	U of MN	2014	1.0	NA	NA	3.7	61.3	292.0	1,093	65,225
Kelser's Pond	8.5	U of MN	2014	1.0	NA	NA	4.8	2.1	13.1	70	118
Mud	40.1	U of MN	2014	1.0	NA	NA	3.9	22.7	110.0	495	4,782
North Lundsten	43.7	U of MN	2014	1.0	NA	NA	2.0	18.3	89.5	204	4,515
Parley	104.4	U of MN	2014	1.0	NA	NA	3.5	26.2	126.5	513	15,265
Piersons	108.1	U of MN	2014	1.0	NA	NA	3.3	3.1	17.7	66	2,400
South Lundsten	29.9	U of MN	2014	1.0	NA	NA	2.3	8.3	42.4	111	1,457
Steiger	67.2	U of MN	2014	1.0	NA	NA	3.2	8.2	41.7	155	3,214
Stone	40.1	U of MN	2014	1.0	NA	NA	4.4	3.8	20.7	107	924
Sunny	19.4	U of MN	2014	1.0	NA	NA	2.6	2.4	14.3	42	314
Turbid	16.4	U of MN	2014	1.0	NA	NA	3.1	25.3	122.4	436	2,290
Wassermann	68.4	U of MN	2014	1.0	NA	NA	3.0	33.1	159.1	555	12,141
West Auburn	58.7	U of MN	2014	1.0	NA	NA	1.9	27.0	130.1	290	8,097
Zumbra	89.4	U of MN	2014	1.0	NA	NA	2.5	7.5	38.3	108	3,931
East Auburn	59.9	U of MN	2015	1.0	NA	NA	1.8	23.6	89.7	211	5,371
Halsted Bay	223.4	U of MN	2015	1.0	NA	NA	3.7	63.7	303.2	1,135	67,727
Kelser's Pond	8.5	U of MN	2015	1.0	NA	NA	NA	NA	NA	0	0
Mud	40.1	U of MN	2015	1.0	NA	NA	3.9	27.7	125.6	521	5,032
North Lundsten	43.7	U of MN	2015	1.0	NA	NA	2.0	9.5	47.8	95	2,090
Parley	104.4	U of MN	2015	1.0	NA	NA	3.5	32.4	155.4	546	16,230
Piersons	108.1	U of MN	2015	1.0	NA	NA	3.3	6.8	39.0	117	4,217
South Lundsten	29.9	U of MN	2015	1.0	NA	NA	2.3	7.9	40.3	92	1,207
Steiger	67.2	U of MN	2015	1.0	NA	NA	3.2	7.9	40.3	131	2,707
Stone	40.1	U of MN	2015	1.0	NA	NA	NA	NA	NA	0	0
Sunny	19.4	U of MN	2015	1.0	NA	NA	2.6	18.6	90.5	236	1,757
Turbid	16.4	U of MN	2015	1.0	NA	NA	3.1	31.7	150.5	470	2,467
Wassermann	68.4	U of MN	2015	1.0	NA	NA	3.0	30.5	141.5	442	9,675
West Auburn	58.7	U of MN	2015	1.0	NA	NA	1.9	30.9	136.2	286	7,994

Lake	Size (Hectare)	Surveyor	Date	Shock Time (hour)	Number of Carp	Average Length (cm)	Average Weight (kg)	CPUE	Estimated Density (carp/ha)	Biomass mean (kg/ha)	Estimated Population Size
Zumbra	89.4	U of MN	2015	1.0	NA	NA	2.5	15.9	77.9	192	6,969
East Auburn	59.9	U of MN	2016	1.0	NA	NA	1.9	22.0	83.5	207	5,004
Halsted Bay	223.4	U of MN	2016	1.0	NA	NA	4.4	50.7	241.7	1,059	54,001
Mud	40.1	U of MN	2016	1.0	NA	NA	4.1	34.5	155.7	683	6,237
North Lundsten	43.7	U of MN	2016	1.0	NA	NA	2.6	9.7	48.7	125	2,127
Parley	104.4	U of MN	2016	1.0	NA	NA	4.0	36.6	175.6	706	18,330
Piersons	108.1	U of MN	2016	1.0	NA	NA	3.3	7.9	44.9	134	4,850
South Lundsten	29.9	U of MN	2016	1.0	NA	NA	2.5	24.1	116.7	297	3,496
Steiger	67.2	U of MN	2016	1.0	NA	NA	3.6	7.7	39.1	142	2,628
Stone	40.1	U of MN	2016	1.0	NA	NA	4.8	2.0	12.2	59	487
Sunny	19.4	U of MN	2016	1.0	NA	NA	3.3	9.5	47.7	156	927
Turbid	16.4	U of MN	2016	1.0	NA	NA	3.7	24.7	117.8	437	1,931
Wassermann	68.4	U of MN	2016	1.0	NA	NA	3.4	23.7	110.7	395	7,572
West Auburn	58.7	U of MN	2016	1.0	NA	NA	2.3	21.1	94.0	239	5,513
Zumbra	89.4	U of MN	2016	1.0	NA	NA	3.0	17.9	87.4	262	7,821
Parley	104.4	MCWD/Wenck	8/01/2018	1.0	27	67.1	4.2	26.6	128.1	544	13,377
Wassermann	68.4	MCWD/Wenck	7/26/2018	1.0	6	59.2	3.3	5.9	30.8	102	2,109
Wassermann	68.4	MCWD/Wenck	8/01/2018	1.0	2	50.9	1.7	2.0	12.5	22	852
East Auburn	59.9	MCWD	6/21/2019	0.7	4	58.8	2.7	5.5	28.8	79	1,724
East Auburn	59.9	MCWD	7/18/2019	0.4	7	54.3	2.2	15.6	76.7	171	4,592
East Auburn	59.9	MCWD	9/13/2019	1.0	13	59.4	2.7	13.0	64.3	175	3,849
Halsted Bay	223.4	MCWD	7/24/2019	0.3	25	61.5	3.5	75.0	356.3	1,245	79,598
Mud	40.1	MCWD	7/22/2019	0.2	12	64.7	3.8	59.5	283.3	1,084	11,348
Mud	40.1	MCWD	10/03/2019	1.0	22	68.8	4.8	22.0	106.7	508	4,273
Parley	104.4	MCWD	7/22/2019	0.5	41	62.1	3.4	89.3	423.6	1,420	44,225
Parley	104.4	MCWD	10/03/2019	1.0	66	51.4	2.0	66.0	313.9	636	32,774
Piersons	108.1	MCWD	7/23/2019	0.5	1	74.5	5.3	2.1	13.1	69	1,419
Piersons	108.1	MCWD	9/25/2019	1.0	4	63.5	3.4	4.0	21.9	74	2,364
Steiger	67.2	MCWD	7/30/2019	0.9	4	51.6	3.5	4.4	23.9	84	1,604

Lake	Size (Hectare)	Surveyor	Date	Shock Time (hour)	Number of Carp	Average Length (cm)	Average Weight (kg)	CPUE	Estimated Density (carp/ha)	Biomass mean (kg/ha)	Estimated Population Size
Steiger	67.2	MCWD	9/20/2019	1.0	9	67.4	4.1	9.0	45.4	185	3,052
Turbid	16.4	MCWD/Wenck	8/28/2019	0.7	29	18.2	0.6	40.5	193.6	107	3,174
Wassermann	68.4	MCWD	6/28/2019	0.4	0	NA	NA	NA	3.0	49	208
Wassermann	68.4	MCWD	7/23/2019	0.6	0	NA	NA	NA	3.0	49	208
Wassermann	68.4	MCWD	9/23/2019	1.0	2	69.7	4.5	2.0	12.5	57	852
West Auburn	58.7	MCWD	6/21/2019	0.8	9	55.6	2.2	11.6	57.7	129	3,385
West Auburn	58.7	MCWD	7/18/2019	0.4	1	60.5	3.1	2.5	14.9	45	874
West Auburn	58.7	MCWD	9/13/2019	1.0	8	58.7	2.6	8.0	40.7	106	2,389
Zumbra	89.4	MCWD	7/30/2019	1.0	13	63.0	3.3	13.0	64.3	211	5,748
Zumbra	89.4	MCWD	9/23/2019	1.0	10	64.9	3.6	10.0	50.1	179	4,484
Big SOB	3.0	MCWD	9/01/2020	0.7	10	56.5	2.5	15.0	73.7	184	224
Mud	40.1	MCWD	7/27/2020	1.0	7	66.2	3.9	7.0	36.0	140	1,443
Mud	40.1	MCWD	7/30/2020	1.0	6	68.5	4.6	6.0	31.3	144	1,254
Mud	40.1	MCWD	8/17/2020	1.0	11	64.6	3.7	11.0	54.9	204	2,198
Mud	40.1	MCWD	8/20/2020	1.0	12	64.1	3.7	12.0	59.6	222	2,386
Mud	40.1	MCWD	9/11/2020	1.0	2	68.5	4.3	2.0	12.5	53	499
Mud	40.1	MCWD	9/17/2020	1.0	6	57.9	2.5	6.0	31.3	79	1,254
North Lundsten	43.7	MCWD/Wenck	8/26/2020	0.8	6	62.7	3.3	7.3	37.6	123	1,645
Parley	104.4	MCWD	7/27/2020	1.0	24	58.8	2.8	24.0	116.1	326	12,120
Parley	104.4	MCWD	7/30/2020	1.0	28	62.3	3.4	28.0	134.9	462	14,087
Parley	104.4	MCWD	8/17/2020	1.0	50	60.1	3.1	50.0	238.5	745	24,906
Parley	104.4	MCWD	8/20/2020	1.0	56	60.6	3.1	56.0	266.8	814	27,856
Parley	104.4	MCWD	9/11/2020	1.0	117	60.4	3.1	117.0	554.1	1,734	57,854
Parley	104.4	MCWD	9/17/2020	1.0	39	63.8	3.9	39.0	186.7	727	19,496
Parley	104.4	MCWD	9/22/2020	1.0	48	67.1	4.1	48.0	229.1	948	23,922
Turbid	16.4	MCWD/Wenck	8/26/2020	0.7	22	28.1	0.5	33.0	158.5	82	2,597
Turbid	16.4	MCWD/Wenck	8/27/2020	0.7	17	24.4	0.5	25.5	123.1	61	2,018
Wassermann	68.4	MCWD	8/18/2020	1.0	0	NA	NA	NA	3.0	49	208
Big SOB	3.0	MCWD	7/19/2020	1.0	0	NA	NA	NA	3.0	49	9

Lake	Size (Hectare)	Surveyor	Date	Shock Time (hour)	Number of Carp	Average Length (cm)	Average Weight (kg)	CPUE	Estimated Density (carp/ha)	Biomass mean (kg/ha)	Estimated Population Size
East Auburn	59.9	MCWD	7/22/2021	1.0	14	60.7	2.8	14.0	69.0	190	4,131
East Auburn	59.9	MCWD	9/09/2021	1.0	9	61.3	2.8	9.0	45.4	126	2,721
East Auburn	59.9	MCWD	10/05/2021	1.0	3	62.9	3.1	3.0	17.2	53	1,028
Mud	40.1	MCWD	7/19/2021	1.0	5	63.8	4.0	5.0	26.6	105	1,065
Mud	40.1	MCWD	10/04/2021	0.7	8	58.7	3.3	12.0	59.5	196	2,385
Parley	104.4	MCWD	7/19/2021	1.0	17	60.3	2.9	17.0	83.1	239	8,677
Parley	104.4	MCWD	8/16/2021	1.0	5	65.0	3.8	5.0	26.6	101	2,776
Parley	104.4	MCWD	10/04/2021	1.0	8	68.6	4.3	8.0	40.7	174	4,252
Piersons	108.1	MCWD	7/27/2021	1.0	11	52.4	2.9	11.0	54.9	159	5,927
Piersons	108.1	MCWD	8/31/2021	1.0	11	56.5	3.3	11.0	54.9	181	5,927
Steiger	67.2	MCWD	7/20/2021	1.0	1	66.4	3.8	1.0	7.8	30	521
Steiger	67.2	MCWD	8/25/2021	1.0	4	69.5	4.3	4.0	21.9	94	1,470
Wassermann	68.4	MCWD	7/20/2021	1.0	1	76.0	6.3	1.0	7.8	49	530
West Auburn	58.7	MCWD	7/22/2021	1.0	6	63.5	3.2	6.0	31.3	99	1,837
West Auburn	58.7	MCWD	9/09/2021	1.0	3	64.6	3.2	3.0	17.2	56	1,008
West Auburn	58.7	MCWD	10/05/2021	1.0	9	66.7	3.7	9.0	45.4	168	2,666
Zumbra	89.4	MCWD	7/29/2021	1.0	4	69.7	4.2	4.0	21.9	92	1,957
Zumbra	89.4	MCWD	9/08/2021	1.0	12	64.8	3.3	12.0	59.6	198	5,327
East Auburn	59.9	MCWD	8/10/2022	1.0	5	61.4	2.8	5.0	26.6	74	1,593
East Auburn	59.9	MCWD	8/30/2022	1.0	5	53.4	3.2	5.0	26.6	85	1,593
East Auburn	59.9	MCWD	9/21/2022	1.0	5	64.4	3.2	5.0	26.6	86	1,593
Parley	104.4	MCWD	8/29/2022	1.0	26	69.4	4.8	26.0	125.5	596	13,103
Parley	104.4	MCWD	9/08/2022	1.0	13	64.3	3.9	13.0	64.3	249	6,710
Parley	104.4	MCWD	9/22/2022	1.0	9	70.5	5.1	9.0	45.4	233	4,743
Parley	104.4	MCWD	10/04/2022	1.0	6	67.6	4.5	6.0	31.3	142	3,268
Piersons	108.1	MCWD	7/28/2022	1.0	7	49.9	1.5	7.0	36.0	54	3,891
Piersons	108.1	MCWD	9/22/2022	1.0	9	72.1	5.3	9.0	45.4	242	4,909
Steiger	67.2	MCWD	9/08/2022	1.0	8	62.0	4.2	8.0	40.7	171	2,735
Steiger	67.2	MCWD	9/28/2022	1.0	1	63.1	3.0	1.0	7.8	23	521

Lake	Size (Hectare)	Surveyor	Date	Shock Time (hour)	Number of Carp	Average Length (cm)	Average Weight (kg)	CPUE	Estimated Density (carp/ha)	Biomass mean (kg/ha)	Estimated Population Size
West Auburn	58.7	MCWD	8/10/2022	1.0	2	70.1	4.3	2.0	12.5	54	731
West Auburn	58.7	MCWD	8/30/2022	1.0	2	64.9	3.3	2.0	12.5	41	731
West Auburn	58.7	MCWD	9/21/2022	1.0	3	65.8	3.5	3.0	17.2	59	1,008
Mud	40.1	MCWD	7/20/2023	0.7	5	72.5	5.3	7.6	38.7	207	1,553
Parley	104.4	MCWD	7/20/2023	1.0	14	63.5	4.3	14.1	69.7	298	7,271
Parley	104.4	MCWD	8/28/2023	1.0	34	48.8	2.9	34.3	164.8	485	17,205
Parley	104.4	MCWD	9/12/2023	1.0	14	47.9	3.1	14.1	69.7	213	7,271
Parley	104.4	MCWD	10/11/2023	1.0	14	63.5	4.2	14.1	69.6	292	7,271
Piersons	108.1	MCWD	8/24/2023	1.0	10	77.0	7.0	10.1	50.6	352	5,472
Piersons	108.1	MCWD	9/08/2023	1.0	1	70.5	4.7	1.0	7.8	37	843
Piersons	108.1	MCWD	9/22/2023	1.0	3	75.7	6.4	3.0	17.3	111	1,872
Steiger	67.2	MCWD	8/24/2023	1.0	3	75.2	6.4	3.0	17.3	111	1,163
West Auburn	58.7	MCWD	9/12/2023	1.0	2	68.0	4.3	2.0	12.6	53	737
East Auburn	59.9	MCWD	7/25/2024	1.0	4	68.1	4.4	4.0	22.1	98	1,322
East Auburn	59.9	MCWD	9/12/2024	1.0	2	63.5	3.3	2.0	12.6	42	752
East Auburn	59.9	MCWD	9/26/2024	1.0	6	62.7	3.6	6.1	31.6	113	1,892
Parley	104.4	MCWD	7/22/2024	1.0	52	56.8	3.3	52.5	250.4	835	26,145
Parley	104.4	MCWD	8/12/2024	1.0	27	54.8	3.3	57.3	275.8	1,076	28,801
Parley	104.4	MCWD	9/13/2024	1.0	53	57.8	3.3	53.5	255.2	849	26,642
Parley	104.4	MCWD	10/11/2024	1.0	33	59.7	4.2	33.3	160.0	667	16,708
Piersons	108.1	MCWD	7/24/2024	1.0	0	NA	NA	NA	3.0	14	328
Piersons	108.1	MCWD	8/21/2024	1.0	3	75.2	6.2	3.0	17.3	107	1,872
Piersons	108.1	MCWD	9/23/2024	1.0	0	NA	NA	NA	3.0	14	328
Steiger	67.2	MCWD	8/15/2024	1.0	7	71.6	5.3	7.1	36.3	194	2,442
Steiger	67.2	MCWD	9/20/2024	1.0	7	75.7	6.4	7.1	36.3	232	2,442
Wassermann	68.4	MCWD	8/21/2024	1.0	4	58.2	2.5	4.0	221.0	56	1,510
Wassermann	68.4	MCWD	9/23/2024	1.0	2	61.3	3.0	2.0	12.6	37	859
West Auburn	58.7	MCWD	7/25/2024	1.0	2	64.6	3.5	2.0	12.6	44	737
West Auburn	58.7	MCWD	9/12/2024	1.0	2	67.1	4.0	2.0	12.6	51	737

Lake	Size (Hectare)	Surveyor	Date	Shock Time (hour)	Number of Carp	Average Length (cm)	Average Weight (kg)	CPUE	Estimated Density (carp/ha)	Biomass mean (kg/ha)	Estimated Population Size
West Auburn	58.7	MCWD	9/26/2024	1.0	0	NA	NA	NA	3.0	12	178
Zumbra	89.4	MCWD	8/15/2024	1.0	15	67.7	4.2	15.2	74.4	311	6,652
Zumbra	89.4	MCWD	9/20/2024	1.0	4	68.0	4.2	4.0	22.1	93	1,973

APPENDIX D

CARP REMOVALS

Lake	Date	Removal Type	Event	Individuals Removed	Removed Weight (kg)	Removed Weight (lbs)	Average Length (mm)	Average Weight (kg)	Cost	Cost/carp	Cost/lb
Auburn	9/07/2018	Box Netting	1	1357	3,664	8,079	NA	2.70	$11,902.33	$6.97	$1.17
Auburn	9/25/2018	Box Netting	2	279	753	1,660	NA	2.70			
Auburn	9/28/2018	Box Netting	3	72	194	428	NA	2.70			
Auburn	5/09/2019	Stream Trapping	1	139	292	644	NA	2.10	NA	NA	NA
Auburn	5/16/2019	Stream Trapping	2	278	584	1,288	NA	2.10	NA	NA	NA
Auburn	5/21/2019	Stream Trapping	3	280	588	1,297	NA	2.10	NA	NA	NA
Auburn	6/04/2019	Stream Trapping	4	243	597	1,316	NA	2.46	NA	NA	NA
Auburn	6/25/2019 7/16/2019 8/16/2019	Box Netting	1-3	119	356	785	613	3.07	$25,000.00	$210.08	$31.83
Auburn	5/12/2022	Stream Trapping	1	726	1,742	3,842	NA	2.40	$16,360.00	$15.52	$2.93
Auburn	5/17/2022	Stream Trapping	2	145	348	767	NA	2.40			
Auburn	5/18/2022	Stream Trapping	3	183	439	968	NA	2.40			
Auburn	5/14/2022	Volunteers	1	65	156	344	NA	2.40	$0.00	$0.00	$0.00
			Auburn - Total Removals	**3,886**	**9,714**	**21,419**			**$53,262.33**	**$232.57**	**$35.93**
Halsted Bay	9/25/2019	Box Netting	1	984	2,804	6,180	600	6.30	NA	NA	NA
Halsted Bay	10/02/2019	Box Netting	2	617	1,803	3,974	605	6.40	NA	NA	NA
Halsted Bay	10/10/2019	Box Netting	3	186	439	967	560	5.20	NA	NA	NA
			Halsted Bay - Total Removals	**1,787**	**5,046**	**11,121**			**NA**	**NA**	**NA**
Piersons	9/1/2022 - 9/30/2022	Box Netting	1-4	68	234	516	237	3.44	$11,191.00	$164.57	$21.70
Piersons	5/12/2023	Stream Trapping	1	460	2,573	5,674	729	5.59	NA	NA	NA
Piersons	5/16/2023	Stream Trapping	2	139	816	1,798	726	5.87	NA	NA	NA
			Piersons - Total Removals	**667**	**3,623**	**7,988**			**$11,191.00**	**$164.57**	**$21.70**
Stieger	9/07/2018	Box Netting	1	236	2,431	5,360	NA	4.70	$11,902.33	$40.21	$1.77
Stieger	9/27/2018	Box Netting	2	60	618	1,363	NA	4.70			
			Stieger - Total Removals	**296**	**3,049**	**6,723**			**$11,902.33**	**$40.21**	**$1.77**

Lake	Date	Removal Type	Event	Individuals Removed	Removed Weight (kg)	Removed Weight (lbs)	Average Length (mm)	Average Weight (kg)	Cost	Cost/carp	Cost/lb
Parley	8/19/2019	Box Netting	1	536	2,720	5,997	732	5.07	$6,200.00	$11.57	$1.03
Parley	8/29/2019	Box Netting	2	766	3,847	8,481	730	5.02	$6,200.00	$8.09	$0.73
Parley	9/09/2019	Box Netting	3	103	630	1,390	768	6.12	$6,200.00	$60.19	$4.46
Parley	9/16/2019	Box Netting	4	273	1,198	2,640	704	4.39	$6,200.00	$22.71	$2.35
Parley	9/27/2019	Box Netting	5	169	827	1,823	725	4.89	$6,200.00	$36.69	$3.40
Parley	10/09/2019	Box Netting	6	486	1,553	3,423	643	3.19	$6,200.00	$12.76	$1.81
Parley	2/24/2020	Winter Seine	1	1791	7,934	17,492	694	4.43	$10,000.00	$5.58	$0.57
Parley	2/25/2020	Winter Seine	2	1001	5,385	11,873	746	5.38	$5,000.00	$5.00	$0.42
Parley	2/26/2020	Winter Seine	3	130	699	1,542	746	5.38	$1,000.00	$7.69	$0.65
Parley	7/28/2020	Box Netting	1	1208	4,711	10,386	672	3.90	$19,059.00	$15.78	$1.83
Parley	8/14/2020	Box Netting	2	1601	8,966	19,766	766	5.60	$13,733.81	$8.58	$0.69
Parley	9/04/2020	Box Netting	3	758	4,245	9,358	766	5.60	$8,388.00	$11.07	$0.90
Parley	7/01/2021	Box Netting	1	297	1,292	2,848	705	4.35	$17,752.00	$30.82	$3.21
Parley	7/16/2021	Box Netting	2	279	1,214	2,676	708	4.35			
Parley	8/06/2021	Box Netting	3	476	2,071	4,565	665	4.35	$7,212.00	$15.15	$1.58
Parley	9/06/2021	Box Netting	4	197	857	1,889	714	4.35	$7,179.00	$36.44	$3.80
Parley	2/XX/2021	Winter Seine	1-3	5422	23,586	51,100	NA	4.35	$17,714.00	$3.27	$0.35
Parley	1/16/2022	Winter Seine	1	6237	27,941	61,600	693	4.48	$16,430.00	$2.63	$0.27
Parley - Total Removals				**21,730**	**99,675**	**218,848**			**$160,667.81**	**$294.02**	**$28.06**
Wassermann	1/23/2017	Winter Seine	1	2450	8,428	18,584	NA	3.44	$0.00	$0.00	$0.00
Wassermann	2/07/2018	Winter Seine	1	1000	4,100	9,041	NA	4.10	$3,000.00	$3.00	$0.001
Wassermann	9/25/2018	Box Netting	1	2	7	15	NA	3.44	$11,902.33	$5,951.17	$865.00
Wassermann - Total Removals				**3,452**	**12,535**	**27,639**			**$14,902.33**	**$5,954.17**	**$865.00**
Zumbra	9/17/2019	Box Netting	1	147	479	1,057	647	3.26	$10,000.00	$68.03	$9.46
Zumbra	9/27/2019	Box Netting	2	48	170	375	663	3.54	$5,000.00	$104.17	$13.33
Zumbra	2/26/2020	Winter Seine	1	9	32	69	NA	3.50	$14,000.00	$1,555.56	$201.60
Zumbra - Total Removals				**204**	**681**	**1,502**	**1,310**	**10**	**$29,000.00**	**$1,727.75**	**$224.39**

APPENDIX E

WATER QUALITY

Annual Lake Means (June-Sept)

Lake	Year	Total Phosphorus (mg/L)	Chlorphyll-A (ug/L)	Secchi Depth (m)
Carl Krey	2006	0.030	3.6	2.10
	2007	0.030	8.9	2.10
	2008	0.021	6.5	2.45
	2012	0.036	8.5	2.25
	2013	0.029	9.0	2.17
	2014	0.004	4.2	2.86
	2015	0.033	8.5	1.78
Church	2006	0.143	1.7	2.95
	2007	0.154	44.8	3.40
	2008	0.077	16.8	2.70
	2012	0.074	18.0	1.30
	2013	0.048	14.0	2.60
	2014	0.019	19.0	1.41
	2015	0.129	77.8	0.54
East Auburn	1988	0.080	27.0	0.70
	1989	0.050	44.0	0.05
	1990	0.140	52.0	0.60
	1991	0.100	97.0	0.40
	2006	0.038	7.3	1.75
	2007	0.053	33.3	0.88
	2008	0.060	56.0	1.45
	2010	0.040	33.2	1.04
	2012	0.050	37.8	0.92
	2013	0.053	28.0	1.48
	2014	0.031	31.2	1.60
	2015	0.035	19.2	1.71
	2016	0.046	28.0	1.51
	2019	0.060	41.8	1.23
	2022	0.039	35.9	1.23
	2024	0.046	31.0	1.10
Kelser's Pond	2009	0.037	23.8	1.36
	2010	0.041	26.0	1.42
	2011	0.037	20.2	1.32
	2012	0.035	13.8	1.84
	2013	0.026	10.8	2.18
	2014	0.014	14.2	1.83
	2015	0.029	18.0	1.86
	2016	0.032	12.5	2.95

Annual Lake Means (June-Sept)

Lake	Year	Total Phosphorus (mg/L)	Chlorphyll-A (ug/L)	Secchi Depth (m)
Marsh	2010	0.024	3.8	3.06
	2011	0.034	4.8	0.80
	2012	0.036	10.4	0.89
	2013	0.032	6.1	0.82
	2014	0.008	7.8	0.95
	2016	0.030	4.7	0.73
Mud	2012	0.222	154.7	0.31
	2013	0.141	65.6	0.38
	2014	0.133	89.5	0.64
	2015	0.207	86.5	0.40
	2016	0.156	68.7	0.46
	2019	0.145	62.5	0.56
	2020	0.191	187.4	0.25
	2021	0.106	67.7	0.45
Parley	1988	0.170	38.0	0.30
	1989	0.200	26.0	1.40
	1990	0.250	35.0	1.30
	1991	0.114	75.0	0.83
	2001	0.108	132.0	0.74
	2003	0.086	77.0	1.10
	2006	0.100	106.2	0.67
	2009	0.063	51.4	0.64
	2010	0.072	69.3	0.72
	2011	0.080	76.6	0.68
	2012	0.081	51.6	0.72
	2013	0.083	40.9	1.05
	2014	0.114	54.5	1.10
	2015	0.104	68.6	0.65
	2016	0.111	69.5	0.72
	2017	0.070	49.4	1.06
	2018	0.084	76.8	0.45
	2019	0.081	69.7	0.71
	2020	0.093	102.0	0.60
	2021	0.064	31.7	0.89
	2022	0.122	120.8	0.46
	2023	0.065	62.7	0.95
	2024	0.087	64.9	0.78

Annual Lake Means (June-Sept)

Lake	Year	Total Phosphorus (mg/L)	Chlorphyll-A (ug/L)	Secchi Depth (m)
Piersons	1988	0.040	3.0	3.00
	1989	0.021	7.0	2.31
	1990	0.330	6.0	1.50
	1991	0.050	11.0	1.10
	2001	0.079	19.0	1.81
	2002	0.022	12.1	1.89
	2003	0.020	10.9	2.94
	2006	0.032	13.4	1.82
	2009	0.032	5.4	2.84
	2010	0.021	7.2	3.18
	2011	0.018	5.8	2.85
	2012	0.022	4.6	3.18
	2013	0.022	5.1	3.12
	2014	0.025	14.5	1.90
	2015	0.021	5.5	2.85
	2016	0.025	6.7	2.65
	2022	0.018	5.9	2.52
Stieger	1995	0.034	11.1	1.54
	1997	0.036	15.9	1.72
	1999	0.038	15.3	1.53
	2000	0.043	10.3	1.80
	2002	0.034	11.4	2.18
	2003	0.040	19.9	1.51
	2005	0.039	19.6	2.08
	2006	0.045	15.7	1.56
	2008	0.040	15.3	1.52
	2010	0.037	10.3	2.23
	2011	0.035	8.7	2.71
	2012	0.029	16.0	1.82
	2013	0.028	17.2	2.71
	2014	0.031	11.3	2.94
	2015	0.034	12.1	2.70
	2016	0.039	20.1	2.10
	2017	0.036	12.7	2.26
	2018	0.030	17.9	2.19
	2019	0.027	24.4	1.79
	2021	0.026	14.1	2.00
	2022	0.039	15.1	1.44
	2023	0.031	11.8	2.00

Annual Lake Means (June-Sept)

Lake	Year	Total Phosphorus (mg/L)	Chlorphyll-A (ug/L)	Secchi Depth (m)
Stone	2000	0.072	24.0	1.71
	2002	0.065	31.2	1.40
	2007	0.043	25.7	1.40
	2008	0.039	17.5	1.76
	2010	0.031	8.0	2.60
	2011	0.027	7.2	2.98
	2012	0.023	5.1	3.53
	2013	0.030	5.0	3.54
	2014	0.035	6.4	2.54
	2015	0.034	6.1	2.69
Sunny	2014	0.016	16.0	2.11
	2015	0.036	14.5	1.96
	2019	0.082	9.1	1.91
Turbid	2006	0.058	19.4	0.95
	2007	0.042	15.2	1.05
	2008	0.077	38.5	1.15
	2010	0.064	16.7	2.15
	2011	0.053	30.5	1.70
	2012	0.068	43.8	1.08
	2013	0.085	36.2	1.35
	2014	0.050	49.8	1.30
	2015	0.080	39.8	0.92
	2016	0.085	44.2	0.61
	2019	0.122	22.2	1.29
Wassermann	2002	0.041	19.3	1.01
	2003	0.059	31.9	1.05
	2006	0.081	45.5	0.86
	2009	0.089	51.6	0.92
	2010	0.076	57.9	1.05
	2011	0.080	41.8	1.10
	2012	0.085	60.0	0.64
	2013	0.082	54.0	0.94
	2014	0.079	40.5	0.98
	2015	0.069	47.6	0.90
	2016	0.060	33.9	1.06
	2017	0.066	45.2	0.91
	2018	0.084	56.5	1.12
	2019	0.085	54.1	0.80
	2020	0.067	51.0	0.90
	2021	0.047	37.4	1.48

Annual Lake Means (June-Sept)

Lake	Year	Total Phosphorus (mg/L)	Chlorphyll-A (ug/L)	Secchi Depth (m)
Wassermann	2022	0.049	34.1	1.41
	2023	0.032	21.9	1.81
	2024	0.064	35.7	1.89
West Auburn	1988	0.040	11.0	1.67
	1989	0.050	37.0	1.18
	1990	0.070	42.0	1.52
	1991	0.040	47.0	1.15
	2002	0.040	15.4	1.79
	2003	0.032	12.0	2.30
	2004	0.033	15.8	2.41
	2005	0.033	17.6	1.64
	2006	0.029	11.7	2.79
	2007	0.033	8.1	2.26
	2008	0.025	5.9	3.06
	2009	0.036	5.2	2.94
	2010	0.029	7.4	2.42
	2011	0.034	14.7	2.60
	2012	0.023	11.5	2.59
	2013	0.032	16.5	3.00
	2014	0.028	15.8	1.88
	2015	0.027	11.6	2.53
	2016	0.027	9.4	2.85
	2017	0.023	10.9	2.88
	2018	0.036	25.2	1.52
	2019	0.033	30.8	1.71
	2021	0.019	7.0	3.14
	2022	0.025	10.3	2.22
	2023	0.022	5.5	3.03
	2024	0.047	23.4	1.81
Zumbra	1988	0.050	21.0	1.94
	1989	0.040	16.0	2.25
	1990	0.020	30.0	1.70
	1991	0.050	36.0	1.19
	1994	0.040	12.2	2.32
	1995	0.040	18.8	1.48
	1996	0.029	6.8	2.41
	1997	0.025	8.8	2.11
	1998	0.026	8.0	1.84
	1999	0.028	10.5	2.70
	2000	0.027	3.7	2.44

Annual Lake Means (June-Sept)

Lake	Year	Total Phosphorus (mg/L)	Chlorphyll-A (ug/L)	Secchi Depth (m)
Zumbra	2001	0.034	12.2	1.86
	2002	0.018	13.7	2.10
	2003	0.026	13.5	2.19
	2004	0.027	10.4	3.14
	2005	0.027	11.0	2.57
	2006	0.025	11.1	2.23
	2007	0.040	11.1	2.24
	2008	0.025	8.3	2.60
	2009	0.028	4.4	3.08
	2010	0.026	6.6	3.47
	2011	0.022	7.2	3.80
	2012	0.022	6.2	4.19
	2013	0.095	7.2	5.07
	2015	0.019	5.3	3.78
	2016	0.027	7.9	3.25
	2017	0.026	9.5	2.64
	2018	0.021	6.7	3.04
	2021	0.020	5.6	3.14
	2022	0.021	7.6	3.08
	2023	0.023	5.2	3.21

APPENDIX F

COMMON CARP ASSESSMENT IN SIX MILE CREEK

Common Carp Assessment in Six Mile Creek Final Report: June 2014 – December 2016

Prepared for the Minnehaha Creek Watershed District -- November 2016

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Future Appendices

Appendix 1. Results of the pilot winter seining study in Wassermann Lake

Appendix 2. Swanson, R. G. 2017. Results of genetic and otolith microchemical analyses of common carp in the Six Mile Creek subwatershed. M. Sc. Thesis. Department of Fisheries, Wildlife, and Conservation Biology, University of Minnesota, Saint Paul, MN.

Project Overview

This report presents the results of the Six Mile Creek Common Carp Assessment which was funded by the Minnehaha Creek Watershed District (MCWD) and conducted by the University of Minnesota (UMN) from July 2014 through March 2017. The stated purpose of this study was to "determine the abundance, seasonal movements, and recruitment patterns of common carp (*Cyprinus carpio*) in the Six Mile Creek Subwatershed to enable development of carp control strategies for restoration of the Six Mile Creek subwatershed". The UMN was contracted to (1) estimate adult carp abundance in at least 7 of the Six Mile Creek lakes, (2) determine the movement patterns and seasonal distributions of at least 100 adult carp throughout the subwatershed, (3) determine the recruitment patterns of carp throughout the subwatershed via annual netting surveys and age determination of at least 200 carp, and (4) to report and interpret all findings and provide recommendations for future carp management strategies.

The UMN has completed all tasks as outlined in the Project Scope of Work. Specifically, the UMN has estimated adult carp abundance and biomass in 15 lakes, implanted radio-tags in 120 carp across the subwatershed, located radio-tagged carp at least once per month for 2 full years, conducted annual trap-net surveys in 23 water bodies, and determined the age structure of carp across the subwatershed based on 378 individuals from 11 lakes. Additionally, the UMN calculated a supplemental mark-recapture population estimate for Parley and Mud Lakes. All findings obtained by December 2016 are presented herein and discussed in the framework of possible carp management strategies specific to the Six Mile Creek subwatershed. Genetic and microchemical analyses of carp in the Six Mile Creek subwatershed are ongoing as part of a M. S. thesis and final results will be made available as appendices to this report. The results of a planned supplemental study on carp winter seining in Lake Wassermann will also be made available as an appendix to this report.

Executive Summary

The common carp (*Cyprinus carpio*; hereafter 'carp'), a benthivorous fish native to Eurasia, is highly invasive in the North American Midwest and many other regions around the world. Invasive populations of carp are often associated with declines in the abundance and diversity of submersed aquatic vegetation as well as invertebrates and can trigger sustained increases in water turbidity, algal growth, and nutrient loading. For these reasons, carp have been the subject of many research and management activities in watersheds throughout the Midwest. In the Six Mile Creek subwatershed, a diagnostic study identified carp as one of the major drivers of its poor water quality and recommended carp assessment and control (Wenck 2013). In 2014, the MCWD partnered with the UMN to initiate a three-year study to obtain a better understanding of carp in the Six Mile Creek subwatershed to inform sustainable control strategies. This study sought to determine patterns in carp abundance, movement, and recruitment across the entire subwatershed.

Three field seasons of data collection are now complete and reveal that the total biomass of carp in the Six Mile Creek subwatershed is approximately five times greater than a threshold value previously identified to cause severe ecological impacts in Midwestern lakes. The study also identified areas in the subwatershed where carp have reproduced successfully in recent years, indicating that the carp population is presently growing. South Lundsten Lake in the middle portion of the subwatershed is of primary concern because it can produce many young carp and is well-connected to other lakes. South Lundsten Lake appears to be the primary source of carp for North Lundsten, West Auburn, and East Auburn Lakes and also contributes low numbers of carp downstream to Parley Lake and as far upstream as Wassermann Lake. Several additional basins throughout the subwatershed appear to have functioned as carp nurseries in the past (i.e. Marsh, Sunny, Turbid, and Mud Lakes), but successful recruitment in these locations has been limited to only five years since the 1960's and has not occurred in the past 15 years.

Movement patterns and age structures of adult carp across the subwatershed suggest there are multiple sub-populations of carp that could function as 4 management units: 1) Piersons-Marsh-Wassermann, 2) Auburn-Lundsten-Turbid, 3) Parley-Mud-Halsted's, and 4)

Carver Park Reserve Lakes (i.e. Steiger, Zumbra, Sunny, & Stone). Each of the lakes in the eastern Carver Park Reserve contains its own isolated subpopulation of carp, but these lakes could be grouped together as a single management unit given their similar ecological conditions, carp management goals, and common jurisdiction within the Three Rivers Park District.

Control of carp in the Six Mile Creek subwatershed may be possible, but will require a strategic, adaptive management framework that is implemented over several years. A possible first step would be to suppress ongoing carp recruitment in South Lundsten Lake and to put measures in place to prevent future recruitment in the locations identified as past carp nurseries. Once this is accomplished, management activities might then focus on reducing the existing carp biomass below 100 kg/ha in each management unit. Specific goals and possible management strategies vary by management unit and are detailed in the management section of this report. As management activities are implemented, ongoing monitoring is recommended to evaluate carp recruitment failure and adult biomass decline.

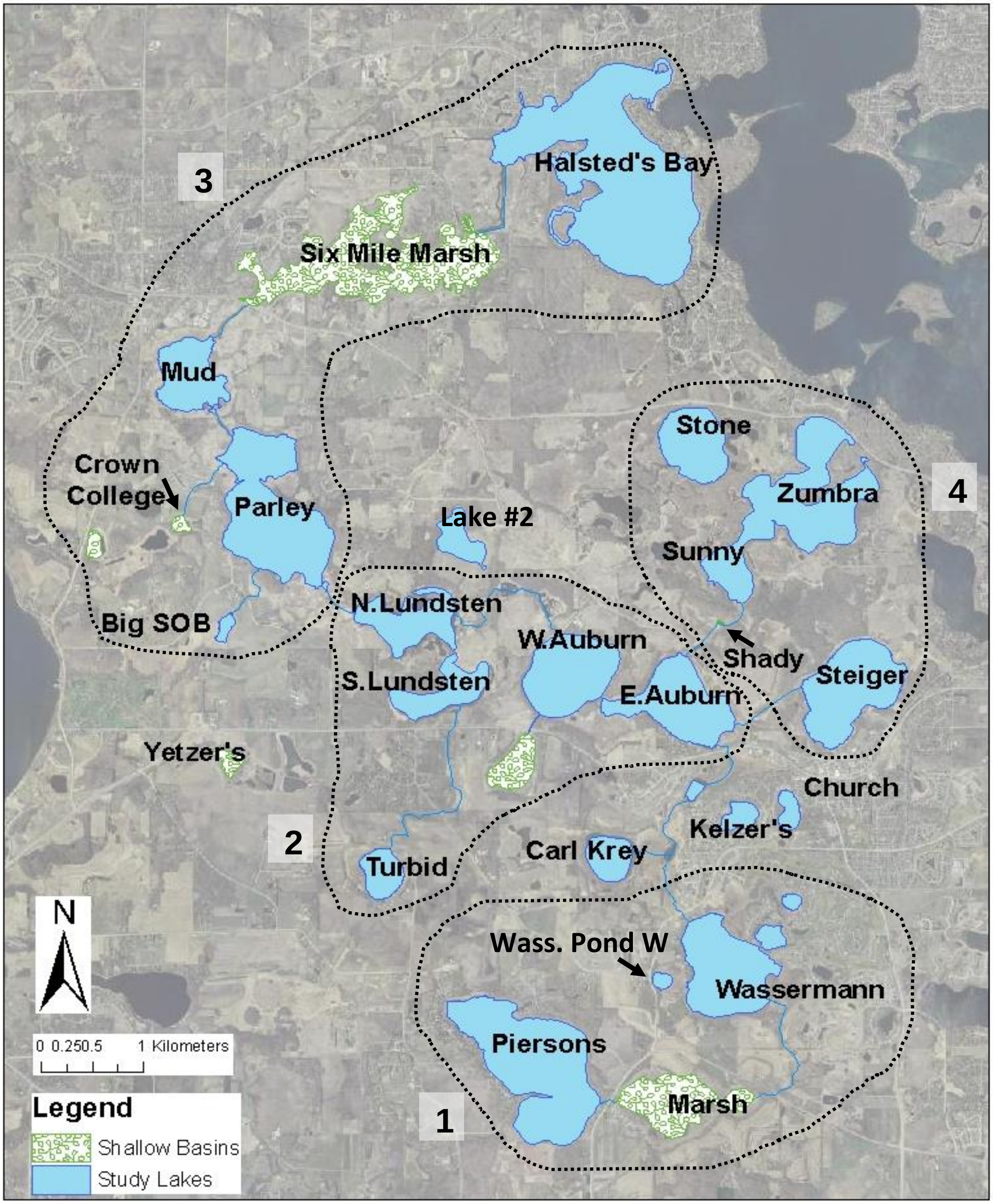

Figure 1. An overview map of the Six Mile Creek subwatershed with possible carp management units outlined: 1) Piersons-Marsh-Wassermann, 2) Auburn-Lundsten-Turbid, 3) Parley-Mud-Halsted's, and 4) Carver Park Reserve Lakes.

1.0 Background

1.1 Site overview

Located in the southwest corner of the Minnehaha Creek Watershed District (MCWD), the Six Mile Creek subwatershed spans roughly 27 square miles and encompasses a chain of 17 lakes (Piersons, Marsh, Wassermann, Carl Krey, Kelzer's, Church, East Auburn, West Auburn, Steiger, Sunny, Zumbra, Stone, North Lundsten, South Lundsten, Turbid, Parley, and Mud) and over a dozen ponds and wetlands (Figure 1). This system has its headwaters at Piersons Lake in Laketown Township and eventually drains north via Six Mile Creek into Halsted's Bay of Lake Minnetonka in Minnetrista, MN. Land use in the subwatershed is predominately agricultural and parkland, but is becoming increasingly developed.

Water quality in the Six Mile Creek subwatershed varies by lake, but many lakes are highly degraded and devoid of healthy native submersed plant communities. In the absence of submersed plants, poor water clarity and nuisance algal blooms are common. Additionally, several lakes currently fail to meet state nutrient standards and are classified as impaired for excess nutrients (phosphorus). Because common carp activity was observed throughout much of this system and internal loading was identified as a significant driver of in-lake phosphorus concentrations, further assessment and management of carp was recommended by Wenck Associates (2013).

1.2 The common carp

The introduction of common carp to Minnesota waters in the 1880s was one of the greatest ecological tragedies to befall our freshwater ecosystems. Being long-lived, mobile, extremely fecund, and tolerant of environmental extremes, the common carp has come to dominate the fish biomass in many lakes in the Upper Midwest (Sorensen & Bajer 2011). Common carp disrupt freshwater ecosystems by uprooting submersed vegetation, altering food webs, and often negatively impacting water quality by increasing turbidity and sometimes nutrient loading (Parkos et al. 2003; Bajer et al. 2009; Weber & Brown 2009; Vilizzi et al. 2015; Bajer et al. 2016). The effects of carp are most pronounced in shallow lakes that do not stratify. In deeper, thermally-stratifying lakes, large decreases in water clarity and reductions in submersed aquatic plant growth in littoral zones have also been observed, but the impacts of carp on nutrient cycling are less straightforward (Bajer & Sorensen 2015). In both shallow and dimictic Midwestern lakes, when adult carp biomass approaches approximately 100 kg/ha, 50% reductions in submersed aquatic vegetation coverage, significant decreases in water clarify, and declines in waterfowl use have been observed (Bajer et al. 2009; Bajer and Sorensen 2015). In a recent review of 73 studies across a variety of freshwater systems worldwide, extreme impacts by carp were observed, on average, at a critical biomass of 198 kg/ha (Vilizzi et al. 2015). Similarly, Bajer et al. 2016 suggest that a carp biomass of about 200 kg/ha causes a 90% reduction in plants in Midwest lakes. This report uses 100 kg/ha as a target value for carp management goals given the high value of these lakes.

Efforts aimed at improving water quality and restoring fish and wildlife habitat are typically futile in carp–infested lakes until densities of carp can be sustainably reduced to levels approaching 100 kg/ha (Bajer et al. 2009, Bajer and Sorensen 2015, unpublished data). Unfortunately, reducing carp biomass in a sustainable manner has proven very difficult due to the complex life history strategies employed by carp. For example, adult carp have a tendency to exploit outlying predator-free ponds and wetlands for breeding, where young carp often thrive and can then disperse to connected waters. This influx of young carp counteracts adult carp removal efforts (Bajer & Sorensen 2010; Sorensen & Bajer 2011; Osborne 2012; Koch 2014). Additionally, carp are very long-lived (up to 64 years; Koch 2014) and have low natural annual mortality rates estimated between 4 and 26% (Brown et al. 2005; Donkers et al. 2011; Bajer et al. 2015). Due to the longevity of carp, it is usually necessary to reduce existing carp biomass through removal of adults in addition to preventing new recruitment (production of young carp) in order to meet management goals.

1.3 Generalized common carp research & management approach

Despite the complex life history of carp, research conducted by the Sorensen Laboratory at the UMN over the past decade has revealed a possible way forward to sustainably control carp in many watersheds without relying on fish poisons such as rotenone. This management approach has three components; (1) understanding carp movement patterns to identify sub-populations and delineate appropriate management units, (2) identifying carp nurseries and suppressing recruitment, and (3) quantifying adult carp abundance and reducing existing biomass below a target of 100 kg/ha.

First, appropriate management units must be defined. Characterizing carp movement patterns along with age structures and/or genetic structures can elucidate sub-populations of carp (i.e. groups that function as a unit across space and time) and inform the delineation of appropriate management units. Presently, carp behavior is too poorly understood to predict when and where they will move across any particular watershed. Further, these fish can migrate large distances and often appear to home to specific spawning areas that may be unknown (Koch 2014). Consequently, in developing a management scheme, it is necessary to collect detailed site-specific demographic data to develop sustainable control strategies at appropriate spatial scales.

Next, the source(s) of juvenile carp (i.e. recruitment) in each management unit should be identified and subsequently remediated, isolated, or eliminated (Bajer & Sorensen 2010; Bajer et al. 2012; Koch 2014). Remediation may be possible if carp nurseries can be restored to support healthy native fish communities comprised of species that consume carp eggs and young (e.g. bluegill sunfish; Silbernagel & Sorensen 2013). Alternatively, nurseries may be isolated from connected lakes using barriers so that adult carp cannot reach them to breed and/or to prevent young carp from dispersing. If isolation is not feasible, control strategies such as water drawdowns or poisonings at regular intervals can be used to eliminate the young carp before significant numbers disperse.

Lastly, existing adult carp should be removed in large enough numbers to improve to ecosystem function. A target biomass of less than 100 kg of carp per hectare is appropriate for shallow Midwestern systems (Bajer et al. 2009) and can also be applied to deeper, dimictic lakes as a conservative threshold (Vilizzi et al. 2015; Bajer et al. 2016). Removal of carp is often possible through the use of multiple tools such as commercial seining, trapping spawning migrants, baited traps, water drawdowns, or piscicides. Seining can sometimes be an efficient means of removal because adult carp often aggregate during winter months where they may be targeted by commercial fishermen if the bottom is free of obstacles and the substrate is amenable to netting. The use of radio-tagged 'Judas' fish can increase the success rate of such seining efforts (Bajer et al. 2011). Seining may not always be feasible because carp can quickly learn to avoid nets, bottom topography can be uneven, or carp may not form wintertime aggregations. Adult carp may also form springtime spawning aggregations which can be targeted, trapped, and removed. If natural aggregations cannot be exploited, aggregation behavior can be induced by training carp to feed in a particular area using baited traps (Bajer et al. 2010). If these strategies are not feasible, whole-lake drawdowns or poisonings can also be used to reduce carp biomass although these methods are not species-specific and therefore require careful evaluation of non-target impacts.

2.0 Research Findings in the Six Mile Creek Subwatershed

2.1 Deliverable 1: Estimates of adult common carp abundance in all accessible lakes

Methods

Adult common carp abundance was estimated by conducting standardized boat electrofishing surveys in each accessible lake (i.e. Piersons, Wassermann, Turbid, Kelzer's, Steiger, Zumbra, Sunny, Stone, East Auburn, West Auburn, North Lundsten, South Lundsten, Parley, Mud, and Halsted's Bay; see Table 1) to calculate mean catch per unit effort values (CPUE; number of carp sampled per hour) and extrapolate to population size using known relationships. Briefly, surveys consisted of sampling the entire littoral area of each lake using a boat electrofisher with pulsed DC current. Estimates of carp density were then calculated from measured CPUE values using published mathematical relationships of electrofishing efficiency from similar locations (Bajer & Sorensen 2012). In lakes in which multiple surveys were conducted, 95% confidence intervals were generated as a measure of precision. Carp biomass (kg/ha) was estimated by multiplying abundance by the average weight of carp in each lake and then dividing by lake surface area.

During the course of our electrofishing surveys, all carp sampled were also marked with external plastic T-bar anchor tags (Hallprint co., Australia) before being released. These fish were tagged to allow for possible supplemental mark-recapture population estimates in the event that enough tagged fish (few percent of the population) were recaptured.

Results

At least four electrofishing surveys were conducted in each of the 15 accessible lakes between June 2014 and October 2016, with most lakes having between 8 and 10 surveys completed (Table 2). Because catch rates were comparable between years and no young fish recruited to the adult populations during the study period, we combined all years to maximize sample size and thus increase the precision of abundance and biomass estimates. Carp throughout the system grew substantially during the 3 year study period (roughly 13% by weight), so although abundance estimates did not change much between 2014 and 2016, biomass estimates increased in each lake (see Table 2, top panel versus bottom panel). We used the average weight of carp sampled in 2016 in our final table (Table 2, bottom panel) to best reflect the present biomass of carp in the system.

Carp biomass in individual study lakes ranged widely from 26 to 1,264 kg/ha, with an average biomass of 491 kg/ha across the entire subwatershed (Table 2). Twelve of the 15 accessible lakes had biomass levels above 100 kg/ha; a threshold known to be ecologically damaging in shallow Midwestern lakes (Bajer et al. 2009). Carp biomass was very high in Wassermann, Turbid, W. Auburn, E. Auburn, Parley, Mud, and Halsted's Bay ranging from 253 to 1,264 kg/ha. Notably, Halsted's Bay was estimated to contain 64,441 (57,769-71,113) individuals with a biomass of 1,264 (1,133-1,394) kg/ha based on nine whole-lake surveys. This exceeds the damaging threshold twelvefold and is the highest carp biomass ever observed by the Sorensen Lab. Carp biomass was moderate (156-204 kg/ha) in N. Lundsten, S. Lundsten, Steiger, Sunny, and Zumbra. Carp biomass was low (≤99 kg/ha) in Piersons, Stone, and Kelzer's. No electrofishing surveys were conducted in Marsh or Carl Krey Lakes due to inaccessibility.

During the course of all electrofishing surveys conducted from 2014 to 2016, 1,763 common carp were tagged with T-bar tags and released. As of December 2016, 87 of these tagged fish have been recaptured. Of the recaptured carp, 37 were sampled relatively evenly throughout the subwatershed and thus represent low recapture rates that do not allow for the statistical computation of supplemental mark-recapture estimates. However, the remaining 50 were recaptured during the commercial seine haul that took place in Parley Lake on March 10th, 2015. This recapture rate allowed us to calculate population estimates for Parley and Mud lakes combined (the lakes could not be separated because all carp from both lakes formed a single large wintertime aggregation in Parley Lake). In total, 6,206 carp were captured in the seine haul, of which 5,564 were individually checked for tags and 50 tagged fish were observed. Given that there were 211 carp tagged in Parley and Mud Lakes before the seining occurred, this recapture rate results in an estimated population size of 23,591 carp based on the Lincoln-Peterson method (i.e. N=Kn/k where N = number of individuals in the population, K = number of marked animals in the population, n = number of animals captured, and k = number of recaptured individuals). This mark-recapture population estimate for Parley and Mud Lakes combined is comparable to the sum of estimates generated from electrofishing surveys in both lakes (i.e. 19,006-23,625) despite violating assumptions of a closed population.

2.2 Deliverable 2: Seasonal distribution and movement patterns of adult carp

Methods

The seasonal distributions and movement patterns of adult carp across the Six Mile Creek subwatershed were determined by implanting carp with radio-tags and manually bi-angulating their locations at least once per month. In October of 2014, 102 radio-tags were implanted in carp throughout the subwatershed (5-15 tags per lake; see Table 1). In the spring of 2015, 18 more radio-tags were implanted in 3 additional lakes for a total of 120 radio-tagged carp. Each tagged carp was given a unique fish identification number ranging from 1 to 120.

In addition to tracking the radio-tagged carp, movement patterns were also elucidated by recapturing carp previously tagged with individually numbered T-bar tags during routine electrofishing surveys. As discussed above, 1,763 carp had been sampled, tagged with T-bar tags, and released since the onset of the study in June 2014.

Results

Radio-tagged carp were located throughout the subwatershed at least once per month for two full years from November 2014 through October 2016 (See Figures 2-29). During April, May, and June, the carp were located twice per month to increase the resolution of data during the pre-spawning and spawning periods. From November 2014 through April 2015, 99% of the tagged fish were located successfully each month. Beginning in late May 2015 and continuing through October 2016, an average of 13 tagged carp were missing each month, primarily from Parley, Mud, and Halsted's Bay. The several missing carp from Parley, Mud, and Halsted's Bay were presumed to be somewhere in greater Lake Minnetonka, but due to time constraints, it was not feasible to search all of Lake Minnetonka. Large portions of Lake Minnetonka were searched on occasion and radio-tagged carp have been located in Priest's Bay, Cook's Bay, West Upper, West Arm, and as far east as Jenning's Bay near the inlet of Painter Creek (see Figure 18).

The first mortality of a radio-tagged carp occurred in May 2015 in Mud Lake. Since then, 32 additional radio-tagged adult carp have died or lost their transmitters for a total mortality rate of 27.5% over two years which is comparable to published annual natural mortality rates in systems with high carp densities (Brown et al. 2005; Bajer et al. 2015). Mortalities were distributed relatively evenly across the subwatershed (i.e. 2 in Halsted's, 4 in Mud, 5 in Parley, 5 in Wassermann, 3 in Lundsten, 2 in Steiger, 1 in Zumbra, 3 in East Auburn, 3 in West Auburn, 2 in Turbid, and 3 in Piersons) and thus did not diminish the scope or resolution of the movement study.

As for movement of carp between lakes, approximately half of the radio-tagged carp (59 of 120; 49%) were located in a lake other than where they were originally tagged at least once during the two-year movement study. A summary of movement corridors, rates, and timing can be found in Table 3 and is summarized on a map in Figure 30. Most carp traveled between just a few lakes and usually returned to their lake of origin. Most movements occurred from deeper lakes to shallow habitats during the spawning season (e.g. from Auburn to South Lundsten and from Parley and Halsted's to Mud) or from shallow lakes to deeper lakes in late fall before ice cover (e.g. from Mud to Parley; Table 3).

The highest average annual movement rates occurred between Parley and Mud Lakes in both directions (81%), between Mud and Halsted's Bay in both directions (47%), and between East and West Auburn Lakes in both directions (73%). Most of these movements occurred from Mud Lake to Parley Lake in late fall each year (see Figures 2-3 & 17-19) or between Parley, Mud, and Halsted's Bay in all directions between late May and August in 2015 (see Figures 10-14) and between late May and October in 2016 (see Figures 24-29). Additionally, 13 of the 45 carp originally tagged in Parley, Mud, or Halsted's Bay have been located in other bays of Lake Minnetonka year-round despite low sampling effort in greater Lake Minnetonka. This high rate of movement to and from the rest of Lake Minnetonka (22%, annually) likely explains our inability to locate some of the tagged carp each month. Several radio-tagged carp have also moved from Wassermann Lake, Auburn Lakes, and North Lundsten Lake into South Lundsten Lake (5%, 43%, & 46%, annually) in May and June of both years and then returned to their respective lakes of origin by late summer (see Figures 11 & 23-25). No movement of radio-tagged carp in or out of Turbid, Zumbra, Sunny, Steiger, or Piersons Lakes was observed during the 2 year study period.

In addition to radio-tagged carp moving between lakes, there have also been seasonal patterns in the spatial distribution of carp within lakes. Specifically, wintertime aggregations of carp (identified by at least 50% of radio-tagged carp being found within a 10 hectare area) formed in both 2014-15 and 2015-16 in all but one of the study lakes (i.e. Steiger Lake). The timing of aggregation formation and location varied, but in general, aggregations formed by December and persisted through February (Table 4). These aggregations contained as many as 100% of radio-tagged carp in some lakes (i.e. Parley-Mud, N. Lundsten, S. Lundsten, Turbid, W. Auburn, E. Auburn, Sunny, Zumbra, and Wassermann), whereas in other lakes (i.e. Halsted's Bay, Piersons), multiple aggregations comprised of roughly 40-60% of tagged fish each were observed. Interestingly, winter aggregations in some lakes formed in same location between years (i.e. Parley, West Auburn, East Auburn, Zumbra, and Piersons) whereas they formed in different places in Wassermann Lake and Halsted's Bay (See Figures 5 and 20).

Recaptures of T-bar tagged carp and visual observations of spawning migrations confirmed the patterns observed during the radio-tag study (i.e. movement between Parley, Mud, and Halsted's Bay and movement between Auburn Lakes and Lundsten Lakes) and contributed some additional information on carp movement patterns. Specifically, recaptures of T-bar tagged carp revealed that it is possible for carp to move through the Parley Lake dam in a downstream direction as evidenced by one carp that was originally tagged in West Auburn Lake in June 2014 that was recaptured in the commercial seine haul in Parley Lake in March 2015. To date, there has been no evidence that the Parley Lake dam is passable by fish in an upstream direction. Mass spawning migrations of carp were also observed prior to deploying radio-tags throughout the system during the spring flooding of 2014. Large numbers of migrating carp were observed downstream of culverts in Turbid Creek at Laketown Road, in Six Mile Creek at the Parley Dam, and in Six Mile Creek at Marsh Lake Road upstream of Wassermann Lake. These observations were consistent with past anecdotal reports of carp spawning migrations (Wenck 2013).

2.3 Deliverable 3: Identification of sources of juvenile carp across the watershed

Carp recruitment during the study period was characterized by sampling for juvenile carp using trap-nets (section 2.3.1) while historic patterns of recruitment were examined by ageing adult carp to determine when they hatched (section 2.3.2). Ongoing work using genetic and biochemical markers is presently being conducted to further investigate past nursery contributions (appendix 2).

2.3.1 Distribution and relative abundance of juvenile common carp in 2014-2016

Methods

To assess the distribution and relative abundance of young-of-the-year carp (YOY; spawned that year) and bluegill sunfish (*Lepomis macrochirus*; a predator of carp eggs and larvae; Bajer at al. 2011; Silbernagel & Sorensen 2013), we conducted standardized trap-net surveys across the subwatershed. Trap-nets are a common type of sampling gear used to survey small fishes in the littoral zone of lakes (e.g. YOY fishes and panfish). Trap-nets consist of a long wall of net (30 ft x 3 ft) that is staked close to shore and directs fish to an underwater frame with a series of hoops and funnels that trap fish in a holding cage at the rear of the net. Five nets were set equidistantly around the perimeter of each accessible lake and pond and were left in place overnight for approximately 24 hours. Trap-net surveys were conducted in August and September, when YOY fishes were large enough to sample, but before lake temperatures dropped. Trap-nets reliably sample YOY carp (<150 mm in total length) and one-year-old carp, but rarely sample older juveniles or adults (Osborne 2012).

Results

Trap-net surveys targeting juvenile common carp were completed in fall 2014, 2015, and 2016 in each of the 15 accessible study lakes along with numerous additional connected ponds (Table 1). Of the 21 sites sampled in 2014, YOY carp were only captured in three locations: Mud Lake (0.2 per net), Crown College Pond (1.0 per net), and Big SOB Lake (19.8 per net). Additionally, one-year-old carp were sampled in 2 locations: Shady Pond (0.67 per net) and Carl Krey Lake (2.0 in a gillnet; Table 5). In 2015, YOY carp were sampled in 4 out of 22 locations: Crown College Pond (332.3 per net), North Lundsten (3.2 per net), South Lundsten (311.2 per net), and Wassermann Lake (0.2 per net). Additionally, one-year-old carp were sampled in 2 locations: Big SOB Lake (1.8 per net) and Wassermann Pond West (0.3 per net). In 2016, no YOY carp were sampled throughout the entire subwatershed, but one-year-old carp were sampled in South Lundsten (0.4 per net) and Crown College Pond (2.3 per net). In total, juvenile carp were sampled at 9 unique sites, but mostly in very low numbers (i.e. <3 per net; Table 5). Extremely high numbers of carp were however observed in South Lundsten Lake and Crown College Pond in 2015 (i.e. >300 per net) and trap-netting in 2016 revealed that at least some portion of these carp successfully overwintered in both locations. Catch rates of YOY carp and one-year-old carp cannot be compared directly because one-year-old carp are not sampled as well in trapnets.

Bluegill sunfish were abundant throughout much of the watershed (Table 6). Bluegill sunfish were sampled in all locations where juvenile carp were sampled except for in Crown College Pond in 2014 and 2015, Shady Pond, and Wassermann Pond West (Table 6). Shady Pond and Wassermann Pond West experience summer and winter hypoxia as evidenced by large numbers of dead fish in August trapnet surveys and low dissolved oxygen readings in February (Table 7). It should be noted that the presence of bluegill sunfish during fall trapnet surveys does not indicate that bluegills were present in the spring during the carp spawning season; it is possible that some basins experienced winterkill conditions that went undetected due to bluegill sunfish recolonization from connected waters.

2.3.2 Historical patterns of carp recruitment via ageing analysis

Methods

To elucidate historical trends in common carp recruitment, ageing studies were conducted throughout most of the subwatershed (Table 1). In 2014, otoliths were collected from Halsted's Bay (n=51), Mud Lake (n=51), Parley Lake (n=51). In 2015, otoliths were collected from North Lundsten Lake (n=31), West Auburn Lake (n=28), East Auburn Lake (n=28), Wassermann Lake (n=37), and Piersons Lake (n=34). In 2016, otoliths were collected from Turbid Lake (n=24), Steiger Lake (n=15), and Zumbra Lake (n=28). Common carp were sampled via electrofishing, removed from the system, and frozen for subsequent analysis following established protocols for common carp outlined in Bajer and Sorensen (2010). Specifically, the asterisci otoliths (i.e. ear bones) were extracted, embedded in epoxy, and sectioned using a slow speed saw. Annual growth rings were counted using a compound microscope by two independent observers.

Results

In total, 378 common carp were collected across the subwatershed for age determination. Carp ages ranged from 2 to 54 years old with just five year-classes (i.e. 2001-2002 and 1990-1992) accounting for 68% of total recruitment system-wide (Figure 31). The age structures of common carp sampled across the subwatershed were not consistent between all study lakes, but were similar between some groups of adjacent lakes (Figure 32). Lakes with similar age structures were grouped as follows: 1) Piersons and Wassermann, 2) East Auburn, West Auburn, North Lundsten, and Turbid, 3) Parley, Mud, and Halsted's Bay, and 4) Steiger and Zumbra Lakes (Figure 33). The age structure results coupled with the results of the movement study (see section 2.2) seem to suggest that there are several sub-populations of carp within the subwatershed (discussed in detail in section 2.4 below).

At the headwaters of the system in Lakes Piersons and Wassermann, there have only been two strong year classes of common carp since the 1960s (i.e. 1991 & 1992; figure 33). These two year classes account for 54% of all carp sampled in these two lakes combined. Aside from a couple of individuals every few years, there is a noticeable lack of young fish in this sub-population indicating that carp recruitment has been largely unsuccessful in recent years. In contrast, in Lakes Auburn and Lundsten, there are relatively consistent year classes almost every year for the past 15 years and a notable absence of older individuals (Figure 33). The strongest year classes were from 2001 and 2002 which accounted for 50% of recruitment in Auburn, Lundsten, and Turbid Lakes combined. This age structure, along with extremely high catch rates of YOY carp in South Lundsten in 2015, indicates that South Lundsten is serving as an active and highly productive carp nursery. In Parley, Mud, and Halsted's Bay, 75% of all carp sampled assigned to the same strong year classes mentioned above (i.e. 1990, 1991, 1992, 2001, & 2002; Figure 33). Similarly, these five years classes accounted for 84% of recruitment in Zumbra and Steiger Lakes as well (Figure 33).

Interestingly, the seven strongest year classes of carp observed in the Six Mile Creek subwatershed (i.e. 1990-92, 2001-02, & 2009-10) closely matches the patterns of carp recruitment observed in the Phalen Chain subwatershed in Saint Paul, MN (Figure 34). The similarities in carp year class strength between the two isolated chains of lakes indicates that whatever is driving carp recruitment in the Six Mile Creek subwatershed is likely not system-specific, but is instead related to outside factors such as climate. Historical water level records for Parley Lake dating back to the 1980s reveal that extended periods of low water preceded both 1991 and 2001 (Figure 35). It is possible that such drought conditions increased the likelihood and severity of winterkills in many of the shallow basins throughout the Six Mile Creek subwatershed and the state during these years.

2.4 Overall conclusions of research findings & resulting management units

Based on the abundance estimates, size structures, movement patterns, and age structures of carp in the Six Mile Creek subwatershed, there appears to be multiple sub-populations of carp throughout the subwatershed and consequently multiple management units. Carp sub-populations are: Piersons-Marsh-Wassermann, Auburn-Lundsten-Turbid, Parley-Mud-Halsted's, and the rest of the isolated lakes individually (i.e. Stone, Zumbra-Sunny, and Steiger). These sub-populations are not entirely independent as there is evidence of low levels of movement between Lundsten and Parley and between Lundsten and Wassermann. Although ongoing carp recruitment in South Lundsten appears to impact both upstream and downstream sub-populations to some degree, dispersal of carp recruits from South Lundsten to other sub-populations appears to be minimal based on the prevailing recruitment patterns observed in each sub-population elucidated from age structures and preliminary genetic analyses (See Figure 33 and Appendix 2). Dispersal from South Lundsten to North Lundsten and Auburn Lakes is common. Cutting off dispersal of new carp recruits from South Lundsten is integral to managing carp throughout the entire Six Mile Creek subwatershed and is likely a prerequisite to dividing the system up into clear manageable units.

If MCWD were to suppress the ongoing recruitment in South Lundsten, the resulting management units would be: 1) Piersons-Marsh-Wassermann, 2) Auburn-Lundsten-Turbid, 3) Parley-Mud-Halsted's, and 4) Carver Park Reserve Lakes (Steiger Lake, Zumbra-Sunny, and Stone). The area between Wassermann and East Auburn (i.e. the wetland complex that includes Carl Krey, Kelzer's Pond, and Church Lake) is not included in any management unit as no carp management activities are recommended there due to a lack of carp movement in and out of these systems and very low numbers of carp in the locations that were sampled. It should be noted that we have a poor understanding of this portion of the system due to limited access with sampling gear. Below is the rationale for delineating each management unit:

Piersons-Marsh-Wassermann

It appears that carp inhabiting Piersons Lake, Marsh Lake, and Wassermann Lake likely comprise a single sub-population that might be managed together. There are multiple lines of evidence that Piersons and Wassermann share a common primary carp nursery. Specifically, the age structures are similar between lakes and are both dominated by the 1991-92 year classes (55% & 51% of total recruitment; Figure 32) and the average size of carp is similar in both lakes (3.3kg & 3.4kg) and is in contrast to connected lakes (Table 2). Additionally, there is evidence of spawning migrations to Marsh Lake from both lakes and pilot studies indicate that genetic structures also appear similar between lakes and are in contrast to downstream lakes (Appendix 2). Although no movement of radio-tagged carp into Marsh Lake was observed during the study period, there are past reports of spawning migrations to Marsh Lake from Piersons Lake (Wenck 2013) and hundreds of carp from Wassermann Lake were observed attempting to migrate towards Marsh Lake at the Marsh Lake Road crossing during spring of 2014.

Although it is possible for carp to move between Wassermann and downstream lakes as evidenced by 2 of 15 radio-tagged carp moving from Wassermann to East Auburn and back again and one moving as far as South Lundsten, movement seems relatively uncommon given the stark contrast between the age structures of carp in Piersons-Wassermann compared to that of Auburn-Lundsten-Turbid (Figure 33). Low levels of connectivity between South Lundsten and Wassermann Lake could explain the elevated presence of the 2001-02 year class in Wassermann Lake (17% of total recruitment) compared to that in Piersons Lake (3%) as well as the higher levels of genetic differentiation in Wassermann Lake (Appendix 2).

Auburn-Lundsten-Turbid

In the central portion of the subwatershed, carp inhabiting East Auburn, West Auburn, North Lundsten, South Lundsten, and Turbid Lakes might also be managed as a single sub-population. There are multiple lines of evidence that these lakes share two common nurseries (i.e. South Lundsten & Turbid Lakes). South Lundsten Lake appears to be the primary nursery for both of the Lundstens and Auburns as evidenced by high catch rates of YOY carp in South Lundsten in 2015 (Table 5), spawning-season migrations of radio-tagged to South Lundsten from North Lundsten and Auburn (Table 3), similar age structures in Lundsten and Auburn dominated by the 2001-02 year classes (34% and 42% of total recruitment, respectively) and lacking the 1990-92 year classes (Figure 32), and similar average sizes of carp in the Lundstens and Auburns ranging from 1.9 kg to 2.6 kg (Table2).

In Turbid Lake, every single carp analyzed assigned to the 2001-02 year classes (Figure 32) and there is some evidence of a genetic bottleneck (Appendix 2). It is possible that Turbid experienced a near complete winterkill in 2001, followed by recolonization by a small number of carp and/or repopulation by a small number of surviving carp. Given this unique situation, carp spawned in Turbid Lake have a distinctive genetic signature that can be used to track their dispersal. Based on the genetic signatures of carp sampled in Lundsten and Auburn Lakes, it appears that roughly 5% of these carp were spawned in Turbid Lake (Appendix 2). There is no evidence of successful recruitment in Turbid Lake since 2002.

Despite the presence of two additional inflowing creeks to East Auburn (i.e. Steiger Lake outflow and Sunny Lake outflow), no radio-tagged fish have been observed moving upstream or downstream in either of these creeks. Additionally, carp in these connected systems (i.e. Zumbra-Sunny, Stone, & Steiger) are significantly larger (> 3.0 kg; Table 2) and older (Figure 32) which provides further evidence that these sub-populations can be managed separately.

Parley-Mud-Halsted's

In the lower portion of the subwatershed, carp inhabiting lakes Parley, Mud, and Halsted's Bay should also be managed as a single sub-population. It would be incredibly difficult to manage any of these lakes individually due to extremely high rates of carp movement between all three lakes (Figure 30). There is also evidence that these lakes share one or more common nurseries. Specifically, between Parley, Mud, and Halsted's Bay, the average size of carp is similar (4.0, 4.1, & 4.4 kg, respectively; Table 2) and the age structures are dominated by the same five year classes (i.e. 2001-02, & 1990-92). Notably, Parley Lake contains more younger carp (spawned post 2000; Figure 32) relative to the other lakes downstream, suggesting that at least a portion of carp in this subpopulation may have originated from nursery areas in closer proximity to Parley Lake (i.e. Crown College Pond and/or South Lundsten Lake). Although carp are not able to move upstream through the Parley Lake dam to access South Lundsten to spawn, carp from above can move downstream as evidenced by one carp originally tagged with a T-bar tag in West Auburn later being recaptured in Parley. The occurrence of spawning migrations below the Parley Lake dam provides further evidence that some carp were likely spawned upstream of the dam because common carp have a tendency to exhibit natal site homing (Koch 2014).

This possible management unit presents challenges because large numbers of carp move readily between Parley-Mud-Halsted's and other bays of Lake Minnetonka (Figure 30). Understanding and quantifying carp movement outside of the Six Mile Creek subwatershed was beyond the scope of this study, but will be important to guide sustainable carp control in this management unit. Presently, this management unit cannot be separated from the rest of Lake Minnetonka without taking actions to isolate Parley-Mud and/or Halsted's Bay from the other bays (e.g. installing a carp barrier between Mud Lake and Halsted's Bay or between Halsted's Bay and Priest's Bay).

Carver Park Reserve Lakes

The rest of the study lakes (i.e. Steiger, Zumbra, Sunny, & Stone) each seem to contain their own isolated sub-population of carp, but we grouped them together as a possible single management unit given their similar ecological conditions, carp management goals, and shared location within the eastern Carver Park Reserve in the jurisdiction of the Three Rivers Park District. Although there was no carp movement in or out of any of these lakes during the study period, it should be noted that man-made barriers were in place in the connections between Stone and Sunny Lakes and between Zumbra and Sunny Lakes. Without these barriers, it is likely that Stone, Sunny, and Zumbra would function as one sub-population.

3.0 Management Recommendations

The overarching aim of the common carp assessment in the Six Mile Creek subwatershed was to develop a rigorous scientific understanding of the carp in this system to develop sustainable control strategies. The first step in any sustainable carp control program is to delineate appropriate management units by determining the spatial and temporal scales at which local carp population dynamics are operating. In the Six Mile Creek subwatershed, four possible management units have been tentatively identified: 1) Piersons-Marsh-Wassermann, 2) Lundsten-Auburn-Turbid, 3) Parley-Mud-Halsted's, and 4) Carver Park Reserve Lakes (see Section 2.4 for details and justifications).

Next, appropriate management objectives and measurable targets must be established for each unit. To achieve long-term, sustainable control of carp populations, ongoing recruitment must be suppressed and future recruitment must be prevented owing to the extreme fecundity and longevity of carp. To mitigate or prevent detrimental impacts to aquatic habitats and water quality, the biomass of carp might then be reduced and/or maintained below thresholds where ecological damage occurs. Specific targets for each management unit are discussed below in Sections 3.1 and 3.2.

Finally, realistic strategies must be identified to meet the specific targets identified for each management unit and these strategies must be implemented in a strategic order. There are multiple ways to approach carp control in the Six Mile Creek subwatershed depending on management priorities. For example, one option would be to suppress recruitment system-wide and then proceed with biomass reduction in each individual management unit. Another approach would be to start in the headwaters of the system by meeting all of the objectives identified in the Piersons-Marsh-Wassermann management unit (i.e. recruitment suppression and existing biomass reduction) and then repeat for the remaining management units. A third approach would be to first eliminate carp movement between the subwatershed and Lake Minnetonka and then proceed with either of the first two options. A fourth approach would be to implement individual management strategies opportunistically where they make sense with other district planning initiatives (e.g. installation of a carp barrier when a road crossing is being rebuilt).

Each of the management approaches outlined above has its own benefits and pitfalls. We recommend the first approach of suppressing carp recruitment system-wide be strongly considered. The rational for choosing this approach is because there is presently ongoing, continuous, and likely large-scale recruitment in South Lundsten Lake that should be addressed immediately to stop the overall carp population from growing. It is also important to address the sporadic recruitment that has occurred in all of the other management units to prevent successful large year classes of carp in the future – a single recruitment event can have devastating consequences. These actions should be prioritized because MCWD is currently in the unique position of having accurate, up-to-date estimates of carp abundance and biomass across the entire subwatershed (see Table 2). If recruitment is not suppressed and the carp population continues to grow, new estimates of carp biomass will be required to adjust the management targets developed in this report. After recruitment is suppressed system-wide, any of the remaining three management approaches seem reasonable. The following sections outline possible carp control strategies specific to each management unit regardless of the order they are implemented.

3.1 Strategies to suppress recruitment

Given the fecundity of adult common carp (2-3 million eggs per large female), suppression of recruitment is the cornerstone of sustainable long-term carp management. After three years of trap-netting for YOY carp and determining the age structure of carp in 11 lakes, a few carp nurseries have been identified in the Six Mile Creek Subwatershed, with South Lundsten Lake being a management priority. Strategies to suppress recruitment are less clear in Piersons-Marsh-Wassermann, Parley-Mud-Halsteds, and the Carver Park Reserve Lakes because the age structures in these lakes suggest that carp recruitment has only been successful in a few years since the 1960s (Figure 33). It is difficult to determine the precise source(s) of carp that were spawned decades ago, but it is possible to speculate on the likely sources based on our study findings, our knowledge of common carp life history, and historical climatic records. It is plausible that Mud Lake and the Marsh Lake both served as carp nurseries in the past because of the large number of carp that move towards them during the spawning season and because they are likely susceptible to winterkill conditions due to their shallow depths.

3.1.1 Piersons-Marsh-Wassermann

In the Piersons-Marsh-Wassermann management unit, aside from one YOY carp sampled in Wassermann Lake and two Age-1 carp sampled in Wassermann Pond West in 2015, no juvenile carp have been sampled during the study period. The age structure of carp in Piersons and Wassermann also confirms that there is very little ongoing successful recruitment as most of the carp were spawned in 1990-92 (54% of total recruitment) compared to only 5% spawned during the past 10 years (Figure 33). Although there has not been any movement of tagged fish from Piersons or Wassermann into Marsh Lake during the study period, past reports of mass spawning migrations to Marsh Lake from both of these lakes indicate that it likely functioned as a nursery in the past. The dissolved oxygen content in Marsh Lake remained high (>9 mg/L; Table 7) during the winters of 2014-15 and 2015-16 and bluegill sunfish catch rates were also very high in fall of 2014, 2015, and 2016 (131.4, 113.5, & 108.6 per net, respectively; Table 6). Based on these findings, it does not appear that Marsh Lake has a tendency to winterkill often, but perhaps extreme climatic conditions (e.g. harsh winters, above average snowfall, drought) could cause periodic winterkills. This could explain the recruitment success of carp in 1990-91 in this system because a winterkill likely occurred in Marsh Lake in 1988-89 due to severe drought conditions across the state causing water levels to drop an average of three feet (MN DNR 1989).

To prevent future successful carp recruitment in Marsh Lake, winter aeration should be considered to mitigate the risk of future winterkills. The feasibility of aerating Marsh Lake is presently unknown and should be explored. If aeration is not feasible, barriers should be installed to block adult carp from accessing Marsh Lake from both Piersons and Wassermann Lakes. Multiple barrier technologies exist, each with their own strengths, weaknesses, and limitations (see Table 8). A barrier between Piersons and Marsh must block carp swimming in the downstream direction whereas a barrier between Wassermann and Marsh must block carp swimming in an upstream direction.

In Wassermann Lake, there is also evidence of some recruitment inputs from the Auburn-Lundsten-Turbid sub-population downstream. Specifically, the 2001-02 year class which is well-represented in Auburn-Lundsten-Turbid, accounts for 17% of total recruitment in

Wassermann Lake compared to 3% in Piersons (Figure 32). The elevated presence of this year class in Wassermann coupled with evidence of radio-tagged carp moving from Wassermann to Auburn and South Lundsten and back confirms that dispersal of carp from South Lundsten to Wassermann is possible. To suppress ongoing recruitment inputs from downstream, recruitment in the Auburn-Lundsten-Turbid sub-population would need to be suppressed (See Section 3.1.2) or a barrier would need to be installed at the outlet of Wassermann Lake. This barrier would only need to be a 1-way barrier that prevented carp from entering Wassermann from downstream waters. Depending on the site specifications, a velocity barrier, vertical drop barrier, or an electric barrier may be effective (see Table 8).

3.1.2 Auburn-Lundsten-Turbid

In this management unit, it appears that South Lundsten Lake is a very productive and active carp nursery. South Lundsten supports extremely high densities of YOY carp and is well-connected to other lakes as evidenced by high catch rates of YOY carp in trapnets in 2015 (>300 per net), movement of radio-tagged carp between North and South Lundsten (56%, annually) and between Auburn and South Lundsten (43%, annually), and the prevalence of young carp inhabiting Lundsten and Auburn Lakes (Figure 33). Although moderate numbers of bluegill sunfish were sampled in South Lundsten Lake during fall trapnet surveys (17.4, 34.2, & 68.8 per net in 2014, 2015, & 2016 respectively; Table 6), the maximum dissolved oxygen content measured by MCWD staff during winter of 2014-15 was 1.5 mg/L (Table 7), just slightly above a level that is lethal to bluegill sunfish (Moss & Scott 1961; Petrosky & Magnuson 1973; Bajer & Sorensen 2010). The dissolved oxygen concentration was measured by MCWD staff in February of 2015 at the deepest point in the lake; it is likely that oxygen levels fell below 1.5 mg/L in shallower parts of the lake or later in the winter resulting in at least a partial winterkill of bluegill sunfish in South Lundsten. It is possible that bluegill sunfish were then able to recolonize South Lundsten from connected waters before our fall surveys were conducted. In winter of 2015-16, the maximum dissolved oxygen content was 10.0 mg/L (Table 7) and trap-netting in South Lundsten in 2016 revealed that many bluegills survived the winter (108.6 and 68.8 fish per net in April and September, respectively) and no YOY carp were present in fall of 2016.

Interestingly, there is a lack of older carp in this sub-population indicating that South Lundsten Lake has not always been an active, productive nursery. Specifically, the 1990-92 year classes that are well-represented everywhere else throughout the subwatershed are missing from Auburn-Lundsten-Turbid (Figure 33). This lack of old carp may be explained by the former presence of a riprap dam between West Auburn and North Lundsten that washed out in the late 1990's (Wenck 2013). This dam (and probable fish barrier) was replaced by a culvert that is easily passable by carp as evidenced by our radio-tagging study results and may have allowed unprecedented access to the prime spawning habitats in South Lundsten.

To suppress ongoing recruitment in Auburn-Lundsten-Turbid, aerating South Lundsten during the winter months is recommended to promote the survival of a robust panfish community year-round in order to increase predation pressure on carp eggs and larvae. The feasibility of aeration in South Lundsten Lake is presently unknown, but it may be increased by manipulating water levels to be higher in the winter via the water control structure at the outlet of North Lundsten Lake (aka the Parley Lake Dam). It should be noted that future aeration will do nothing to address the juvenile carp that are already in South Lundsten, including the sizeable 2015 year class. These carp could be removed as adults later using a variety of techniques (see section 3.2.2) or actions could be implemented in 2017 to eliminate them from South Lundsten Lake before large numbers start dispersing to connected lakes (e.g. whole-lake poisoning or water drawdown).

Although South Lundsten is the primary carp nursery for this sub-population, there is also some evidence that low levels of successful recruitment has occurred in North Lundsten and Turbid Lakes as well. Specifically, small numbers of YOY carp were sampled in trap-nets in North Lundsten in 2015 (3.2 carp per net; Table 6) and preliminary genetic evidence indicates that roughly 5% of the carp in Auburn and Lundsten Lakes originated from Turbid Lake (Appendix 2). To prevent future sporadic recruitment in North Lundsten and Turbid Lakes, wintertime aeration is recommended to promote dissolved oxygen concentrations adequate for bluegill sunfish survival.

If aeration is not feasible in South Lundsten, North Lundsten, and/or Turbid Lakes, barriers could be installed to isolate one or more of these lakes. It would be difficult to isolate

South Lundsten from North Lundsten due to their close proximity and minimal separation by a low-lying horse path that is prone to flooding. A better place for a barrier may be the culvert between North Lundsten and West Auburn, the site of the former riprap dam. If isolation is not feasible, these lakes could be monitored annually for successful recruitment (see section 3.3) and then regularly drawdown and/or poisoned to eliminate juvenile carp before they are able to disperse to connected lakes. Additionally, it may be possible to manipulate water levels during the spawning season to decrease carp recruitment rates (Shields 1958). This may be accomplished by operating the North Lundsten outlet structure to lower water levels immediately following peak carp spawning behavior in attempts to desiccate vulnerable eggs and larvae. This feasibility of this strategy depends on the outlet structure design and lake bathymetry.

3.1.3 Parley-Mud-Halsted's

In this possible management unit, carp may be coming from multiple sources including South Lundsten, Mud, or one or more peripheral ponds where YOY carp have been sampled during the study period (i.e. Big SOB Lake and/or Crown College Pond). Based on the age structure of carp in these lakes, with roughly half of all individuals assigning to the 1990-92 year classes and a very low representation of these year classes in Auburn-Lundsten-Turbid (Figure 33), it seems likely that most of these older fish were spawned in locations below the Parley lake dam (i.e. not South Lundsten). In contrast, roughly 20% of carp in this management unit assigned to the 2001-02 year classes (Figure 33), with these younger fish being twice as prevalent in Parley compared to Mud or Halsted's Bay (Figure 32). Because these year classes are more prevalent in Parley Lake and were also well-represented in Auburn-Lundsten, it follows that these individuals may have been spawned in South Lundsten Lake. Observations of carp moving successfully through the Parley Lake Dam in the downstream direction and past occurrences of large spawning migrations of carp trying to pass through the Parley Lake dam in an upstream direction coupled with the homing tendencies of carp support this hypothesis (Koch 2014).

To suppress the ongoing recruitment inputs to Parley-Mud-Halsted's from South Lundsten Lake, recruitment would have to be suppressed in Auburn-Lundsten-Turbid (strategies discussed above in section 3.1.2) or carp movement through the Parley Lake Dam would have to be prevented. Preventing future recruitment below the Parley Lake Dam is more complicated due to the uncertainty surrounding where exactly young carp were historically produced. Due to the statewide drought conditions in 1988-89, it is possible that Mud Lake winterkilled in 1989-90 creating ideal carp spawning conditions the next spring for the same reasons discussed above for Marsh Lake. Specifically, water levels in Parley Lake reached record lows during 1988-1990 (2.5ft lower than average conditions; Figure 35), which would have made Mud Lake approximately 1 foot deep on average during those years. It is also possible that carp were spawned in one or more of the peripheral basins where YOY carp were sampled during the study period as these basins would have likely winterkilled that year as well. The role that these peripheral basins have in contributing carp recruits to the greater sub-population is however unclear. The YOY carp that were sampled in Big SOB Lake in 2015 were likely an artifact of a rotenone poisoning carried out by the property owner the preceding fall which mimicked winterkill conditions and was followed by high spring water levels which facilitated recolonization by adult carp from Parley. Crown College Pond likely suffers partial or complete winterkills most years as evidenced by it freezing solid to the bottom in winter 2014-2015 and experiencing very low dissolved oxygen concentrations in winter 2015-16 (1.85 mg/L) despite mild conditions (Table 7). Although very high numbers of YOY carp were sampled in Crown College Pond in fall of 2015 (>300 per net), few one-year-old carp were sampled in April of 2016 (2.6 per net) indicating relatively high overwinter mortality rates. Nevertheless, at least some carp did survive the winter in Crown Pond despite suboptimal oxygen conditions, indicating that Crown Pond could serve as a source of carp to connected waters if emigration is possible.

To prevent future recruitment in Parley-Mud-Halsted's, wintertime aeration of Mud Lake is recommended. If aeration of Mud Lake is not feasible, isolating Mud Lake from both Parley and Halsted's Bay using barriers is recommended. Isolating Mud Lake would be difficult because carp frequently move through these corridors in both directions (Table 3). Because 100% of our radio-tagged carp left Mud Lake by December 2015 to overwinter in Parley, there should be a window of time between December and ice-out to install barriers while Mud Lake does not contain many carp. As for the peripheral potential carp nurseries, it is unknown if Big

SOB Lake experiences winter hypoxia under natural conditions, but it is currently being aerated by the private landowner and should continue to support a healthy panfish community if aeration continues. In Crown College Pond, aeration is likely not feasible due to its tendency to freeze solid in some years, so isolation of this pond is recommended instead. The creek flowing from Crown Pond to Parley flows intermittently and is not passable by carp most of the year; a simple physical barrier blocking adult carp from accessing Crown from Parley may be sufficient.

3.1.4 Carver Park Reserve Lakes

No YOY carp were sampled in any of the lakes within the Carver Park Reserve management unit (i.e. Steiger, Zumbra, Sunny, and Stone) and the age structures in Zumbra and Steiger lakes indicate that successful recruitment has largely been restricted to the 2001-02 and 1990-92 year classes (Figure 33). Furthermore, all of these lakes contain low to moderate numbers of carp which indicates that population abundance has not been increasing rapidly. It is difficult to determine where the carp were produced in past years, but reports of a history of winterkill in Sunny Lake (Wenck 2013) along with very low dissolved oxygen concentrations measured in Sunny in February 2015 (0.9 mg/L; Table 7) draw attention to Sunny as a potential carp nursery. No signs of winterkill were observed in Sunny Lake during the study period (i.e. bluegill catch rates > 38.0 fish/net each year) and no movement of carp was observed in or out of any of these lakes towards Sunny although manmade barriers were in place at the outlets of Stone and Zumbra during the entire study period.

As a precautionary measure to prevent possible future recruitment in Sunny Lake, aeration of Sunny should be considered. Additionally, the barrier at the Stone outlet should be maintained and the barrier at the Zumbra outlet should be fortified. The current barrier at the Zumbra outlet is not very robust and is also prone to flooding (See Figure 36). The wide spacing of the Zumbra outlet barrier should be maintained to promote recolonization of Sunny Lake by bluegill sunfish in the event of a winterkill.

3.1.5 Summary of recruitment suppression strategies

- To suppress the consistent, ongoing carp recruitment occurring in South Lundsten Lake, winter aeration of South Lundsten should be a management priority. Aerating South Lundsten should not only eliminate the primary source of carp in Auburn-

Lundsten-Turbid, but it will also reduce recruitment inputs to Wassermann Lake and Parley-Mud-Halsted.

- To prevent additional strong year classes of carp in areas that were identified as past productive carp nurseries, wintertime aeration should be considered for Marsh, Mud, Sunny, Turbid, and North Lundsten Lakes. These lakes contained robust populations of bluegill sunfish during the study period, but are vulnerable to climatic extremes that may induce winterkill. Supplemental stocking of bluegill sunfish is likely not necessary because native fishes appear to readily repopulate all locations.
- The feasibility of winter aeration in the aforementioned lakes is unknown and should be determined. It is presently unclear whether aeration can prevent carp recruitment if it is only partially successful because the critical density of bluegill sunfish required to control carp eggs and larvae is unknown.
- In locations where aeration is not feasible or practical, barriers may be deployed in attempts to isolate nurseries from connected waters.
    - Simple physical barriers (e.g. fences or culvert screens) may be appropriate for sites with low discharge, little debris, and well-defined channels. Simple physical barriers are already in place at the outlets of Stone and Zumbra Lakes to block access to Sunny Lake. The barrier at the Zumbra Lake outlet should be enhanced if Sunny Lake is not aerated as it is currently prone to flooding.
    - A simple physical barrier should be considered at the outlet of Crown College Pond to prevent access by carp from Parley Lake.
    - Specialized site-specific barriers would be required to isolate Marsh, Mud, North Lundsten, and/or South Lundsten Lake in the event that aeration is not feasible or practical. Barriers at these locations would need to be designed to accommodate moderate to high discharge rates, considerable amounts of debris, and the need to prevent carp movement in upstream, downstream, or both directions.

- In locations where neither aeration nor isolation is feasible, recruitment prevention may not be possible, but recruitment mitigation may be possible. This may be accomplished through whole-lake manipulations such as water drawdowns or poisonings to eliminate existing juvenile carp before they disperse to connected waters.
    - This type of strategy could be considered to address the 2015 year class in South Lundsten Lake that recruited during the study period. Alternatively, these fish could be removed as adults throughout the Auburn-Lundsten-Turbid management unit in the future (see Section 3.2.2).
- As recruitment suppression management actions are implemented, there will be a need for ongoing monitoring of carp recruitment (see Section 3.3)
- Emergency response contingency plans should be developed to be able to respond quickly to unplanned events such as aeration failure.

3.2 Strategies to reduce the biomass of adult carp

Once recruitment is under control, it is reasonable to remove adult carp with the goal of reducing carp biomass below damaging levels (i.e. 100 kg/ha). Based on multiple electrofishing surveys conducted across the subwatershed over three years, it is clear that there are locations that both warrant and do not warrant adult carp removal to meet a carp biomass target of 100 kg/ha (See Table 2). The only lakes that will likely not require any adult carp removal are Piersons, Stone, and Kelzer's. The total abundance of carp in the Six Mile Creek subwatershed is approximately 130,459 individuals with an average weight of 3.63 kg for a total biomass of 491 kg/ha. This estimate should be considered slightly conservative because it only applies to the 15 study lakes that were accessible with electrofishing boat and thus excludes Marsh, Carl Krey, Church, Big SOB, Crown, and Wassermann Pond West although numbers of resident adult carp in these locations are expected to be minimal. The Six Mile Creek subwatershed would need an overall reduction of 80% of its existing adult carp biomass (roughly 100,000 individuals) in order to meet a target threshold of 100 kg/ha. Specific carp removal goals for each management unit (see Table 9) and possible strategies to achieve them are discussed below (Sections 3.2.1-3.2.4) after a brief overview of carp removal options.

There are multiple different strategies to reduce carp abundance, each with its own strengths, weaknesses, and limitations. These strategies are not mutually-exclusive and can often be employed in combination. Under-ice commercial seining can be a useful strategy to remove large numbers of carp with very little non-target impacts. The feasibility and success of seining depends on ice conditions, substrate conditions at the aggregation site, bathymetry at the aggregation site, as well as the level of commercial fishing expertise and funds available (the relative cost of removing fish increases as their number decreases). It is very likely that multiple systematic seining attempts over many years will be necessary to significantly reduce existing adult biomass in most locations. Where seining is not possible or practical, trapping and removal of spawning migrants may be another viable management strategy. For example, this method has been very successful in removing adult carp from Piersons Lake where roughly 4,000 carp have been removed at the outlet to Marsh Lake (Wenck 2013), bringing the current estimated carp biomass below 100 kg/ha. High rates of carp movement have been observed in Six Mile Creek between Halsted's Bay and Mud Lake, between Mud and Parley Lakes, between West Auburn and North Lundsten Lakes, and between East Auburn and West Auburn. Bidirectional traps in these locations could be very effective in removing large numbers of migrating carp. Another option for removing carp is via baited traps such as box nets baited with corn. This method is useful when natural aggregations do not occur or when carp abundance is low because it can induce carp to aggregate in a desired location by training them to come to a food source (Bajer et al. 2010). This method only works during the summer and fall when carp are actively feeding and requires several days of baiting to induce an aggregation. Average harvest rates depend on net size and food availability, but catch rates of roughly a few hundred individuals can typically be expected. It is also possible to reduce carp numbers by inducing whole lake fish kills through water level drawdown and freeze out or by using poisons such as rotenone. These strategies are often the most economical, but also have the greatest impacts to non-target species. There are also some emerging technologies currently under development such as species-specific fish toxin delivery systems and engineered diseases, but these methods will likely not be available for use in natural systems for decades.

3.2.1 Piersons-Marsh-Wassermann

This management unit presently contains approximately 13,611 carp with a total biomass of 247 kg/ha. To achieve 100 kg/ha of carp, the sub-population would need to be reduced by 60% or 8,107 carp (Table 9). Because the carp biomass in Piersons Lake is already below 100 kg/ha, removal should occur in Wassermann Lake.

Removing 8,107 carp from Wassermann may be possible with a combination of techniques including seining, baited nets, and/or installing a one-way fish barrier at the outlet of Wassermann Lake. A large portion of these fish could be removed in a few successful seine hauls given the tendency of 100% of the radio-tagged carp to tightly aggregate in this lake from December through February. It should however be noted that under-ice seining has failed in Wassermann in the past apparently due to unfavorable substrate conditions in some portions of the lake (muck and debris). Repeated strategic seining attempts would likely be required and debris removal may also be necessary. A baited box net would likely be another viable option to remove carp from Wassermann Lake. It would be incredibly labor-intensive to remove ~8,000 carp using a box net, but it could be an efficient option if only a few thousand carp remained in the lake. The box net would need to be deployed in an area with sandy substrate (e.g. most of the eastern or southern shorelines). Another option to reduce the carp abundance in Wassermann Lake would be to install a one-way barrier at the outlet designed to let carp leave Wassermann, but not return (e.g. electric, velocity, or vertical drop barrier). Based on the annual movement rates of radio-tagged carp that left Wassermann to travel to Auburn or Lundsten Lakes downstream and then later returned, a roughly 22% reduction in carp abundance could be expected if reentry to Wassermann Lake was blocked. This type of barrier would have the added benefit of protecting Wassermann Lake from downstream recruitment inputs, but would also require the adult carp from Wassermann Lake to be removed from the system downstream in the Auburn-Lundsten-Turbid management unit. It is possible that a trap could be installed in conjunction with a one-way barrier to block reentry into Wassermann while also removing fish from the system. One example of an electric barrier paired with a trap that had success blocking and removing invasive sea lamprey is discussed in Johnson et al. (2016). This technology has not yet been tested on common carp.

3.2.2 Auburn-Lundsten-Turbid

This management unit presently contains approximately 20,802 carp with a total biomass of 286 kg/ha. To achieve 100 kg/ha of carp, the sub-population would need to be reduced by 65% or 13,527 carp (Table 9). Carp are distributed relatively evenly across these lakes and therefore all will need adult carp removal to achieve targets. Because carp move readily between East Auburn, West Auburn, North Lundsten, and South Lundsten, they cannot be managed independently. The number of carp in this sub-population will likely continue to increase given the ongoing recruitment observed in South Lundsten, including the 2015 year class. Because this sub-population is comprised of young, fast-growing carp, it likely has not been experiencing damaging levels of carp for long which might explain its relatively good water quality despite its high carp biomass. Removal of roughly 12,000 carp from Auburn and Lundsten Lakes combined along with another 1,500 carp from Turbid would be necessary to achieve targets.

In Auburn-Lundsten, under-ice seining is likely feasible in both East and West Auburns, but not in North or South Lundsten. Tight aggregations of 100% of radio-tagged carp formed in West Auburn from January through February and in East Auburn from December through February. Under-ice seining may not be feasible in Lundsten Lake due to limited access and its shallow depth with dense vegetation growth. In addition to seining, trapping carp that are migrating between West Auburn and North Lundsten could also be effective because an average of 43% of radio-tagged carp from East and West Auburn Lakes passed through this corridor annually (~4,500 carp). The site of the former riprap dam in the Carver Park Reserve might be a good location to trap carp in this corridor because the channel is restricted to a ~4 foot culvert. Baited box nets may be a useful tool to supplement removal in West Auburn Lake, but the substrate in East Auburn or either of the Lundstens is too mucky and not likely amenable to box-netting. Another possible option for reducing carp in Auburn-Lundsten would be to drawdown and freeze out North and South Lundsten if the North Lundsten outlet structure (aka Parley Lake Dam) could be operated to reduce water levels enough to promote winterkill. Whole-lake poisonings of South and North Lundsten could also be conducted (applying toxins in conjunction with a drawdown would reduce dosage requirements). These strategies could eliminate the resident adult population of carp in North and South Lundsten combined (~5,000 carp) as well as any juvenile carp that were present (e.g. the 2015 year class). In attempting whole-lake fish kills, precautions should be taken to avoid creating conditions that instead promote increased carp recruitment. For example, incomplete kills of adult carp or recolonization of adult carp before panfish populations rebound could create ideal carp spawning conditions.

Although Turbid Lake has the highest carp biomass (514 kg/ha) within the Auburn-Lundsten-Turbid management unit, it only contains 2,300 carp. A removal target of 1,500 carp is appropriate and could be achieved through under-ice seining, open water seining (a seine net could cover the vast majority of the lake due to its small size), or via baited box-netting along the sandy Eastern shoreline. Permission from a local landowner would be required for access.

3.2.3 Parley-Mud-Halsteds

This management unit presently contains approximately 85,759 carp with a total biomass of 981 kg/ha. To achieve 100 kg/ha of carp, abundance would need to be reduced by 90% or 77,014 individuals (Table 9). The biomass of carp is incredibly high in all three lakes and movement rates are also very high between all lakes. This management unit is complicated by its connection to the rest of Lake Minnetonka (an average of 22% of the carp radio-tagged in Parley, Mud, or Halsted's Bay moved to other bays of Lake Minnetonka annually) and presently cannot be managed independently from Lake Minnetonka. Because managing carp in Parley, Mud, and all of Lake Minnetonka combined is likely not realistic, these locations could be divided up into smaller management units using barriers to isolate portions of the system.

Parley and Mud Lakes could be isolated from Lake Minnetonka by installing a barrier between Mud Lake and Halsted's Bay. Carp in Parley and Mud Lakes are vulnerable to removal via under-ice seining because all of the radio-tagged carp from both lakes formed a single tight aggregation in Parley Lake during both years of the study. Additionally, there is a history of successful seining in Parley Lake as evidenced by 6,206 of 21,315 carp (29% of the total carp population in Parley-Mud) being captured in one seine haul in March of 2015 and tens of thousands of pounds of carp being captured and removed in the early 2000's (MN DNR Carver County commercial fishing records). It should be noted that most of the carp captured in the

2015 seine haul escaped back into Parley Lake as they were awaiting transport because the holding pens were vandalized. In addition to seining, carp could be removed from Parley and Mud Lakes by trapping spawning migrants at one or more locations. Carp could be removed in traps between Parley and Mud Lake, especially in late November/early December as carp leave Mud Lake to overwinter in Parley or in spring as carp return to Mud Lake after ice-out. An average of 81% of radio-tagged carp from Parley or Mud Lakes moved through this corridor annually. Additionally, carp from Parley and Mud could be removed between Mud Lake and Halsted's Bay if traps were installed in conjunction with the barrier recommended at this location. This barrier/trap system could be designed to remove carp moving in both directions which would reduce the numbers of carp in Halsted's Bay as well. An average of 47% of radio-tagged carp from Parley, Mud, or Halsted's Bay moved through this corridor annually during the study period.

If a barrier was installed between Mud Lake and Halsted's Bay as discussed above, Halsted's Bay could be managed with the rest of Lake Minnetonka. Given the high rates of carp movement between Halsted's Bay and other bays, it would need to be isolated from the rest of Lake Minnetonka to be managed for carp independently. Isolating Halsted's Bay from the other bays would be challenging given the need for a navigable channel between Halsted's and Priest's Bays. The only safe, available fish deterrence technology that would not impede boat traffic would be a Bio-Acoustic Fish Fence system (BAFF; http://www.fish-guide.com/baff-system.html). A BAFF system optimized to deter carp is currently being designed and tested by the Sorensen Lab group at the UMN. This type of system would likely work best installed at an angle to deflect carp into traps versus as a cross-stream barrier to impede movement. If Halsted's Bay could be successfully isolated from the rest of Lake Minnetonka, carp could be removed via seining, stream traps, or baited box nets although box nets would be impractical until carp abundance was drastically reduced.

3.2.4 Carver Park Reserve Lakes

This management unit presently contains approximately 10,247 carp with a total biomass of 180 kg/ha. To achieve 100 kg/ha of carp, abundance would need to be reduced by 45% (Table 9). Because the lakes in this management unit (i.e. Steiger, Zumbra, Sunny, and

Stone) each contain their own sub-population of carp, adult removal strategies can be implemented independently. In Stone Lake, carp biomass is already below the target threshold and immigration of new carp is prevented by a barrier at the outlet, so no carp removal is necessary. Modest amounts of carp removal would be required to meet the 100 kg/ha target in Steiger, Zumbra, and Sunny Lakes (approximately 1000, 3000, and 400 individuals, respectively).

In Steiger Lake, because the radio-tagged carp never formed winter aggregations during the study period, under-ice seining is probably not feasible. A baited box net could likely be used to remove ~1,000 carp in just a few good hauls. Preliminary baiting experiments conducted in Steiger Lake by Drs. Ratna Ghosal and Jessica Eichmiller of the UMN as part of an unrelated study demonstrated that 23 of 25 (92%) radio-tagged common carp aggregated by a corn baiting station within 7 days (Ghosal, Eichmiller, et al., in prep). In Zumbra Lake, 3,000 carp could be removed via under-ice seining or baited box nets. The radio-tagged carp in Zumbra Lake formed tight winter aggregations in the Northwest bay from January through February in both years of the study. In Sunny Lake, adult carp removal would be difficult due to limited access, mucky substrate, and dense coontail growth.

3.2.5 Summary of adult removal strategies

- To meet a target carp biomass threshold of 100 kg/ha, removal of adult carp is necessary in all locations throughout the subwatershed except Piersons Lake, Stone Lake, and Kelzer's Pond.
- Removal methods are not mutually-exclusive; implementing a combination of methods over several years or possibly decades will likely be required to achieve biomass targets system-wide.
- Whenever possible and practical, the most efficient way to remove carp without severely impacting non-target species is to exploit naturally occurring aggregations of carp such as winter aggregations or spawning migrations.
    - Targeting winter aggregations via under-ice commercial seining may be feasible in Wassermann, East Auburn, West Auburn, Turbid, Zumbra, Parley, and Halsted's Bay.

    - Targeting migrating carp using stream traps may be feasible in the corridors between Wassermann and East Auburn, West Auburn and North Lundsten, Parley and Mud, Mud and Halsted's Bay, and Halsted's Bay and Preist's Bay.
- If aggregations do not occur naturally or if individuals are in low abundance, it may be possible to induce targetable aggregations via baiting.
    - Removing carp via baited box nets may be feasible in Wassermann, West Auburn, Turbid, Steiger, Zumbra, Parley, and Halsted's Bay.
- When physical removal of adults is not possible or practical, whole-lake manipulations to eliminate fish such as water drawdowns or poisonings could be considered.

3.3 Monitoring recommendations

When implementing management strategies using an adaptive management approach, ongoing monitoring is necessary to measure progress and evaluate success. In terms of carp management in the Six Mile Creek subwatershed, it will be necessary to monitor all putative carp nurseries (i.e. Marsh, South Lundsten, North Lundsten, Turbid, Sunny, Mud, and Crown) for successful recruitment and to monitor carp biomass levels as adults are removed.

To monitor carp recruitment, winter dissolved oxygen in all putative carp nurseries should be measured monthly every year and visual observations for fish carcasses should be conducted each spring immediately following ice-out. Monitoring dissolved oxygen content is especially important in the event that aeration systems are installed. If any signs of winterkill are observed (i.e. dissolved oxygen <1.5 mg/L, fish carcasses present), standardized trap-net surveys should be carried out in the spring to assess bluegill sunfish survival and in the fall to assess YOY carp production and bluegill sunfish recolonization. In the event that putative nurseries are isolated with barriers, regular visual observations at barrier sites should be conducted throughout the open water season and after all rainfall events. In the event that a barrier is breached, fall trap-net surveys should be conducted in all relevant nurseries to assess YOY carp production.

To monitor adult carp biomass, boat electrofishing surveys should be conducted following the protocols established in Bajer and Sorensen (2012). Adult carp biomass should be monitored as needed in the event of successful recruitment causing population growth or to verify population decline as a result of management actions (e.g. winter seining, stream trapping, box netting, poisoning). Additionally, where adult carp removal is successful, MCWD should be prepared to monitor the response of aquatic plants and nutrients.

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Tables & Figures

Table 1. Overview of study design -- Attributes of study lakes in the Six Mile Creek Subwatershed and available sampling data collected by the University of Minnesota. X's denote sampling that has occurred each year and asterisks (*) denote sampling conducted by MCWD staff.

Location	Surface Area (ac)	Max Depth (ft)	Electrofishing Survey			Trapnet Survey			Aging Studies			Radio Telmetry (# of Tags)	Winter Dissolved Oxygen*
			2014	2015	2016	2014	2015	2016	2014	2015	2016		
Halsted's Bay	552	30	X	X	X		X	X	X			15	
Mud	144	6	X	X	X	X	X	X	X			15	X
Parley	257	19	X	X	X	X	X	X	X			15	
Crown College	6	3				X	X	X					
Big SOB	7.5	25			X	X	X	X					X
Yetzer's Pond	12	2				X							
N. Lundsten	114	7	X	X	X	X	X	X		X		5	X
S. Lundsten	77	9	X	X	X	X	X	X				5	X
Turbid	40	35	X	X	X	X	X	X			X	5	
Lake #2	36	N/A				X							
W. Auburn	145	80	X	X	X	X	X	X		X		7	
E. Auburn	148	40	X	X	X	X	X	X		X		8	
Shady Pond	0.5	>5				X	X	X					X
Sunny	48	N/A	X	X	X	X	X	X				3	X
Zumbra	193	50	X	X	X	X	X	X			X	7	
Stone	99	30	X	X	X	X	X	X					
Steiger	166	37	X	X	X	X	X	X			X	10	
Kelzer's	21	34	X	X	X	X	X	X					X
Church	16	54					X	X					X
Carl Krey	50	16				X	X	X					X
Wassermann	164	41	X	X	X	X	X	X		X		15	
N. Wassermann Pond	6	27											X
S. Wassermann Pond	13.3	27											X
W. Wassermann Pond	6.5	18					X	X					X
Marsh	143	5				X	X	X					X
Piersons	297	40	X	X	X	X	X	X		X		10	

Table 2. Attributes of 15 assessable study lakes, mean catch rates of common carp from whole-lake boat electrofishing surveys (CPUE), and resulting estimates of carp abundance and biomass in the Six Mile Creek Subwatershed. Electrofishing surveys were conducted between June and October and are shown for 2014 alone (top) and 2014, 2015, and 2016 combined (bottom).

2014

Lake Name	Area (ha)	# of Surveys	CPUE (SE) (# / hr)	Abundance, mean (95%CI)	Average Weight (kg)	Biomass (kg/ha) (95%CI)
Halsted's Bay	223.4	4	61.3 (4.6)	65,225 (55,803-74,646)	3.74	1,093 (935-1,251)
Mud	37.6	6	26.3 (5.2)	4,782 (2,969-6,595	3.89	495 (307-683)
Parley	104.4	6	30.4 (1.6)	15,265 (13,709-16,820)	3.51	513(461-566)
North Lundsten	43.7	2	21.3 (9.2)	4,515 (795-8,234)	1.98	204 (36-372)
South Lundsten	29.9	1	9.7 (NA)	1,268 (NA)	2.29	97 (NA)
West Auburn	53.8	3	31.3 (3.1)	8,097(6,552-9,641)	1.92	290 (234-345)
East Auburn	46.9	3	36.6 (12.6)	8,237 (2,761-13,712)	1.84	323 (108-538)
Turbid	16.2	2	29.4 (2.1)	2,290 (1,983-2,597)	3.09	436 (378-495)
Wassermann	66.0	4	38.4 (5.2)	12,141 (8,956-15,326)	3.01	555 (409-700)
Piersons	120.1	5	3.6 (0.7)	2,400 (1,661-3,140)	3.33	66 (46-87)
Steiger	67.1	4	9.5 (3.3)	3,214 (1,175-5,254)	3.24	155 (57-254)
Sunny	19.4	1	2.8 (NA)	314 (NA)	2.61	42 (NA)
Zumbra	89.4	4	8.7 (1.8)	3,931 (2,472-5,390)	2.46	108 (68-148)
Stone	39.3	1	4.4 (NA)	924 (NA)	4.40	104 (NA)
Kelzer's	8.0	1	2.5 (NA)	118 (NA)	4.77	70 (NA)
All Six Mile	**965.2**	**47**		**132,721**	**3.01**	**414**

2014-2016 Combined

Lake Name	Area (ha)	# of Surveys	CPUE (SE) (# / hr)	Abundance, mean (95%CI)	Average Weight (kg)	Biomass (kg/ha) (95%CI)
Halsted's Bay	223.4	9	60.6 (3.2)	64,441 (57,769-71,113)	4.38	1,264 (1,133- 1,394)
Mud	37.6	10	28.4 (3.3)	5,148 (4,019-6,277)	4.12	564 (440-687)
Parley	104.4	10	32.2 (1.2)	16,167 (14,987-17,348)	4.02	623 (577-668)
North Lundsten	43.7	7	12.9 (3.1)	2,793 (1,557-4,029)	2.56	164 (91-236)
South Lundsten	29.9	4	16.5 (3.8)	2,414 (1,354-3,474)	2.54	204 (115-295)
West Auburn	53.8	9	27.8 (1.9)	7,201 (6,267-8,136)	2.33	311 (271-352)
East Auburn	46.9	10	27.0 (3.9)	6,121 (4,421-7,820)	1.94	253 (183-323)
Turbid	16.2	8	29.2 (1.5)	2,273 (2,051-2,496)	3.66	514 (464-564)
Wassermann	66.0	10	31.6 (3.1)	10,031 (8,149-11,912)	3.44	523 (425-621)
Piersons	120.1	11	5.7 (0.8)	3,580 (2,644-4,516)	3.32	99 (73-125)
Steiger	67.1	10	8.5 (1.6)	2,886 (1,915-3,857)	3.62	156 (103-208)
Sunny	19.4	4	10.1 (3.3)	981 (398-1,565)	3.26	165 (67-263)
Zumbra	89.4	10	13.5 (1.6)	5,953 (4,630-7,276)	2.99	199 (155-243)
Stone	39.3	5	1.7 (0.9)	427 (108-746)	4.77	52 (13-91)
Kelzer's	8.0	5	0.5 (0.4)	43 (11-74)	4.77	26 (7-45)
All Six Mile	**965.2**	**122**		**130,459**	**3.63**	**491**

Table 3. Summary of radio-tagged common carp movement patterns across the Six Mile Creek subwatershed over the 2 year study period. Year 1 is from November 2014 to October 2015 and Year 2 is from November 2015 to October 2016. Movement rates (% living radio-tagged carp that moved from where they were originally tagged [origin] to any other location [destination]) are shown for each year, each movement path, and both directions. The average annual movement rates are reported here and are shown for each movement path on a map in Figure 30.

Movement Path: origin to destination **↔: moved there and back** **→: Move there & stayed or died**	**% radio-tagged carp that moved**			**Timing**
	Year 1	**Year 2**	**Annual Avg.**	
Wassermann ↔ East Auburn	7%	27%	17%	left May-June, returned July-Sept
Wassermann ↔ South Lundsten	0%	9%	5%	left June, was most of the way back in Oct 2016
Auburns/Lundstens ↔ Wassermann	0%	0%	0%	
East Auburn ↔ West Auburn	63%	88%	75%	Throughout open water season
West Auburn ↔ East Auburn	57%	86%	71%	Throughout open water season
Auburns ↔ Lundstens	27%	33%	30%	left May-June, returned June-July
Auburns → Lundstens	0%	27%	13%	left May-June, died in June-Aug
Lundstens ↔ Auburns	0%	0%	0%	
North Lundsten ↔ South Lundsten	25%	67%	46%	left May, returned June
South Lundsten ↔ North Lundsten	20%	0%	10%	left Nov, returned May
Parley ↔ Mud	73%	56%	64%	Throughout open water season
Parley → Mud	13%	11%	12%	Throughout open water season
Mud ↔ Parley	100%	62%	81%	Left Dec, returned April-June
Mud → Parley	0%	8%	4%	Left Nov, stayed in Parley
Parley/Mud ↔ Halsted	13%	32%	23%	Left May-June, returned July-Oct
Parley/Mud → Halsted	23%	18%	21%	Left June-August
Hasted↔ Parley/Mud	33%	50%	42%	Left May-June, returned July-Oct
Hasted → Parley/Mud	13%	0%	7%	Left May-June
Parley/Mud/Halsted's ↔ Greater Minnetonka	11%	21%	16%	Year-round
Parley/Mud/Halsted's → Greater Minnetonka	9%	3%	6%	Year-round

Table 4. Summary of winter aggregation occurrence and timing in the Six Mile Creek study lakes from November 2014 through March 2016. An aggregation is defined as when at least 50% of radio-tagged carp were confined to an area of less than 10 hectares. Note that radio-tags were implanted in four additional lakes in spring of 2015.

Location	Year	November	December	January	February	March
Halsted's Bay	2014-15				x	
	2015-16		x		x	
Mud	2014-15					
	2015-16					
Parley	2014-15		x	x	x	x
	2015-16			x	x	x
N. Lundsten	2014-15	NA	NA	NA	NA	NA
	2015-16		x	x	x	x
S. Lundsten	2014-15	NA	NA	NA	NA	NA
	2015-16	x	x	x	x	x
W. Auburn	2014-15			x	x	
	2015-16			x	x	
E. Auburn	2014-15	x	x	x	x	x
	2015-16		x	x	x	
Zumbra	2014-15			x	x	x
	2015-16			x	x	
Sunny	2014-15	NA	NA	NA	NA	NA
	2015-16		x	x	x	x
Steiger	2014-15					
	2015-16					
Wassermann	2014-15		x	x	x	
	2015-16		x	x	x	x
Turbid	2014-15	NA	NA	NA	NA	NA
	2015-16		x	x	x	x
Piersons	2014-15	x	x	x	x	x
	2015-16				x	x

Table 5. Catch rates of young-of-year (YOY) and age-1 carp from standardized trap-net surveys conducted in the Six Mile Creek subwatershed. Asterisks (*) denote catch rates from gill net surveys. NS denotes locations that were not sampled that year.

Location	YOY carp catch rate (#/net)			Age-1 carp catch rate (#/net)		
	2014	2015	2016	2014	2015	2016
Halsted's Bay	NS	0.0	0.0	NS	0.0	0.0
Mud	0.2	0.0	0.0	0.0	0.0	0.0
Parley	0.0	0.0	0.0	0.0	0.0	0.0
Crown College	1.0	332.3	0.0	0.0	0.0	2.3
Big SOB	19.8	0.0	0.0	0.0	1.8	0.0
Yetzer's Pond	0.0	NS	NS	0.0	NS	NS
N. Lundsten	0.0	3.2	0.0	0.0	0.0	0.0
S. Lundsten	0.0	311.2	0.0	0.0	0.0	0.4
Turbid	0.0	0.0	0.0	0.0	0.0	0.0
Lake #2	0.0	NS	NS	0.0	NS	NS
W. Auburn	0.0	0.0	0.0	0.0	0.0	0.0
E. Auburn	0.0	0.0	0.0	0.0	0.0	0.0
Shady Pond	0.0	0.0	0.0	0.7	0.0	0.0
Sunny	0.0	0.0	0.0	0.0	0.0	0.0
Zumbra	0.0	0.0	0.0	0.0	0.0	0.0
Stone	0.0	0.0	0.0	0.0	0.0	0.0
Steiger	0.0	0.0	0.0	0.0	0.0	0.0
Kelzer's	0.0	0.0	0.0	0.0	0.0	0.0
Church	NS	0.0	0.0	NS	0.0	0.0
Carl Krey	0.0	0.0	0.0	2.0*	0.0	0.0
Wassermann	0.0	0.2	0.0	0.0	0.0	0.0
Wassermann Pond W.	NS	0.0	0.0	NS	0.3	0.0
Marsh	0.0	0.0	0.0	0.0	0.0	0.0
Piersons	0.0	0.0	0.0	0.0	0.0	0.0

Table 6. Catch rates (#/net) of bluegill sunfish from standardized annual fall trap-net surveys conducted in the Six Mile Creek subwatershed from 2014 to 2016. Asterisks (*) denote catch rates from gill net surveys. NS denotes locations that were not sampled that year.

Location	**Bluegill Catch Rate (# /trapnet)**		
	2014	**2015**	**2016**
Halsted's Bay	NS	122.0	94.2
Mud	84.0	32.8	132.8
Parley	19.2	38.4	25.0
Crown College	0.6	1.3	22.0
Big SOB	32.6	52.0	107.6
Yetzer's Pond	0.0	NS	NS
N. Lundsten	38.0	113.2	109.0
S. Lundsten	17.4	34.2	68.8
Turbid	32.8	81.4	47.6
Lake #2	0.0	NS	NS
W. Auburn	29.4	203.0	66.2
E. Auburn	55.2	74.2	122.8
Shady Pond	6.9	0.0	0.0
Sunny	38.0	45.6	59.6
Zumbra	12.7	128.6	55.8
Stone	0.0	0.0	0.0
Steiger	20.6	90.5	98.2
Kelzer's	23.2	75.7	103.3
Church	NS	0.0	0.0
Carl Krey	15.0*	98.2	101.3
Wassermann	12.5	96.0	67.5
Wassermann Pond W.	NS	0.0	0.2
Marsh	131.4	113.5	108.6
Piersons	24.0	102.0	54.8

Table 7. Dissolved oxygen maxima (mg/L) measured by Minnehaha Creek Watershed District staff in select study sites in the Six Mile Creek subwatershed. Measurements were taken in late February just beneath the ice surface at approximately the deepest point in the waterbody. “NS” denotes locations that were not sampled that year; “Frozen” denotes locations that were frozen solid to the bottom.

Location	Dissolved oxygen (mg/L)	
	2015	2016
Marsh	12.9	9.4
Turbid	5.7	NS
Carl Krey	9.9	8.9
Crown College	Frozen	1.9
Mud	6.1	9.4
South Lundsten	1.5	10.0
North Lundsten	1.6	NS
Sunny	0.9	NS
Shady	0.8	NS
Wassermann Pond West	1.3	3.8
Kelzer's	7.2	NS
Church	1.6	NS

Table 8. An overview of possible barrier options to deter the movements of fishes. The upper panel is a summary of non-physical barriers from table 1 in Noatch & Suski (2012). The lower panel is a summary of physical barriers generated for this report.

Table 1. Summary of different non-physical barriers that could be implemented to deter the movements of fishes. Also listed are deployment conditions where barriers are likely to be successful, advantages and disadvantages of different barrier types, and representative citation showing the barrier in use.

Barrier/Deterrent	Deployment conditions	Advantages	Disadvantages	Relevant citations
Electricity	Site with adequate power source; appropriate water conductivity	Flexible deployment, very effective against recruited fish	May not affect smaller fish	Bullen and Carlson 2003; Savino et al. 2001; Clarkson 2004
Strobe lights	Consistent low water turbidity	Less infrastructure, potentially lower cost	Lower effectiveness, especially in daytime	Johnson et al. 2005*a*; Hamel et al. 2008
Sound (AFD)	Site with adequate acoustic characteristics	Effective across a wide range of environmental conditions	Variable effectiveness; frequencies must be chosen per species	Maes et al. 2004; Sonny et al. 2006
Bubble curtains	Low water turbidity, relatively shallow water	Few as a stand-alone deterrent; may enhance other deterrents	Low effectiveness, may not work under all conditions	Patrick et al. 1985; Stewart 1981
Water velocity	Target species that is a weak swimmer; narrow channel with adequate water flow	Selectively excludes nuisance species	Major modification to channel; few sites meet criteria	Hoover et al. 2003; Katopodis et al. 1994
Hypoxia and hypercapnia	Relatively shallow water, space needed for bulk gas storage	Potential to exclude virtually all fish	Large investment of research time and capital	
Pheromones	Confined spaces and (or) short term application	Potential to selectively exclude particular fish	Time and effort to procure pheromones in bulk quantity	Little and Calfee 2006; Johnson et al. 2005*b*
Chlorine	Highly constricted deployment space	Potential to exclude virtually all fish	Deleterious to almost all aquatic fauna; negative public perception	Giattina et al. 1981; Wilde et al. 1983
Electromagnetism	Constricted areas, choke points	Cost effective, low environmental impact	May not work on all teleost fishes	Northcutt et al. 1994; Gibbs and Northcutt 2004

Barrier	Deployment conditions	Advantages	Disadvantages
Fence or screen	Low discharge & minimal debris	Can be highly effective, cost effective	Requires regular cleaning, not species-specific
Vertical drop/dam	Sufficient vertical relief	Can be highly effective	Only deters upstream movement, may require major modification to channel, not species-specific

Table 9. Common carp abundance and biomass for all Six Mile Creek Lakes combined and broken down by management unit. Also included is the number and percent of carp required to be removed in order to meet the 100 kg/ha biomass threshold.

Management Unit	Surface area (ha)	Total carp abundance	Mean carp weight (kg)	Mean carp biomass (kg/ha)	# Carp removal required to achieve 100 kg/ha	% carp removal required to achieve 100 kg/ha
All Six Mile Creek Study Lakes	965.2	130,459	3.63	491	103,869	80%
Piersons-Wassermann	186.0	13,611	3.38	247	8,107	60%
Auburn-Lundsten-Turbid	190.6	20,802	2.62	286	13,527	65%
Parley-Mud-Halsted	365.4	85,759	4.18	981	77,014	90%
Carver Park Reserve Lakes	215.2	10,247	3.79	180	4,568	45%

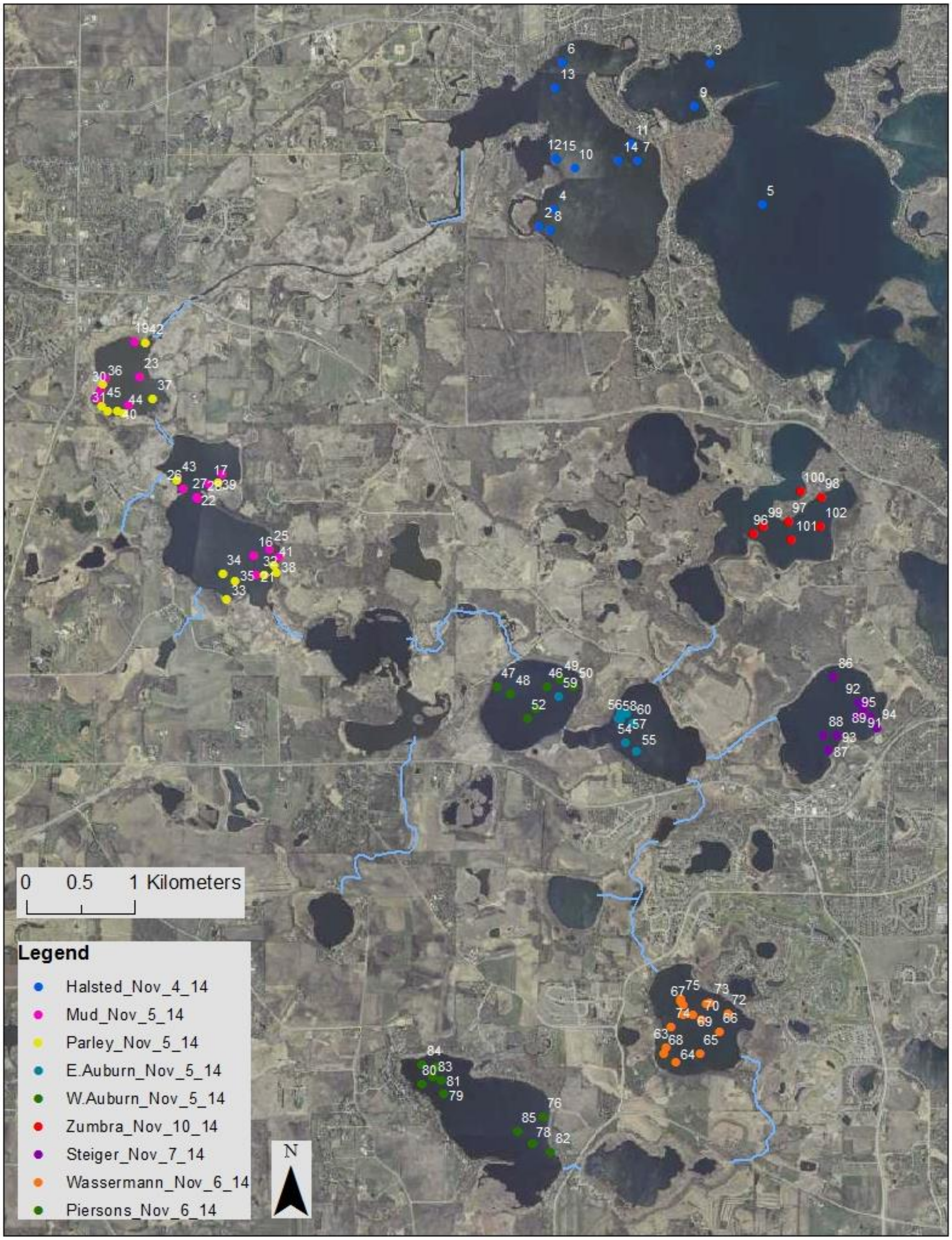

Figure 2. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in November 2014. Individuals are labeled with unique identification numbers (white).

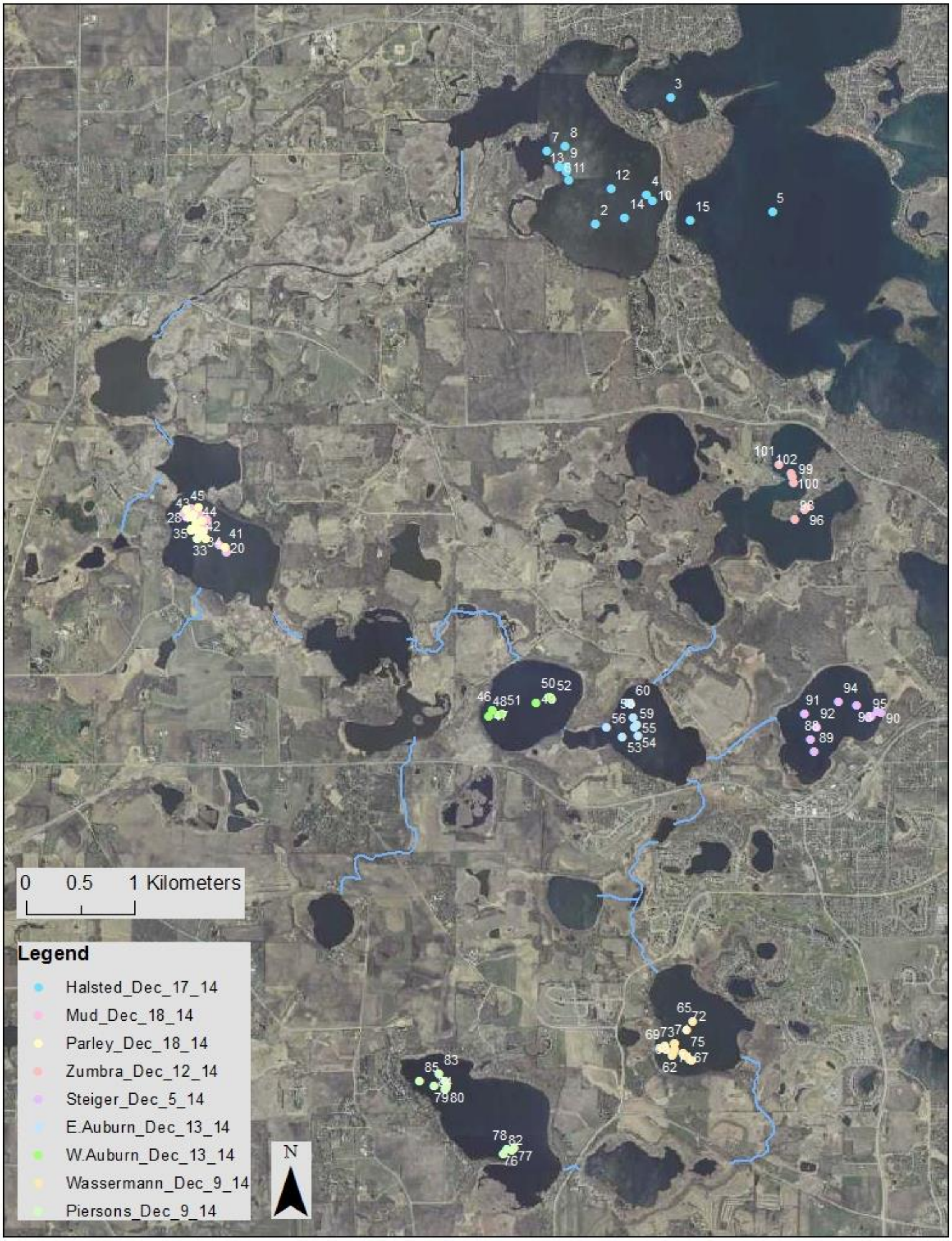

Figure 3. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in December 2014. Individuals are labeled with unique identification numbers (white).

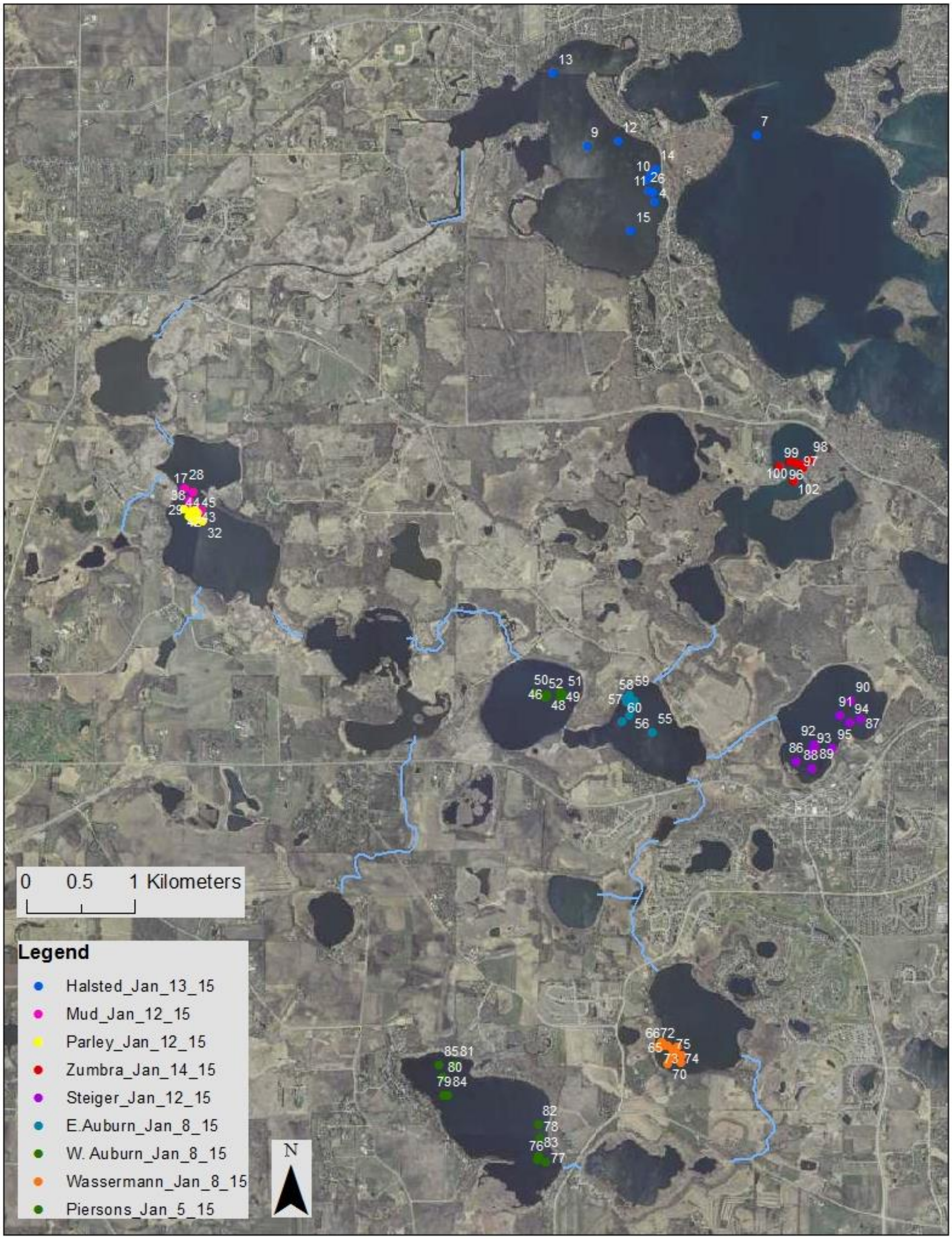

Figure 4. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in January 2015. Individuals are labeled with unique identification numbers (white).

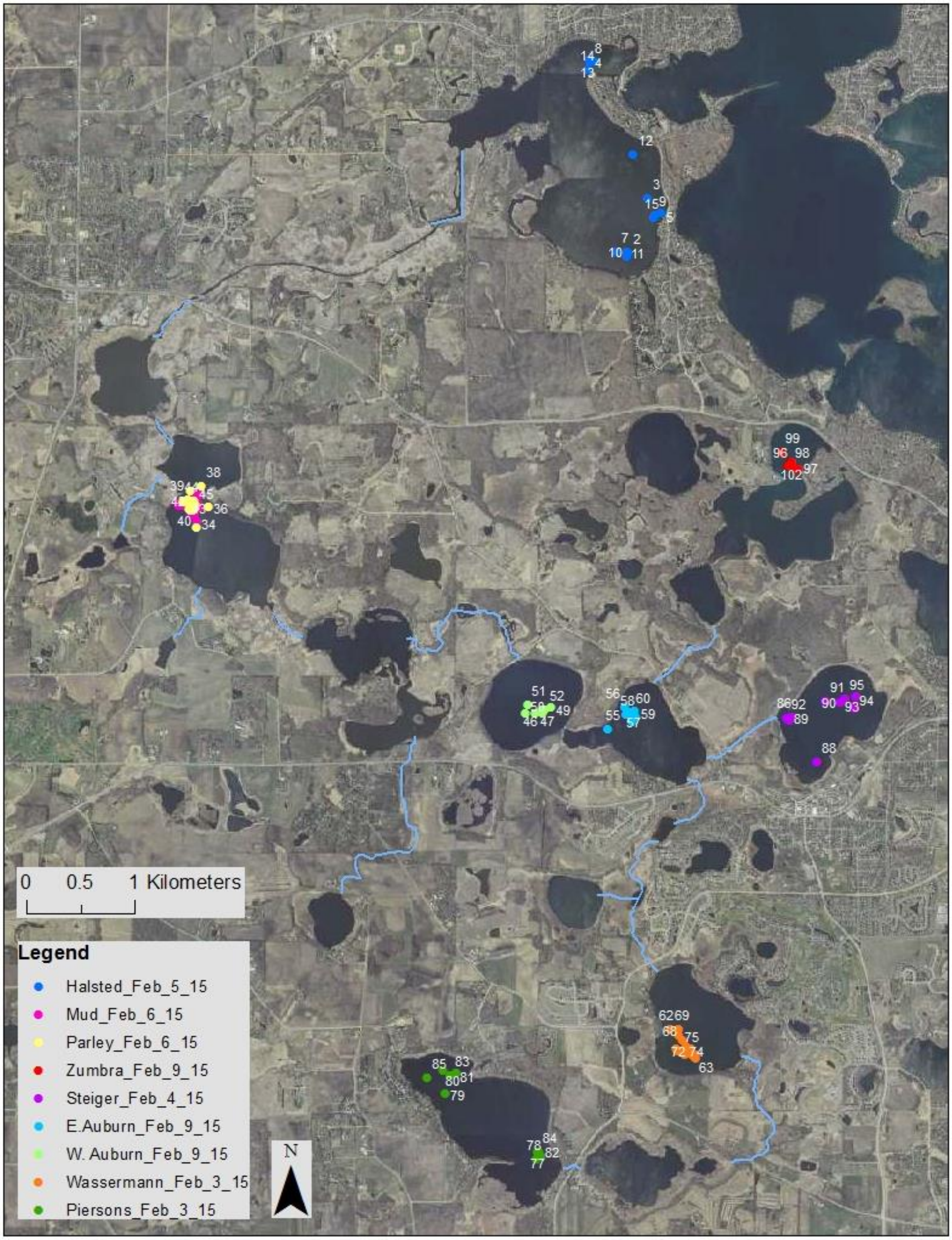

Figure 5. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in February 2015. Individuals are labeled with unique identification numbers (white).

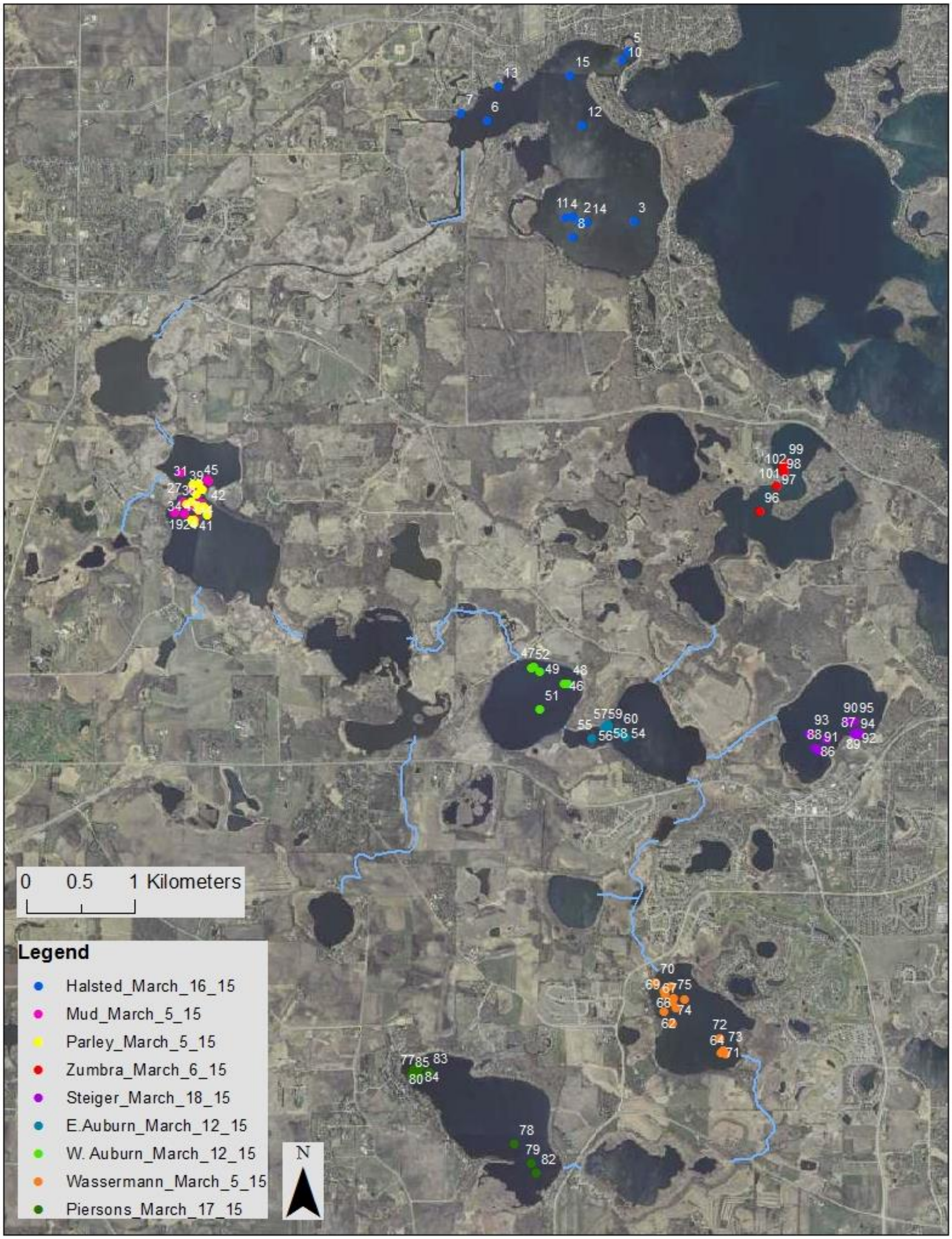

Figure 6. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in March 2015. Individuals are labeled with unique identification numbers (white).

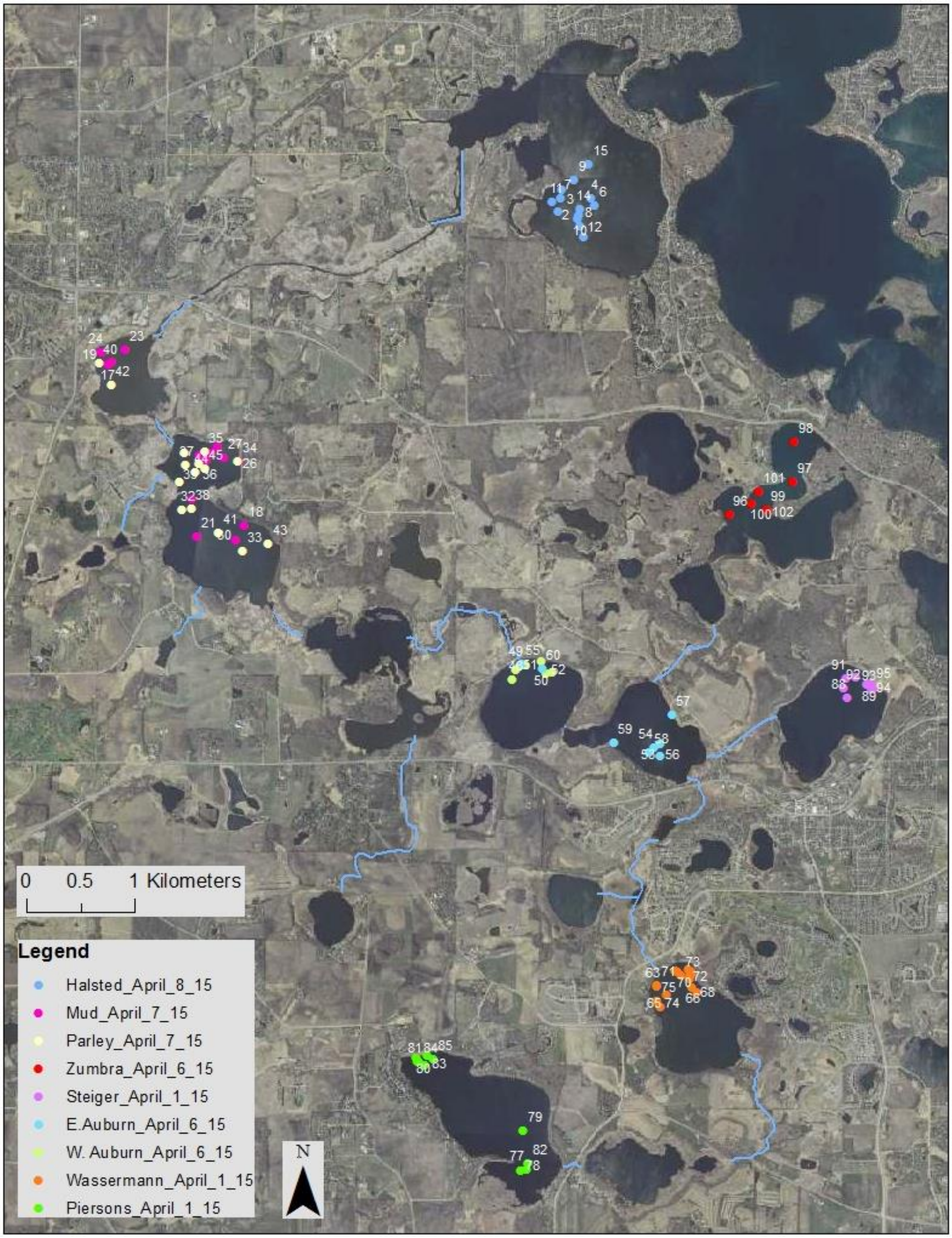

Figure 7. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in early April 2015. Individuals are labeled with unique identification numbers (white).

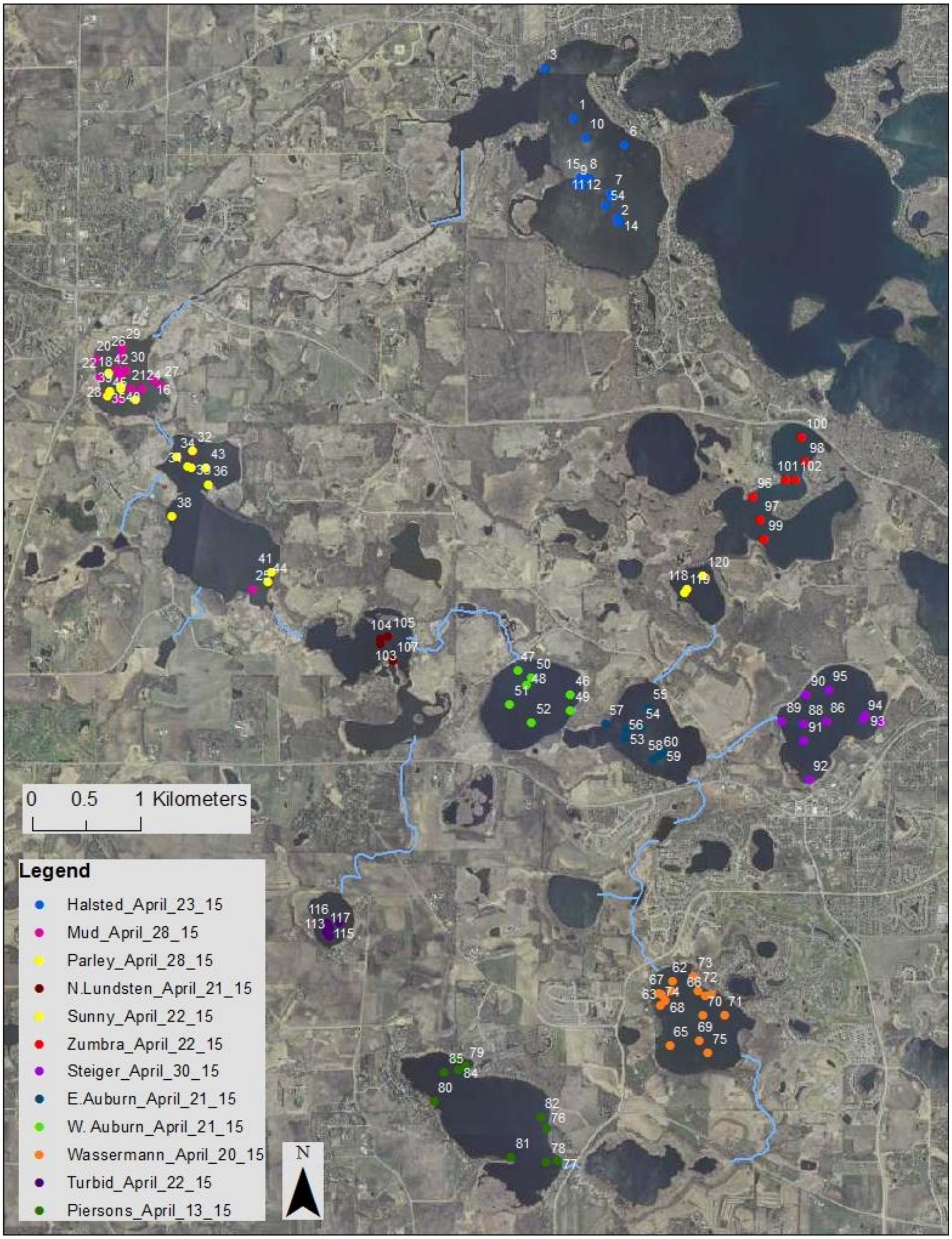

Figure 8. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in late April 2015. Individuals are labeled with unique identification numbers (white).

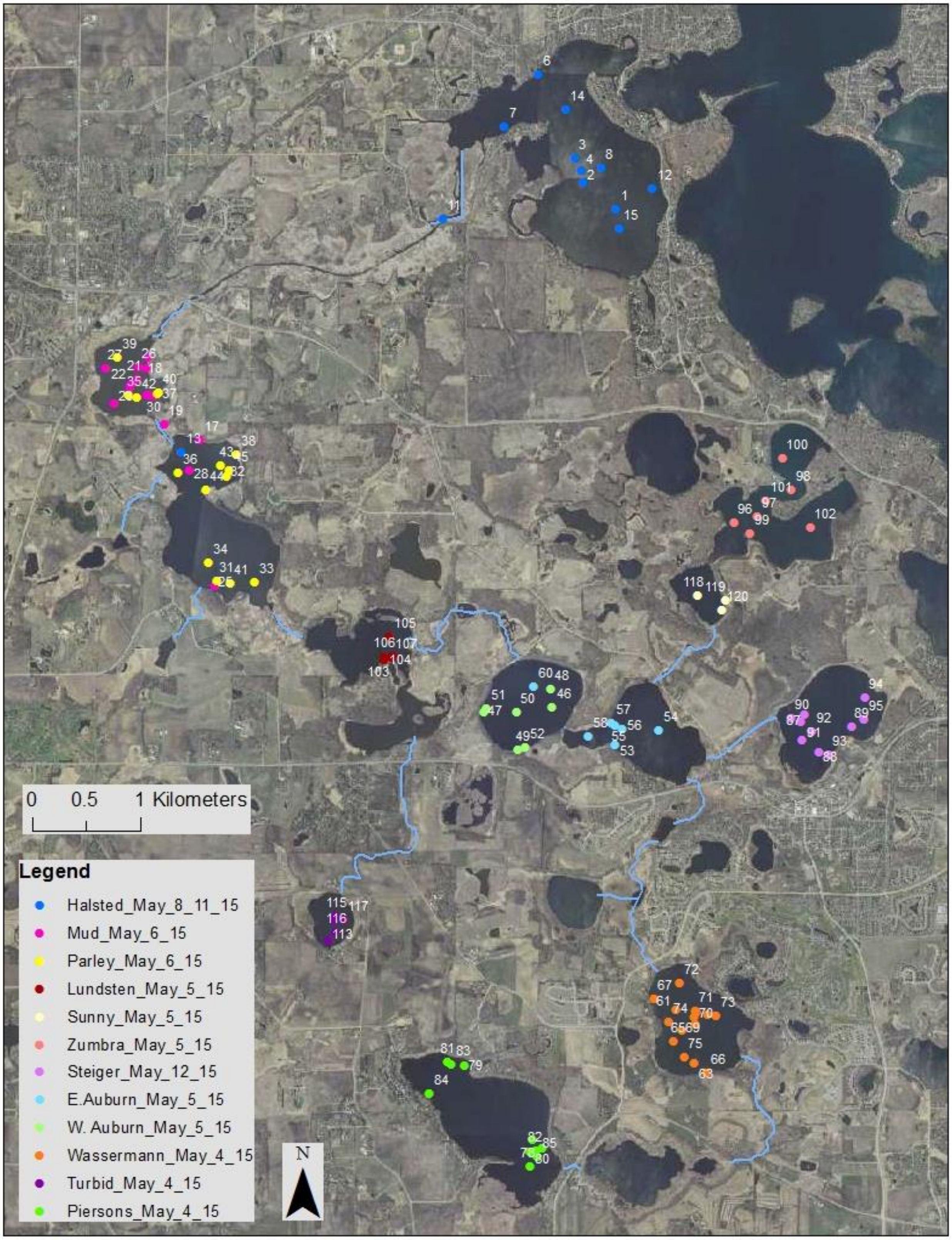

Figure 9. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in early May 2015. Individuals are labeled with unique identification numbers (white).

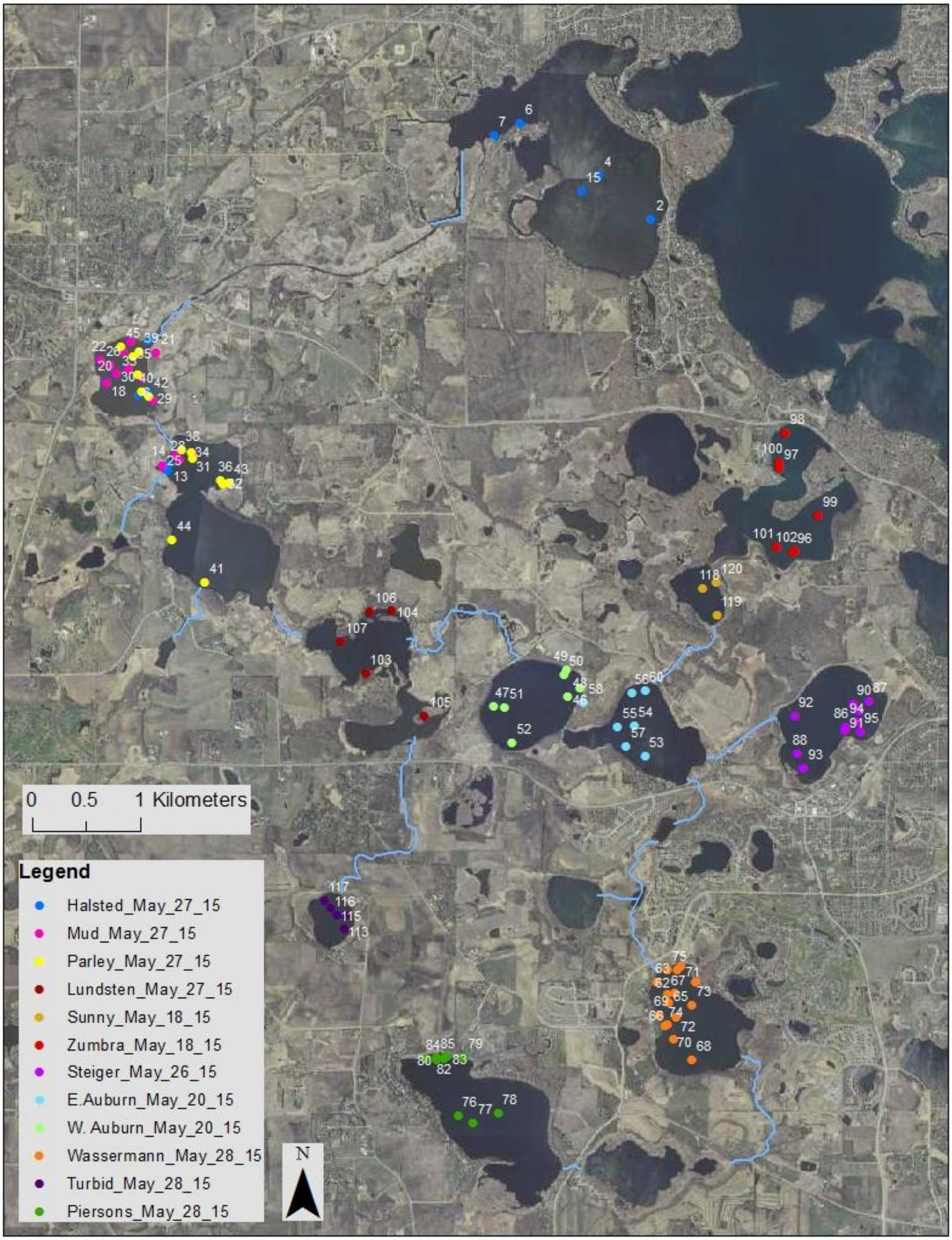

Figure 10. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in late May 2015. Individuals are labeled with unique identification numbers (white).

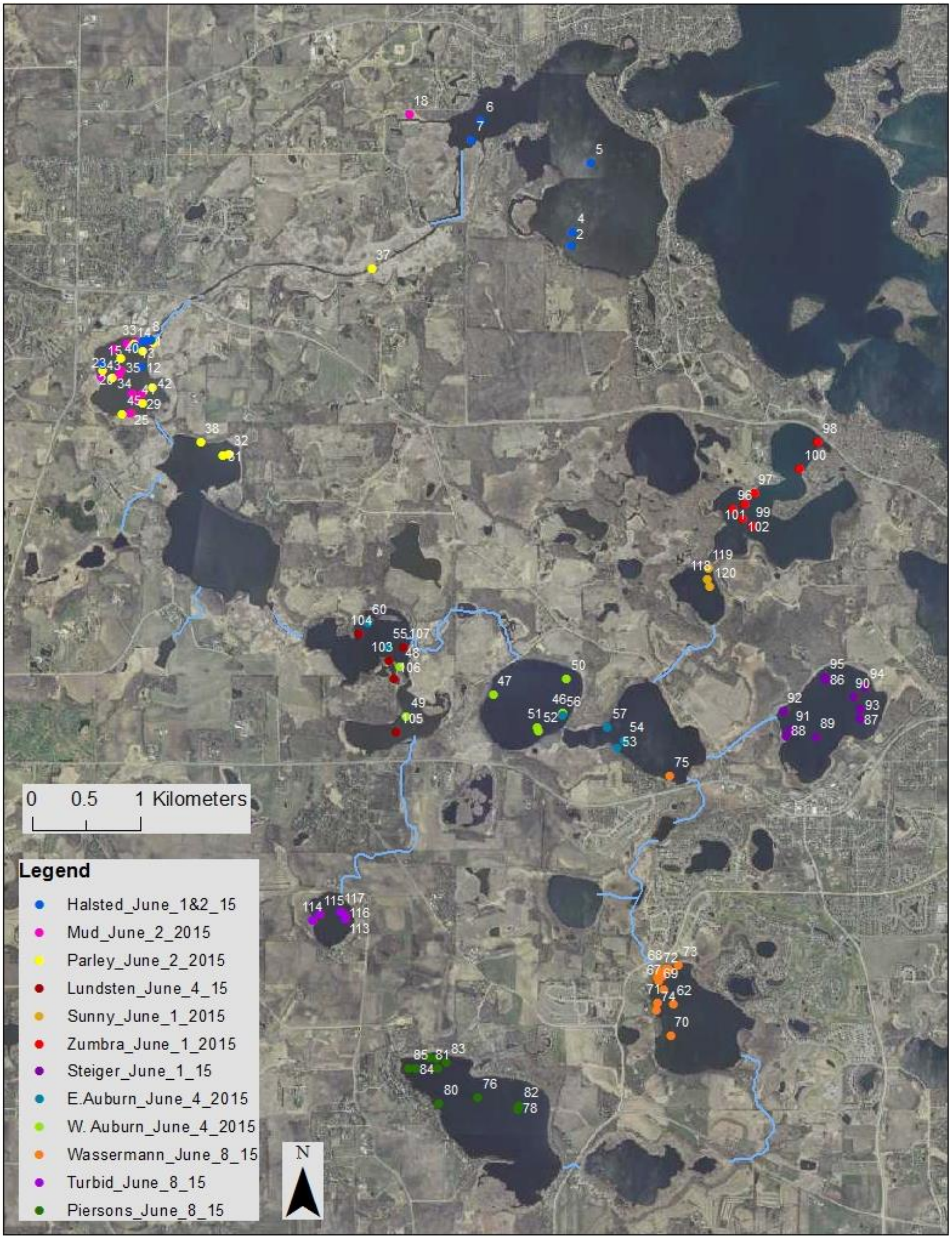

Figure 11. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in early June 2015. Individuals are labeled with unique identification numbers (white).

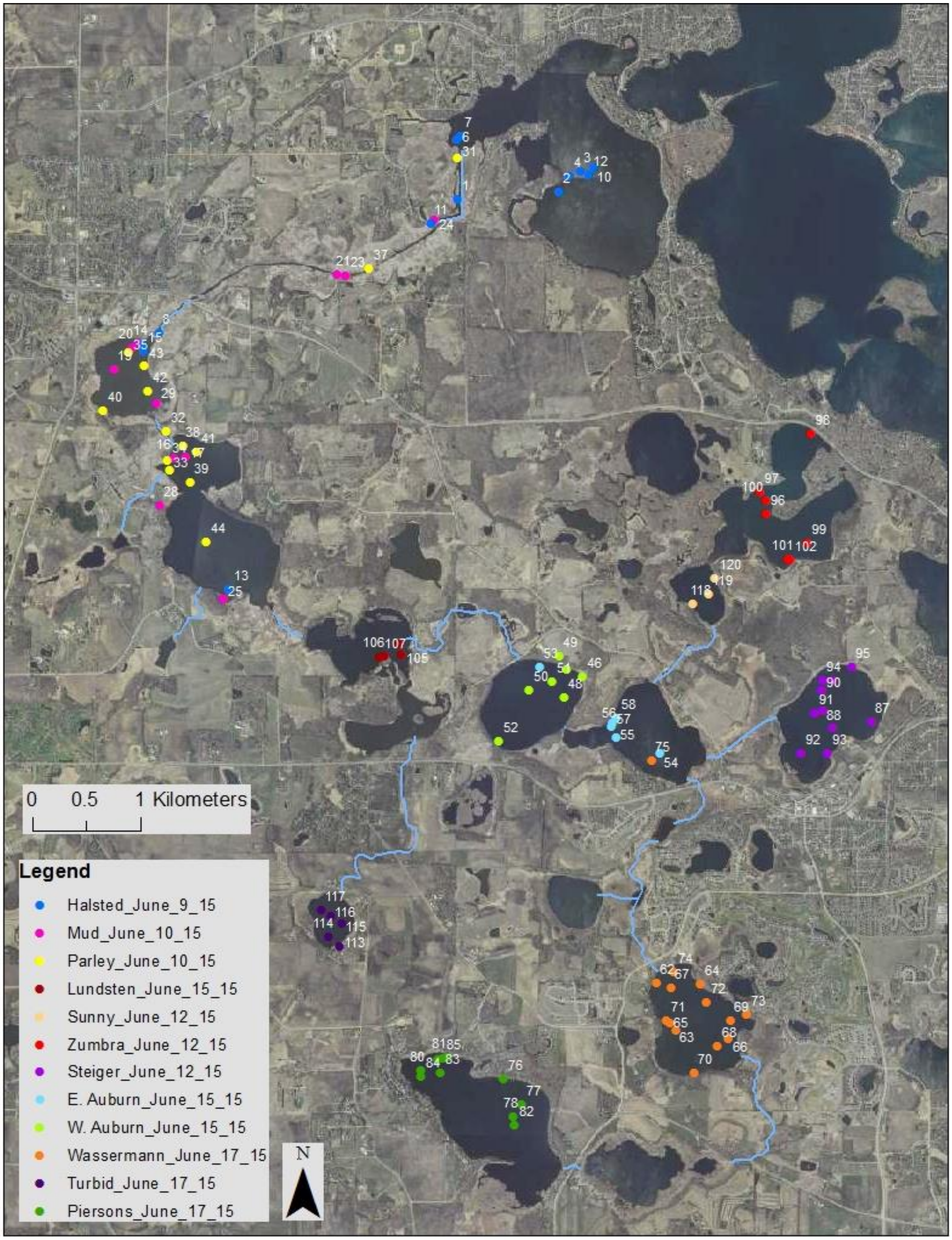

Figure 12. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in late June 2015. Individuals are labeled with unique identification numbers (white).

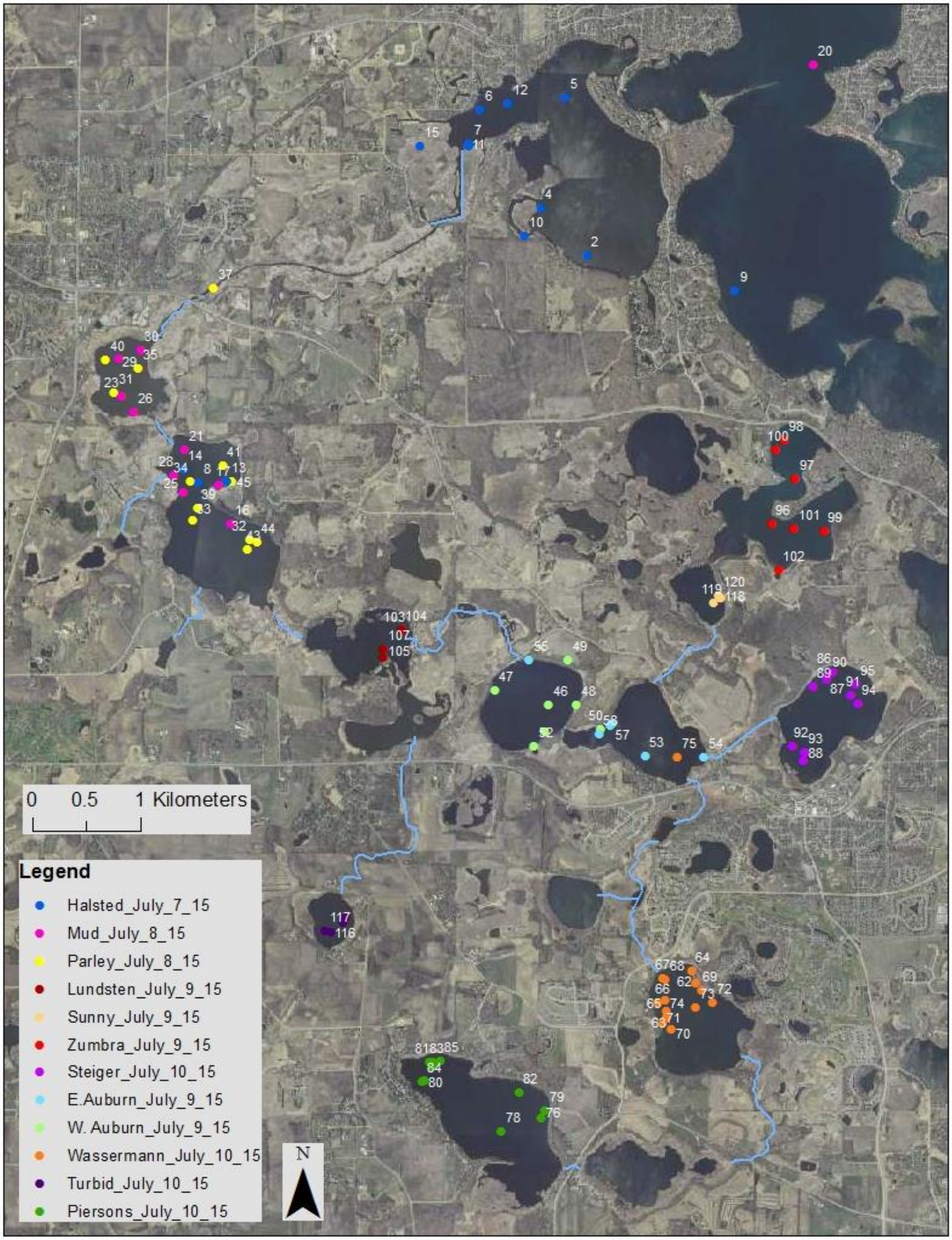

Figure 13. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in July 2015. Individuals are labeled with unique identification numbers (white).

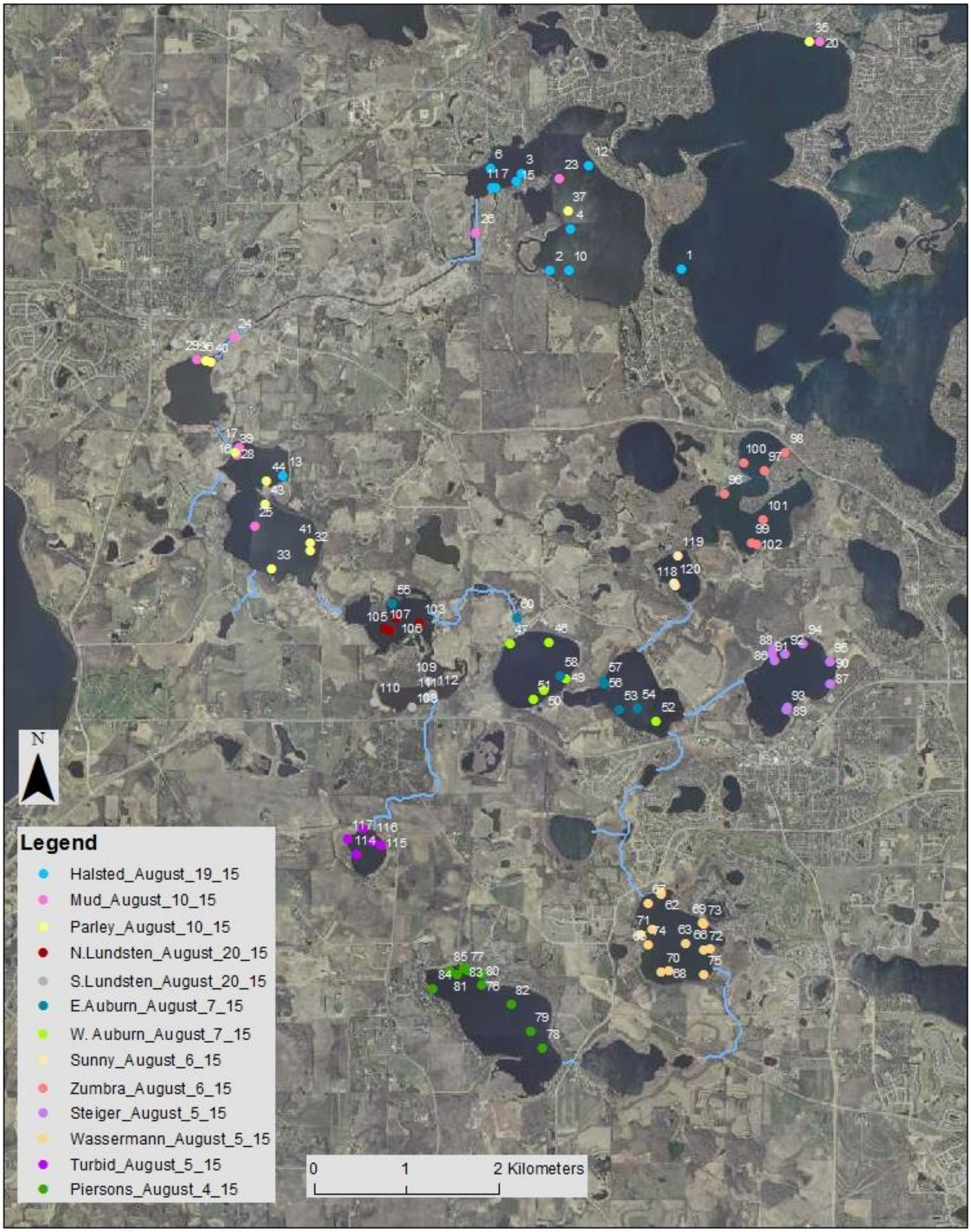

Figure 14. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in August 2015. Individuals are labeled with unique identification numbers (white).

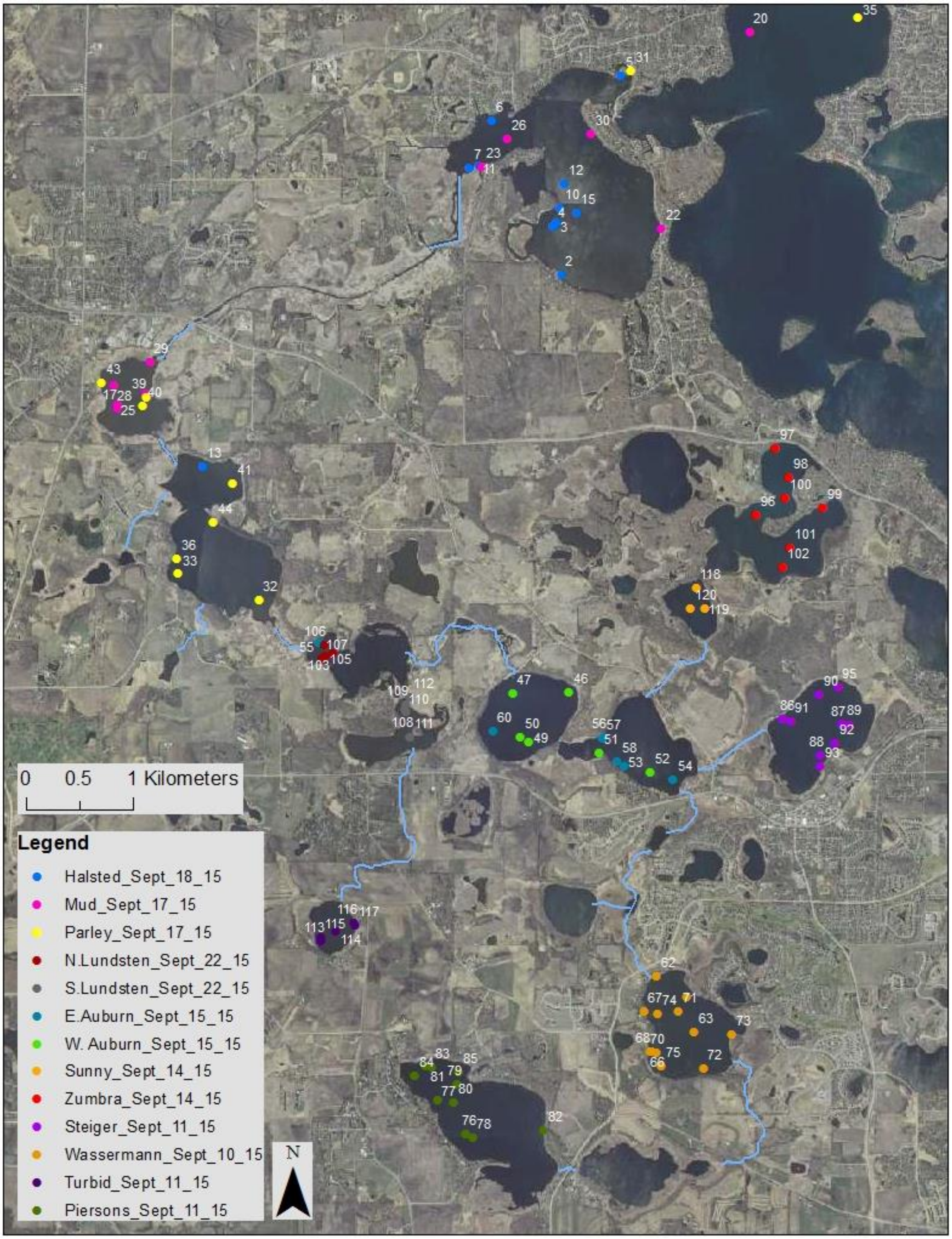

Figure 15. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in September 2015. Individuals are labeled with unique identification numbers (white).

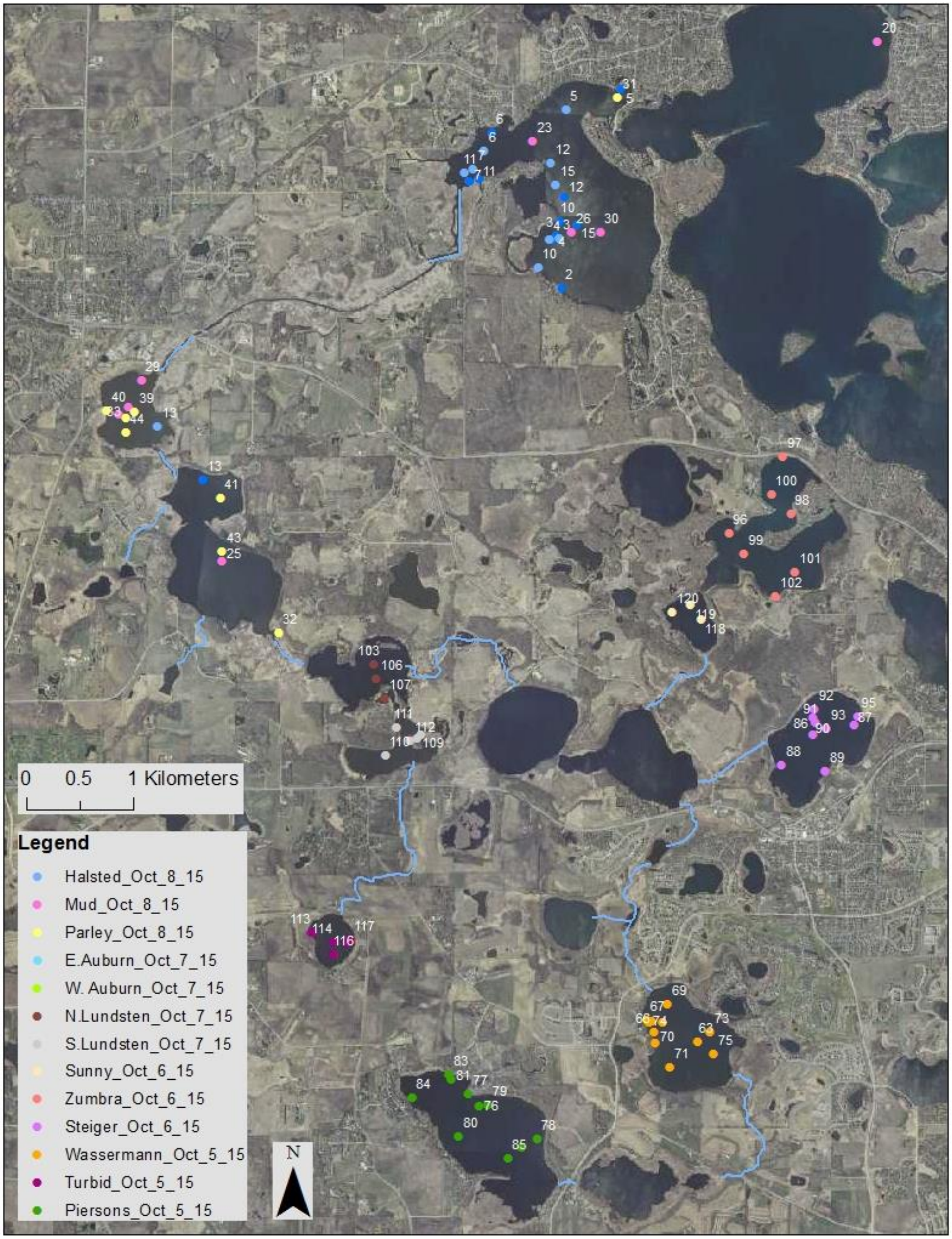

Figure 16. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in October 2015. Individuals are labeled with unique identification numbers (white).

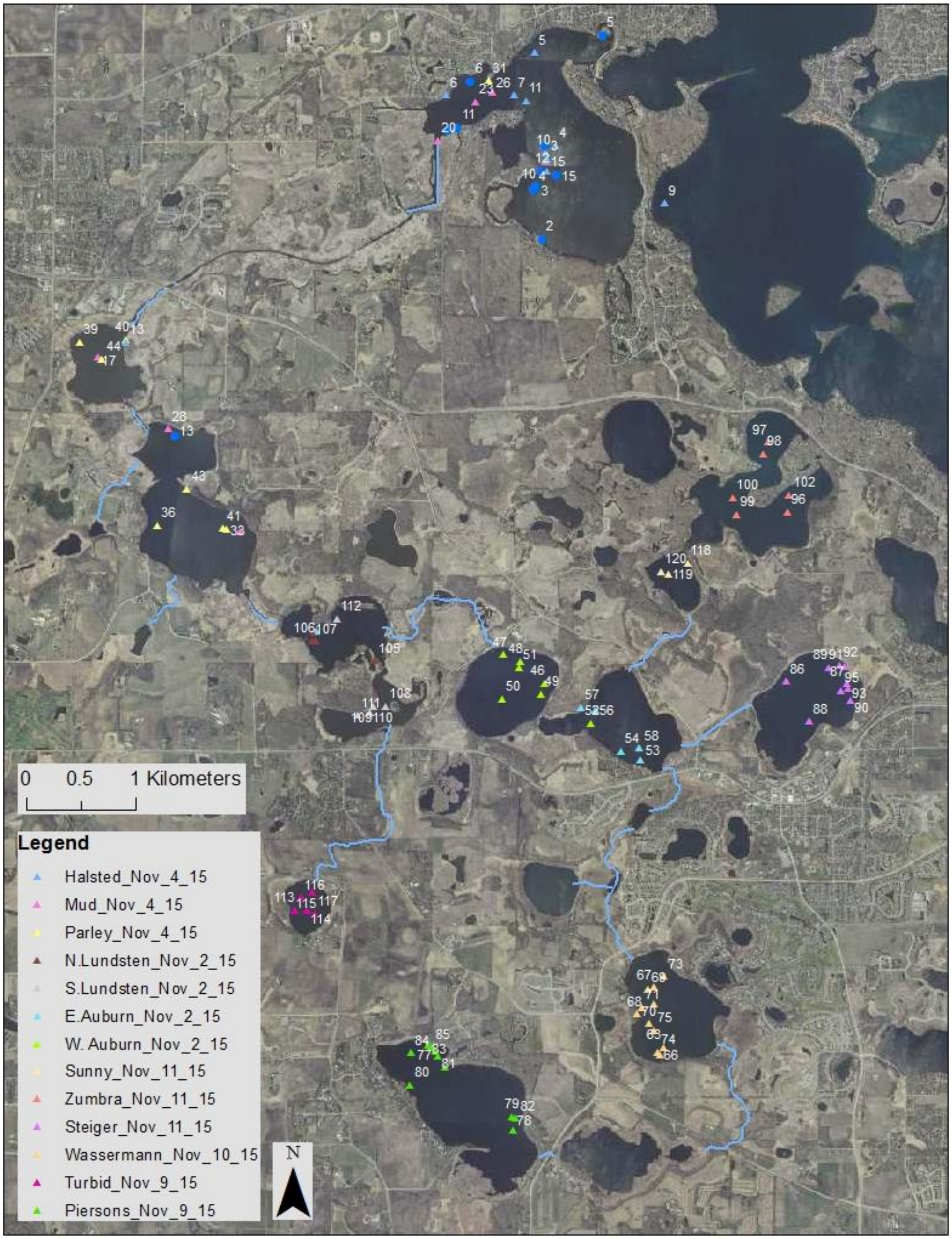

Figure 17. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in November 2015. Individuals are labeled with unique identification numbers (white).

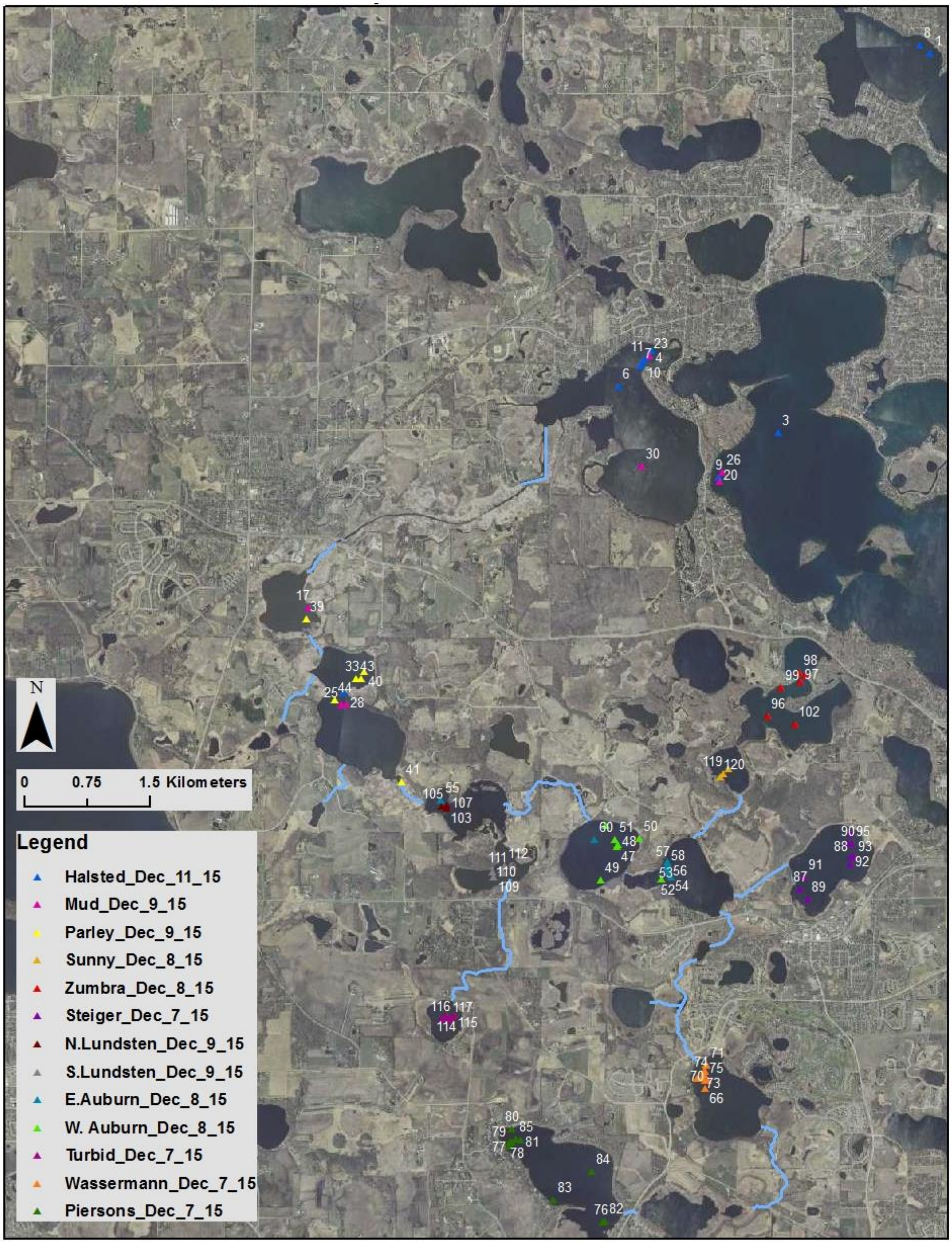

Figure 18. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in December 2015. Individuals are labeled with unique identification numbers (white).

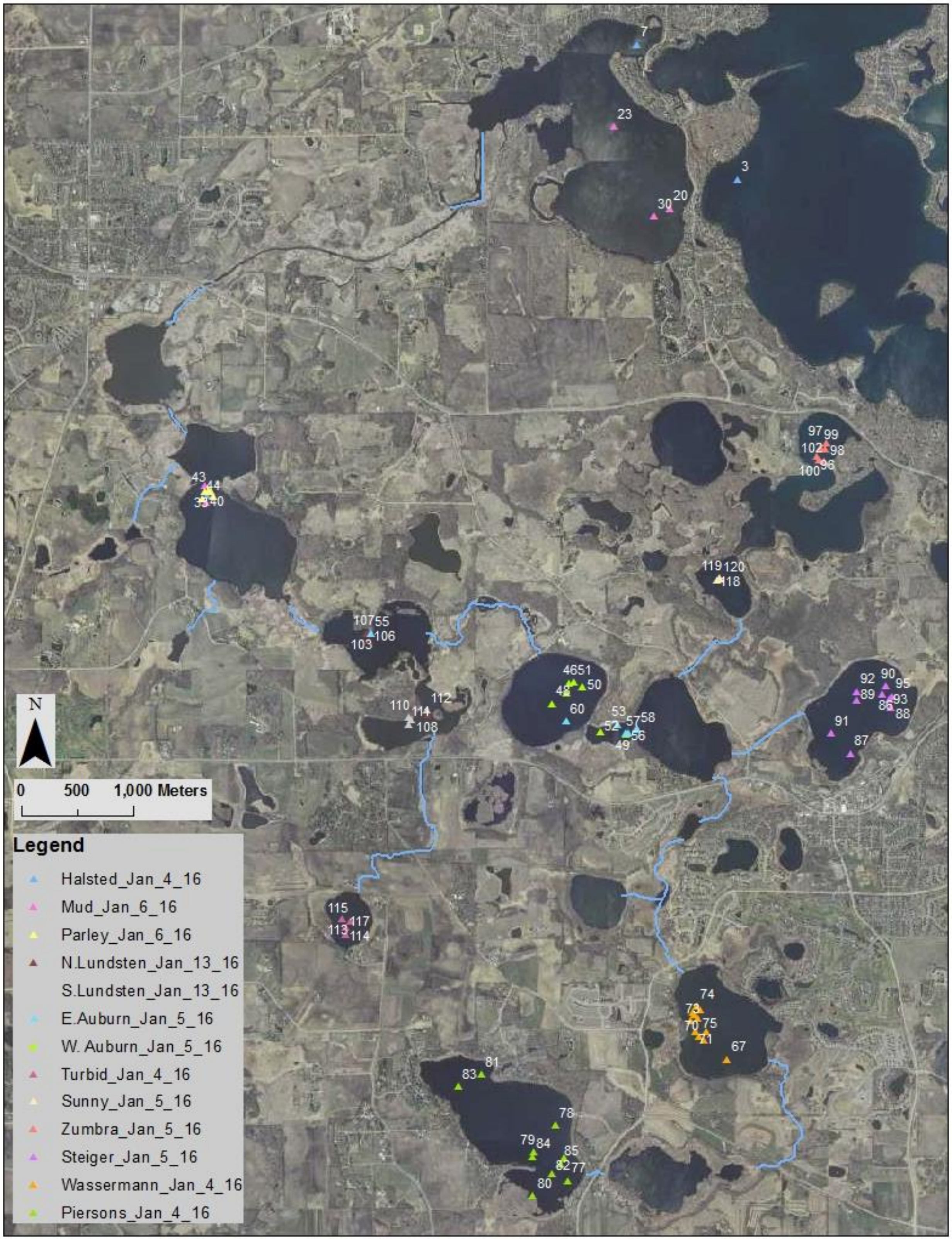

Figure 19. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in January 2016. Individuals are labeled with unique identification numbers (white).

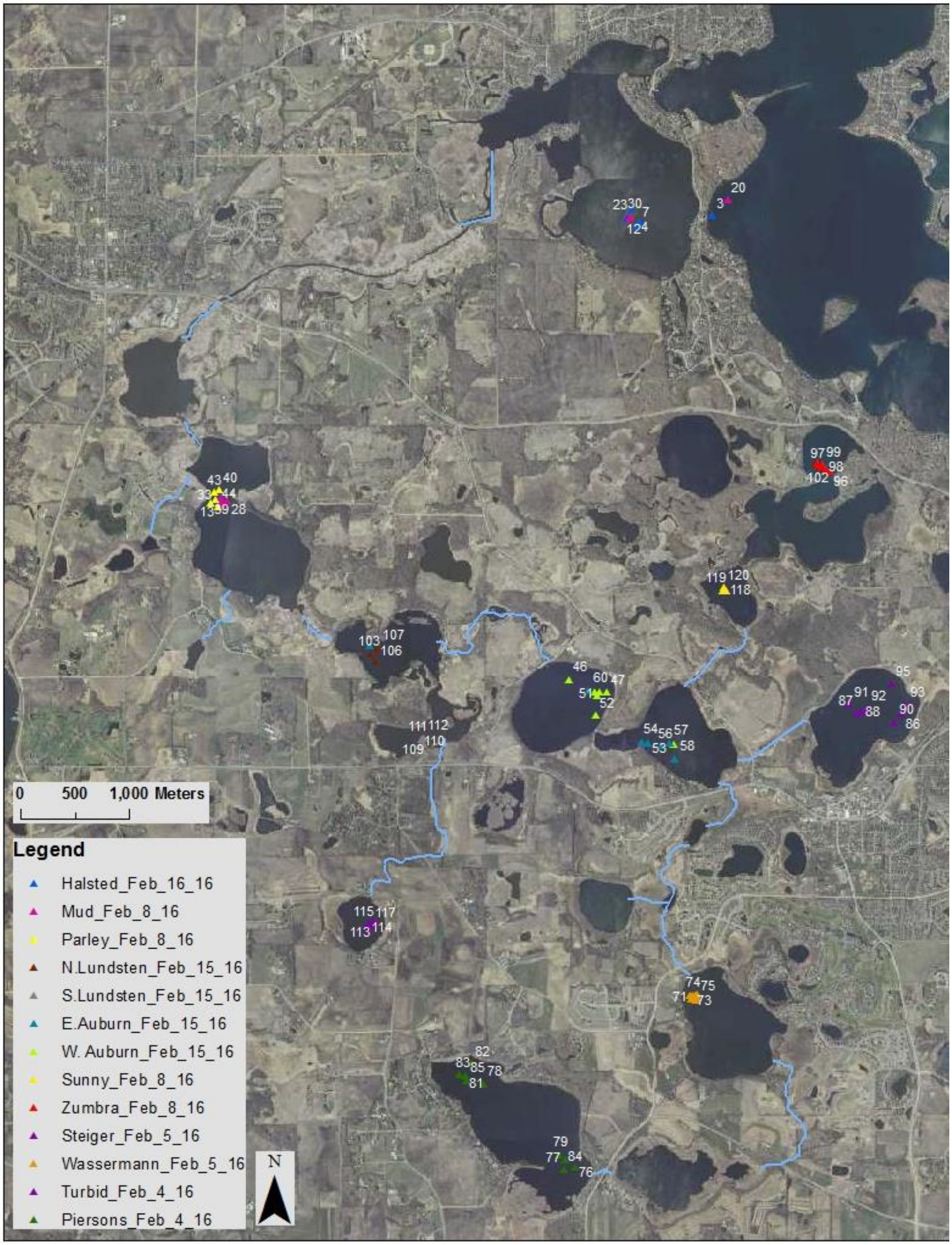

Figure 20. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in February 2016. Individuals are labeled with unique identification numbers (white).

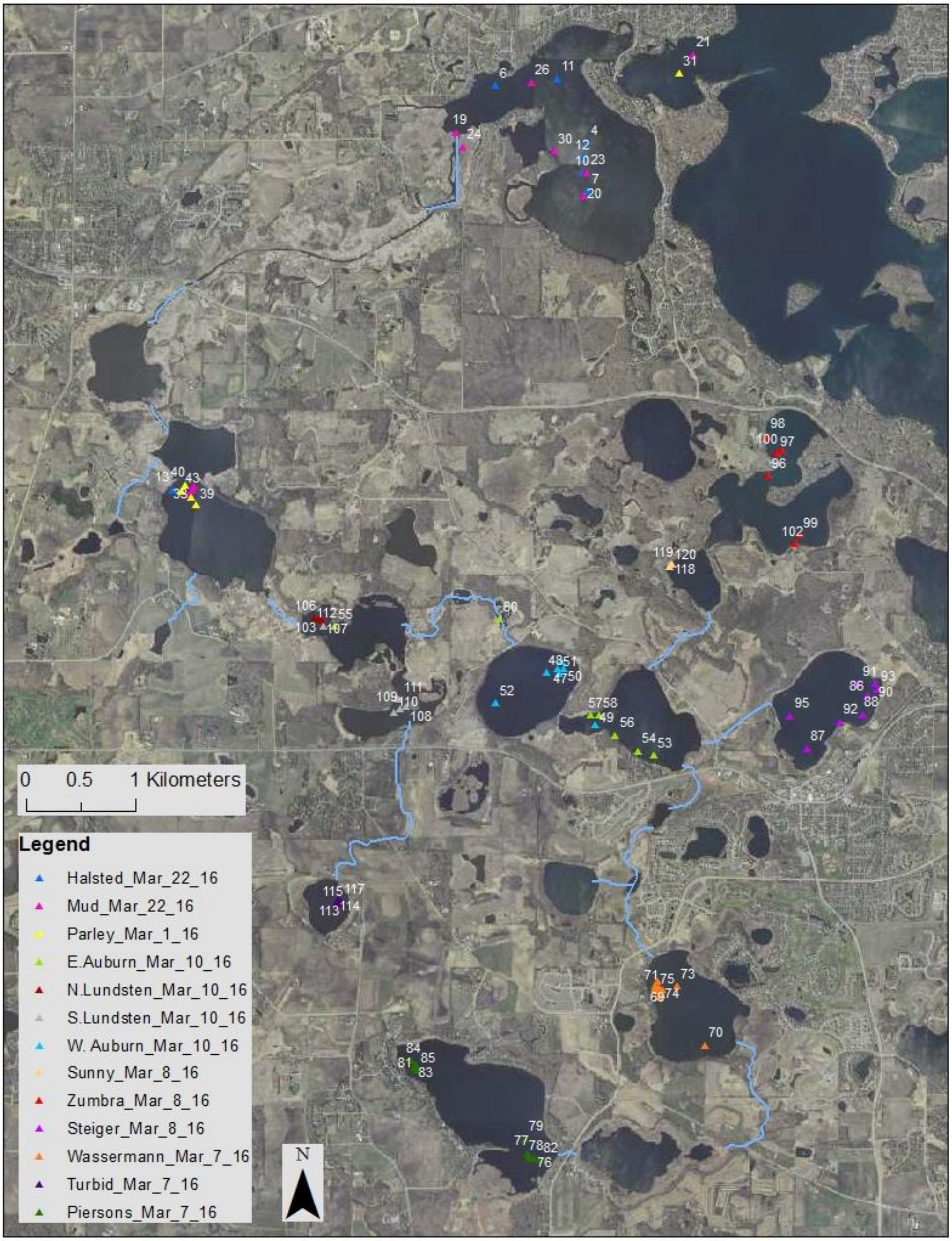

Figure 21. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in March 2016. Individuals are labeled with unique identification numbers (white).

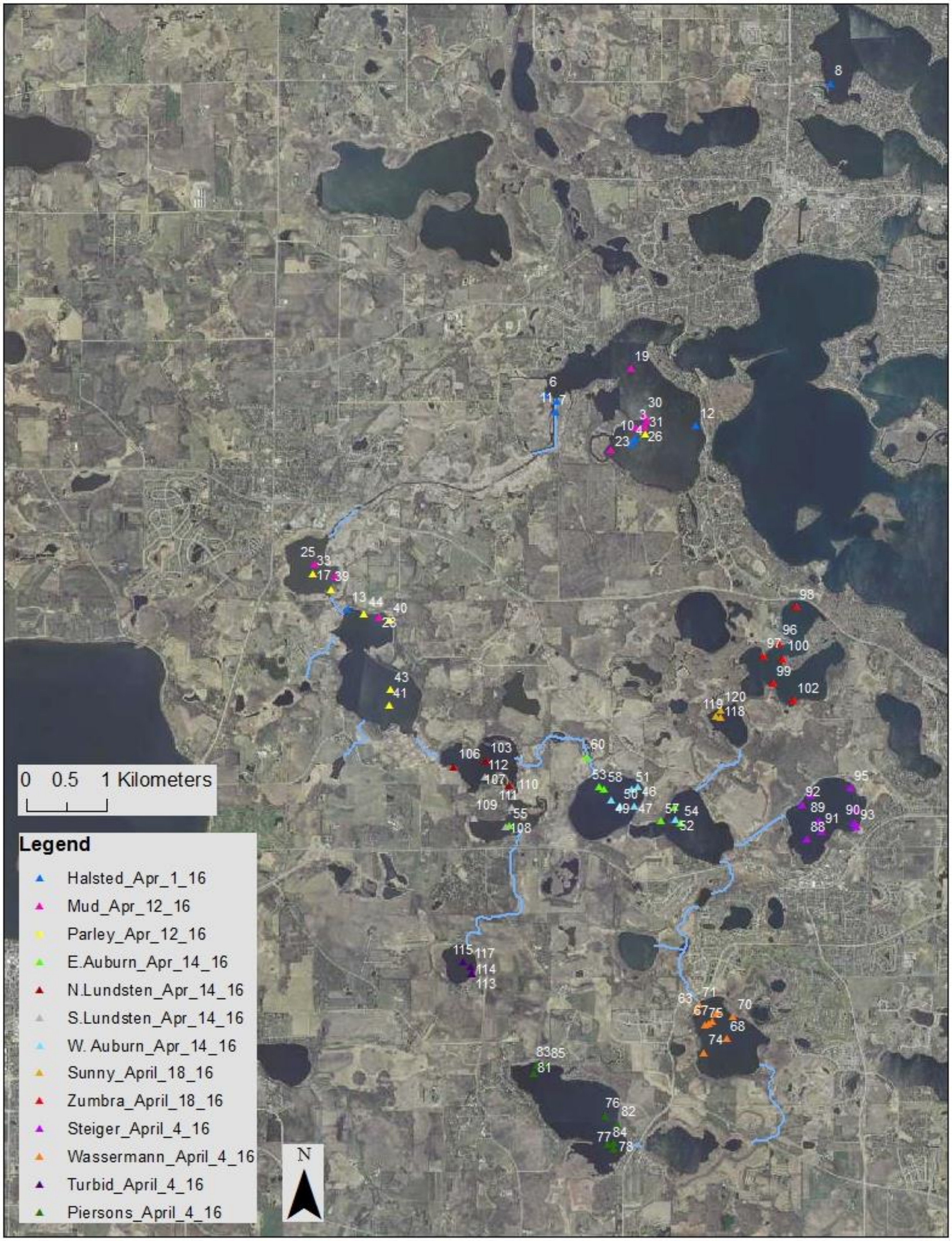

Figure 22. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in April 2016. Individuals are labeled with unique identification numbers (white).

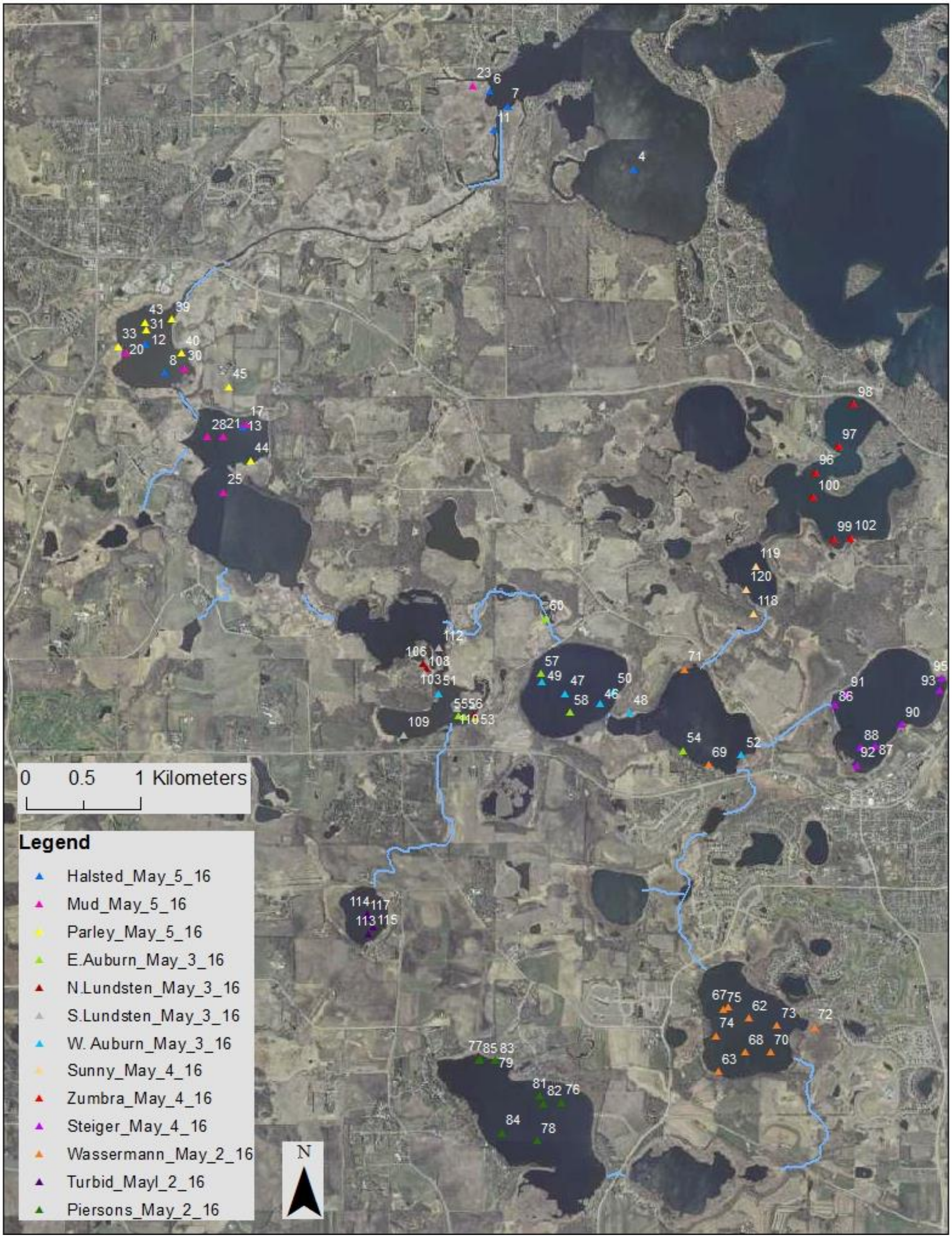

Figure 23. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in early May 2016. Individuals are labeled with unique identification numbers (white).

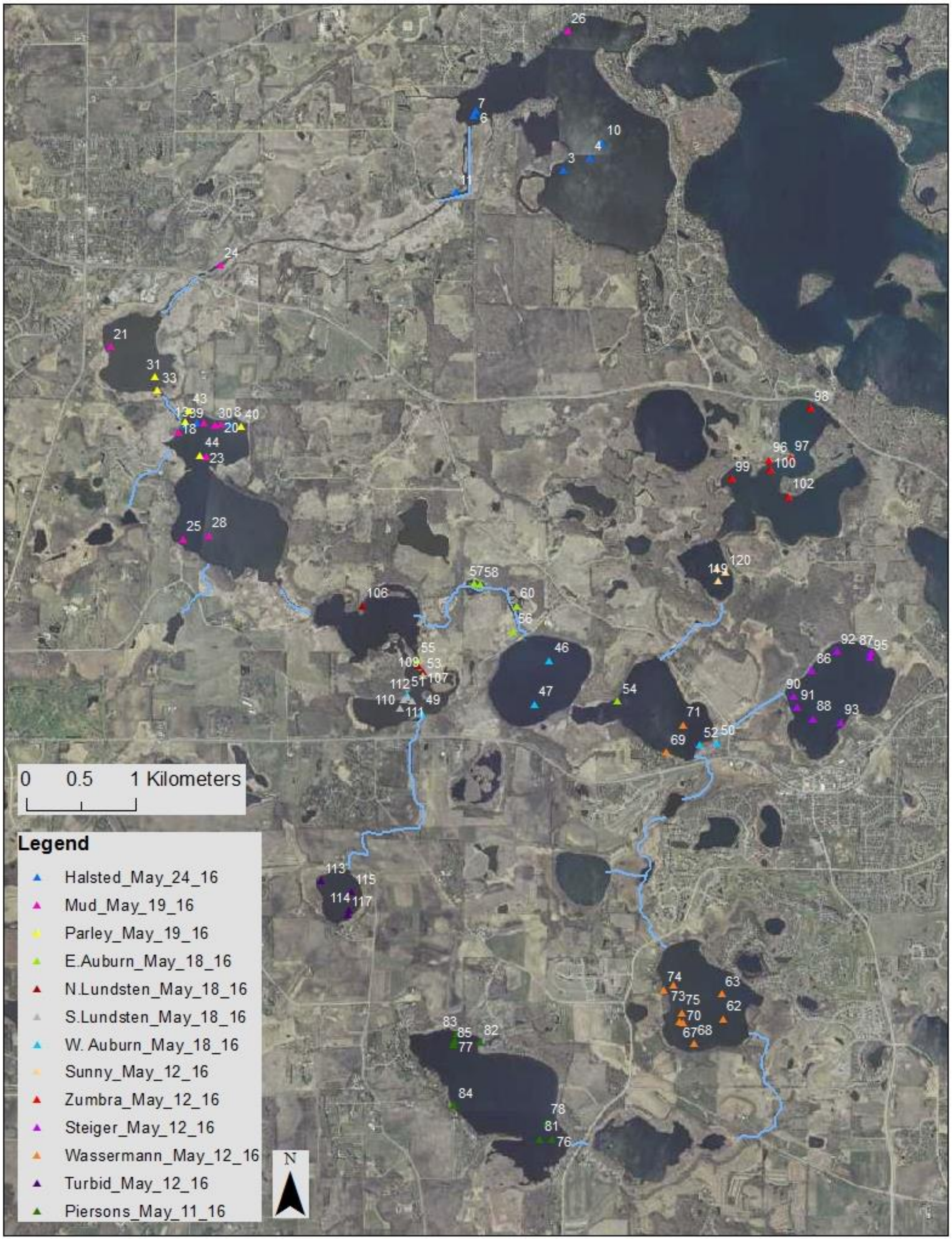

Figure 24. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in late May 2016. Individuals are labeled with unique identification numbers (white).

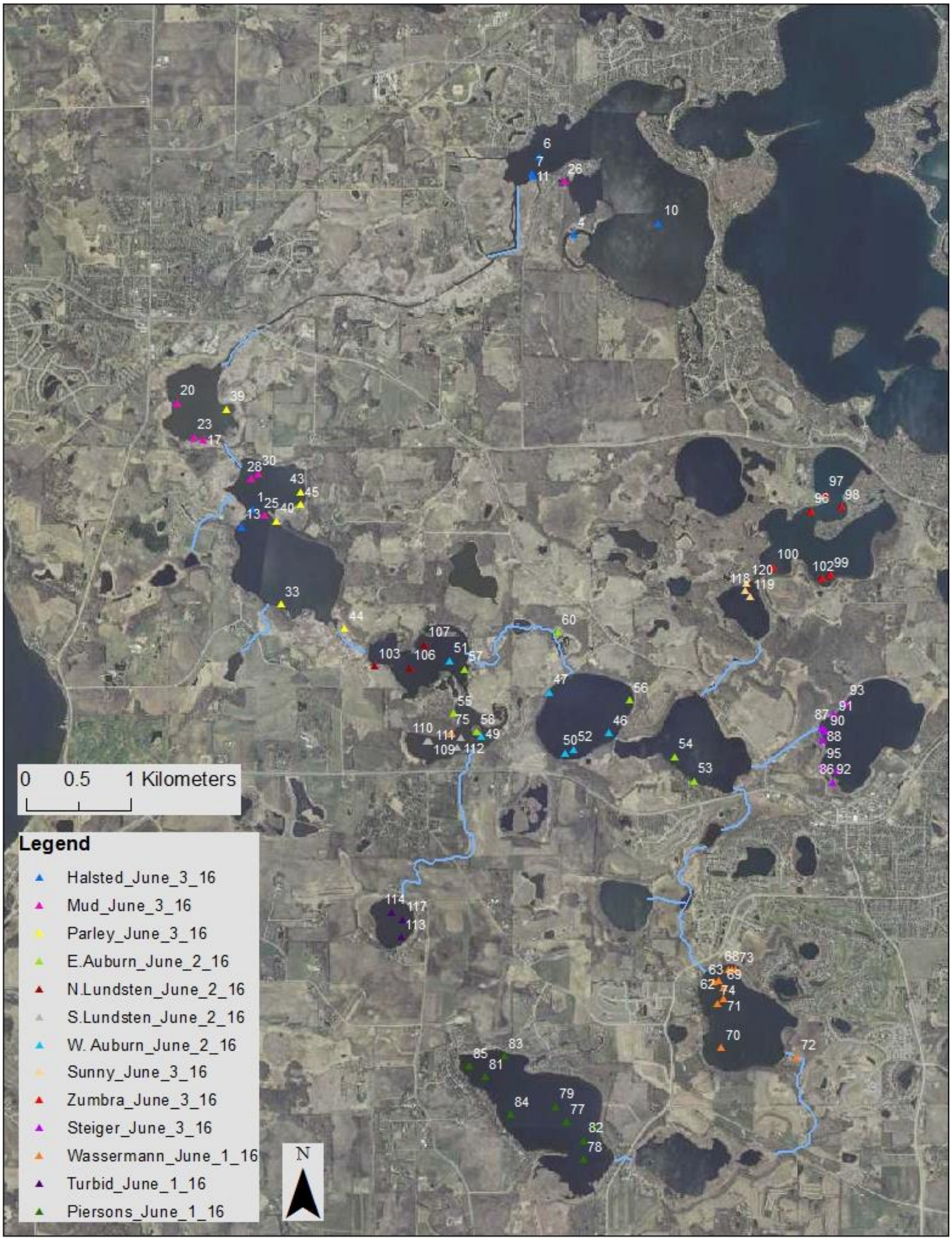

Figure 25. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in June 2016. Individuals are labeled with unique identification numbers (white).

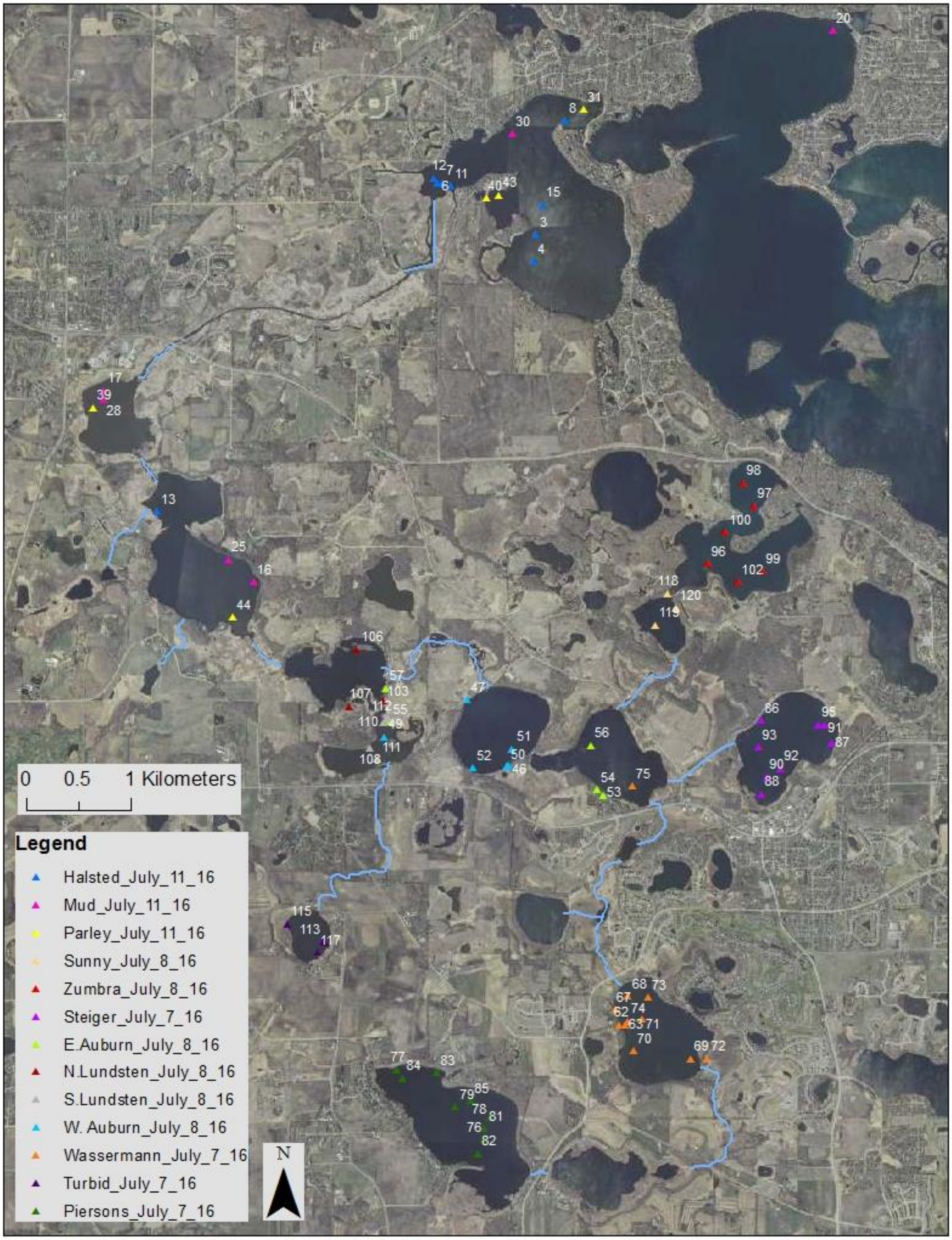

Figure 26. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in July 2016. Individuals are labeled with unique identification numbers (white).

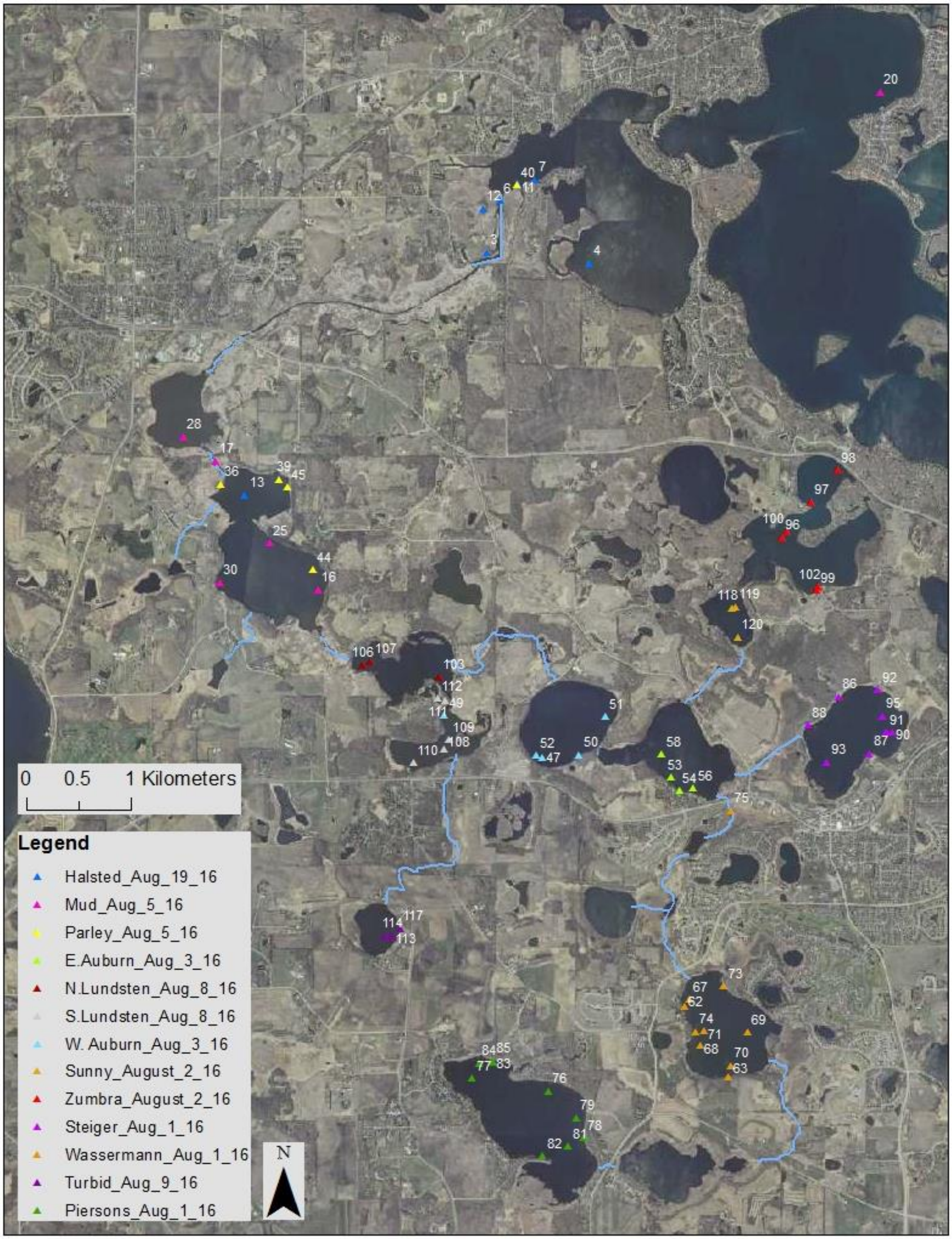

Figure 27. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in August 2016. Individuals are labeled with unique identification numbers (white).

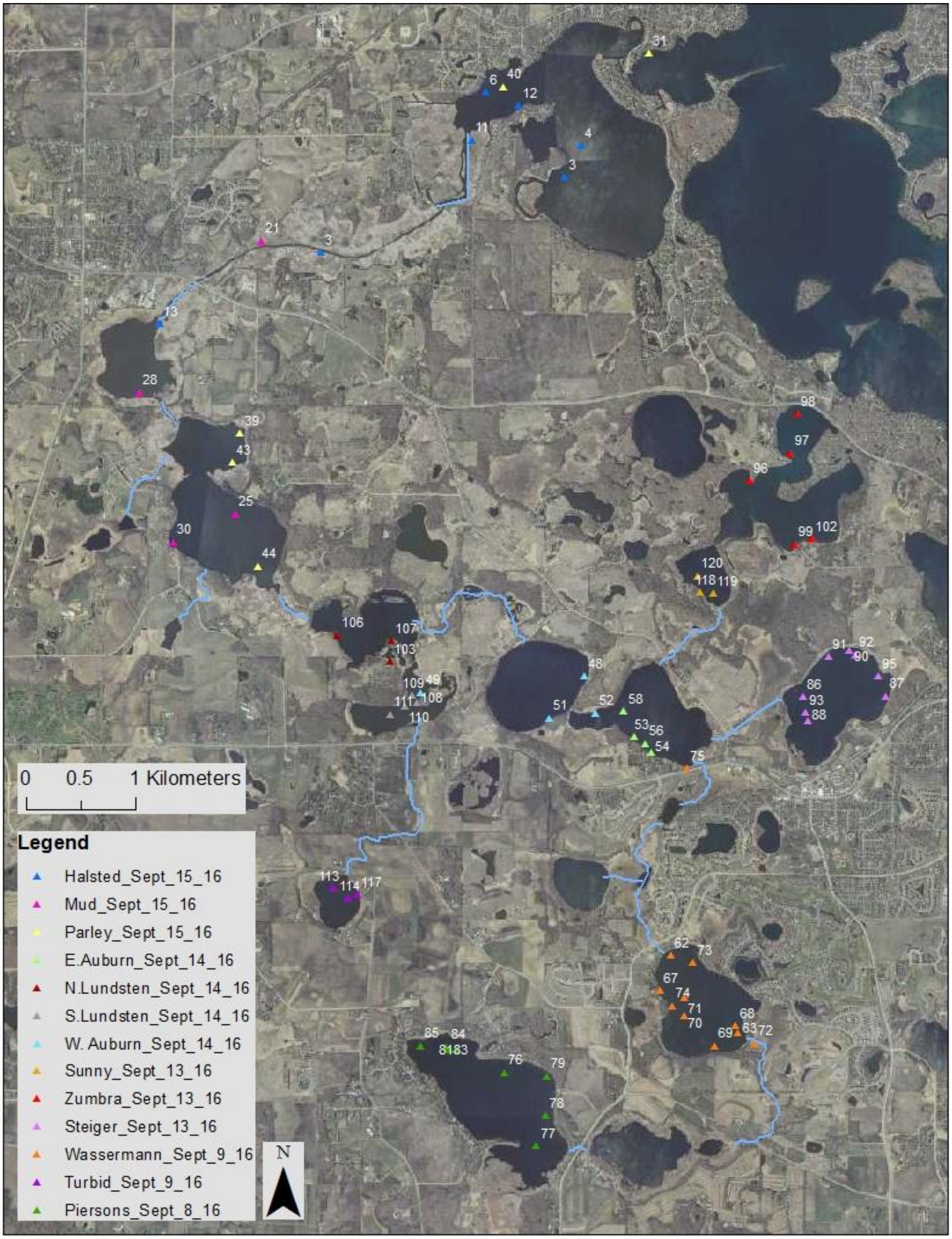

Figure 28. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in September 2016. Individuals are labeled with unique identification numbers (white).

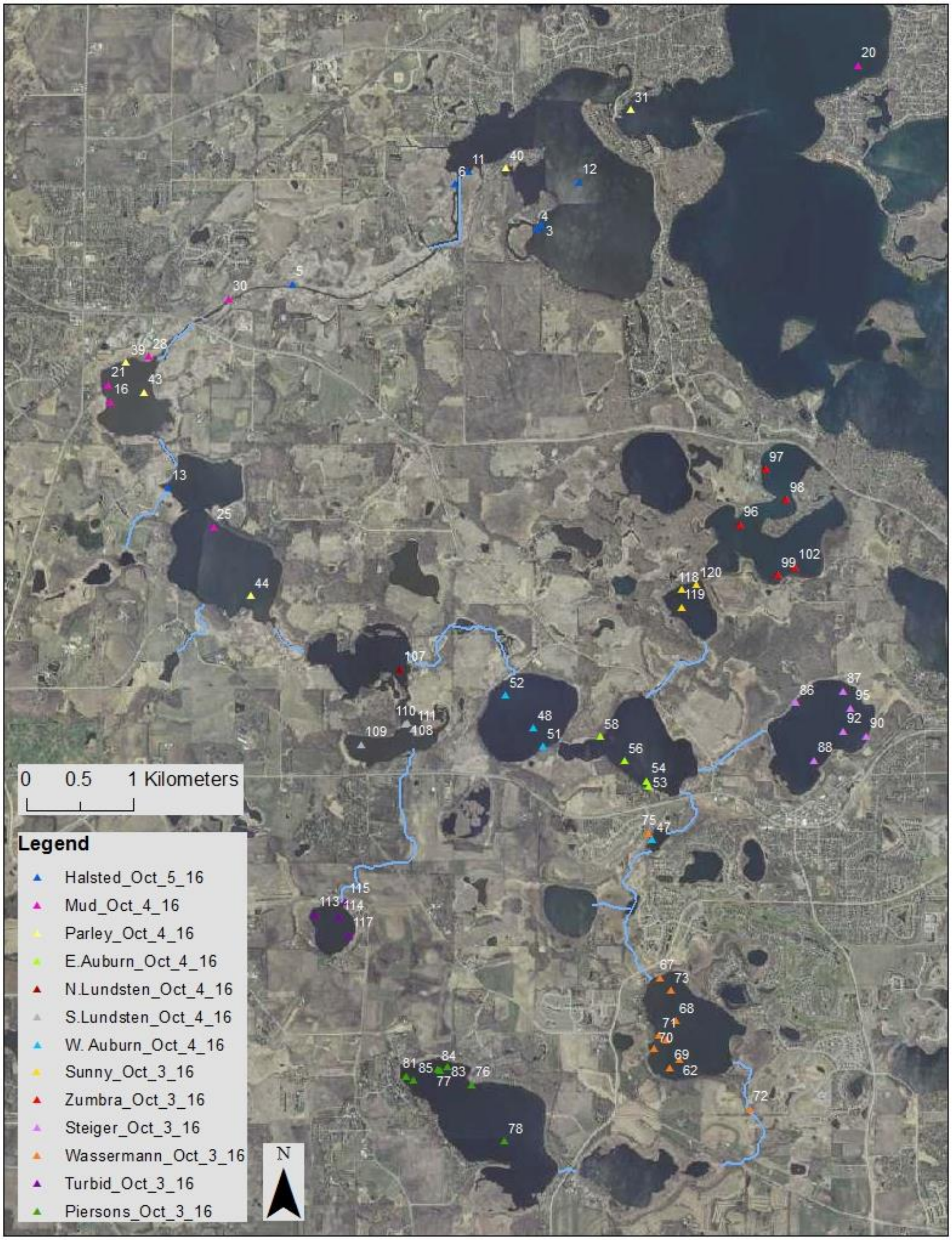

Figure 29. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in October 2016. Individuals are labeled with unique identification numbers (white).

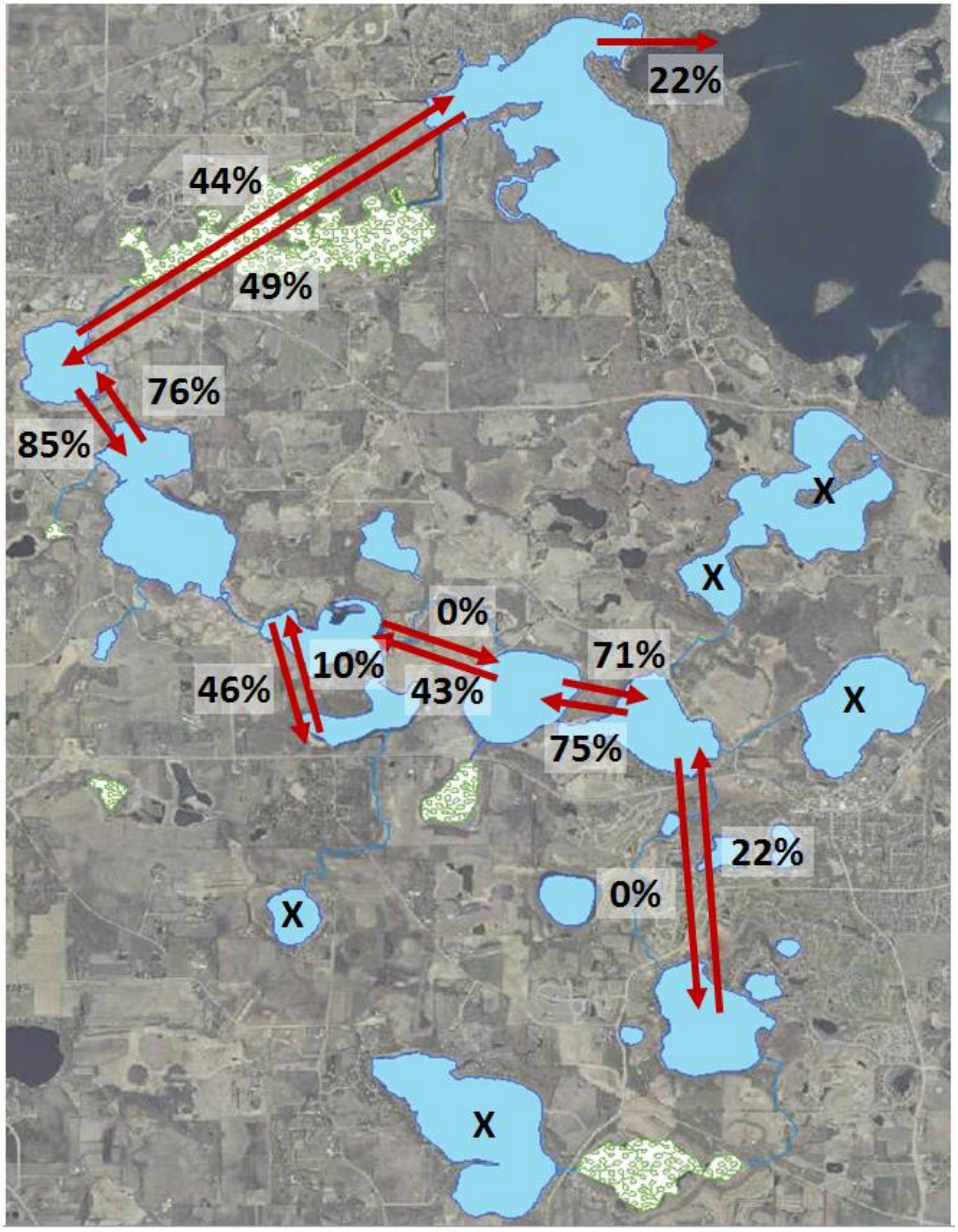

Figure 30. Summary of radio-tagged common carp movement patterns across the Six Mile Creek subwatershed from November 2014 through October 2016. Mean annual movement rates (% living radio-tagged carp that moved from origin to destination) are shown for each movement path indicated by a red arrow. An “X” indicates lakes with radio-tagged carp where

no carp movement was observed during the study period. A detailed breakdown of movement rates and timing by year can be found in Table 3.

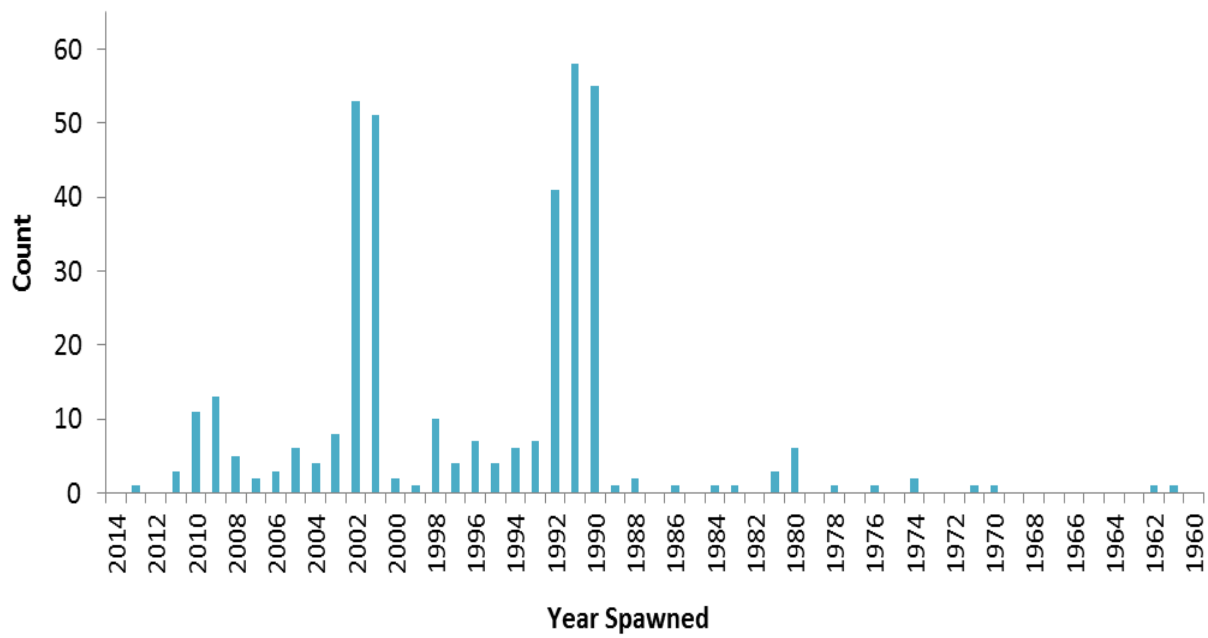

Figure 31. The age structure of common carp (n=378) across the Six Mile Creek Subwatershed. Common carp were sampled from Halsted's Bay (n=51), Mud Lake (n=51), and Parley Lake (n=51) in 2014, North Lundsten Lake (n=31), West Auburn Lake (n=28), East Auburn Lake (n=28), Wassermann Lake (n=37), and Piersons Lake (n=34) in 2015, and Turbid Lake (n=24), Steiger Lake (n=15), and Zumbra Lake (n=28) in 2016.

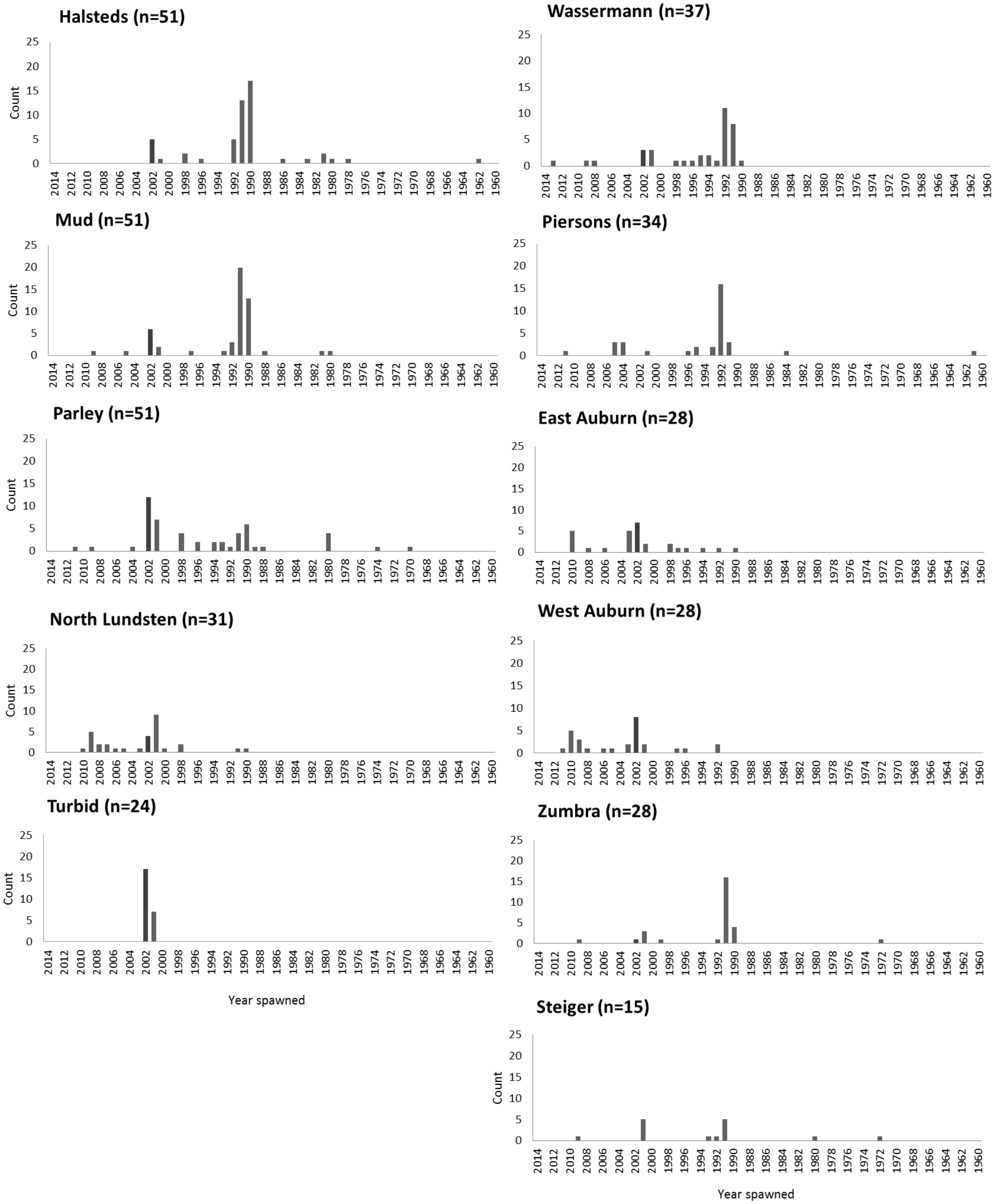

Figure 32. The age structures of common carp sampled across the Six Mile Creek Subwatershed shown individually by lake. Sample sizes are shown parenthetically.

Figure 33. The age structures of common carp sampled across the Six Mile Creek Subwatershed shown by sub-population: 1) Piersons & Wassermann, 2) Auburn, Lundsten, & Turbid, 3) Parley, Mud, & Halsted's Bay, and 4) Zumbra & Steiger. Sample sizes are indicated parenthetically.

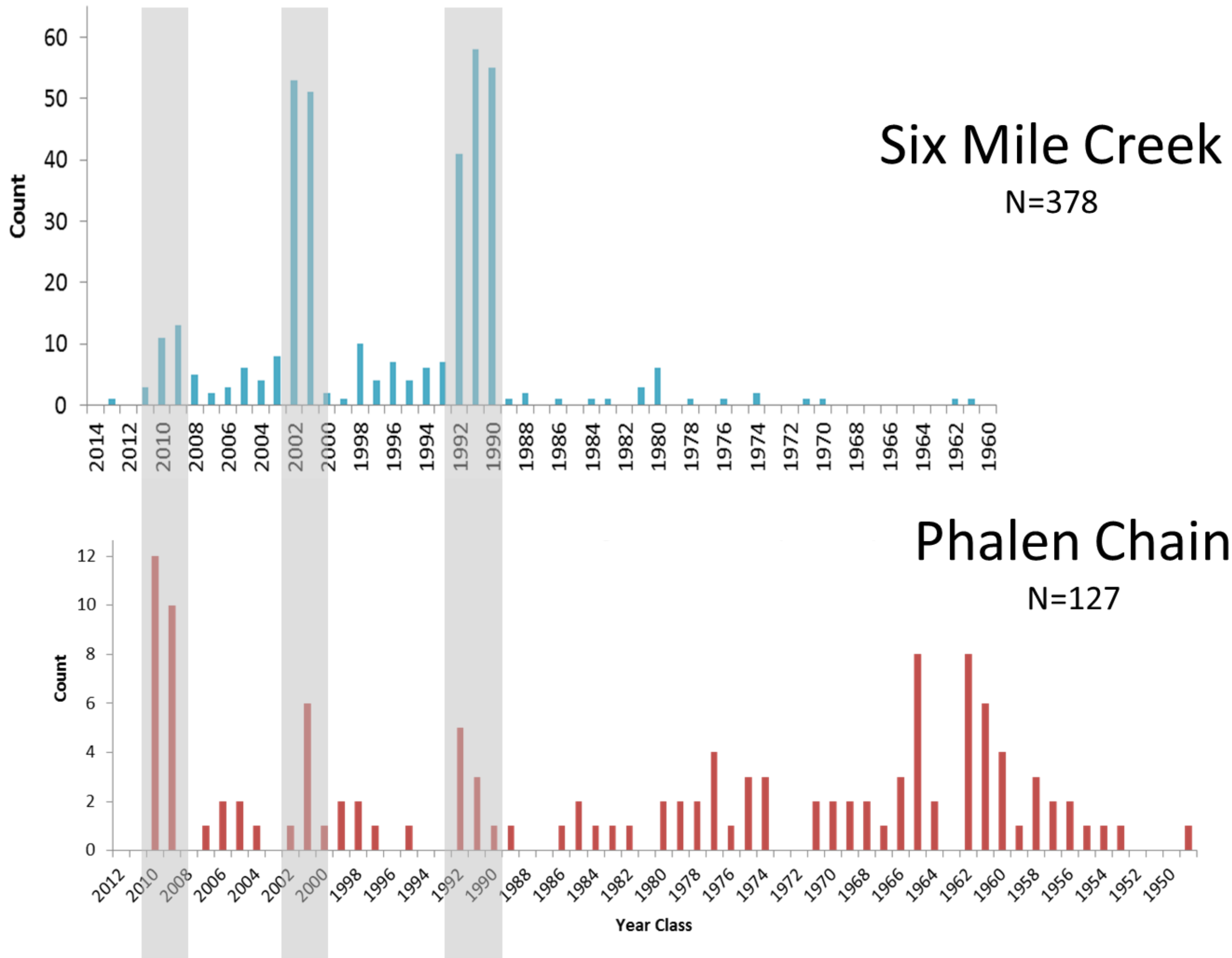

Figure 34. The age structure of common carp sampled in the Six Mile Creek subwatershed in the southwestern twin cities metropolitan area from 2014-2016 (n=378) compared with that of common carp sampled in the Phalen Chain subwatershed in the northeastern twin cities metropolitan area from 2011-2013 (n=127). The shaded rectangles highlight the similarities in year class strength between the two isolated systems.

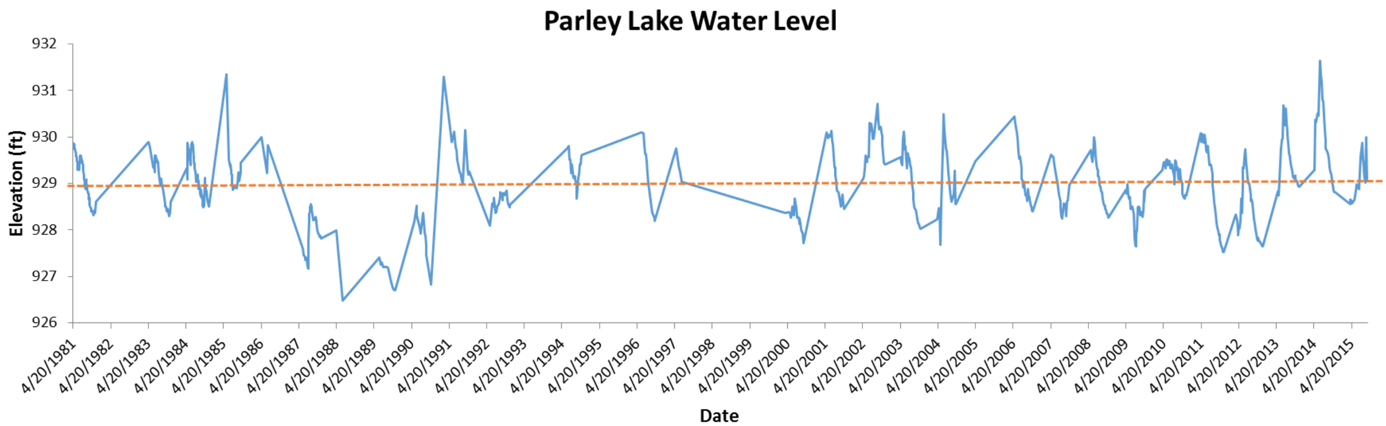

Figure 35. Parley Lake surface water elevation from April 1981 through November 2015. The average surface water elevation for this time period (929 feet) is shown by the dashed line. Note the extended periods of low water prior to 1991 and 2001. Source: MN DNR; http://www.dnr.state.mn.us/lakefind/showlevel.html?downum=10004200

Figure 36. A photograph of the barrier in place at the Zumbra Lake outlet to Sunny Lake in the Carver Park Reserve. Lake levels were observed overtopping this barrier in August of 2016.

APPENDIX G

SIX MILE - HALSTED BAY SUBWATERSHED
CARP MANAGEMENT IMPLEMENTATION PLAN

MINNEHAHA CREEK WATERSHED DISTRICT
QUALITY OF WATER QUALITY OF LIFE

Six Mile – Halsted Bay Subwatershed
Carp Management Implementation Plan

Updated: October 9, 2017

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Executive Summary

The Six Mile – Halsted Bay Subwatershed is located in the western portion of the Minnehaha Creek Watershed District, in Carver County. It is composed of several deep and shallow lakes, has numerous wetlands, and eventually flows into Halsted Bay of Lake Minnetonka. Several lakes in this subwatershed are impaired for excess nutrients, and can be characterized as generally turbid with poor water clarity and degraded aquatic plant communities that provide poor habitat for fish and waterfowl. Common carp (*Cyprinus carpio*) are abundant in the Six Mile – Halsted Bay Subwatershed, and are a known driver of poor water quality and ecological conditions. Managing carp is a top priority for management and restoration of this subwatershed, and is part of a broader plan in the District's 2017 Comprehensive Plan to improve water quality and ecological conditions across that entire system.

In 2014, the Minnehaha Creek Watershed District (MCWD) partnered with the University of Minnesota (U of M) to complete a 3-year assessment of common carp in the Six Mile – Halsted Bay Subwatershed. Its purpose was to determine the abundance, recruitment patterns, and seasonal movements of carp to enable the development of carp control strategies for restoration of the Six Mile – Halsted Bay Subwatershed. Adult carp biomass in 12 of the 15 lakes was found to exceed 100 kg/ha (89 lbs/acre), a threshold where ecological damage can occur. Several carp nurseries were identified, with South Lundsten Lake being a top management priority. South Lundsten was found to be an active carp nursery, contributing high abundances of juvenile common carp to several lakes in the subwatershed, including downstream to Parley Lake, upstream to Auburn Lake, and even as far as Wassermann Lake. Other carp nurseries were identified, although some have not produced juvenile carp in many years, but likely provide successful carp recruitment in harsh winter conditions, or drought years, that allow winterkill of bluegill sunfish. Movement data of common carp identified four distinct populations in the subwatershed, which can be managed separately with some use of barriers. For management purposes, one of these populations will be separated into two management units to facilitate adult carp removal by adding a barrier between Mud Lake and Halsted Bay. The following are the carp management units for this system: 1) Pierson-Marsh-Wassermann, 2) Auburn-Lundsten-Turbid, 3) Parley-Mud, 4) Carver Park Reserve Lakes and 5) Halsted Bay.

There are two approaches to managing carp in this subwatershed. The first approach would be an aggressive, short-term approach that could provide management over a 3 to 5 year time period across the entire subwatershed concurrently. Alternatively, management could be implemented in a more phased approach over 7 to 8 years, first addressing carp recruitment system-wide in priority areas, and then removing adult carp biomass one management unit at a time. The first approach is preferred, as an aggressive, short-term timeframe for carp management can lead to earlier implementation of additional restoration strategies, and earlier restoration of the subwatershed; however, the approach chosen will be directed mainly by funding and resources available. It is expected that even with an aggressive, short-term approach, continued management will be needed to meet all management goals beyond the 3-year time-frame, and long-term monitoring and maintenance will be needed indefinitely regardless of the approach chosen. Management will need to be adaptive, as the results of each action taken can inform and possibly change future actions. With either approach, there will be three main objectives: 1)

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Suppress carp recruitment system wide, 2) Install a barrier/trapping system between Mud and Halsted bay, and 3) Adult carp biomass removal.

Suppressing carp recruitment is a top priority to prevent new carp from being produced into the system. This will be accomplished by using winter aeration in some waterbodies to prevent winterkill of bluegill sunfish, which feed very effectively on carp eggs. In other waterbodies, physical barriers will prevent access by adult carp in nearby lakes.

Concurrently, a barrier/trapping system between Mud and Halsted Bay should be installed, and adult biomass removal can begin in waterbodies that exceed the damaging carp biomass threshold. A carp barrier/trap between Mud and Halsted Bay will separate carp populations in the Six-Mile Creek Lakes from Lake Minnetonka, containing the populations, and improving removal strategies for Halsted Bay and Parley and Mud Lakes. This corridor is frequently used as a carp migration route, and including a trapping system in the design will facilitate removal of carp from both management units.

Adult carp removal will involve three main strategies: winter or open-water seining, baited box-net trapping, and trapping migratory carp in stream channels. Strategies will vary by management unit, waterbody, and progress towards achieving removal goals. Based on carp population data from the U of M assessment, target numbers of carp for removal have been set for each waterbody to bring the carp population under 100 kg/ha (89 lbs/acre).

As carp removal occurs, ongoing monitoring is necessary to track carp removal progress and monitor for carp recruitment. Monitoring will also occur to document changes in water quality and ecological conditions. Metrics that will be tracked include: total phosphorus, chlorophyll-a, water clarity, total suspended solids and aquatic plant community metrics.

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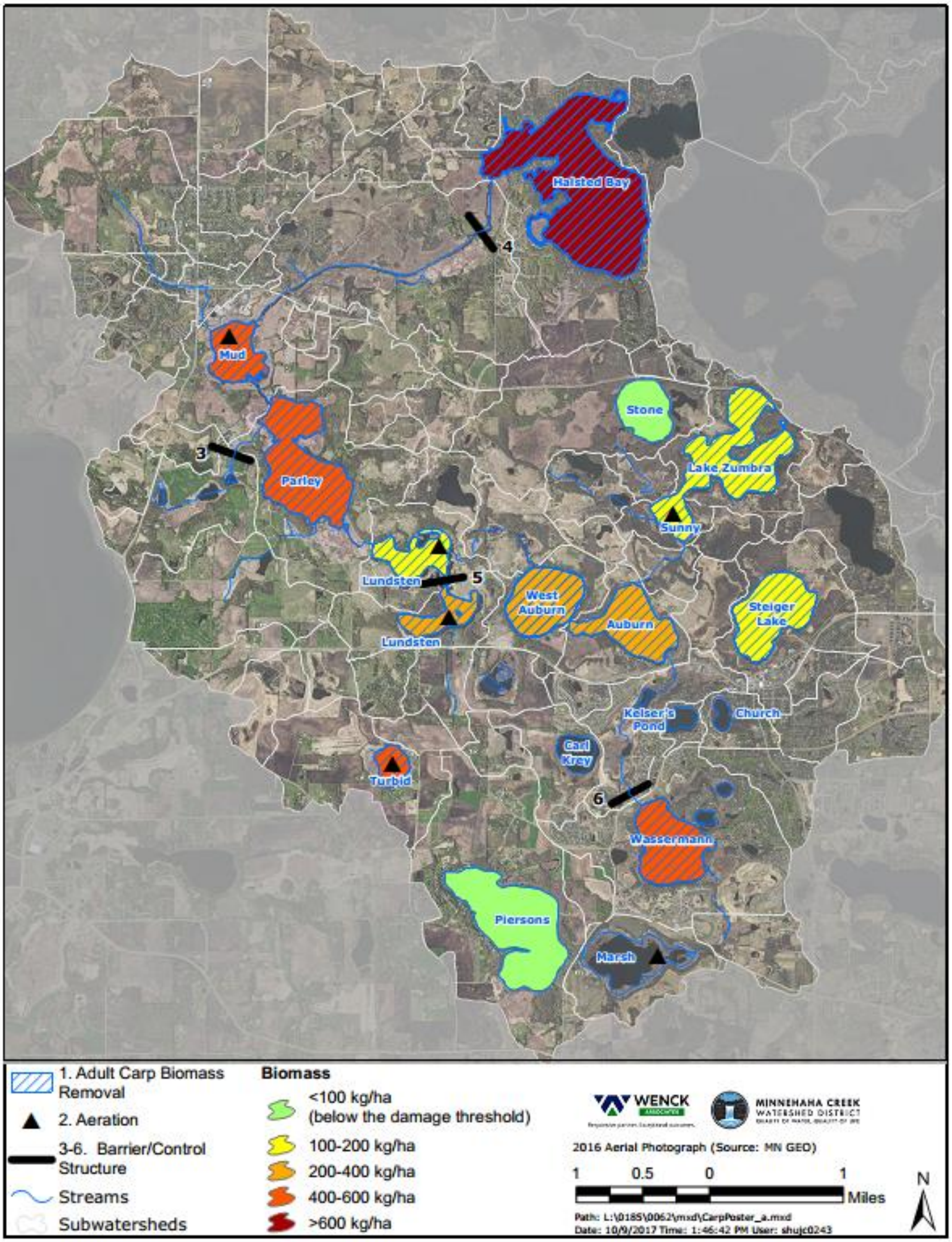
Figure 1. Carp Implementation Map



Overview of Carp in Six Mile – Halsted Bay Subwatershed

Adult carp biomass in 12 of the 15 lakes in the subwatershed were found to exceed the 100 kg/ha (89 lbs/acre) threshold; a threshold known to be ecologically damaging in shallow Midwestern lakes (Bajer et al. 2009). In the remaining sections of this plan, carp biomass will be referenced as pounds per acre (lbs/acre). Lakes with very high biomass ranging from 226 to 1,128 lbs/acre include: Wassermann, Turbid, West Auburn, East Auburn, Parley, Mud, and Halsted Bay. These are priority lakes for management. Halsted Bay had the highest carp biomass ever observed by the Sorensen Lab (U of M), with an estimated biomass of 1,128 lbs/acre, twelve times the threshold for ecological damage. Several lakes had more moderate densities ranging from 139 to 182 lbs/acre and included: North Lundsten, South Lundsten, Steiger, Sunny and Zumbra. Carp removal is warranted in these lakes, but make up a second tier priority for management. Carp biomass was generally low (≤ 88 lbs/acre) in Piersons, Stone and Kelzer's lakes, and requires no current management. Removal efforts may be conducted in Piersons Lake, as it is close to the threshold. Carp populations can mix between different lakes in each unit, so while there are target removal numbers for each lake, the most important number is the total number of carp removed from the management unit.

Several carp nurseries were identified in the subwatershed, with South Lundsten being especially important. South Lundsten appears to be the primary source of carp for North Lundsten, West Auburn and East Auburn. It also contributes low numbers of carp to downstream lakes including Parley, and as far upstream as Wassermann Lake. Other nurseries that need to be addressed include North Lundsten, Marsh Lake, Sunny Lake, Turbid Lake, Crown College Pond, Big SOB Lake and Mud Lake. Carl Krey is another lake that needs more monitoring, it was inaccessible during most of the study period for trap-net surveys. Each will be discussed further in context of their management units.

A number of carp in each waterbody were also radio-tagged and tracked frequently throughout the assessment. Movement patterns of carp were observed over a variety of seasonal conditions, and indicated there were several mostly distinct populations of carp in the subwatershed. These distinct carp populations form separate management units that will require unique goals and strategies to manage. For management purposes, one of these units will be separated by adding a barrier between Mud Lake and Halsted Bay to facilitate adult carp removal. The following will be the carp management units for this system: 1) Pierson-Marsh-Wassermann, 2) Auburn-Lundsten-Turbid, 3) Parley-Mud, 4) Carver Park Reserve Lakes and 5) Halsted Bay.

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Management Unit Goals

For each management unit and individual lakes, a target number for carp removal was provided by the U of M assessment based off current population estimates in comparison to the aforementioned ecological threshold. Updated population surveys will be conducted as management occurs to track population changes and determine progress in achieving management goals. The following are carp management goals for each management unit.

Piersons-Marsh-Wassermann (Management Unit 1)

Suppress carp recruitment in South Lundsten and Marsh Lake, and reduce carp population in Wassermann Lake by at least 4,920 carp to achieve a carp biomass of less than 89 lbs/acre. Monitor carp population in Piersons Lake, and remove carp as needed to remain below the 89 lbs/acre threshold.

Auburn-Lundsten-Turbid (Management Unit 2)

Suppress carp recruitment in South Lundsten, North Lundsten and Turbid Lakes, and reduce carp population in the management unit by at least 12,750 carp to achieve a carp biomass of less than 89 lbs/acre.

Parley – Mud (Management Unit 3)

Install barrier/fish-trap between Mud and Halsted Bay. Suppress carp recruitment in South Lundsten, Big SOB, Crown College Pond and Mud Lake, and reduce carp population in the management unit by at least 17,800 carp to achieve a carp biomass of less than 89 lbs/acre.

Carver Park Reserve Lakes (Management Unit 4)

Suppress carp recruitment in Sunny Lake, and reduce carp population in the management unit by at least 4,400 carp to achieve a carp biomass of less than 89 lbs/acre.

Halsted Bay (Management Unit 5)

Install barrier/trapping system between Mud Lake and Halsted Bay, and reduce carp population in Halsted Bay by at least 59,350 to achieve a carp biomass of less than 89 lbs/acre. Future management will be needed to address carp immigrating and emigrating from the rest of Lake Minnetonka via the channel between Priests Bay and Hasted Bay.

Carp Management Objectives

There are three main objectives to sustainably manage carp in this system.

Objective 1. Suppress carp recruitment system-wide
Objective 2. Install a barrier/trapping system between Mud Lake and Halsted Bay
Objective 3. Removal of adult carp biomass

Suppressing carp recruitment is the top priority for carp management, as it prevents new carp from being produced into the system. Installation of a barrier/trapping system between Mud Lake and Halsted Bay, as well as removal of adult carp biomass, could be conducted concurrently while suppressing carp recruitment, however, without achieving objective 1, long-term sustainability of carp removal cannot occur.

Implementation Plan

Initial management will be focused on suppression of carp recruitment areas across the subwatershed. This will occur winter aeration of several waterbodies that are prone to winterkill, and installing barriers to block access to others. Preventing winterkill by using winter aeration should help maintain a healthy bluegill population, which feed on carp eggs very effectively. Installation of a barrier/fish-trapping system will be installed to prevent carp passage from Mud Lake to Halsted Bay and vice versa, which will allow Halsted Bay and Parley-Mud to be separate management units. Halsted Bay will require long-term management due to its connection to greater Lake Minnetonka, and may even require carp management in other areas of Lake Minnetonka and adjoining subwatersheds to achieve carp management goals in Halsted Bay.

Removal of existing adult carp biomass is also needed. Depending upon the approach used and resources available, concurrent removal across all management units could occur. If a more phased implementation approach is selected, initial carp removal could begin in the headwaters of the subwatershed and continue to other management units once good progress has been made in meeting management goals in the headwaters area.

Monitoring will be necessary to both inform ongoing management decisions, as well as to document water quality and ecological changes following carp management. This adaptive management framework will be a critical component of how this plan is implemented. Each strategy and action will have certain results that will inform, and possibly change subsequent strategies and actions taken. A monitoring section is included with more details.

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Six Mile – Halsted Bay Carp Management Timeline

		LSOHC Grant Period - July 1, 2018 - June 30, 2021															
	2017	2018				2019				2020				2021			
Objective/Task	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Acquire all necessary permits & landowner permissions	x	x	x	x		x				x				x			
Objective 1. Suppress Carp Recruitment																	
Task 1. Run electric for aeration units				x													
Task 2. Operation of aeration units					x	x			x	x			x	x			x
Task 3. Install permeable berm at outlet of Crown College Pond				x													
Task 4. Install barrier and water level control structure between North & South Lundsten								x									
Objective 2. Install barrier/fish-trap between Mud Lake and Halsted Bay				x													
Objective 3. Adult carp biomass removal																	
Task 1. Install barrier structure at Wassermann outlet				x													
Task 2. Implant Radio Tags				x													
Task 3. Box-Net Trapping				x	x		x	x	x		x	x	x		x	x	x
Task 4. Winter/Open-water Seining					x	x	x		x	x	x		x	x	x		
Task 5. Carp trapping in stream channels				x	x		x	x	x		x	x	x		x	x	x
Task 6. Maintain barriers				x	x		x	x	x		x	x	x		x	x	x
Monitoring																	
Task 1. Carp population surveys				x				x				x				x	
Task 2. Winter Dissolved Oxygen Monitoring		x				x				x				x			
Task 3. Spring Trap Net Surveys			x				x				x				x		
Task 4. Fall Trap-Net Surveys				x				x				x				x	
Task 5. Radio tag tracking					x	x	x		x	x	x		x	x	x		
Task 6. Aquatic Plant Surveys			x	x			x	x			x	x			x	x	
Task 7. Water Quality Monitoring			x	x			x	x			x	x			x	x	
Task 8. Water Quality Monitoring in aerated lakes					x	x	x		x	x	x		x	x	x		x
Reporting					x				x				x				x

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Objective 1 - Suppressing Carp Recruitment

The goal with suppressing carp recruitment is to prevent the addition of new carp to the system. This is key to effective carp management, and is typically accomplished by either blocking movement of adult carp to these waterbodies, or preventing winterkill of bluegill sunfish by aerating carp nurseries during the winter.

Winter Aeration

Aeration units will be installed in North Lundsten, South Lundsten, Mud, Sunny, Turbid and Marsh Lake. These units would be operated from November to April (ice-on to ice-off). South Lundsten should be prioritized among these waterbodies, as it currently provides for frequent carp recruitment to several lakes in the subwatershed. The remaining waterbodies are still a priority to address, but would be considered a secondary priority to South Lundsten. Winter aeration requires a DNR permit, which has safety precautions required such as thin ice signage around the lake. Electricity is also required to operate the aeration units, many of these sites will require electric to be run to the lake.

Barriers

A permeable berm will be constructed at the outlet of Crown College Pond, which was found by the U of M assessment to also provide frequent carp recruitment. The pond does not support a permanent adult carp population because it freezes to the bottom most years and has a small outlet with intermittent flow, so the simplest measure here is to isolate the pond from the system by installing a permeable berm. The berm will not only prevent fish passage, but it will require less maintenance than physical barrier structures, and will be designed to add additional flood storage to the watershed. Installation of this barrier should be considered a priority management activity. DNR permits will be required for all barriers.

Between North and South Lundsten, in addition to aerating these waterbodies, a variable crest weir will be installed that will provide the option of installing a temporary barrier when needed. A stilling well will also be installed, that will provide the flexibility to manipulate water levels in both of these shallow lakes. The flexibility to be able to manipulate water levels and add a temporary barrier provides another layer of protection if carp recruitment did occur. Manipulating water levels can also be a useful shallow-lake habitat restoration strategy, and could improve the aquatic plant community in the shallow lakes. The ability to raise water levels in drought years would also provide more protection to the lake from possible winterkill of bluegill sunfish. A management plan for operating the water control structure will be required along with a DNR permit.

Big SOB Lake, which is a private and man-made lake that flows into Parley Lake, can also serve as a carp nursery. The U of M sampled abundant young-of-year carp in this lake in 2014, but indicated it was likely the result of a rotenone treatment carried out by the property owner in 2013, which likely killed off any bluegill sunfish and was recolonized by carp during the spring flooding in 2014 which created for optimum conditions for carp recruitment. The property owner has since installed a barrier at the outlet of the lake and now aerates the lake annually in the winter. No management action is required at this time, but communication/coordination with the landowner should continue.

Objective 2 – Install barrier/fish-trap between Mud Lake and Halsted Bay

Preventing fish passage and installing a trapping system between Mud Lake and Halsted Bay will effectively separate the rest of the Six-Mile Creek lakes from Halsted Bay and greater Lake Minnetonka. This will additionally address Objective 3, facilitating adult carp removal in Parley-Mud and Halsted Bay management units, by trapping migrating carp by the barrier. The U of M assessment found that almost 50% of the carp in the Parley-Mud-Halsted original management unit use this passageway. Trapping fish in this location would be very effective in removing adult carp to achieve target population levels.

Objective 3 – Adult carp biomass removal

Removal strategies and goals for removal will be broken out by each management unit and individual lakes. For each unit, there will be a target number of carp to be removed to meet the 89 lbs/acre carp biomass threshold, which is the maximum carp density that the lakes can support before ecological damage could start occurring. Within each unit, there will be target removal numbers for each lake. Carp populations can mix between different lakes in each unit, so while there are target removal numbers for each lake, the most important number is the total number of carp removed from the management unit. These target numbers are meant to be a guide, and more removal could occur in one lake over another as carp move through the system, and still achieve the goals of each unit. It should also be noted that these target numbers are fluid, carp grow year to year and overall biomass will change. Updated population numbers will be gathered throughout implementation, and target numbers may change accordingly.

Various strategies will be used for removal of adult carp, including winter seining, open-water seining, open-water baited box-net trapping and trapping in migratory stream channel areas. Strategies used in each management unit will vary.

Prioritization for removal should be given to waterbodies with the highest abundances of common carp, and includes the following waterbodies: Wassermann, East Auburn, West Auburn, Turbid, Parley, Mud and Halsted Bay. Of moderate priority, is removal of carp in: Zumbra, Steiger, Sunny, North Lundsten and South Lundsten. No removal is currently required in Piersons, Kelzers or Stone Lakes. This prioritization can be useful if resources are limited.

Costs and management strategies for each unit are estimated over a three-year time period. It is expected that good progress towards meeting management goals in each unit will be made within the first three years, however, the timeline in each unit will vary depending upon success of the actions taken. Some may take longer than three years, such as removal in Halsted Bay, which will require ongoing removal over a longer time period due to its connection to Lake Minnetonka. To achieve management goals in Halsted Bay, removal and recruitment suppression may even need to occur in other areas of Lake Minnetonka. Once management goals are achieved, there will be a need for ongoing management and occasional removal to maintain those levels.

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Piersons-Marsh-Wassermann Management Unit

<u>Management Goal</u>:

Suppress carp recruitment in South Lundsten and Marsh Lake, and reduce carp population in Wassermann Lake by at least 4,920 carp to achieve a carp biomass of less than 89 lbs/acre. Monitor carp population in Piersons Lake, and remove carp as needed to remain below the 89 lbs/acre threshold.

Piersons-Marsh-Wassermann Summary Table

Surface area (acres)	Total Carp Abundance
460	10,411

Individual Lakes Summary Table

Lake	Surface area (acres)	Avg. carp weight (lbs)	Carp Abundance	Carp biomass (lbs/acre)	Total carp abundance to equal 89 lbs/acre	# carp to be removed to achieve 89 lbs/acre
Piersons	297	7.3	3,580	88	3,616	0
Wassermann	163	7.6	6,831	318	1,914	4,917

Management Strategies

Carp removal in Wassermann Lake could involve a combination of winter seining, box-net trapping and trapping of fish in the channel at the outlet of Wassermann Lake. A barrier structure will be installed to contain the populations during removal.

<u>Barrier at Wassermann Outlet</u>

A barrier will be installed and maintained at the Wassermann outlet during management of the Piersons-Marsh-Wassermann and Auburn-Lundsten-Turbid management units. While the barrier can be temporary, to aid in the maintenance and success of the barrier, a permanent sheetpile weir will be installed with slots built in that will allow a barrier to be dropped in and removed as needed. This will prevent carp from downstream lakes from re-colonizing Wassermann Lake while removal occurs. Once management goals are met in Wassermann Lake and the downstream management unit of Auburn-Lundsten-Turbid, the barrier could be removed. The barrier will be installed prior to water temperatures reaching 7 degrees Celsius (C), as carp are known to spawn around 10 degrees C. Waiting until 7 degrees C also allows Northern Pike to move freely to their spawning grounds, as they spawn earlier than common carp, in water temperatures as low as 4 degrees C. The barrier will be maintained at least twice/week, and more frequently around heavy rain events, to keep the barrier clear of debris. Once the barrier is installed, if Northern Pike are observed trying to re-enter Wassermann Lake, action should be taken to help move the Pike past the barrier and back in to Wassermann Lake.

<u>Carp Movement Tracking</u>

To aid in removal, 15 radio-tagged carp will be tracked as needed to inform management in Wassermann Lake. 4 of these tags were implanted in the fall of 2016 by the U of M, and 11 more were implanted on April 17, 2017 with funds remaining from the U of M Assessment.

<u>Winter Seining</u>
Two to three seine attempts per year could be attempted in Wassermann Lake as needed. Winter seining is the best opportunity to remove a larger number of carp all at once, but can have variable success.

<u>Baited Box-Net Trapping</u>
Baited box-net trap removals will be scheduled annually during the open water season. This can be a labor intensive process, and typically can remove anywhere from 200 to 1,000 carp per removal.

<u>Trapping in channel at Wassermann outlet</u>
As opportunities arise, there may be a chance to trap fish in the channel area at the Wassermann outlet. Based off of tracking data during the U of M study, carp don't leave Wassermann Lake every year, and when they do, it typically involves only a portion of the population moving to downstream lakes. A temporary barrier will already be installed near the culvert of Wassermann Lake to prevent carp from downstream waterbodies from recolonizing Wassermann Lake. If carp are observed stacking up at the barrier trying to head downstream, another temporary barrier could be installed behind them and carp could be trapped in the channel and removed. Conversely, if carp stack up on the downstream side of the barrier trying to enter Wassermann, it is possible the other barrier could be installed upstream, the temporary barrier by the culvert could be opened, and carp could again be trapped and removed. Removal would require MCWD to obtain a DNR permit, as well as means for disposal.

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Management Progress
Management progress will be tracked and updated as removals and new population surveys occur. Population surveys will occur annually on Wassermann until management goals are achieved. Winter seining in early 2017 removed 2,450 carp from the lake, which reduces the number of carp left to remove to reach the goal population biomass, and is reflected in the goals stated above.

Auburn-Lundsten-Turbid Management Unit

<u>Management Goal</u>:
Suppress carp recruitment in South Lundsten, North Lundsten and Turbid Lakes, and reduce carp population in the management unit by at least 12,750 carp to achieve a carp biomass of less than 89 lbs/acre.

Auburn-Lundsten-Turbid Summary Table

Surface area (acres)	Total Carp Abundance
471	21,802

It is expected that the total carp abundance in this management unit is greater than what is listed here. There are approximately 750 carp from Wassermann Lake that are currently somewhere in this management unit. The 750 carp represents one radio tagged carp that was initially tagged in

Wassermann Lake, but last tracked in East Auburn Lake. A barrier at the Wassermann Lake outlet prevents these fish from moving back into Wassermann. Additionally, the juvenile carp from the 2015 year class spawned in South Lundsten are now almost 3 years old, and are likely dispersed among lakes in this management unit. Updated population surveys will be needed.

Individual Lakes Summary Table*

Lake	Surface area (acres)	Avg. carp weight (lbs)	Carp Abundance	Carp biomass (lbs/acre)	Total carp abundance to equal 89 lbs/acre	# carp to be removed to achieve 89 lbs/acre
East Auburn	116	4.3	6,121	227	2,418	3,703
West Auburn	133	5.1	7,201	276	2,307	4,894
North Lundsten	108	5.6	2,793	145	1,704	1,089
South Lundsten	74	5.6	2,414	183	1,178	1,236
Turbid	40	8.1	2,273	460	442	1,831
Total			**20,802**		**8,049**	**12,753**

**Carp populations in this management unit mix fairly frequently, especially between East and West Auburn and North and South Lundsten. Management goals for each waterbody are approximate targets, but overall reductions are needed across the management unit as a whole.*

Management Strategies
Management strategies in these lakes could involve a combination of winter seining, open-water seining, box-net trapping and trapping of migratory fish in stream channels. Lakes conducive to winter seining and potentially open-water seining include East Auburn, West Auburn and Turbid Lakes. North and South Lundsten, given their shallow depth, mucky substrate, and limited accessibility, would be difficult to seine. A more likely carp removal strategy for these lakes would be to either trap the carp as they migrate from North Lundsten to West Auburn, or remove them once they enter West or East Auburn. The installation of a variable crest weir between North and South Lundsten, which would include brackets for a temporary barrier, would allow for the future option to drawdown South Lundsten Lake. Drawdown could be a rapid response tool if aeration fails, and carp recruitment occurs. Temporary barriers would also be needed to aide in trapping and removal between North Lundsten and West Auburn.

<u>Carp Movement Tracking</u>
To aid in removal, carp in East and West Auburn and Turbid will be implanted with 5 to 8 radio tags each to track movement and inform timing of management strategies. Radio-tagged carp will be tracked as needed to inform management.

<u>Winter Seining/Open-Water Seining</u>
Winter and/or open-water seining is expected to be a strategy for carp removal in East Auburn, West Auburn and Turbid Lake. Turbid Lake, given its small size, may be a good candidate for an open-water or winter seine, however, accessibility and bottom debris may be an issue. Two to three seine attempts per year could be attempted in East Auburn, West Auburn and Turbid Lakes as needed. North and South Lundsten are not good candidates for seining due to depth and accessibility, and will primarily be managed as carp move from these lakes into stream channels or other lakes. Seining provides the best opportunity to remove a larger number of carp all at once, but can have variable success

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Baited Box-Net Trapping

Baited box-net trapping is an option for West Auburn and Turbid Lake, conditions are likely not suitable in East Auburn or either Lundsten Lakes due to mucky or silty bottom substrates, and accessibility. Baited box-net trap removals will be scheduled annually during the open water season. This can be a labor intensive process, and typically can remove anywhere from 200 to 1,000 carp per removal.

Drawdown

The installation of a variable crest weir and stilling well between North and South Lundsten will provide the flexibility to manipulate water levels. The weir will also include a temporary barrier that can be removed as needed. Water drawdown and the temporary barrier could be a rapid response tool to control the carp if aeration fails. The installation of this weir will require the current trail crossing between the two lakes to be built up to reduce flooding potential and potential fish passage. A drawdown is not planned as an initial strategy, but the option will be there if other strategies are not effective. A management plan for operating the water control structure will need to be developed.

Trapping carp in the channel between North Lundsten and West Auburn

The stream between North Lundsten and West Auburn is a frequent migratory passageway for carp in this management unit. The U of M Assessment observed that around 43% of carp originally tagged in West and East Auburn pass through this channel annually, on their way to North Lundsten, and there is likely a similar number that returns to West Auburn. With proper timing, installing a couple of temporary barriers in this location could effectively trap carp for removal. Trapping would likely be most effective just downstream of the culvert located between West Auburn and North Lundsten. To catch carp coming to North Lundsten from Auburn Lake, a barrier will be installed downstream of the culvert, and once carp pass the culvert area, a second barrier will be installed in front of the culvert on the downstream side to effectively block carp in. This strategy can be reversed as fish attempt to leave North Lundsten and move upstream. Tracking of radio-tagged fish, in combination with analyzing historical tracking data from the U of M Assessment will guide the timing of trapping. There could be some costs for equipment and disposal of removed carp.

Management Progress

Management progress will be tracked and updated as removals and new population surveys occur. Population surveys will occur annually on each waterbody until management goals are achieved.

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Parley-Mud Management Unit

Management Goal:
Install barrier/fish-trap between Mud and Halsted Bay. Suppress carp recruitment in South Lundsten, Big SOB, Crown College Pond and Mud Lake, and reduce carp population in the management unit by at least 17,800 carp to achieve a carp biomass of less than 89 lbs/acre.

Parley-Mud Summary Table

Surface area (acres)	Total Carp Abundance
351	21,315

Individual Lakes Summary Table

Lake	Surface area (acres)	Avg. carp weight (lbs)	Carp Abundance	Carp biomass (lbs/acre)	Total carp abundance to equal 89 lbs/acre	# carp to be removed to achieve 89 lbs/acre
Parley	258	8.9	16,167	558	2,592	13,575
Mud	93	9.1	5,148	504	912	4,236
Total			**21,315**		**3,504**	**17,811**

Management Strategies
Carp removal in these lakes could involve a combination of winter seining, open-water seining, baited box-net trapping and trapping of migratory fish in stream channels. Removal in this management unit will be facilitated by the barrier/trapping system to be installed between Mud Lake and Halsted Bay. Carp in Mud Lake often move to Parley Lake by late fall, over-winter in Parley, and move back to Mud early spring. Management strategies will take advantage of that movement pattern, and focus on removing carp from this management unit when all carp are in Parley Lake. Carp also move frequently between Mud and Halsted Bay, and with the presence of a trapping system between these two lakes, additional removal could occur in this location.

<u>Carp Movement Tracking</u>
To aid in removal, 10 carp in each of the two lakes will be implanted with radio tags to track movement and inform timing of each management strategy. Radio-tagged carp will be tracked as needed to inform management.

<u>Winter Seining/Open-Water Seining</u>
Winter and/or open-water seining is expected to be one of the primary strategies for carp removal in Parley Lake. Carp from Mud Lake over-winter in Parley, making winter removal in Parley ideal for removing carp from the management unit. Two to three seine attempts per year could be attempted as needed. Winter and open-water seining provide the best opportunity to remove a larger number of carp all at once, but can have variable success.

<u>Baited Box-Net Trapping</u>
Baited box-net trap removals will be scheduled annually during the open water season. This can be a labor intensive process, and typically can remove anywhere from 200 to 1,000 carp per removal. The substrate in Mud Lake is not conducive to box-netting, so all attempts will occur in Parley Lake.

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Trapping carp Six-Mile Creek

The U of M Assessment found that 50% of carp in this management unit move annually through the channel between Mud and Halsted Bay. With the installation of barrier/trapping system in this channel, removal could occur throughout the open-water season.

Management Progress

Management progress will be tracked and updated as removals and new population surveys occur. Population surveys will occur annually on Parley and Mud until management goals are achieved.

Carver Park Reserve Management Unit

Management Goal:

Suppress carp recruitment in Sunny Lake, and reduce carp population in the management unit by at least 4,400 carp to achieve a carp biomass of less than 89 lbs/acre.

Carver Park Reserve Lakes Summary Table

Surface area (acres)	Total Carp Abundance
532	10,247

Individual Lakes Summary Table

Lake	Surface area (acres)	Avg. carp weight (lbs)	Carp Abundance	Carp biomass (lbs/acre)	Total carp abundance to equal 89 lbs/acre	# carp to be removed to achieve 89 lbs/acre
Zumbra	221	6.6	5,953	178	2,984	2,969
Sunny	48	7.2	981	147	595	386
Steiger	166	8.0	2,886	139	1,851	1,035
Stone	97	10.5	427	46	821	0
Total			**10,247**		**6,251**	**4,390**

Management Strategies

Carp removal in the Carver Park Reserve Lakes could involve a combination of winter or open-water seining and baited box-net trapping.

Carp Movement Tracking

To aid in removal, 10 carp in Zumbra Lake will be implanted with radio tags to track movement and inform timing of management strategies. Each lake in this management unit is a somewhat contained population with limited to no movement between lakes. Because of management strategies planned for Sunny and Steiger, tracking fish in those lakes will not be critical. Radio-tagged carp will be tracked as needed to inform management.

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Winter/Open-Water Seining
Seining is expected to be a strategy for carp removal in Zumbra Lake, and possibly Sunny Lake. It is expected that two to three seine attempts per year could be attempted as needed. Seining provides the best opportunity to remove a larger number of carp all at once, but can have variable success.

Baited Box-Net Trapping
Baited box-net trapping is an option for Zumbra, Steiger and Sunny Lakes. Removals will be scheduled annually during the open water season. This can be a labor intensive process, and typically can remove anywhere from 200 to 1,000 carp per removal.

Management Progress
Management progress will be tracked and updated as removals and new population surveys occur. Population surveys are tentatively scheduled to occur annually on each waterbody until management goals are achieved.

Halsteds Bay Management Unit

Management Goal:
Install barrier/trapping system between Mud Lake and Halsted Bay, and reduce carp population in Halsted Bay by at least 59,350 to achieve a carp biomass of less than 89 lbs/acre. Future management will be needed to address carp immigrating and emigrating from the rest of Lake Minnetonka via the channel between Priests Bay and Hasted Bay.

Halsteds Bay Summary Table

Lake	Surface area (acres)	Avg. carp weight (lbs)	Carp Abundance	Carp biomass (lbs/acre)	Total carp abundance to equal 89 lbs/acre	# carp to be removed to achieve 89 lbs/acre
Halsteds Bay	552	9.65	64,441	1128	5,091	59,350

Management Strategies
Management strategies for Halsteds Bay will be complex, and may need to involve removal in other areas of Lake Minnetonka to reach management goals. A barrier/trapping system will be installed between Mud Lake and Halsteds Bay, which will aid in containing the population to Halsted Bay and Lake Minnetonka, and also be a primary removal tool. The U of M assessment observed Six Mile Creek between Mud Lake and Halsted Bay to be a frequent migratory route for carp. Almost 50% of carp in this bay pass through this channel annually. Both open water seining and winter seining will also be management strategies for this lake. Baited box-net trapping could also be successful in this lake, but will not be used until a significant number of carp have already been removed through seining and trapping

Barrier & Trapping System in Six Mile Creek between Mud Lake and Halsted Bay
This system is described in Objective 2 of this carp management plan. The U of M assessment found that almost 50% of carp in Halsted Bay use this passageway to reach Mud Lake and Parley Lake. By cutting that passageway off with a barrier/trapping

system, it not only contains the population in this management unit to Halsted Bay and greater Lake Minnetonka, but it also acts as primary carp removal tool by removing carp on an ongoing basis as carp pass through the trap.

Carp Movement Tracking
To aid in removal, 15 carp in the lake will be implanted with radio tags to track movement and inform timing of each management strategy. Radio-tagged carp will be tracked as needed to inform management. A portion of the carp population in Halsted Bay are known to go out into greater Lake Minnetonka, so it is expected that tracking will need to occur not only in Halsted Bay, but other areas of the lake.

Winter Seining/Open-Water Seining
Winter and open water seining are expected to be a main strategy to remove carp in Halsted Bay. Two open water seining attempts could occur annually, as well as up to three winter seining attempts, all as needed. Seining provides the best opportunity to remove a larger number of carp all at once, but can have variable success. As more carp are removed from the lake, the costs to get commercial fisherman to seine the lake becomes greater.

Baited Box-Net Trapping
Baited box-net trapping is an option for Halsted Bay as numbers are reduced. Its unlikely box-nets will be required in the first three years of management due to the large number of carp in this bay, seining will be a more cost-effective solution to begin with.

Assessing Carp in greater Lake Minnetonka
Assessing carp in greater Lake Minnetonka is not directly part of the initial carp management plan for Halsted Bay, however, as carp biomass is removed from the lake, it may become necessary to start addressing carp in other bays of Lake Minnetonka, and other connected subwatersheds. For instance, during the U of M assessment, carp tagged in Halsted Bay have been observed moving into nearby Priests Bay and Cooks Bay, and even as far as Jennings Bay. Jennings Bay is connected to both the Dutch Lake Subwatershed and Painters Creek Subwatershed, both of which carp are suspected of being an issue. Addressing carp in those subwatersheds and Jennings Bay would likely provide positive benefits in achieving management goals in Halsted Bay.

Management Progress
Management progress will be tracked and updated as removals and new population surveys occur. Population surveys will occur annually on Halsted Bay until management goals are achieved.

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Additional Information

Equipment & Operational Needs

One-time costs for equipment will include the purchase of trap-nets, electrofishing boat, box-net, backpack electrofisher and supplies in year one of management. The District already owns telemetry equipment to track carp. The District will use trap-nets to monitor potential carp recruitment areas. If carp recruitment occurs, a rapid response would need to occur to control the new juvenile carp produced. An electrofishing boat will be used to provide updated carp population surveys that will track management progress, as well as monitor populations long-term. Box-net traps will be baited with corn, and used to trap and remove carp. Backpack electrofisher will be used to stun carp trapped in stream channels to aid in removal. Operational needs include supplies and other materials needed for repair and maintenance of equipment and barriers, operating costs of running aeration units, as well as permit fees for winter aeration and thin ice signage as required by the MN DNR. Funds may also be used for clearing submerged debris in lakes that interfere with the success of seining and other management strategies, and equipment rental to aid in removal of carp in stream channels.

Contingency

If an aeration system fails, or barriers are compromised, carp recruitment could occur. If recruitment occurs, a rapid response would need to occur to control the new juvenile carp population. Rapid response could include strategies such as drawdowns, fish poisonings, trapping fish in migratory streams or removal as adults once they move into other waterbodies. Different scenarios need to be developed. Funds will be budgeted for annually for these types of responses.

Monitoring Plan

Monitoring will be necessary to inform management, track progress on achieving management goals, and assessing ecological changes as removal occurs.

Monitoring to Inform Management

Monitoring activities that inform management and track progress on achieving management goals include performing updated carp population surveys, monitoring for carp recruitment, and tracking radio-tagged fish to inform management. Monitoring for carp recruitment includes performing winter dissolved oxygen monitoring and trap-net surveys in suspected carp nurseries. Updated carp population estimates requires the completion of electrofishing surveys. Tracking radio-tagged carp involves the use of telemetry gear, and implanting radio tags in a subset of carp. A description of those activities is described further in this section.

Updated Carp Population Surveys

Carp population surveys will be conducted annually by performing electrofishing surveys on all accessible waterbodies to monitor management progress. Surveys will occur late summer/early

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fall, following protocol developed by the University of Minnesota. Two surveys will be conducted, and results will be averaged. If survey results do not fall within 20% of each other, a 3rd survey will be performed. Once management goals are met in each waterbody, the frequency of updated surveys could be decreased to once every five years.

List of lakes to receive annual population surveys

Piersons-Marsh-Wassermann	Auburn-Lundsten-Turbid	Parley-Mud	Carver Park Reserve Lakes	Halsted Bay
Wassermann	East Auburn	Parley	Zumbra	Halsted Bay
Piersons	West Auburn	Mud	Steiger	
	North Lundsten*		Sunny*	
	South Lundsten*			
	Turbid			

**Accessibility may be an issue for these lakes*

<u>Winter Dissolved Oxygen Monitoring</u>

Winter dissolved oxygen is monitored to assess the potential for winterkill of bluegill sunfish. Winterkill could result in optimum conditions for carp recruitment. Winter dissolved oxygen readings below 2 mg/L at the surface will prompt a spring trap-net survey to be conducted to determine status of the sunfish community.

List of lakes to receive annual winter dissolved oxygen monitoring

Lake	Frequency
Marsh	2 to 3 times per winter
North Lundsten	
South Lundsten	
Sunny	
Mud	
Turbid	
Carl Krey	

<u>Spring Trap-Net Surveys</u>

Trap-Net surveys are used to sample young-of-year carp, as well as panfish like bluegill sunfish. Spring trap-net surveys will be performed on potential carp nursery lakes if the threat of winterkill is possible. Winter dissolved oxygen (DO) will be monitored, and if DO falls below 2 mg/L at the water's surface, it will prompt a spring trap-net survey to assess the status of bluegills. If a winterkill occurred, rapid response planning will begin to address possible juvenile carp in the system. An early fall survey can confirm if carp recruitment actually occurred, and the rapid response can then be implemented.

Potential Spring Trap-Net Lakes	
Marsh	Sunny
North Lundsten	Mud
South Lundsten	Turbid
Carl Krey	

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Fall Trap-Net Surveys

Trap-Net surveys are a way to sample young-of-year carp, as well as panfish like bluegill sunfish. Fall is the optimum time to sample for juvenile carp, as they would be large enough by this time to be trapped in the nets. These surveys will occur annually on the lakes below, and confirm if carp recruitment occurred.

List of lakes that will receive annual fall trap-net surveys

Fall Trap-Net Survey Lakes	
Marsh	Sunny
North Lundsten	Mud
South Lundsten	Turbid
Carl Krey*	

**If accessible*

Carp Tracking

Radio-tagged carp will be tracked as needed to inform management strategies such as seining or stream trapping.

Monitoring to Assess Ecological Changes

Carp are known to exacerbate internal phosphorus loading, reduce water clarity and uproot aquatic vegetation. Metrics for assessing changes in water quality and ecological conditions will include the following: total phosphorus, chlorophyll-a, water clarity, total suspended solids and aquatic plant community metrics.

Monitoring Activities

A detailed description of the monitoring activities is described in this section. These monitoring activities will be conducted on each lake to assess ecological changes as carp are managed in the system.

Aquatic Plant Surveys

Updated aquatic plant surveys will be performed on each waterbody as carp removal occurs, as well as annually for at least 3 years once carp management goals are met. Surveys will follow standard point-intercept protocol established by the Minnesota Department of Natural Resources (MN DNR), and may occur in both early summer and late summer. Early summer surveys capture early season plant growth, including the invasive Curlyleaf Pondweed. Late summer plant surveys capture native vegetation when it should be at its peak biomass, as well provides a better representation of invasive Eurasian Watermilfoil. During all surveys, acoustic mapping will occur that will provide further metrics to evaluate the changes in the aquatic plant community. Metrics that will tracked from aquatic plant surveys include: Floristic Quality Index (FQI), percent occurrence of each species, maximum depth of plant growth, percent area of the lake vegetated, and average aquatic vegetation biovolume.

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List of lakes receiving updated aquatic plant surveys

Halsted Bay	Steiger
Marsh	Sunny
Wassermann	North Lundsten
East Auburn	South Lundsten
West Auburn	Parley
Turbid	Mud
Zumbra	

Water Quality Monitoring

Water quality monitoring will occur annually during removal, and for least 3-years once carp management goals are met. Ongoing water quality monitoring needs will be reassessed after that 3-year post carp management time period.

Water quality monitoring will provide data to assess changes in nutrients, algal abundance and water clarity. Parameters being analyzed will include Total Phosphorus, Chlorophyll-a, Total Suspended Solids and Water Clarity. Sampling will occur monthly May – September in deep lakes, and twice per month May – September in shallow lakes.

List of lakes receiving water quality monitoring (TP, Chl-a, TSS, Clarity) once per month May – September

East Auburn	Zumbra
West Auburn	Steiger
Turbid	Sunny

List of lakes receiving water quality monitoring (TP, Chl-a, TSS, Clarity) twice/month May – September

North Lundsten	Mud
South Lundsten	Halsted Bay
Wassermann	Parley

Other Monitoring

Additional monitoring will occur in several waterbodies that are receiving annual aeration. Aeration in shallow lakes has the potential to impact sediment resuspension and sediment release of phosphorus. Grab samples will be collected to monitor for any water quality impacts from aeration. Samples will be taken three times during the winter while aeration is occurring; once before the aeration unit is turned on (November), once while in operation (Jan./Feb.), and once after the unit is shutdown at ice-off (March/April). Samples will be analyzed for Total Phosphorus and Total Suspended Solids. Monitoring will occur for three years to assess if aeration is having any detrimental effects on water quality.

Aeration lakes to receive water quality monitoring	
Marsh	Sunny
North Lundsten	Mud
South Lundsten	Turbid

Reporting

Annual reports will be generated to update progress on achieving management goals in each waterbody and management units, as well as provide any new updates to the management plan, as it is an adaptive process.

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