Developing and Testing a Strategy to Control Common Carp in Long Lake, New Brighton, MN

Cumulative Report for Years 1-3

Prepared for: Rice Creek Watershed District

Prepared by: Carp Solutions LLC;
Przemyslaw Bajer, Aaron Claus, & Jordan Wein

June 26, 2018

www.carpsolutionsmn.com

Executive Summary

In this report, we present the results of work conducted during June 2015 – April 2016 (Year 1), May 2016 – April 2017 (Year 2), and May 2017-May 2018 (Year 3) to describe key attributes of the common carp population inhabiting Long Lake and adjacent lakes. This work is intended to support the Rice Creek Watershed District's (RCWD) development of strategic control measures for this invasive fish.

We determined that carp biomass in Long Lake varied between approximately 380 and 700 kg/ha between years and between seasons within each year. This variability is driven by seasonal migrations between Long Lake and Lino Lakes, immigration of juvenile carp from Lino Lakes to Long Lake and carp removal in Long Lake. Overall, carp biomass significantly exceeds the management threshold of 100 kg/ha.

We determined that the carp population is comprised of multiple year classes (0-31 years old), which shows that young carp frequently recruit into the population but in moderate numbers, and that the population is long-lived. We determined that the Lino Chain of Lakes comprise a key nursery for adult carp from Long Lake. Each spring, the majority of adult carp swim from Long Lake to Lino Lakes. The timing of those migrations varies between years. They may start between late March and mid-May. Electronic antennas have been used to track these migrations. The carp then return to Long Lake through late spring and summer, with many carp moving back and forth several times; often 3-4 migration bouts occur in each season.

Carp's spawning success in Lino Lakes varies among years. We documented a strong year class in 2015 and no detectable year classes in 2016 and 2017. We found no significant numbers of juvenile carp in other lakes in the watershed, including Long Lake. We documented the migration of juvenile carp (ages 0, 1, 2) from Lino Lakes to Long Lake using electronic antennas and ageing analyses. We found that following the strong 2015 year class, approximately 3,000 age-1 carp moved from Lino Lakes to Long Lake. As of late 2017, approximately 20% of carp in Long Lake were comprised of the 2015 cohort from Lino Lakes.

We tested several removal methods. Winter seining under the ice was not successful (< 1,000 carp removed between 2015 and 2017). Although winter aggregations of carp could easily be found in Long Lake using telemetry, seine nets were not effective at capturing those fish due to snags on the bottom. Open water seine was more successful catching ~4,300 carp (~ 25% of population) in November 2016. Baited box nets were also successful. In 2017, ~ 3,500 (29% of population) carp were removed in only three attempts using 3 relatively small nets. This technique is not hindered by debris on the bottom and can be easily scaled up.

We also tested an electric guidance system (EGS) to see if carp can be blocked during their spawning migrations and directed into a trap. Preliminary tests in fall 2017 showed that approximately 80% of carp were directed into a mock trap and that no carp were able to cross the electric guidance system. Data from spring 2018 showed that the EGS also performed well under high-water spring conditions. The system was also easy to deploy and maintain. The EGS could be used as a key component to trap carp during spawning migrations.

Finally, using the data collected over the three seasons we developed a model to simulate the dynamics of the carp population under various management scenarios. The model shows that sustained control (biomass < 100 kg/ha) might be feasible in Long Lake within 5-10 years by combining multiple strategies. This could be achieved by, for example, removing >50% of adults annually (via seining, box nets, or traps associated with the EGS). Carp control would be enhanced and occur even faster by reducing immigration of juvenile carp from Lino Lakes (electric deterrent) by 50% while also blocking the return of adults from Lino Lakes to Long Lake by at least 50% (electric deterrent). Model results represent estimates, and should be regularly updated. Specifically, the model should be updated by monitoring how often carp are able to produce young in Lino Lakes and rates which these young carp migrate to Long Lake.

Management Recommendations

1. Aggressively remove carp using any of the following options:
    a. Commercial seining when convenient and cost effective.
    b. Baited box net – tests show it is selective, consistent and reliable. Scaling up is possible and would decrease cost per carp captured.
    c. Stream trapping in conjunction with EGS – initial tests show great promise. We suggest a permanent power supply be established. With further development, we may find that using the EGS may be most cost effective method of adult removal

2. Annually deploy the EGS system to block downstream migration of juvenile carp

3. Monitor changes in carp biomass and age structure in Long Lake to see if removal is effective:
    a. Annual boat electrofishing surveys to estimate population and mark individuals for recapture.
    b. Ageing analysis of a sample of 100 carp in Long Lake to understand rate of recruitment to Long Lake occurs after removals.

4. Monitor carp recruitment in Lino Lakes and the movement of juvenile (and adult) carp
    a. Annual trapnet surveys in Lino Lakes to assess survival of YOY
    b. PIT antenna array maintenance to insure accurate tracking of movement patterns
    c. Annual PIT data analysis
    d. Strategically add PIT tags to carp especially YOY and juvenile carp caught in Lino Lakes

5. Maintain EGS systems in Rice Creek to block adult spawning migrations and juvenile recruitment into Long Lake from Lino Lakes
    a. Clear debris and maintain cathodes and anodes in creeks
    b. Maintain PIT antennas associated with mock trap

6. Update the population model using current data and use it to guide future management.

Introduction

The common carp (*Cyprinus carpio*) is an invasive fish that was introduced to North America in late 1800s. The carp is known for its tendency to root in lake sediments while searching for food and by doing so increasing water turbidity, releasing sediment-bound nutrients and uprooting aquatic vegetation (Bajer et al. 2009, Bajer and Sorensen 2014; Vilizzi et al. 2015). Productive lakes of south-central Minnesota represent a region of extremely high carp abundance, which often exceeds 400 kg/ha. Carp become damaging to lake ecosystems once their biomass exceeds approximately 100 kg/ha (Bajer et al. 2009), which is often recommended as a management goal.

Until recently, management of carp populations in Minnesota was limited because processes that drive carp abundance were not well documented and statistical models that could guide carp management efforts were not developed. Recently, much research has been done to demonstrate that carp populations can indeed be controlled in this region by exploiting a few weaknesses in their life cycle. First, carp are unable to recruit (have young) in lakes dominated by bluegill sunfish (*Lepomis macrochirus*) and other native predators that consume carp eggs and larvae. To overcome these recruitment bottlenecks, carp need to migrate to winterkill-prone, bluegill-free marshes to successfully reproduce (Bajer et al. 2012). Second, it takes (typically) approximately 2 years for the juveniles to leave these marshy areas and migrate back to lakes in large numbers (Bajer et al. 2015); migartion tendencies in the first and second year of life appear to be very low. Lastly, adult carp form dense winter aggregations that can be located with telemetry and targeted with seine nets for removal. Up to 90% of adult carp can be removed in a single haul in small lakes (Johnsen and Hasler 1977) (Bajer et al. 2011).

Long Lake is currently inhabited by a large population of carp, as suggested by commercial catch rates (over 200,000 lbs in last 5 years). However, the ecology of the system suggests that sustainable control might be possible. Specifically, data suggest that carp are unable to successfully reproduce in Long Lake, likely due to abundant bluegill population, and that most (if not all) juvenile carp originate from the five shallow lakes upstream of Long Lake to which the adults migrate annually to spawn. The fact that all of these nurseries are located in one area suggests that they might be controlled by a single management strategy, such as a strategically placed deterrent to juvenile carp movement. Meanwhile, various tools could be used to systematically reduce the abundance of adults in Long Lake. An existing population dynamics model developed specifically for mobile carp populations that inhabit lake-marsh systems (Bajer et al. 2015) could be adopted to test what management actions are needed to control carp in Long Lake in a sustainable and cost-effective manner.

Study System

This project was conducted on the population of common carp inhabiting an interconnected chain of lakes consisting of Long Lake (New Brighton, MN), the five shallow marshes upstream of Long Lake collectively called Lino Lakes (Baldwin, Rice, Marshan, Reshanau, George Watch; Fig. 1), and in selected potential carp nurseries located along the Lake Johanna – Josephine system that flows into Long lake from south-east (Table 1; Fig. 2). For the purposes of this project, the carp population within this reach of Rice Creek is considered mostly closed because there are significant barriers to fish movement upstream of George Watch lake and downstream of Long Lake (Fig. 1). The majority of adult carp in this system of lakes overwinter in Long Lake (the deepest lake in the system). Most of these fish (~ 90%; Banet 2016) migrate to Lino Lakes to spawn in early spring and then return back to Long Lake (Banet 2016).

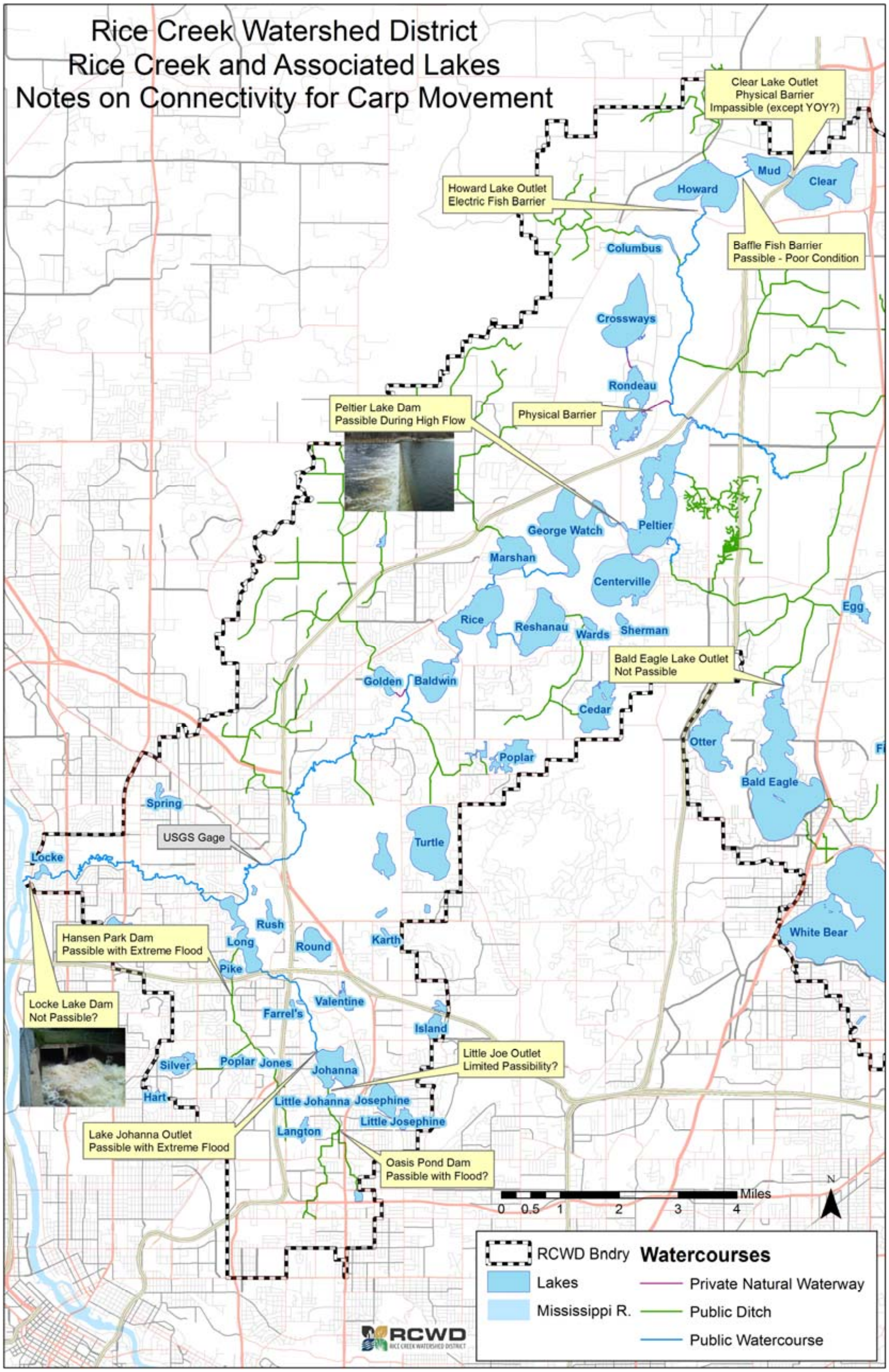


Figure 1. Rice Creek Watershed District Overview Map (Provided by Matt Kocian, RCWD).

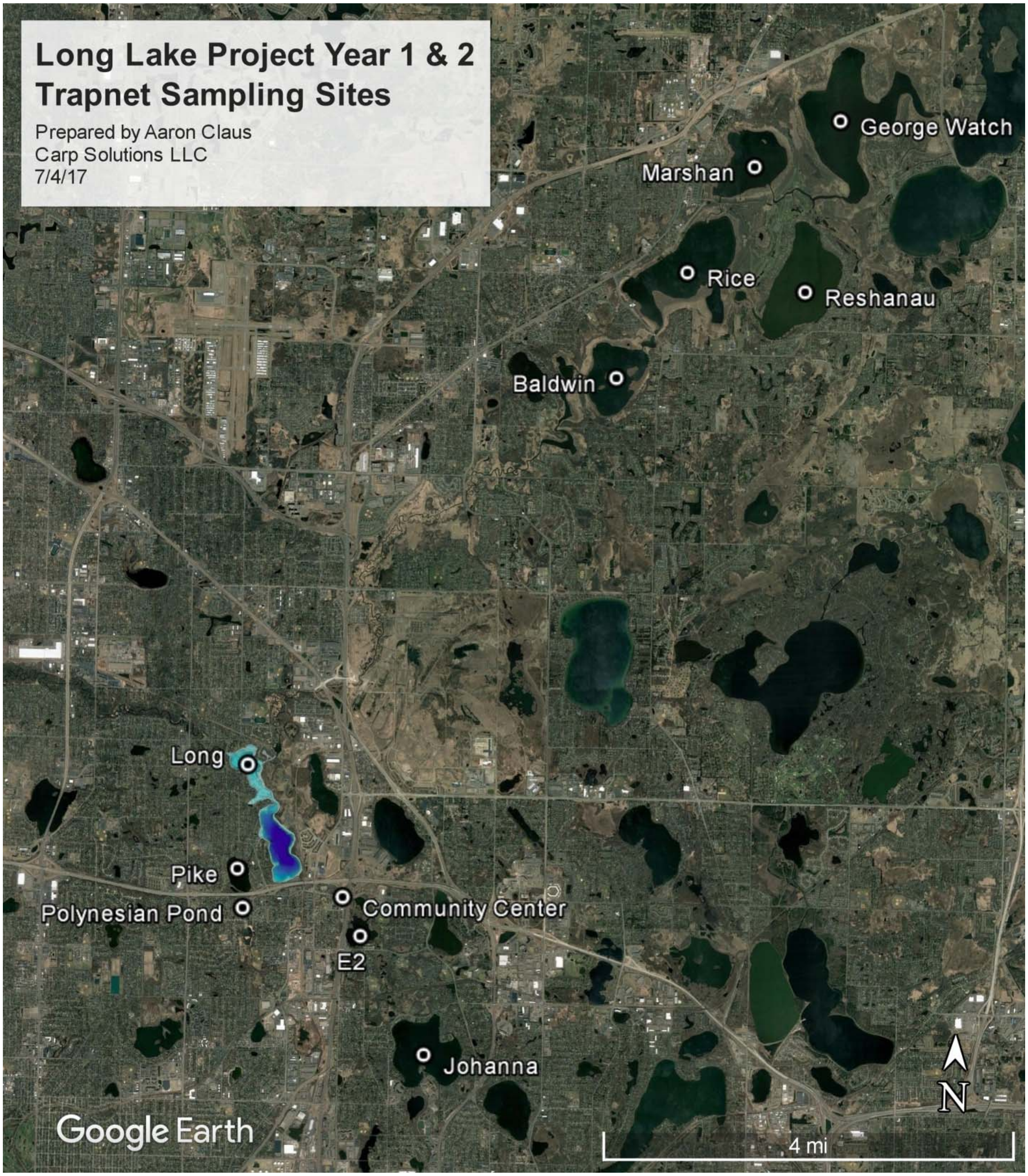


Figure 2. Common carp nursery habitat sites sampled 2015-2017.

Task 1: Estimate the abundance and biomass of carp in Long Lake

Year 1

To estimate the number and biomass of carp in Long Lake we conducted mark-release-recapture analyses. First, to mark the carp, we set two box traps in Long Lake that were baited with corn to attract carp, while not attracting native fish. These nets are comprised of a 20 x 20' mesh bottom surrounded by four 8' tall sides also made out of a soft mesh. Metal posts with winches, counterweights, ropes and release mechanism surround the net allowing for rapid lifting the sides to catch the carp that aggregate at the bait (Fig. 3). Initially, these nets were laid flat on the lake bottom and cracked corn was placed in a mesh bag in the center of the net. The bait was weighed and replaced daily with fresh corn. After 2-4 days, the carp appeared to be trained to consume large quantities of corn. Once that occurred, we returned to the net before sunrise on a daily basis to spring the net and catch the carp (up to 163 carp were captured each time). Each captured carp was measured, given a fin clip and released back to the lake. This routine continued between September 30 and November 5 until 700 carp were marked and released. To ensure that marked fish were distributed more evenly throughout the population, we used one box net in the northern and one in the southern part of the lake.

To recapture the marked carp and estimate the population we partnered with a commercial fisherman (Mr. Jeff Riedemann) to locate aggregations of carp under the ice and catch them using a large seine net (~ 1,600' long net). To track the locations of the carp we used radiotagged carp that were already present in the lake as a result of recently finished research project by the University of Minnesota (Banet 2016). With the assistance of RCWD staff, the radiotagged carp in Long Lake were tracked on 8 occasions between January 15 and March 1. The carp were not tightly aggregated until February 2016 at which time carp aggregation was found near the inlet to Long Lake (Figure 4).

Figure 3. A Carp Solutions LLC box net (with the walls raised) used to catch carp that are attracted to bait placed in the center of the net (photo credit: Anita Jader).

Figure 4. Location of carp aggregation in Long Lake on February 15, 2016.

The commercial fishermen determined that the depth in the area where the carp were aggregated was suitable to pull the net, however they were somewhat concerned about possible snags on the bottom as they never seined in that area before. To reduce the risk of snags, the net was deployed to cover a minimal area of the bottom by driving the fish into the net with noise (driving truck on ice while monitoring the movement of radiotagged carp). This strategy appeared successful as 18 out of 25 radiotagged carp that were present in the area were successfully surrounded with the net. Initial stages of the net deployment were progressing smoothly. However, at some point, one side of the net became buried in the mud and the fishermen needed to lift it off the bottom. Sections of the net kept getting buried in the mud over much of the seining. To dislodge the net, the fishermen had to pull it with great tension, which caused the net to be stretched and not adhere to the bottom along its entire length. This created gaps underneath the net allowing most of the carp to escape. After the net was pulled, only 340 carp were captured, including only three of the original 18 radiotagged carp. Among the 340 captured carp, 11 carried marks (fin-clips) from the previous box netting. This allowed us to estimate the abundance of carp in Long Lake using an equation (Chapman estimator) where N is number in the population, C is the number captured on the second visit, M is the number marked on the first visit, R is the number recaptured on the second visit:

$$N = \frac{(C+1)\cdot (M+1)}{(R+1)} - 1$$

This equation allowed us to estimate that Long Lake was inhabited by 20,686 carp in the fall of 2015. Given the average carp weight of 2.6 kg, we estimate that carp biomass in Long Lake was 773 kg/ha. This biomass level is extremely high, in most Minnesota lakes infested with carp their biomass does not exceed 400 kg/ha (Bajer and Sorensen 2012), and exceed a level that is considered to be causing ecological damage in lakes (100 kg/ha; Bajer et al. 2009) by seven folds. However, we know from previous studies (Banet 2016) that some adult carp migrate out of Long Lake to the Lino Lakes in the spring and summer. This would periodically reduce the biomass in the lake. Nevertheless, the biomass of carp in Long Lake is very high. A sample of 100 carp captured in the seine was measured to determine length structure of the population. It showed that the carp were relatively large, with fewer than 10% of the population being comprised by smaller (younger fish) in the 300-400 mm range (Figure 5). We later determined these young fish to be 2-3 years old (see below).

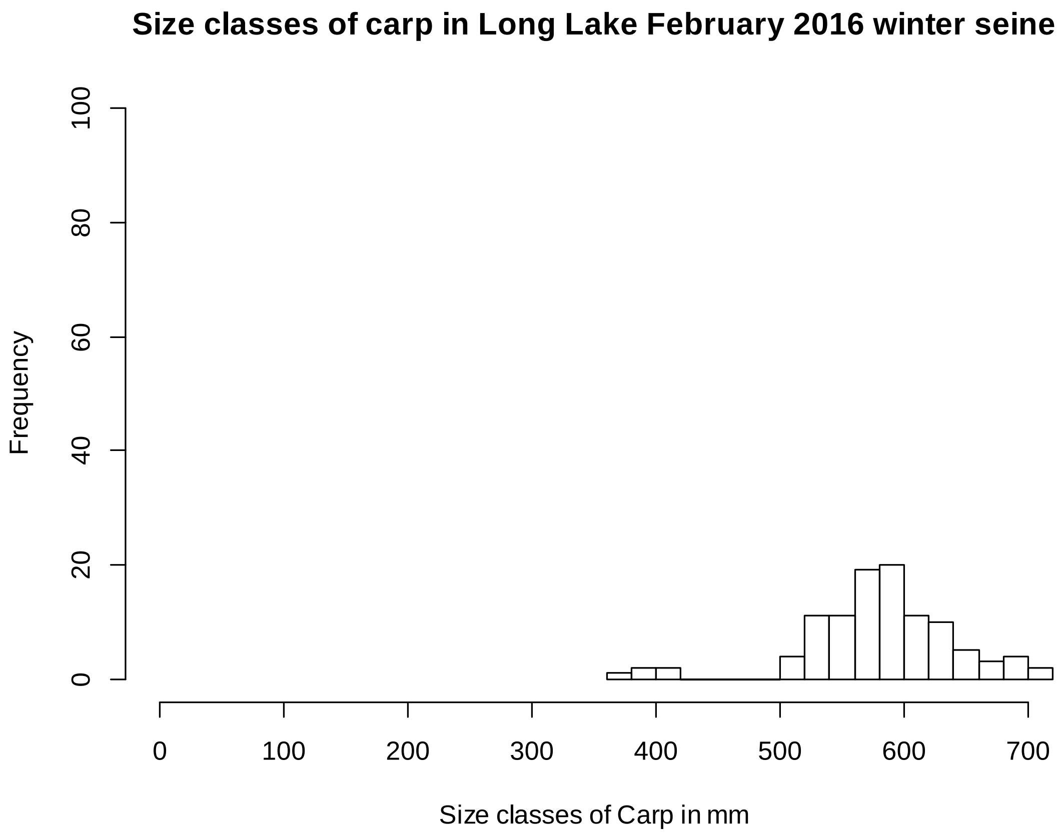


Figure 5. Length frequency of common carp captured in Long Lake using winter seine on February 15, 2016.

Year 2

<u>Mark-release-recapture</u>

Because length frequency histograms showed that carp population in 2016 was comprised of two size classes (< 500 mm and >= 500 mm; Fig. 6), we estimated the abundance of carp in each size class separately and then combined them to estimate the overall abundance and biomass of carp in Long Lake in 2016. To estimate the abundance of the larger carp (>= 500 mm), 384 carp in that size range were captured in the box net in the fall 2016, marked with pelvic fin clips and released. An open water seine was conducted on 11/22/2016. 4417 carp > 500 mm were captured in the seine net including 133 marked individuals. Thus, in the fall of 2016 Long Lake was inhabited by 12,753 carp greater than 500mm in total length. Given the average carp weight of 3 kg, we estimate that biomass of carp greater than 500mm in total length in Long Lake was 547 kg/ha.

To estimate the abundance of carp < 500 mm, 681 carp in that size range were captured using the box net in the fall 2016, marked with pelvic fin clips and released. In May 2017, box net was used again and resulted in capturing 300 carp < 500 mm, of which 46 had marks from the fall of 2016. This suggested that in the Fall of 2016, Long Lake was inhabited by 4,367 Common Carp less than 500mm in total length. Given the average weight of .83 kg, we estimate that biomass of carp greater than 300mm but less than 500mm in total length in Long Lake was 52 kg/ha.

In combination, abundance estimates for the two size classes suggest that there were 17,120 carp greater than 300mm in total length inhabiting Long Lake at the end of 2016, with a corresponding total biomass of ~600 kg/ha.

<u>Boat Electrofishing</u>

Boat electrofishing provides an alternative (although usually less accurate) approach for estimating the abundance and biomass of carp (Bajer and Sorensen 2012). In this approach, the number of carp caught per one hour of electrofishing is used to estimate the density of carp in the lake (carp/ha; Carp per hectare = 4.71* catch per hour + 3). Boat electrofishing surveys conducted in July 2016 in Long Lake resulted in capturing 201 carp. The mean catch per hour (53.5) suggested that the lake was inhabited by approximately 17,560 carp at that time; which is very close to the mark-recapture estimate for year 2.

Boat electrofishing is also believed to provide an accurate representation of the size structure of the population. Length and age of captured carp showed that approximately 16.3% of the population (2,862 carp) was comprised of age-1 carp (the 2015 year class born in Lino

Lakes; Fig. 6). This suggested that approximately 2870 carp were recruited into Long Lake between July 2015 and July 2016 from the 2015 year class produced in Lino Lakes (Bajer & Lechelt 2017 in press).

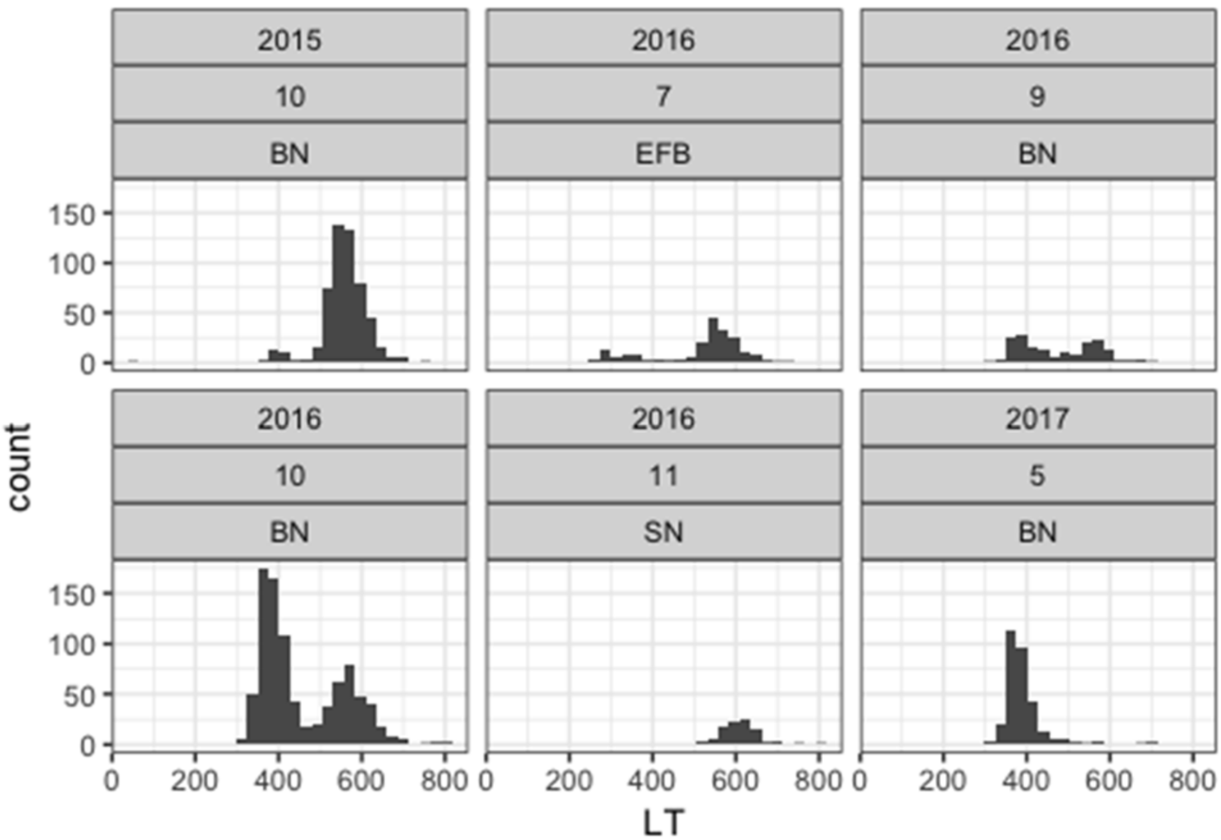


Figure 6. Carp length frequency histograms in Long Lake by year, month and gear type; BN is box net, EFB is electrofishing boat, SN is seine net. This shows an increase in the abundance of small carp (<500 mm) between October 2015 and October 2016. It also shows how different sampling gears sample different sizes of carp.

Year 3

Boat Electrofishing

Identical methods were used to survey Long lake for abundance of common carp using an electrofishing boat. Mean CPUE for this survey was 40.1 carp per hour of shock time (Length frequency: Figure 7). Using an updated relationship developed using the growing data pool from CS projects in the region we estimate that the abundance of common carp in Long Lake on the 27th of September 2017 was 11,773 individuals (25,816 kg). This abundance estimate translates to 368.8 kg/ha of lake area.

This decrease from 2016 (~600 kg/ha – see above) may be caused by the movement of carp between Long Lake and Lino Lakes. Also, ~ 5,800 carp were removed from Long Lake between November 2016 and May 2017 (see removal section below).

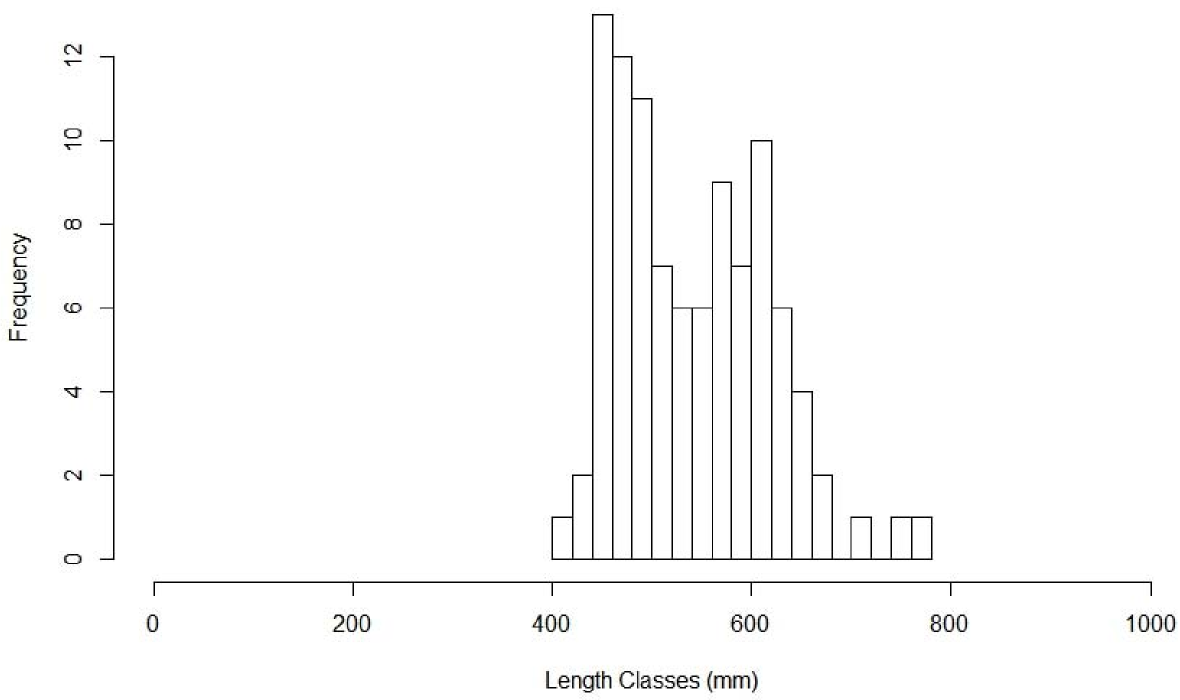


Figure 7. Length structure of the carp population in Long Lake in September 2017, based on boat electrofishing survey (sample n=99).

Task 2: Test Common Carp removal methods in Long Lake

Because carp are long lived, physical removal is often necessary to reduce their abundance in a reasonable amount of time. As mentioned under Task 1, winter seining has traditionally been the most effective carp removal strategy in Minnesota, because carp form tight aggregations under the ice. Thus, the winter seining conducted under Task 1 to estimate population abundance was also used to estimate percent population that can be removed with winter seine. For year 2, box netting techniques described previously were repeated enough through marking activities to allow for a rough estimate of their capture efficiency.

Year 1

There is a history of successful winter seining in Long Lake. Mr. Jeff Riedemann, commercial fisherman who operates in Ramsey County, has seined in the lake 5 times over the last 10 years catching between 20,000 kg and 90,000 kg of carp each time (up to 1,100 kg/ha). However, carp abundance in Long Lake was not known at the time those seines were conducted, thus it was not known what percentage of the population can be removed with winter seines each year. Further, radiotransmitters have not been used during those attempts to learn how carp might be reacting to the net and how many are able to escape winter seines.

We attempted to quantify the effectiveness of winter seining by using our carp population estimate (Task 1) and by monitoring the response of radiotagged carp to the net. As described in Task 1, we determined that the carp can escape the net relatively easily if the net snags on the bottom or needs to be lifted to release it from the mud. Only 1.6% of the population were captured in the net, whereas we estimate that more than 50% of the population were initially surrounded with the net (> 10,000 carp).

Following that first unsuccessful attempt we continued tracking the carp for the next two weeks hoping that they would move to an area that was better suited for seining. The aggregation moved to the south basin of the lake near the western shore (Figure 8). However, commercial fishermen determined that this area was not seineable due to suspected presence of tree stumps on the bottom and sharp dropoff in that area. Due to warming temperatures, there was no other opportunity to conduct winter seine in 2015/16. After year 1 was complete, we recommend that detailed bathymetric maps of Long Lake be developed in 2016, including tree stumps, large rocks and other potential snags, so that winter seining could be conducted more effectively in 2016/2017.

High-resolution bathymetric surveying and side-scan sonar was completed in September 2016 by Rice Creek Watershed District staff. Side-scan sonar, effective at identifying debris in shallow (<6ft) depths, indicated few obvious obstructions to seining. However, the bathymetric surveys indicated a prominent sediment hump, previously unmapped, near the inlet of Rice Creek.

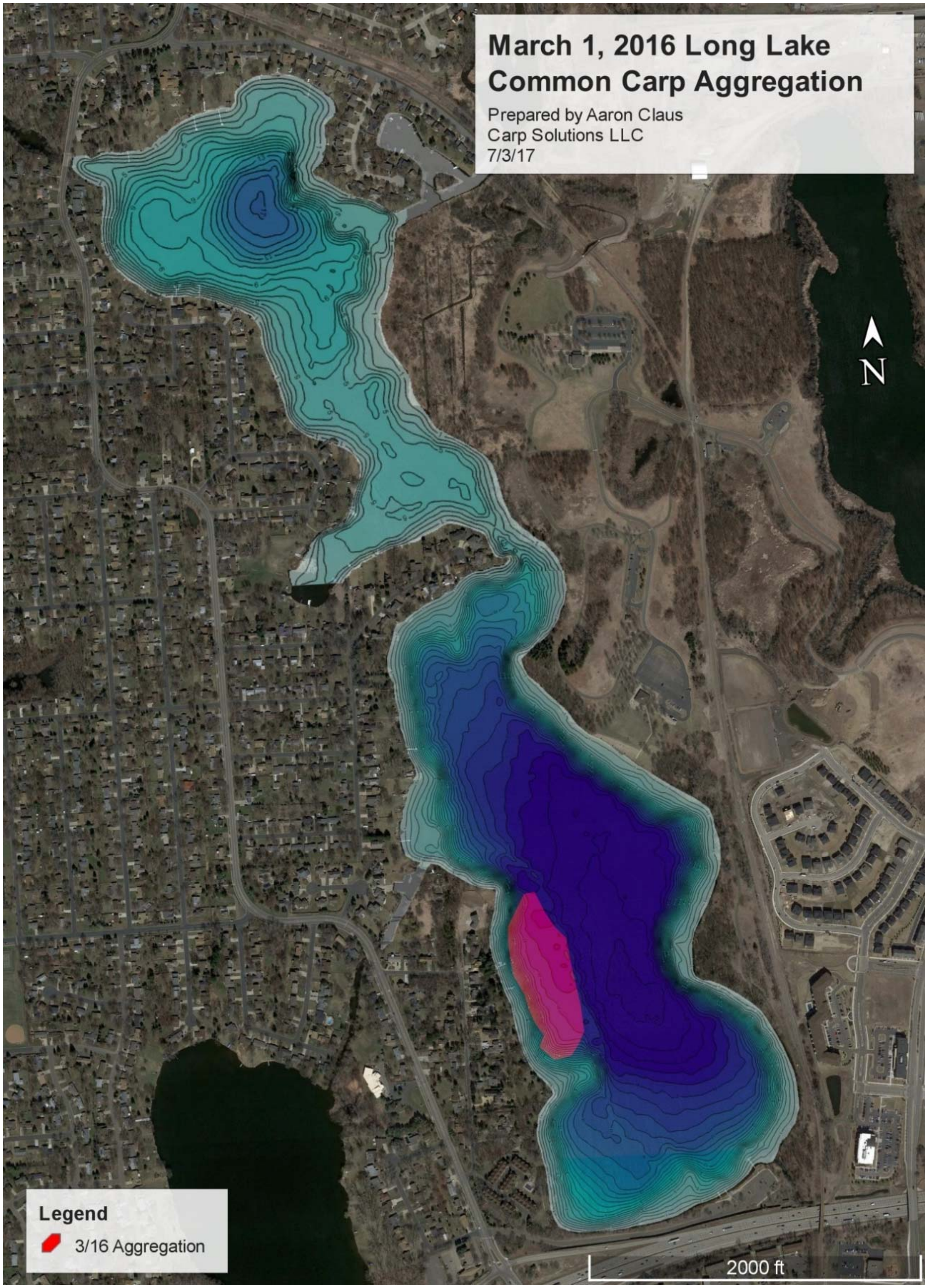


Figure 8. Location of carp aggregation in the south basin of Long Lake on March 1, 2016. Commercial fishermen concluded that the net could not be pulled through that area.

Year 2

Seining

An open water seine net haul was executed on November 22nd 2016 by Mr. Jeff Reidemann's crew in collaboration with Carp Solutions and RCWD staff who provided radiotelemetry support to guide the fishermen in where to seine. Their net captured 4,438 carp (Figure 9); this was approximately 25% of the population.

A winter seine net haul was executed on January 31st 2017 by Mr. Jeff Reidemann's crew in collaboration with Carp Solutions and RCWD staff who provided radiotelemetry support to guide the fishermen in where to seine. There were 23 tags aggregated by the Rice Creek inlet to the north basin of Long Lake (very similar to location in Figure 4). The previously identified sediment hump was avoided during the seine pull. Unfortunately, the aggregation moved while the net was being closed and the net snagged irreversibly on the bottom, capturing only 2 carp.

Baited Box Net

While box netting was used primarily to sample carp for mark-recapture analyses, it proved to be quite effective in capturing large numbers of carp, thus we report on its efficiency as a removal method as well. Box nets were used on 4 occasions in the fall 2016 and spring 2017, capturing 1374 carp (343 per day) with a crew of only 2 people (Figure 10).

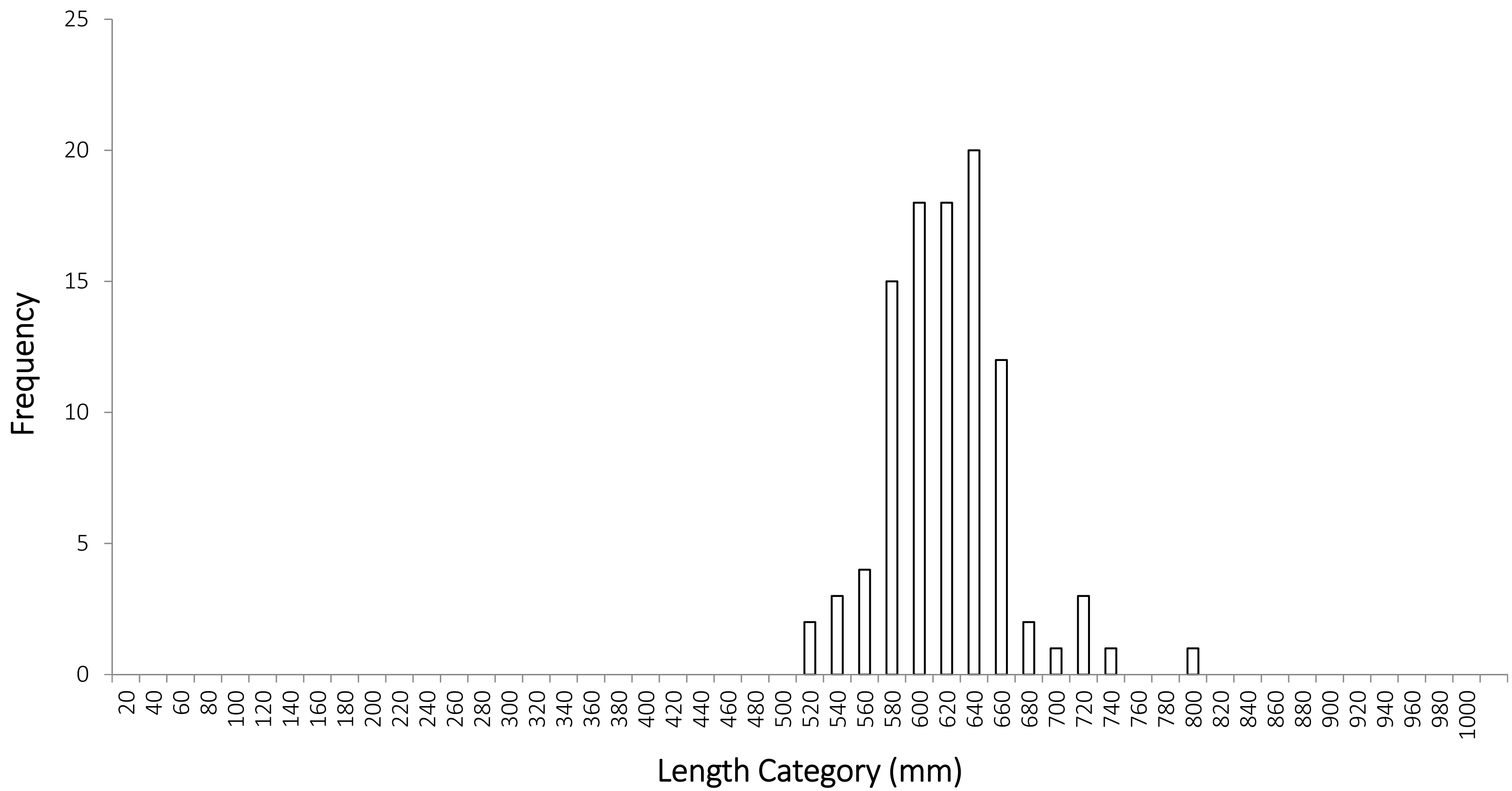


Figure 9. Length frequency of random sample of carp taken from the 11/22/2016 open water seine haul conducted by Jeff Reideman (n=100).

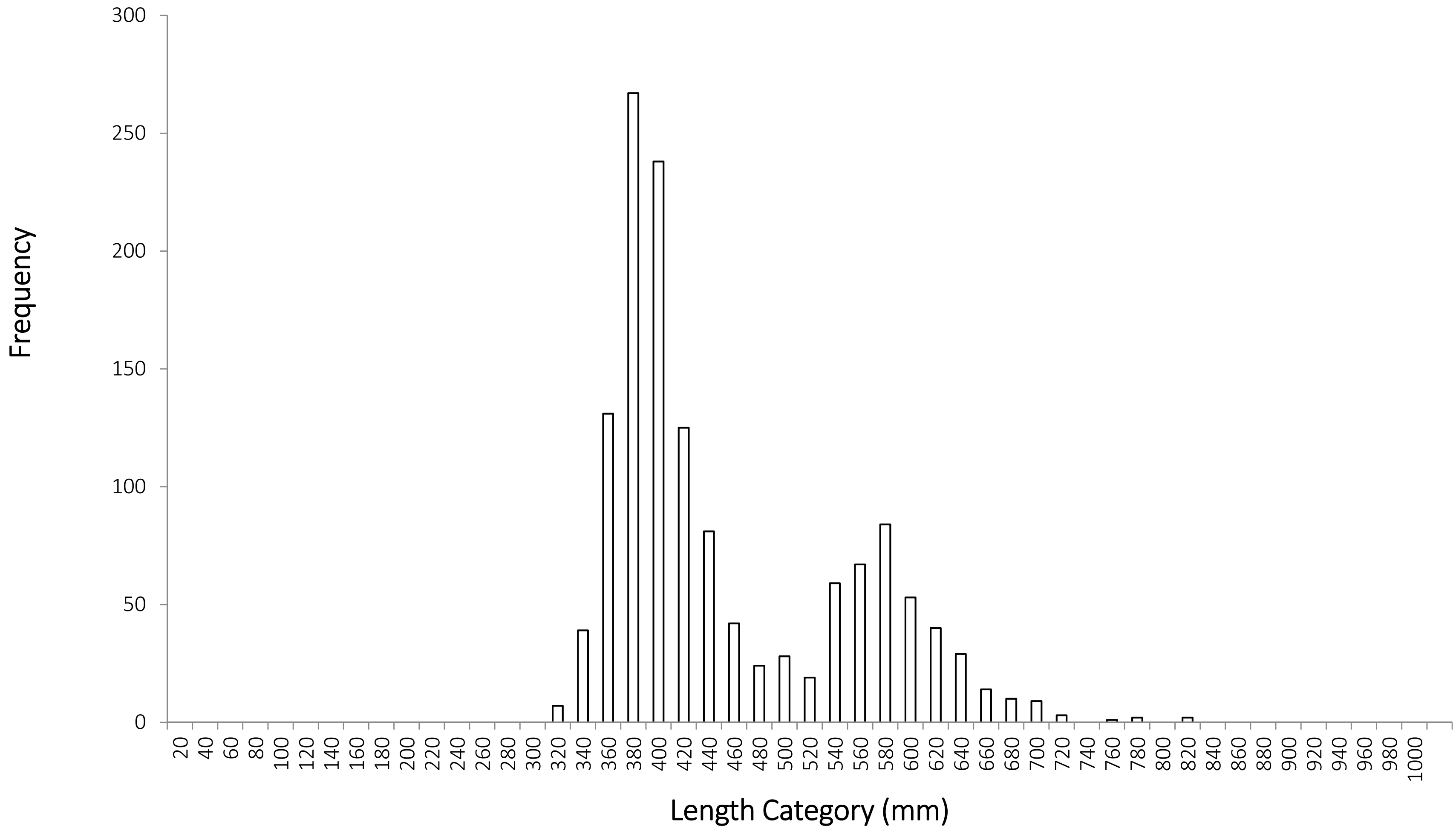


Figure 10. Length frequency histogram of carp captured in box net during fall 2016-spring 2017.

Year 3

Seining

Mr. Riedemann conducted carp removal in Long Lake in the winter and spring of 2018. However, Mr. Riedemann did not alert Carp Solutions or RCWD prior to seining; we have no specific information about the success of this effort.

Baited Box Net

Three baited box net traps were used on 3 occasions in the fall of 2017, capturing and removing 3447 carp, or approximately 29% of the population that inhabited Long lake at the time box nets were used (based on boat electrofishing surveys; see above); Mean Length = 540mm, Mean Weight = 2.1 kg; (Figure 11). A total of 7,332 kg of common carp were removed (104.7 kg/ha).

With relatively low effort (3 nets on 3 days), box netting showed substantial promise. With an overall cost of $14,970, that averages to around $4.35 per carp removed. However, when the overall cost is reduced through RCWD staff or volunteer labor, bait cost offset, and an inexpensive option for disposing of the carcasses, the cost is reduced to about $3.00 per carp. Furthermore, if more nets were installed (perhaps 5 instead of 3) and were lifted more times each year (perhaps 6 times instead of 3), we are confident that box netting could reach a cost of about $1.80 per carp or about $0.35/pound. This is in part due to the cost of installation and decontamination (which happen only one time per year) and increases in efficiency and equipment. It is also noteworthy to mention that this method was very selective as over 99% of captured fish were common carp. Finally, this method is relatively simple to coordinate and is not affected by obstacles/debris on the bottom of the lake. Effectiveness and cost-efficiency may be increased by engaging local volunteers to bait the traps.

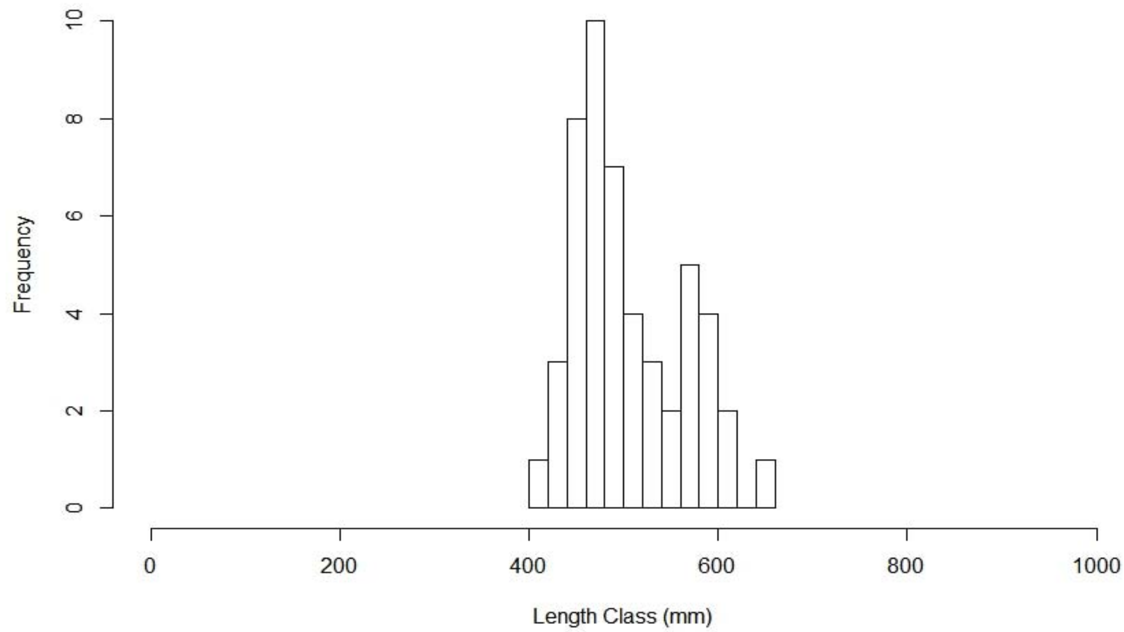


Figure 11. Length frequency histogram of carp captured in box net during fall 2016-spring 2017 (n=50).

Task 3: Determine the age structure and recruitment history of carp in Long Lake

Determining the age structure of the carp population is very important because it allows us to estimate how often carp are able to successfully produce offspring and how long-lived they are (i.e. what is their natural mortality rate). An age structure with many year classes present would suggest that young carp are able to recruit into the population relatively frequently whereas an age structure with large gaps in-between age classes would suggest the opposite.

Year 1

To determine the age structure of the carp population in Long Lake, we randomly selected 88 carp from the winter seine conducted in February 2016. These fish were euthanized and their inner ear bones (otoliths) were extracted. The otoliths accrue annual growth increments (much like trees) and can be used to accurately determine the age of each fish. The otoliths were embedded in epoxy, sectioned using a high precision saw and read under a microscope (Fig. 13). Each otolith was examined by two independent readers.

Our ageing analyses for year 1 suggested that the majority of carp in Long Lake are relatively old with the median age of 11. The youngest group of carp in the population was comprised by a group of 3-year-old fish, which comprised ~ 6% of the population (Fig. 14). The oldest fish was 31 years old, which suggests that natural mortality of carp in Long Lake is approximately 14% per year. Overall, carp ageing analysis suggested that over the past 30 years, there were 23 year classes, suggesting that young carp recruit into the population on a quasi-annual basis, although in relatively modest numbers (Fig. 14). While ageing analyses shows how often (and approximately how many) young carp are able to recruit into the population each year, it does not say whether these carp were born in Long Lake or immigrated from external nurseries; Task 4 below answered this question.

Year 2

To determine the age structure of carp population in Long Lake, we randomly selected 116 carp caught while electrofishing in 2016 and in a box net pull conducted in May 2017. We followed methods explained above.

Our ageing analyses for year 2 suggested that majority of carp in Long Lake are relatively old with the median age of 14. The youngest group of carp in the population was comprised by a group 1 year old fish, which comprised ~ 2% of the population (Fig. 15). The oldest fish in this sample was 25 years old, which suggests that natural mortality of carp in Long Lake is approximately 16% per year. Overall, carp ageing analysis suggested that over the past 25 years, there were 18 year classes, again suggesting that young carp recruit into the population on a quasi-annual basis, although in relatively modest numbers (Fig. 15)

Most important to management efforts, ageing analyses in year 2 showed that a large number of age-2 carp, approximately 3,494 individuals, appeared in Long Lake in 2017. These fish were born in Lino lakes in 2015 and immigrated to Long Lake in the summer of 2016. For more details see the section under Task 4 on juvenile carp movement below.

Year 3

A sample of 30 small carp was collected in Long Lake in September of 2017. These fish were aged using otoliths. The purpose of this ageing analysis was to look at the smallest carp in Long Lake to determine if they were the 2015 cohort that recruited into Long Lake from Lino lakes in 2016. We also wanted to track the growth rate of those fish. The analysis confirmed that the majority of the carp were age-2 individuals (2015 cohort: Fig. 16). Overall, the age sample (Fig. 16) and unbiased length sample (Fig. 12) suggested that age-2 carp comprised ~ 18% of the population.

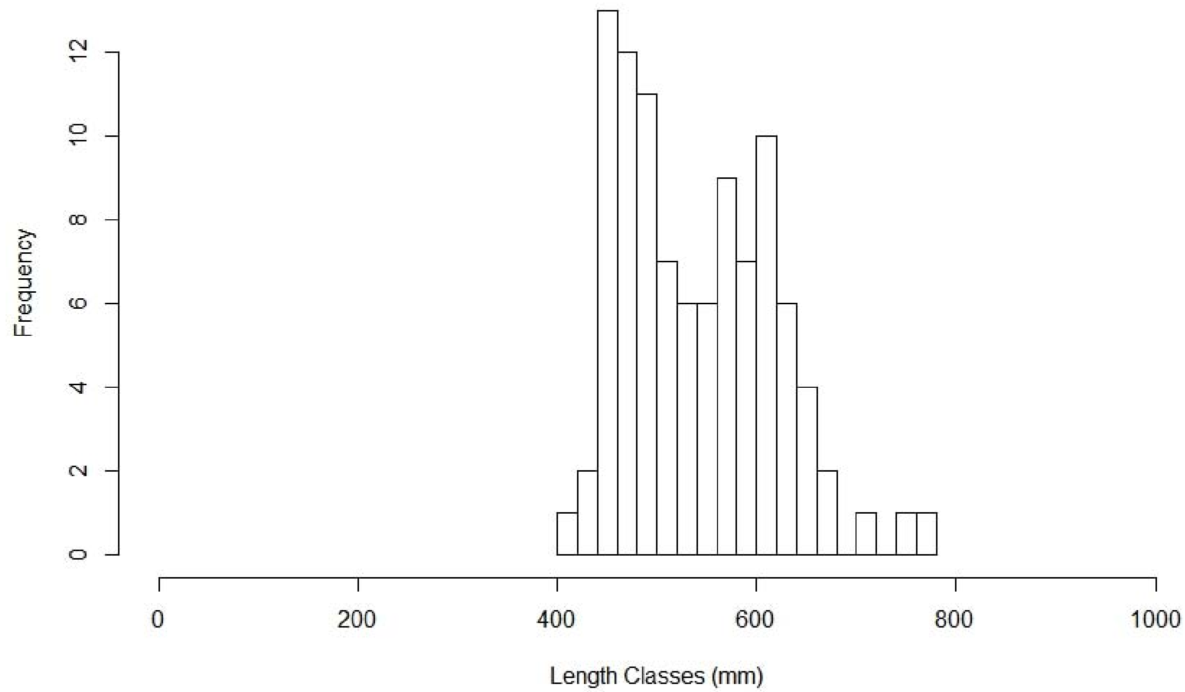


Figure 12. Length structure of the carp population in Long Lake in September 2017, based on boat electrofishing survey (sample n=99). This suggests that ~ 40% (39/99=39.4%) of the population are carp <=500 mm, of which ~ 52% are age-2 carp (the 2015 cohort); i.e. the 2015 cohort comprised ~ 20% of the population.

Figure 13. An example of a mounted cross section of carp otolith; age 14.

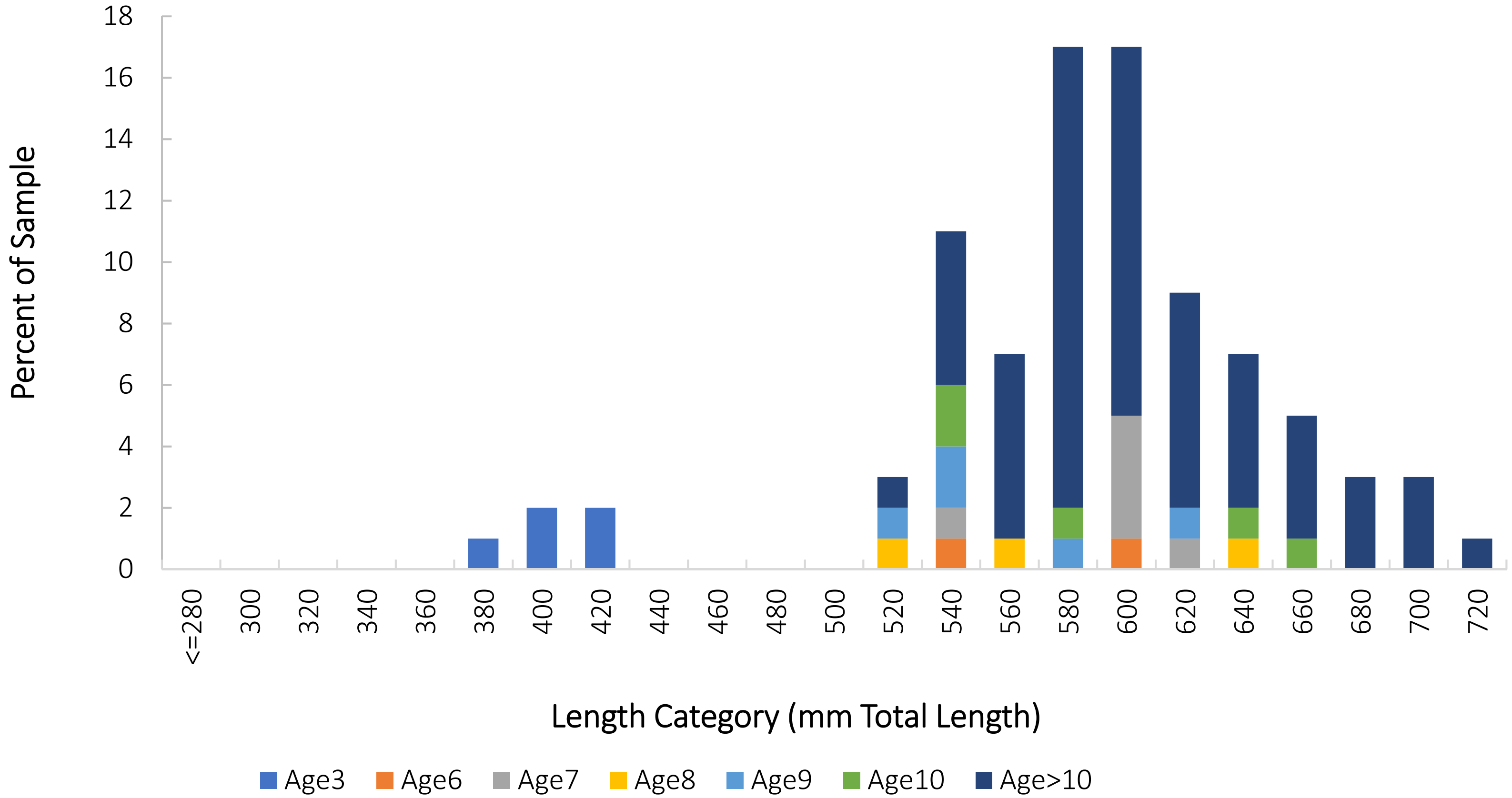


Figure 14. Year 1 age structure of Long Lake common carp sample taken on February 15, 2016 (n = 88).

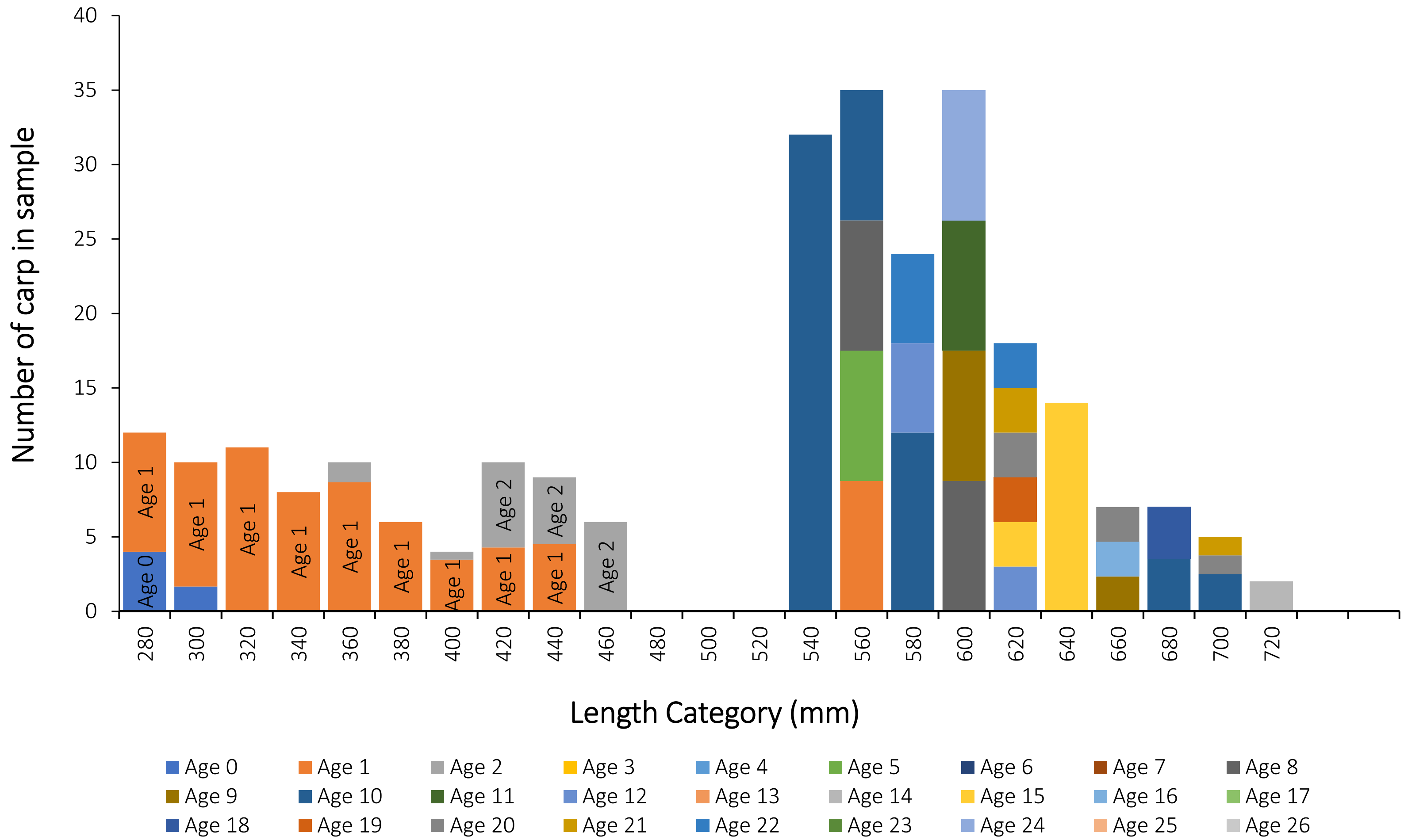


Figure 15. Length and age structure of carp in Long Lake in July 2016. The age-1 carp are most likely from the strong 2015 cohort in Lino Lakes (see trapnet survey section below).

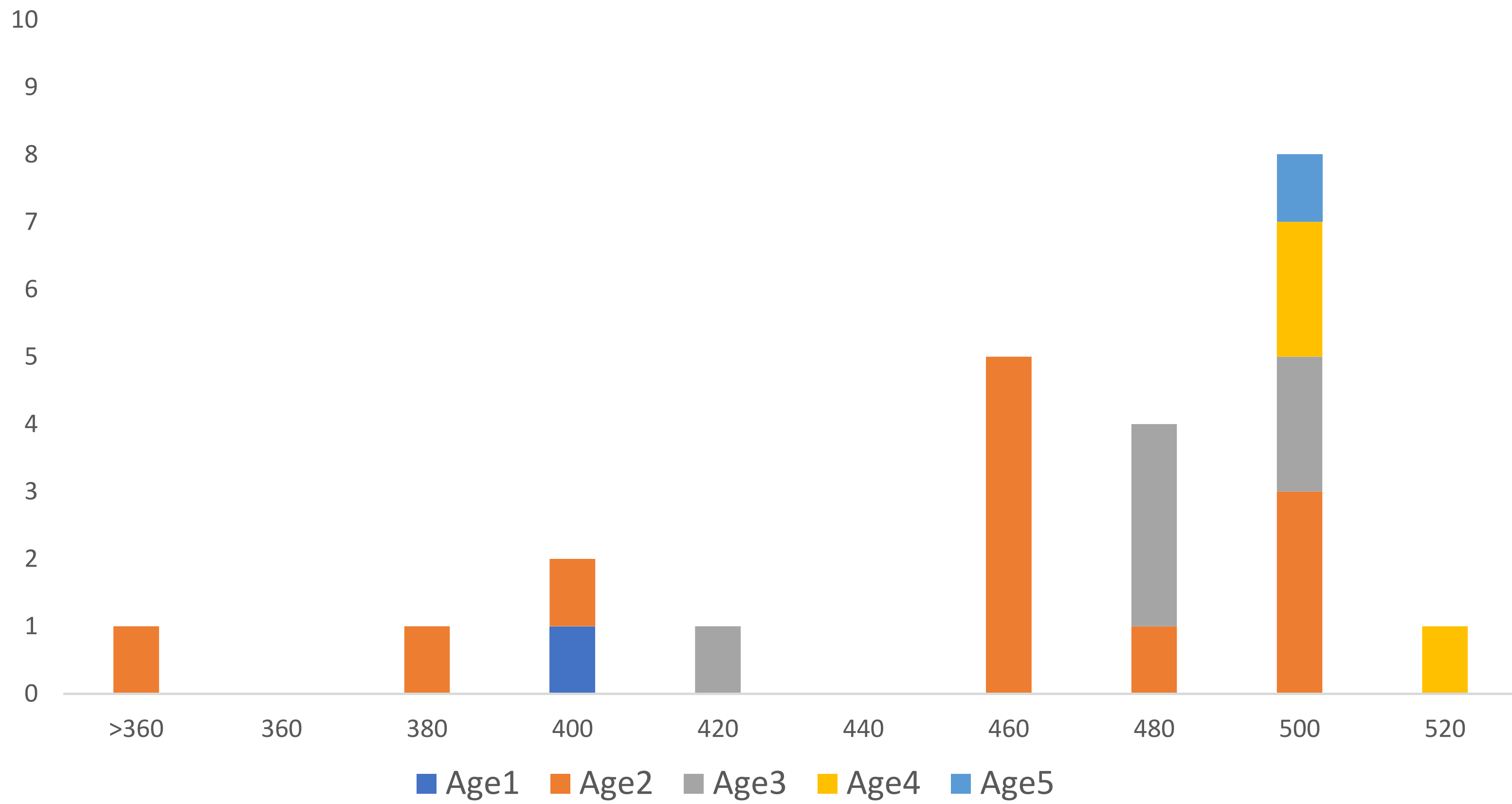


Figure 16. Length and age structure of carp in Long Lake in September 2017. Only a sample of 30 small carp were aged. The purpose of this ageing analysis was to look at the smallest carp in Long Lake to determine if they were the 2015 cohort that recruited into Long lake from Lino lakes. We also wanted to track the growth rate of those fish.

Task 4a: Estimate the source of young carp in Rice Creek watershed and the inflow of young carp into Long Lake from external nurseries.

Research at the University of Minnesota showed that common carp are unable to successfully produce young in "typical" deep lakes in which abundant populations of bluegills and other native fish forage heavily on carp eggs, larvae and fry (Bajer et al. 2012). While the carp often spawn in such lakes, their young typically do not survive. On the other hand, shallow marshes that winterkill and which have low abundance of native fishes during most springs, often function as carp nurseries in the landscape; adult carp migrate from lakes into such marshes in early spring to spawn and return back to the lakes in the summer (Bajer et al. 2015). Young carp then disperse from such marshes into the lakes completing the life cycle. The key questions are: 1) How many carp nurseries (winterkill-prone marshes) exist in the watershed? and 2) How many juveniles migrate out of those marshes and into the lakes, when, and how often? Juveniles that do not leave the nursery often die during subsequent winters in winterkills thus migration in the first year of life is of main importance.

Locating common carp nurseries within RCWD

We hypothesized that carp are unable to successfully reproduce in Long Lake due to abundant bluegill population and expected that most (if not all) carp that currently live in Long Lake once originated from the complex of five shallow and winterkill-prone lakes: Baldwin, Rice, Marshan, George Watch and Reshanau, collectively called Lino Lakes. We also suspected that there might be other less important carp nurseries located to the south and east of Long Lake. To determine which lakes function as carp nurseries within RCWD, we conducted trapnet surveys in 11 lakes, including all major shallow marshes. In each lake, we set five trapnets overnight in late summer of 2015. These nets are constructed using small mesh (18 mm bar) and are effective at capturing small carp. We measured and counted all captured fish, and identified young-of-year (YOY) carp by their length; YOY carp are typically smaller than 150 mm by mid-summer (we aged 20 of these carp to verify they were YOY).

Year 1

Of the 11 locations surveyed in 2015, YOY were found in all of the Lino lakes in 2015 (Table 1). Low numbers of YOY carp were also found in Long Lake (Table 1), but these fish most likely immigrated from Lino Lakes (see below). No YOY carp were found in other lakes or ponds in 2015 (Table 1). Length structure of carp captured in Lino Lakes also showed that in addition to having large numbers of YOY carp, some of those lakes (Reshanau) also had large numbers of young adult carp in the 300-400 mm range. It is likely that these fish will be migrating to Long Lake in 2016.

Year 2

Of the 10 locations surveyed with trapnets in 2016, YOY common carp were found only in Marshan Lake (Table 1). Trapnet catch per unit effort for 2015 and 2016 of young of year common carp and the dominant native egg and larval predator of common carp, the bluegill sunfish, are shown in Figures 17-20. A negative correlation between bluegill abundance and YOY common carp appears to exist in these data between 2015 and 2016.

Following the 2015 cohort that was born in Lino Lakes in 2015, we documented no evidence of fish from that cohort in Long Lake in 2015 or in the spring of 2016. However, samples collected in Long lake in the fall of 2016 (box net) showed high abundance of 300-400 mm carp (Fig. 11). These fish were age-1 carp (the 2015 cohort) that moved to Long Lake in the summer of 2016.

Year 3

A subset of locations sampled in 2015 and 2016 was again sampled in 2017 with identical trapnet methodology (Rice, Marshan, George Watch, and Reshanau Lakes) as contracted. Common carp were sampled in low abundance in Marshan and George Watch lakes (<1 per net; average length 428 and 503 mm respectively) with no YOY sampled, suggesting that relative to 2015 the survival of carp eggs are larvae was again relatively low as it appeared to be in 2016 (Table 1). Bluegill abundance was also relatively low again in 2017 compared to 2015 survey numbers (maximum of 18.8 fish per net with an average length of only 148 mm in George Watch lake).

Table 1. Mean Trapnet CPUE in 11 locations within RCWD (2017 survey in grey shading).

	COMMUNITY CENTER		E2 WETLAND		PIKE		JOHANNA		POLYNESIAN		LONG		MARSHAN			BALDWIN		RICE			GEORGE WATCH			RESHANAU		
Sample Year	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2017	2015	2016	2015	2016	2017	2015	2016	2017	2015	2016	2017
Common Carp YOY	0.0	NS	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4	0.0	48.8	0.6	0.0	8.2	0.0	41.8	0.0	0.0	25.0	0.0	0.0	0.4	0.0	0.0
Common Carp >150mm TL	0.0	NS	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.2	0.3	0.3	1.8	0.6	0.2	0.8	1.3	2.3	0.0	3.8	3.0	0.8	6.2	2.6	0.0
Blugill Sunfish	30.0	NS	50.3	18.5	26.3	21.2	62.2	24.5	1.0	16.8	87.6	35.0	4.5	29.4	5.0	14.4	14.0	10.3	25.3	0.0	12.6	31.8	18.8	5.2	4.2	1.5
Green Sunfish	1.0	NS	13.3	8.8	4.5	4.2	18.2	3.8	1.3	8.2	2.6	5.7	0.3	0.2	0.0	0.0	0.0	0.3	0.0	0.0	0.0	7.2	0.2	0.2	0.0	0.0
Pumpkinseed Sunfish	1.0	NS	1.7	0.0	4.3	3.8	1.2	5.8	0.0	2.0	5.8	1.0	0.3	17.0	1.4	0.2	1.3	0.0	0.8	0.5	0.4	2.0	4.4	0.0	0.0	0.0
Black Crappie	2.0	NS	2.3	1.5	1.3	3.0	2.6	0.3	1.3	3.0	9.4	3.3	15.8	3.0	2.2	3.0	2.4	8.5	2.0	0.0	8.2	2.0	0.6	3.6	4.0	0.5
Largemouth Bass	0.0	NS	0.0	0.8	0.0	0.0	0.4	0.5	0.3	0.2	0.2	0.0	2.5	0.0	0.2	0.3	0.2	2.0	0.3	0.0	5.8	0.6	0.2	0.2	0.0	0.0
Northern Pike	0.0	NS	0.0	0.0	0.0	0.0	0.2	0.3	0.3	0.0	0.4	0.0	0.0	0.2	0.0	0.3	0.2	0.0	0.3	0.0	0.6	0.0	0.0	0.0	0.6	0.0
Walleye	0.0	NS	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
Yellow Perch	0.0	NS	0.0	0.0	8.8	1.2	0.6	0.3	5.0	8.2	0.4	0.0	0.3	0.0	0.0	0.5	0.4	2.3	0.0	0.0	1.4	0.4	0.0	1.2	0.0	0.0
Bigmouth Buffalo	0.0	NS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Black Bullhead	42.5	NS	2.3	0.0	2.8	12.0	0.2	0.0	1.7	18.8	13.0	4.0	33.5	27.8	2.0	8.8	7.0	69.8	17.0	1.0	27.4	20.4	13.0	11.0	4.2	0.3
Brown Bullhead	0.0	NS	0.0	0.0	0.0	1.8	0.0	0.0	0.0	2.6	0.0	0.0	1.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	1.0	1.4	0.0	3.0	0.2	0.0
Yellow Bullhead	1.0	NS	0.0	2.0	4.8	1.2	0.8	0.3	1.7	10.2	0.0	5.0	0.0	14.2	1.6	6.0	4.8	4.3	6.5	0.0	6.8	17.0	9.8	1.2	1.4	0.3
Bowfin	0.0	NS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.8	0.5	0.4	0.3	0.0	0.0	0.0	1.0	3.8	2.8	0.0	0.0
White Sucker	0.0	NS	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Golden Shiner	0.5	NS	10.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.2	0.0	0.0	0.8
Mudminnow	0.0	NS	1.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

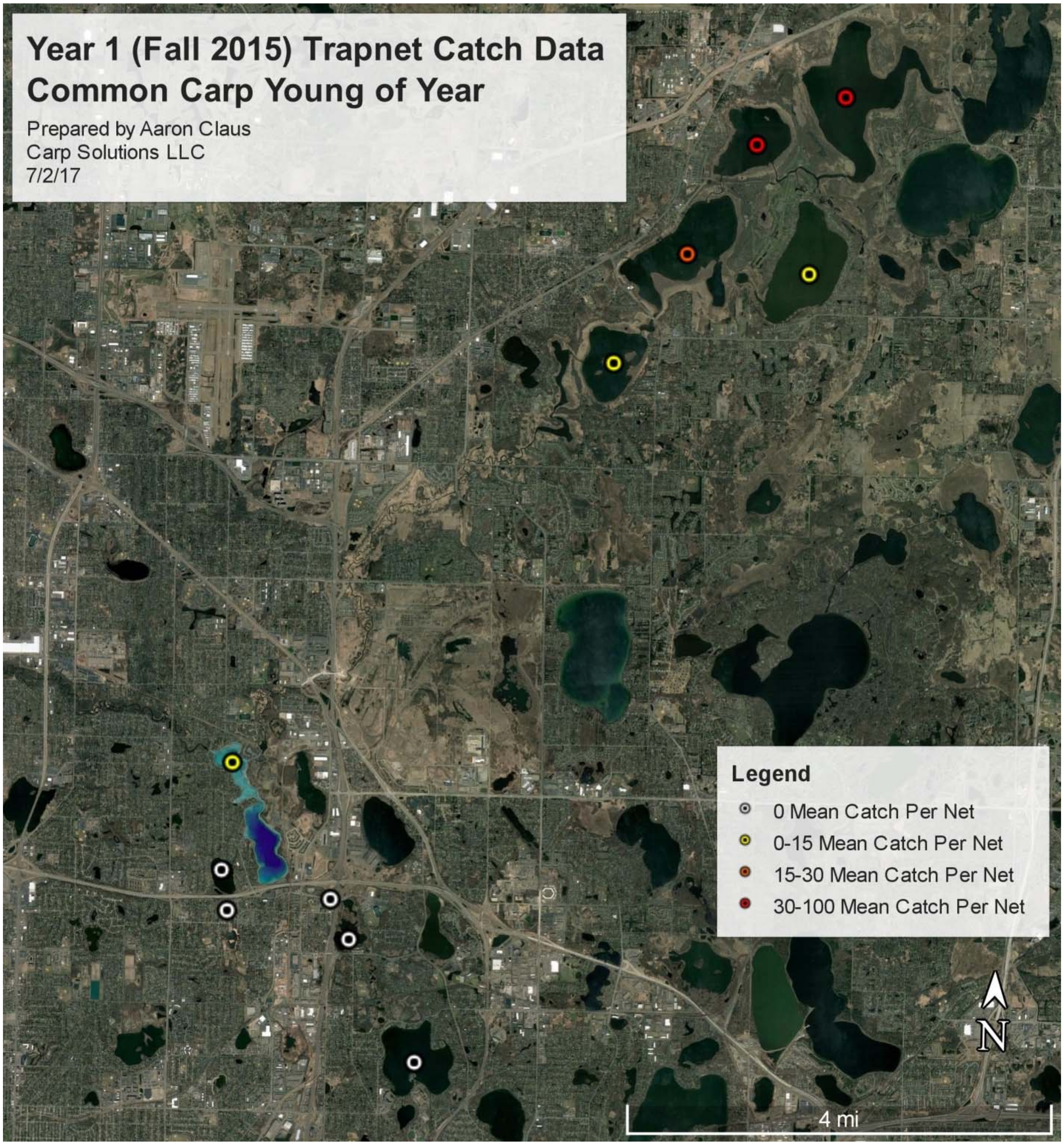


Figure 17. Year 1 YOY Carp trapnet catch summary (Fall 2015).

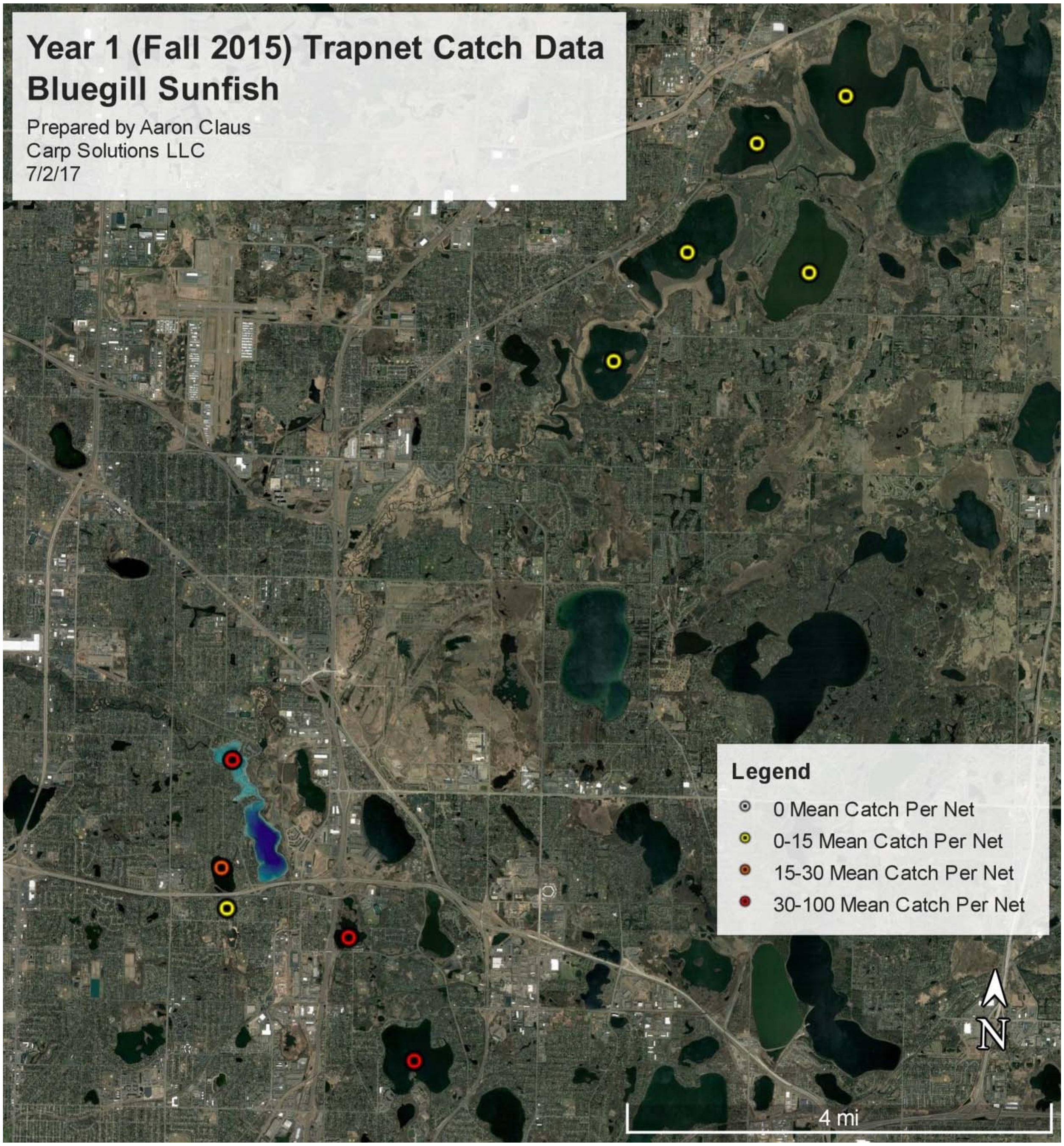


Figure 18. Year 1 Bluegill sunfish trapnet catch summary (Fall 2015).

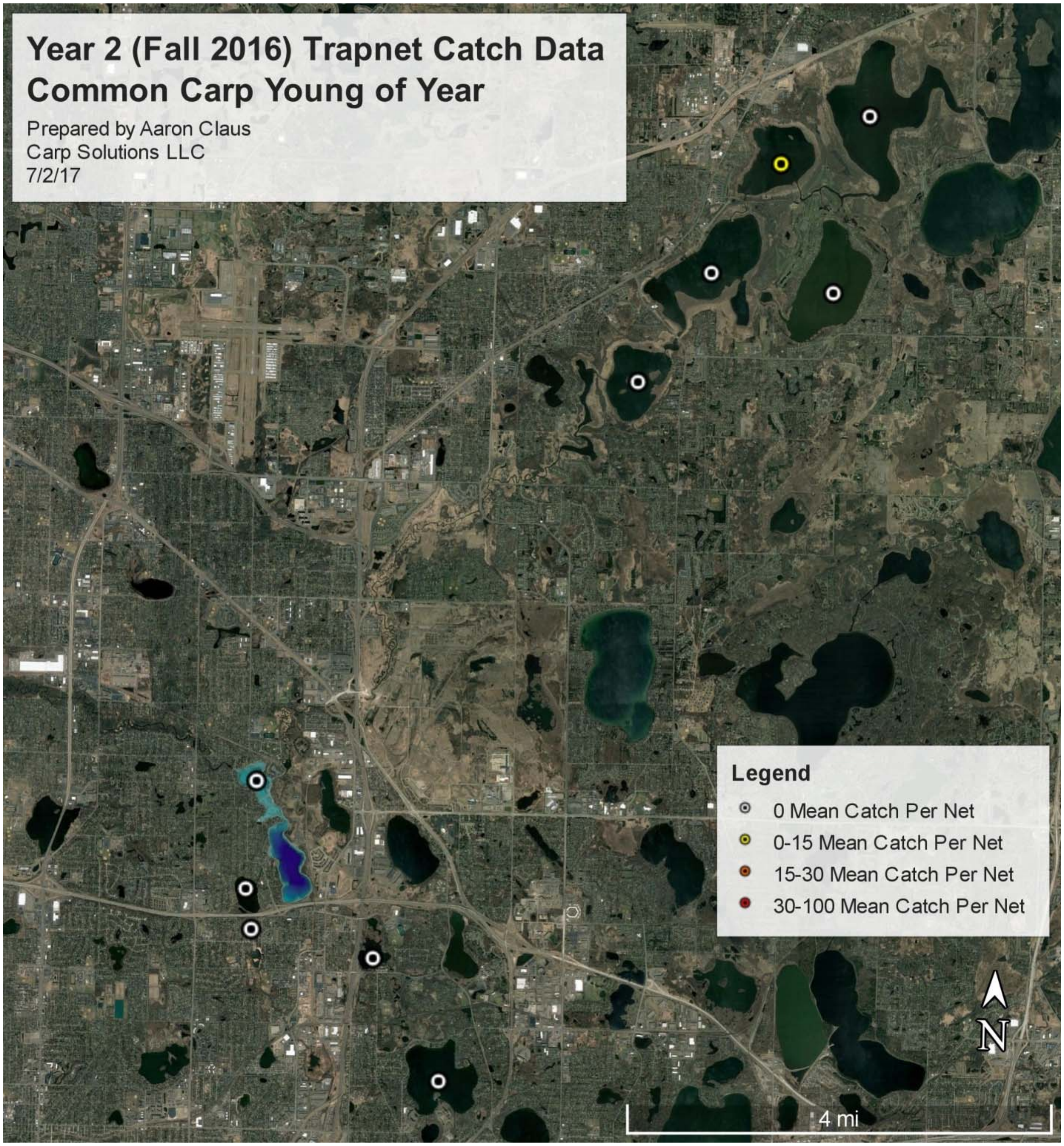


Figure 19. Year 2 YOY Carp trapnet catch summary (Fall 2016).

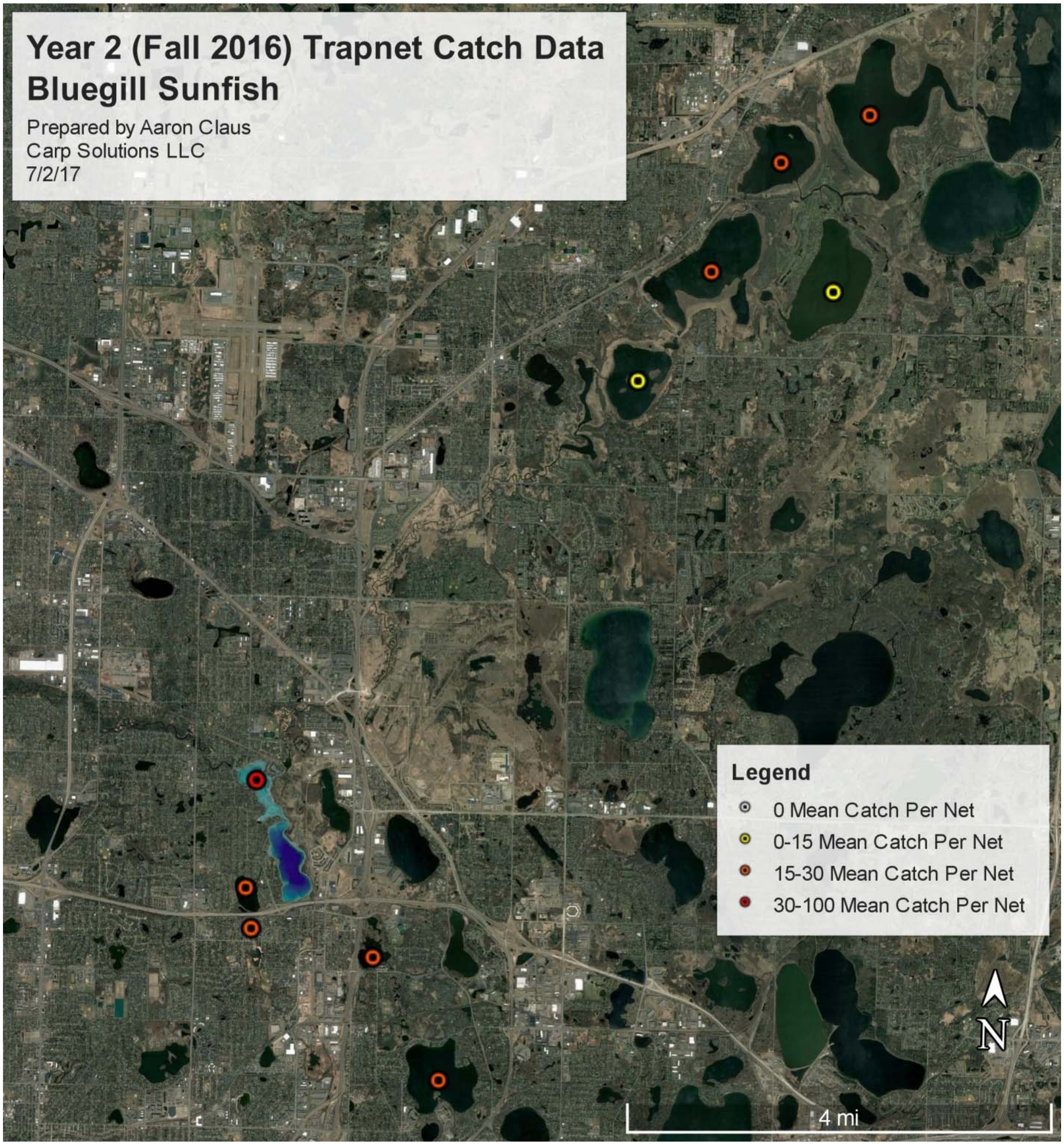


Figure 20. Year 2 Bluegill sunfish trapnet catch summary (Fall 2016).

Movement of YOY Common Carp from Lino Lakes to Long Lake

Year 1

Once carp nurseries were identified to be located in Lino Lakes, we conducted supplementary sampling of those lakes with boat electrofishing to capture and tag over 800 YOY carp with Passive Integrated Transponder (PIT) tags. We also installed a PIT antenna in Rice Creek downstream of Lino Lakes to detect the movement of YOY carp from Lino Lakes into Long Lake. 12mm Oregon RFID HDX PIT tags were implanted in all sizes of carp. The antenna was maintained year-round by RCWD personnel who downloaded the data on a weekly basis. In addition to tagging YOY carp, we also tagged a small number of adult carp captured in Lino Lakes. These fish were used as a “positive control” because we knew that adult carp move frequently between Lino Lakes and Long Lake (Banet 2016) thus we were expecting high passage rates of those fish, which would indicate that the antenna was working properly. Finally, we also conducted weekly backpack electrofishing surveys in Rice Creek to determine presence of YOY carp in the stream. These surveys were conducted on the upstream and downstream side of the antenna (50 m). All YOY carp captured in those surveys were also implanted with PIT tags and released.

Of the 872 YOY carp that we tagged with PIT tags in Lino Lakes between August and October 2015, only 25 have crossed the antenna through the end of December 2015. That only a small number of YOY carp moved from Lino lakes to Long Lake in 2015 was corroborated by winter seining (Task 1), which caught no YOY carp among the 304 adult carp that were captured; also no YOY carp were captured in box nets in the fall (Task 1). Further, backpack electrofishing surveys conducted on 9 occasions between 8/20/15 and 11/3/15 in Rice Creek captured only 35 YOY carp total, of which most were captured during multiple surveys suggesting that these fish were residing in the same pools for weeks rather than moving quickly to Long Lake. This was confirmed by the PIT antenna that recorded the presence of those carp near the antenna for several weeks (227 detections of 35 fish in total). Nevertheless, because the densities of YOY carp can reach 1,000 to 5,000 per hectare, the abundance of YOY carp in Lino Lakes, which collectively comprise 878 ha, is likely to range between several hundred thousand and four million YOY carp per year. Therefore, even low outmigration rates might result in large numbers of YOY carp moving to Long Lake each year. To assess exactly how many YOY carp migrated from Lino lakes to Long Lake in 2015, electrofishing surveys were conducted in 2016 followed by another population estimate.

Year 2

We attempted to implant more juvenile carp with PIT tags in Lino Lakes in 2016. Because of low abundance of juvenile carp in 2016 (Table 1; high overwinter mortality in Lino Lakes), we tagged only 22 additional carp. All of those fish were less than 200mm in total length.

In 2016, only 6 carp of the YOYs tagged in Lino Lakes in 2015 were detected at HWY 8 PIT antenna (Fig. 21). Movement of carp implanted with PIT tags in combination with mark-recapture and ageing analyses (see above) showed that of the strong year class that was born in Lino Lakes in 2015, approximately 3,494 carp moved into the Long Lake by the end of 2016. This is important information for developing sustainable management strategies because it suggests what removal rates are needed to counteract the immigration of young carp into Long Lake. It also informs the use of the electric guidance system (ProCom Systems) that is being installed in Rice Creek in 2017. More information on juvenile carp outmigration in 2015 and 2016 was published in a peer-reviewed article (Lechelt et al. 2016). See Year 3 for updated statistics on the 2015 YOY cohort (Fig 21).

Year 3

A significant cohort of young of year carp (YOY) has not been sampled since 2015, thus we continued to track the 2015 YOY cohort via PIT detections at the Highway 8 site. Out of 872 young of year common carp tagged in Lino Lakes chain in 2015, 7 have been detected at the highway 8 PIT antenna site in 2017, and 2 in 2018 (Fig. 21).

Overall, 33 out of 872 young of year common carp tagged in Lino Lakes chain in 2015 have been detected at the highway 8 PIT antenna site (3.8%) to date; 25 in 2015, 6 in 2016, 7 in 2017, and 2 in 2018.

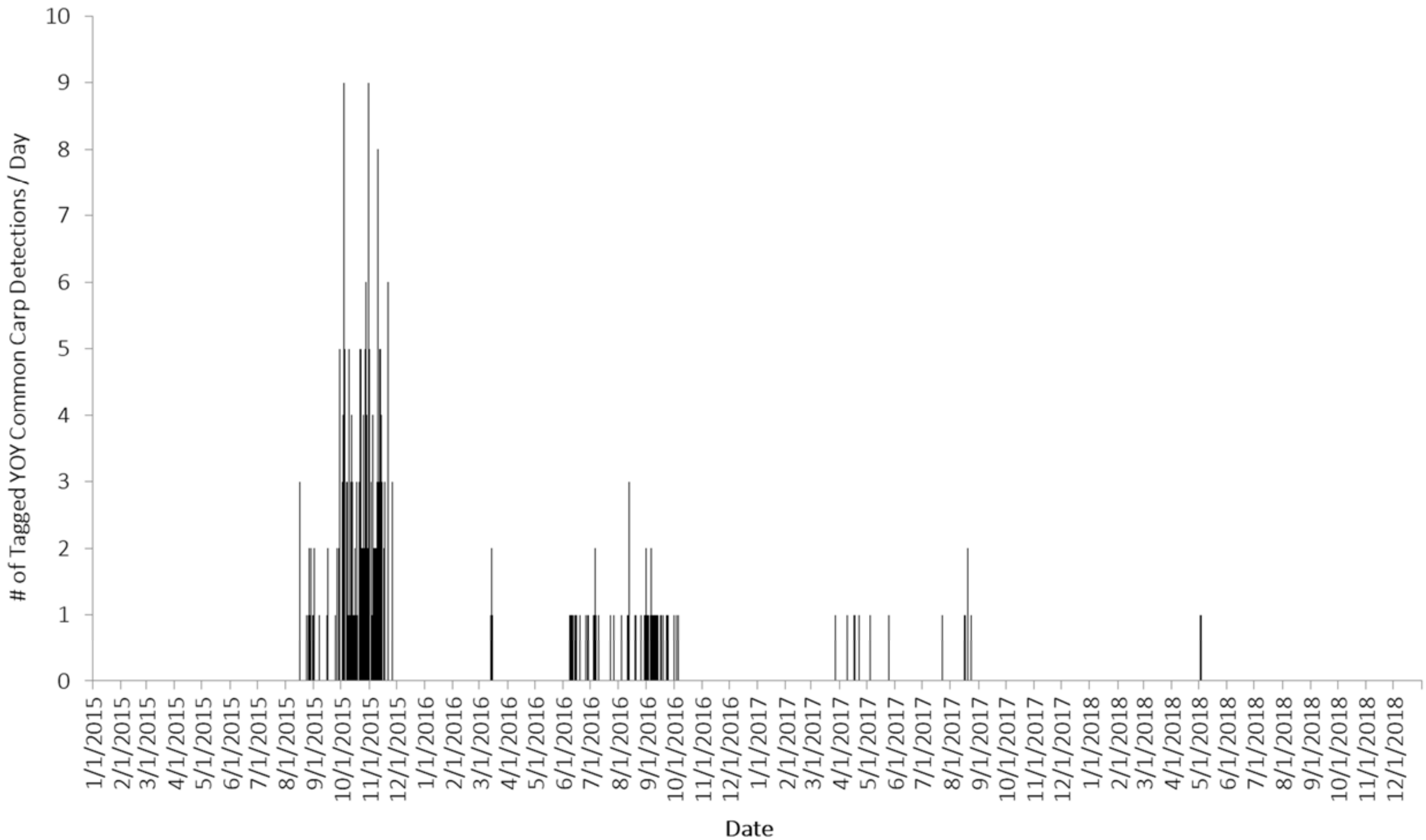


Figure 21. Number of young of year carp implanted with PIT tags in 2015 and detected by the Highway 8 PIT antenna between 2015 and 2018. A total of 872 YOY carp were tagged in 2015.

Task 4b: Movement of Adult Common Carp between Long Lake and Lino Lakes

Year 1

Contrary to the low movement rates of YOY carp, adult carp moved very extensively. Of the 29 adult carp that were PIT tagged in Lino Lakes in the summer 2015, 12 (41%) crossed the antenna, many on multiple occasions (Figure 22 a,b). This corroborates the results of recent University of Minnesota study (Benet 2017; Master's thesis, University of Minnesota) that adult carp move between Long and Lino Lakes multiple times a year.

Year 2

In 2016, additional 743 adult carp (> 200 mm) were implanted with PIT tags in Long Lake. 320 of these were detected by the Highway 8 PIT antenna by the end of 2016 (Table 2; Figure 18). The carp began their migration from Long to Lino Lakes in March (Fig. 22 b,c). This spring pulse correlated with the pre-spawning migration of sexually mature individuals. These fish returned to Long Lake during July-September, with some fish moving back and forth multiple times. No movement was detected during November-February, both in 2015 and 2016 (Fig. 22 b,c).

It appears that most adult carp are moving through the antenna reach of Rice Creek at night (Figure 23).

Year 3

In 2017, 341 additional adult common carp (> 200 mm) were captured and implanted with PIT tags in Long Lake, bringing the overall number of tagged adult carp to 2159 (Figure 22a-e). In 2017, carp began moving upstream from Long Lake to Lino lakes in mid-May/early June. Several other peaks of movement occurred throughout the summer and fall (Fig. 22c).

In 2018, carp began their upstream spawning migration from Long Lake to Lino Lakes in late April (Fig. 22d) when water temperature in the stream was only 4C and Long Lake was still covered with ice.

Overall, across the three years (2016-18), carp showed a substantial difference in the onset of the spring spawning migration ranging between late March and mid-May. In some years (2018), the migration began before ice-out in Long Lake. A large proportion of movements occurred at night (Fig 23).

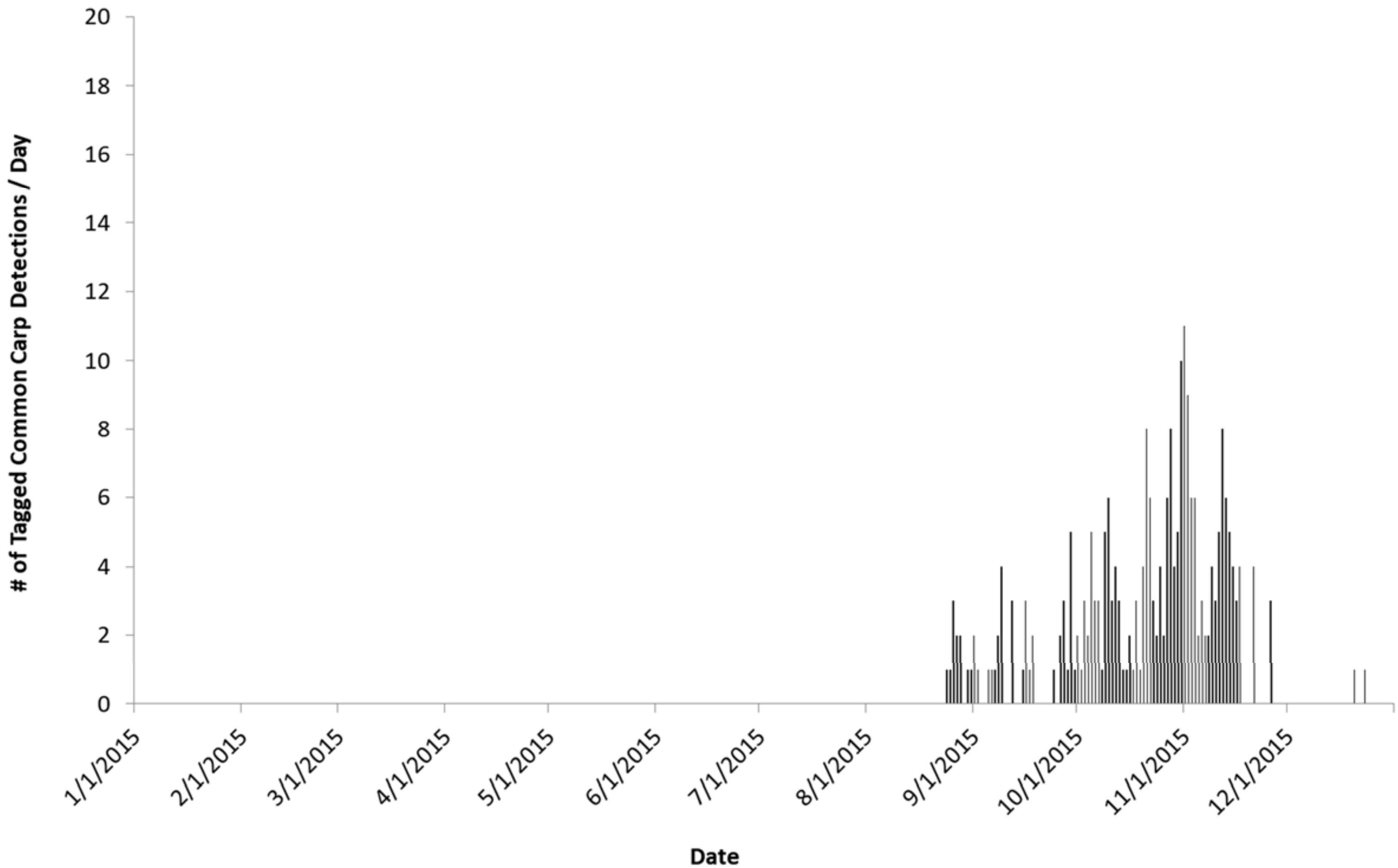


Figure 22a. The total number of carp detected by the Highway 8 PIT antenna by date in 2015.

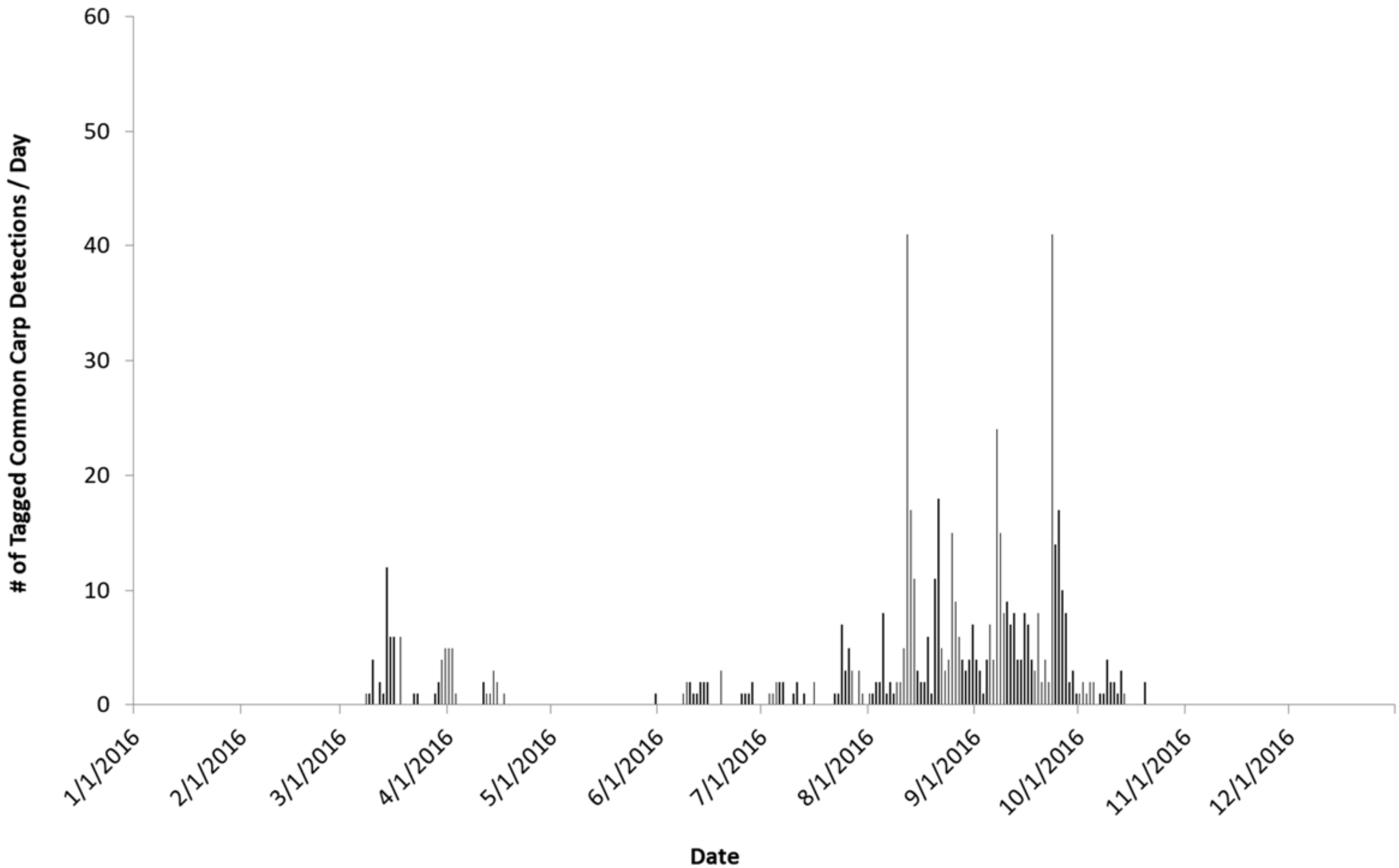


Figure 22b. The total number of carp detected by the Highway 8 PIT antenna by date in 2016.

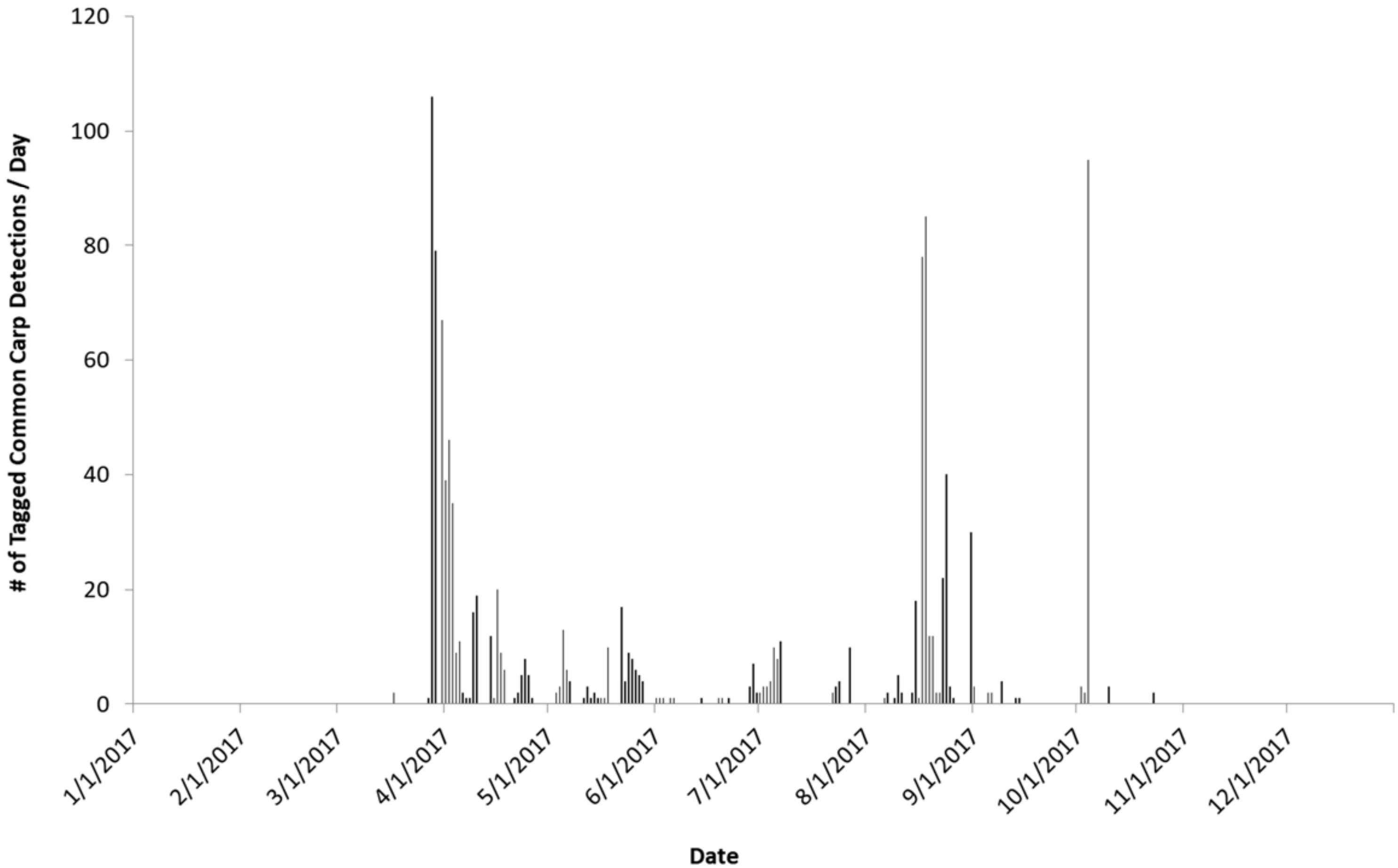


Figure 22c. The total number of carp detected by the Highway 8 PIT antenna by date in 2017.

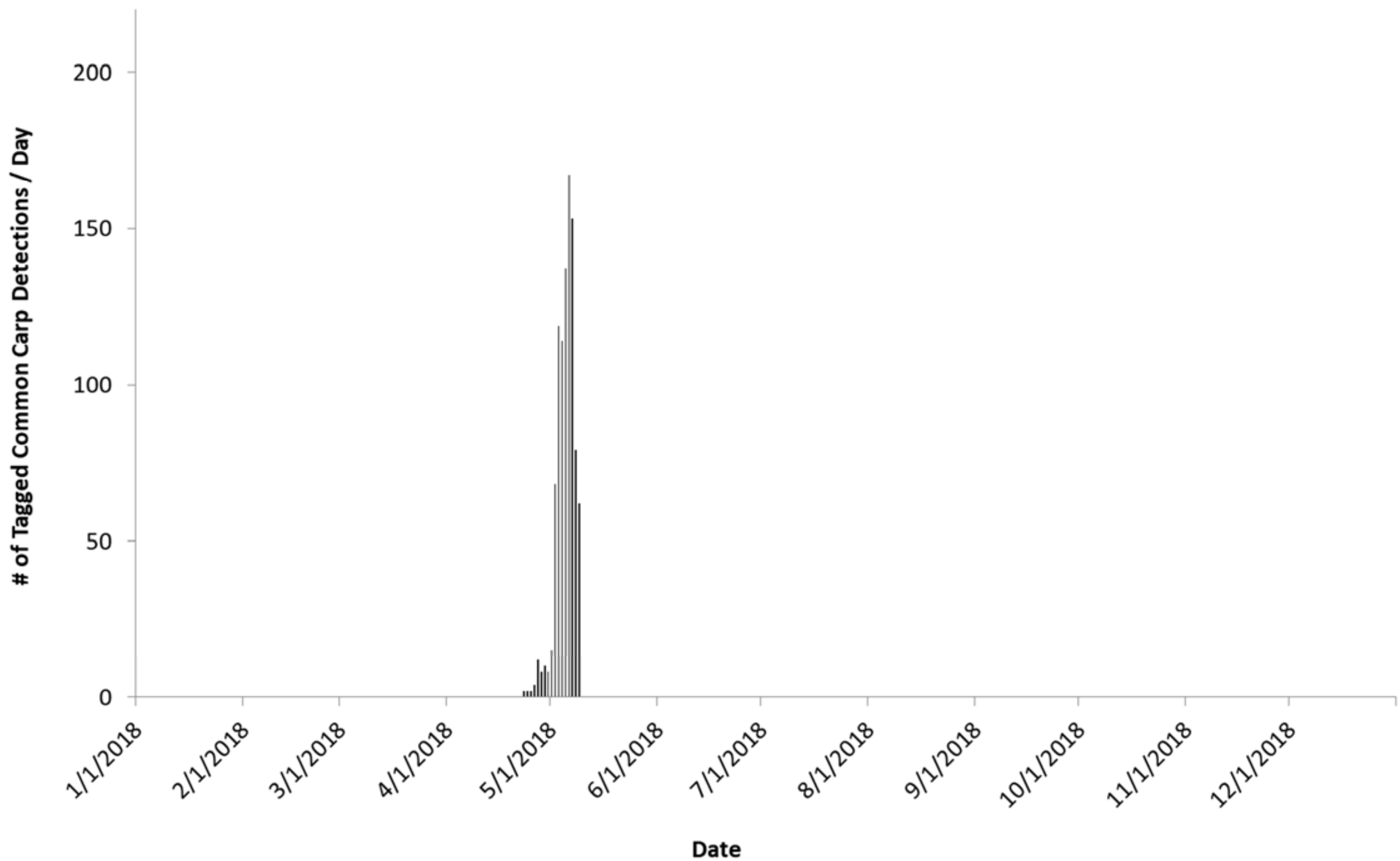


Figure 22d. The total number of carp detected by the Highway 8 PIT antenna by date in 2018.

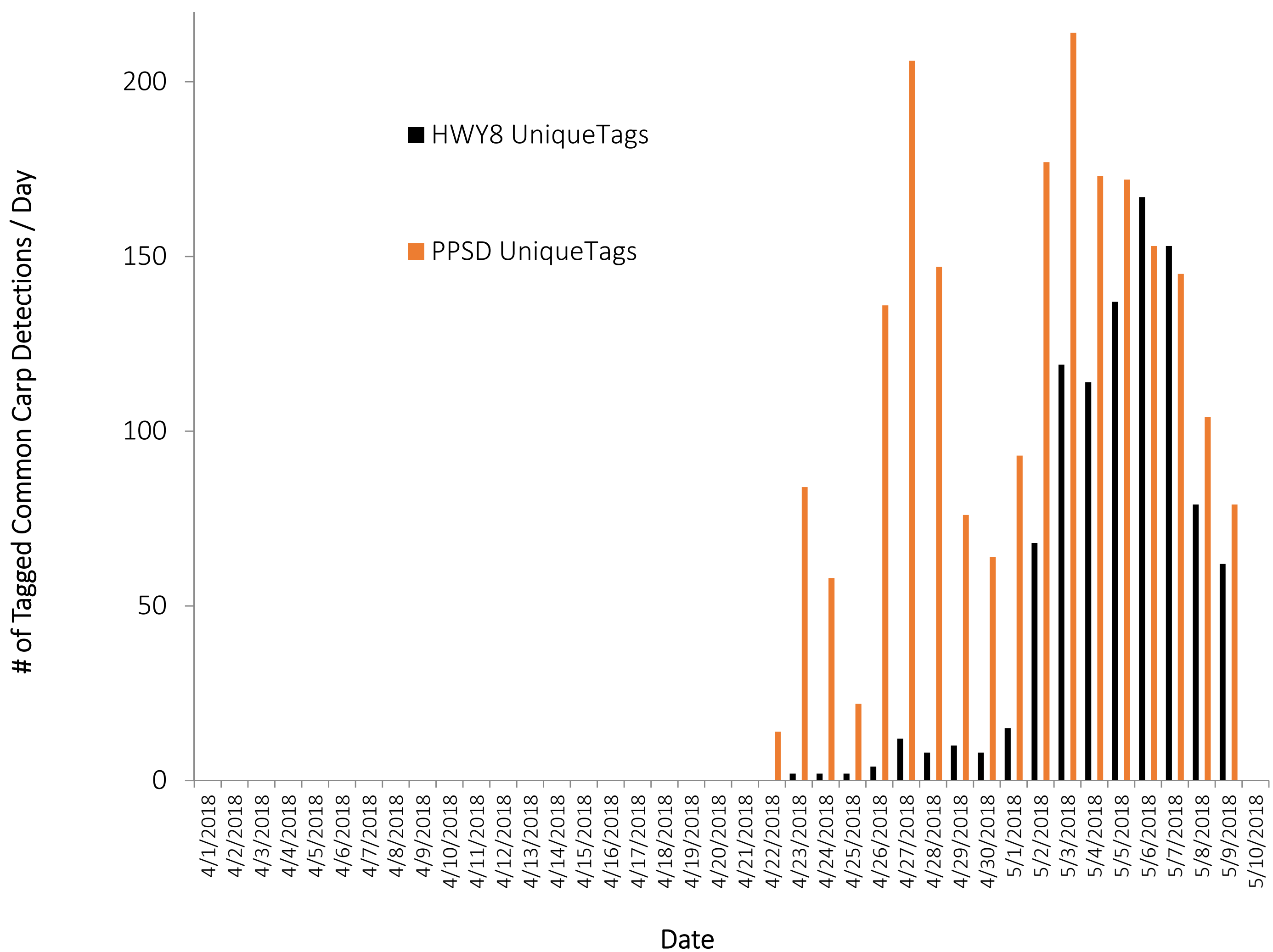


Figure 22e. The total number of carp detected by the Highway 8 and Poppyseed PIT antenna by date in 2018. The generator powering the EGS failed on the morning of May 2, suggesting a strong deterrent effect of the EGS prior to that date.

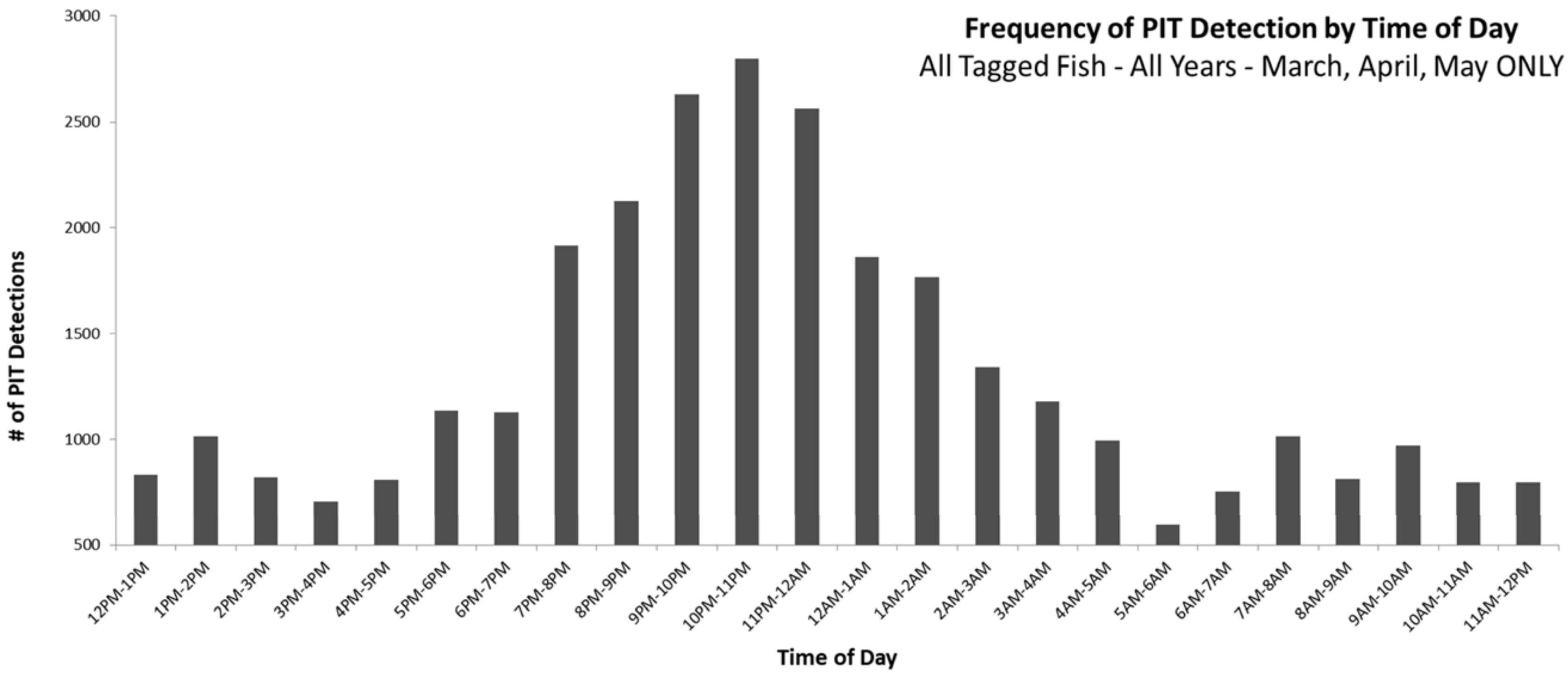


Figure 23. The frequency of tagged carp detections by Highway 8 PIT antenna by time of day during the months of March, April, and May (All Years).

Task 5: Testing the performance of the electric guidance system to direct migrating carp into a removal system (Whooshh System or a trap).

In 2017, RCWD supported the installation of two electric guidance systems to direct migrating carp into a trap or a specialized carp removal device, the Whooshh System. Testing the Whooshh system is a collaborative project with the University of Minnesota and will not be reported here. However, the electric guidance system will be described here, because that work was contracted with Carp Solutions, not the University. While the EGS could facilitate the performance of the Whooshh System, it serves a broader generic purpose because carp can be directed with it into conventional traps, not only the Whooshh System.

Two EGS were installed. One just upstream of Long Lake to direct upstream migrating carp (carp swimming upstream to spawn in Lino Lakes), and one at Hodgson Road to direct the downstream migrating carp (carp returning to Long Lake from spawning sites in Lino Lakes and juvenile carp spawned in Lino Lakes). In this report, we will describe the performance of the system for upstream moving carp because it is of primary importance.

The effectiveness of the upstream EGS was tested in the fall of 2017. Results of that test are described in detail in a peer-reviewed publication (Bajer, in press). The system was tested on 6 occasions: 3 days with EGS off and 3 days with EGS on. Approximately 40 adult carp were used in each test. Passive integrated transponder (PIT) tags/antennas and visual markers were used to monitor the behavior of the carp (Fig. 24). When the EGS was on, 74% of the carp were successfully guided into the mock trap within 24 hours and no carp were able to cross through the EGS (despite over 300 attempts); the remaining carp presumably remained downstream of the EGS or went back downstream to Long Lake. When the EGS was off, only 18% of carp swam into the mock trap, and carp were able to swim through the EGS (21% of attempts). The electric field generated by the EGS was mild and did not cause fish paralysis. The EGS required little on-site engineering and was deployed in only a few days. Overall, the EGS shows a great promise to block the carp during their spawning migration from Long Lake to Lino Lakes and to direct them into a trap.

The EGS system was also tested in the Spring 2018 for naturally migrating carp under high water conditions. This test showed that during the period of April 22 - May 1, 2018, there were 753 crossing attempts (unique fish x day combination) at the EGS site. While only 73 crossings (unique fish x day combination) were detected at the HWY 8 antenna upstream. This suggests ~ 90% barrier efficiency (Fig. 22e).

The success of the EGS system suggests that it could be used as a stream-wide, non-physical barrier to carp movement to deflect them into a trap without significantly altering water flow in the stream.

This work continues under the Whooshh project with the University of Minnesota.

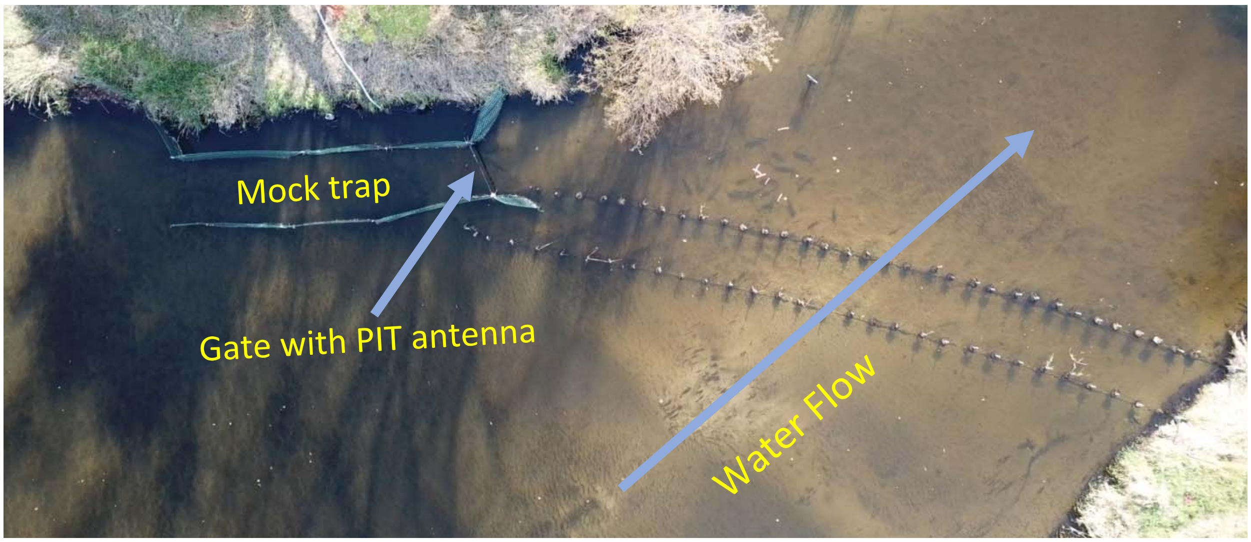


Figure 24. Overhead view of the EGS and the study site; photo credit Greg Prunty.

Task 6: Develop a population dynamics model for carp in Long Lake.

Developing a numerical model of a population is very important to plan and coordinate management strategies. We adopted an existing population model for carp inhabiting systems of lakes and marshes (Bajer et al. 2015) and modified it to mimic physical conditions present in RCWD. Further, we used the data collected in the system since 2015 to populate the model with information that mimics the behavior and ecology of carp in the Long Lake-Lino Lakes system.

Specifically, we modified the model to represent carp population in Long Lake and the five shallow marshes upstream, Lino Lakes. We focused on this subset of the watershed because 1) adult carp rarely migrate to other parts of the system in significant numbers, 2) carp extensively migrate between Long and Lino Lakes, 3) Lino Lakes comprise the main nursery area for carp from Long Lake, and 4) most young carp immigrate into Long Lake from Lino Lakes.

The model is biologically realistic and it keeps track of every single individual in the population throughout the year, including movement, growth, survival and number of offspring, which then become members of the population and their fate is tracked as well. Modeling started by seeding the Long lake population with 21,000 carp (using our population estimates in Task 1). These fish are allocated to age categories ranging from 0 (young of year) to 31 accordingly to our ageing analysis. Each of these carp is then allowed to migrate to Lino Lakes to spawn with a probability of 90% (Nate Banet, 2016). The carp that do not migrate spawn in Long Lake. The model than calculates the number of offspring per female that spawns either in Lino Lakes or Long Lake. Females that spawn in Long Lake produce between 0 and 2 YOY per year (most zero). The reproductive success of females that spawn in Lino Lakes depends on whether these lakes winterkilled or not. If not, their reproductive success is the same as carp in Long Lake. If, however, winterkill occurred, each female can produce up to 800 YOY carp at the end of the summer. This is driven by the fact that after winterkills, Lino lakes are largely void of native predatory fishes that forage on carp eggs, larvae and fry. The probability with which Lino Lakes winterkill and carp produce numerous young was set at 0.33 (every third year), based on trapnet surveys (strong recruitment occurred in Lino Lakes in 2015 but not in 2016 or 2017).

Following the spawning season, the adults return from Lino Lakes to Long Lake with 0.9 probability. The YOY carp that were born in Lino Lakes migrate downstream to Long Lake with a certain probability, approximately 2.8%. We updated this model parameter using data collected in Year 2. Specifically, we updated immigration rates to mimic observed data where approximately 3000-4000 age-1 carp imigrated to Long Lake from Lino Lakes in their second year of life (2016) following a recruitment event in Lino Lakes in 2015. YOY carp that do not migrate out of Lino Lakes, overwinter there. We updated the overwinter mortality of these carp using our trapnet surveys. Mortality of those fish appears to be very high even during a non-winterkill winter. This is shown by trapnet catch rates of age-0 carp in 2015 in Lino Lakes (N=1011) and age-1 carp in 2016 (N=33), which declined by 97%. Consequently, we assumed 97% overwinter mortality in Lino Lakes during a non-winterkill year. If a winterkill occurs, we assumed that between 95% and 100% (randomly drawn value between 0.95 and 1.0) of the carp perish.

Using the data from PIT antennas, we assumed that carp that survive winter in Lino lakes and become age-1, migrate to Long lake with 22.9% probability. We assumed that the probability of outmigration in the third year of life (and all following years; if they survived subsequent winters in Lino Lakes) was 0.5.

We modeled several management scenarios and their combinations that included 1) removal of adult carp (using winter seining, baited box nets or in the stream), 2) reduced immigration of young carp from Lino Lakes into Long Lake using the electric deterrent system, 3) “blocking” carp of all ages in Lino Lakes - allowing adult carp to swim into Lino Lakes to spawn and then blocking them from exiting Lino Lakes using the electric deterrent, while at the same time also blocking juvenile carp born in Lino Lakes from immigrating to Long Lake. This strategy might work becase carp suffer high overwinter mortality in Lino lakes, thus forcing them to remain in Lino lakes during winters could be used to control the population. We also modeled a "do nothing scenario.

Modeling results suggested several possibe scenarios that would reduce carp biomass in Long Lake below 100 kg/ha, which is the managemnt goal. Specifically, 30% adult carp removal and 80% blocking in Lino Lakes, or 50% adult carp removal annually and 50% blocking in Lino lakes achieved the management goal within < 10 years (Fig 26).

These results should be viewed as tentative, because they are based on only three years of data, and only one significant receruitment event (2015).

Scenario 1: Do nothing – in this scenario carp biomass ranged between ~ 500 and 2000 kg/ha encompassing our empirically estimated value of 770 kg/ha. It was surprising that the model predicted carp biomass levels as high as 2000 kg/ha, which rarely exceeds 500 kg/ha in Minnesota lakes. This is explained by Long Lake being located downstream of five large carp nurseries from which carp migrate in the summer and fall. Mr. Riedemann captured 90,000 kg of carp in Long Lake in 2007 (or 1,150 kg/ha), which supports the conclusion that carp biomass can exceed 1,000 kg/ha in Long Lake during some years.

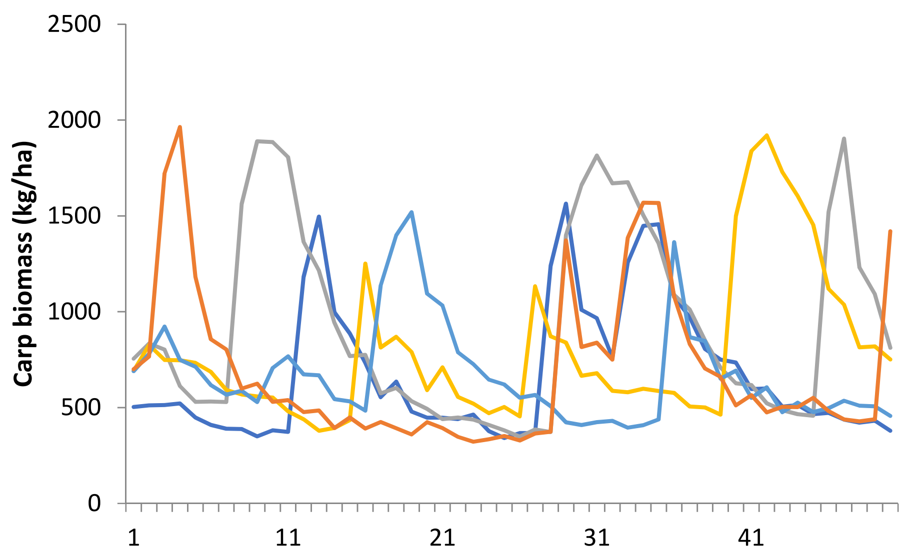


Figure 25. Modeling results for the "do nothing" scenario.

Scenario 2: Various rates of adult carp removal annually

The removal could occur using baited box nets, stream removal with EGS or commercial seining.

This shows that 50% adult removal might be sufficient to reduce carp biomass below 100 kg/ha within few years, but it will rebound after recruitment events in Lino Lakes. Removing 80% of adults would achieve management goals within <5 years (Fig. 26).

Scenario 3: Using the electric deterrent system

This system would be used to prevent carp (all ages) to return to Long Lake from Lino Lakes after their spawning migration. This also includes young carp born in Lino Lakes. This scenario suggested that 80% blocking efficiency might be required to achieve desired management effect (Fig. 27).

Scenario 4: Combination of scenarios 2 and 3: combining adult carp removal (by seining, baited nets or at the barrier) with trapping carp (all ages) in Lino Lakes by preventing them from returning into Long lake after their spawning migration. This also includes young carp born in Lino Lakes.

This scenario suggested that moderate rates of removal and blocking may be sufficient to control the population (biomass < 100 kg/ha). For example, this could be achieved with 50% removal and 50% blocking (Fig. 28).

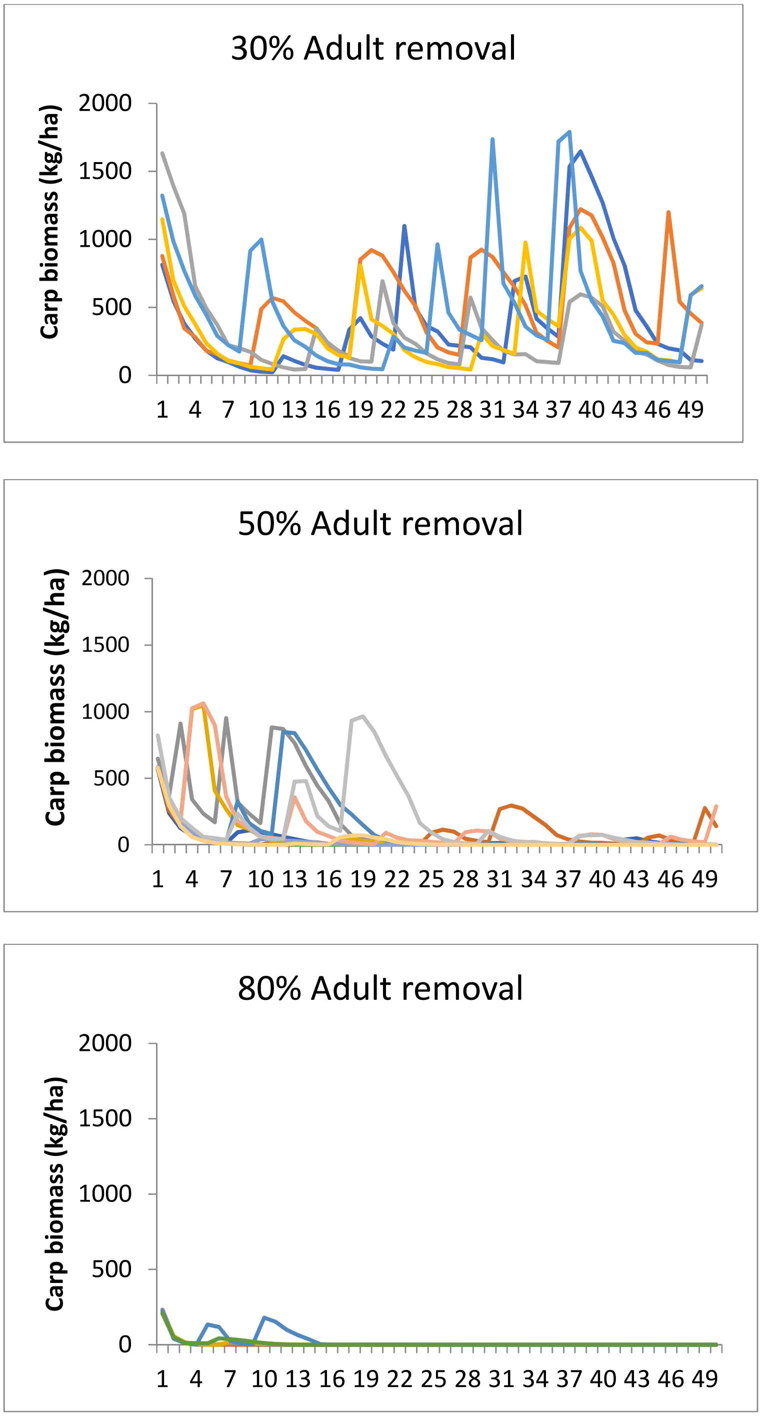
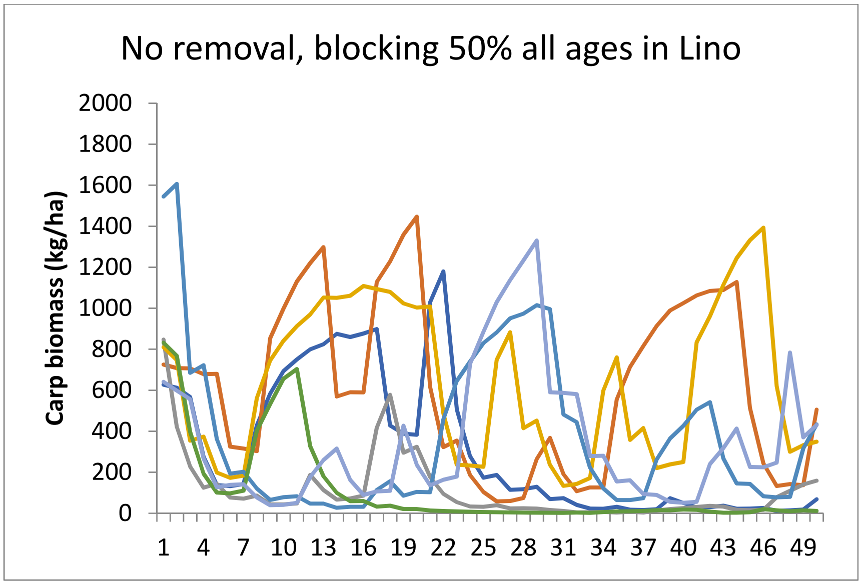


Fig 26. Effects of different rates of adult carp removal on carp biomass in Long Lake



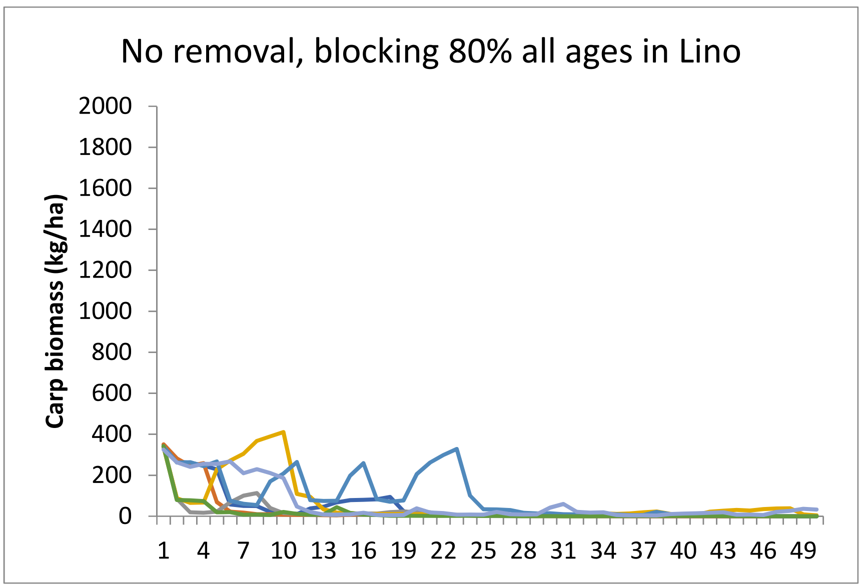
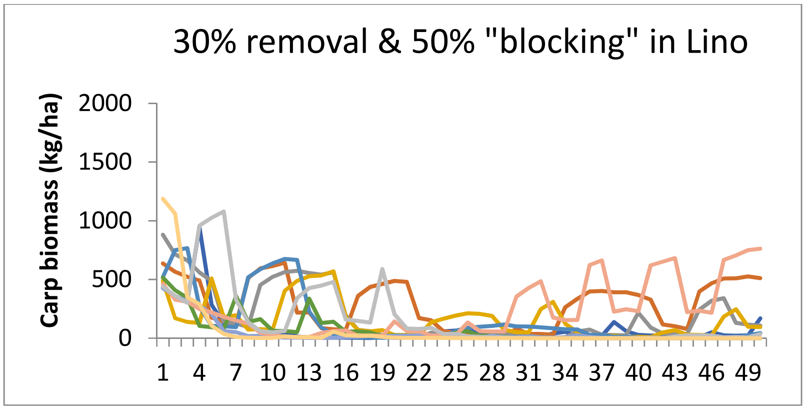
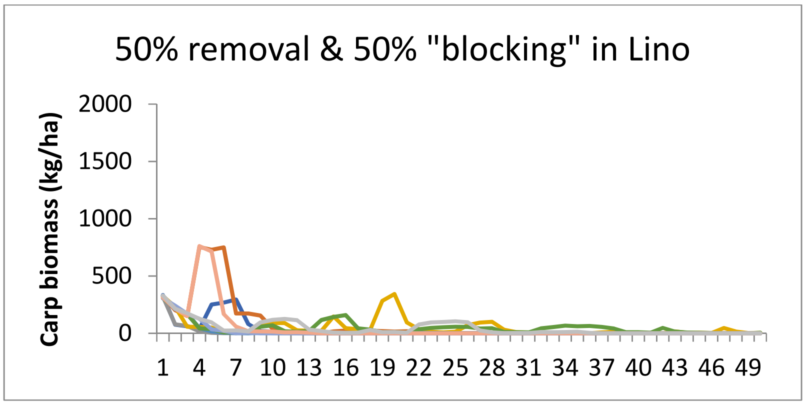


Fig 27. Effects of using the electric deterrent system to prevent carp (all ages) from returning to Long Lake from Lino Lakes after their spawning migration. This also includes young carp born in Lino Lakes





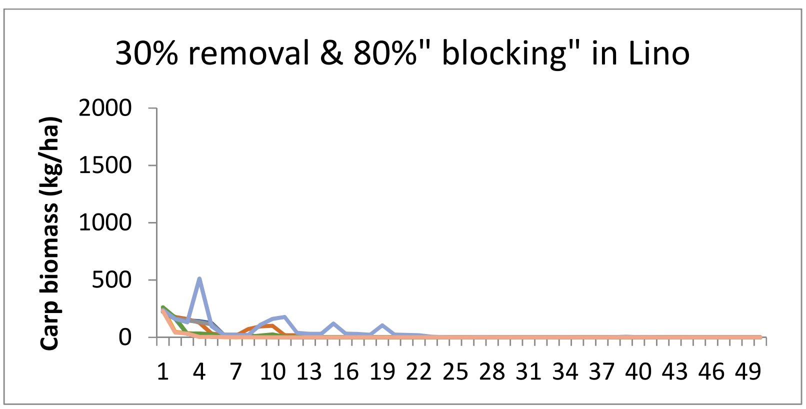


Figure 28. Combination of scenarios 1 and 2: combining adult carp removal (by seining, baited nets or at the barrier) with trapping carp (all ages) in Lino Lakes by preventing them from returning into Long lake after their spawning migration. This also includes young carp born in Lino Lakes.

Findings Summary:

1. The most recent estimated biomass of carp in the Long Lake system is 368.8kg/ha. Compared to other Minnesota lakes, this is more than three times the management threshold and confirms carp to be a consistent significant impairment to water quality.
2. Various adult removal methods were tested
    a. Winter seining, while efficient, is not a reliable nor consistent means for removing adult carp in the Long Lake system
    b. Box netting was successful at removing adult carp, and should be a reliable tool. Predicted $1.80/carp or $0.35/pound
    c. Removal associated with the EGS system shows great promise. In one test, >70% of migrating adults were directed into a trap. In another test, the EGS was 90% effective at blocking spring migration
3. Aging work suggests that although multiple recent age classes are represented, significant recruitment happens around every 3 years and is strongly dependent on significant winker kills in nursery lakes in the Lino Lakes chain.
4. Monitoring of adult and juvenile movement between Lino Lakes and Long Lake suggest:
    a. Nearly every adult moves from Long Lake to Lino every spring via Rice Creek to spawn
    b. Survival of YOY carp is inversely related to the presence of bluegill sunfish in Lino Lakes (see Figures 17-20)
    c. Juvenile carp are joining (i.e. recruiting to) the Long Lake population between 1-3 years of age. Carp that survive their first year have a much better chance of recruiting to the Long Lake population.
5. The EGS as a means of blocking adult spawning migration to nursery lakes preliminarily showed great success. This may very well be a key component to drastically reducing recruitment long-term in the Long Lake/Lino Lakes chain.
6. Modeling scenarios show that a combination of annual removal of adults by 50%, blocking of adult spawning migrations by 50%, and blocking of juvenile recruitment from nursery ponds into Long Lake by 50% would sustainably reduce the carp biomass below the threshold level in less than 10 years.

Management Recommendations

1. Remove adult carp using either of the following options:
    a. Commercial seining – this strategy has been successful in the past but attempts over the last three years showed that large commercial seine nets often snag on the bottom. Carp are also likely to learn avoidance behaviors if unsuccessfully targeted multiple times. Open water seining in late fall was more successful. While this option can be efficient, it is not reliable. Thus, it should be utilized when possible, but not relied upon to achieve removal objectives.
    b. Baited box net – this strategy was shown to be effective and not hindered by debris on the bottom. It is very selective (catches only carp) and can be scaled up.
    c. Stream trapping in conjunction with EGS – this strategy showed strong promise in the fall of 2017 and spring of 2018 but needs to be developed more. Using EGS would require permanent power supply. Using EGS to trap the migrating carp may require least amount of human labor and time to remove the carp.

2. Annually deploy the EGS system to block downstream migration of juvenile carp

3. Monitor changes in carp biomass and age structure in Long Lake to see if removal is effective:
    a. Annual boat electrofishing surveys – we recommend a minimum of 6 random 20 min electrofishing surveys in Long Lake to track the abundance of carp. This could also be used to mark and release carp in advance of removal efforts.
    b. Ageing analysis of a sample of 100 carp in Long Lake – this is necessary to track the influx of juvenile carp from Lino lakes into Long Lake and how quickly carp population can recover after removal.

4. Monitor carp recruitment in Lino Lakes and the movement of juvenile (and adult) carp between Lino and Long lakes via PIT array. Production of juvenile carp in Lino Lakes and their movement to Long Lake is the least understood and most critical aspect of carp management in the system. Our current assessment of this phenomenon is based on only one recruitment event in Lino lakes in 2015. We recommend that this aspect of carp biology is monitored annually using the following:
    a. Annual trapnet surveys in Lino Lakes – we recommend annual surveys to track carp recruitment in Lino Lakes.
    b. PIT antenna array maintenance – this system has been shown to be very effective at detecting the movement of juvenile carp out of Lino Lakes and into Long Lake.
    c. Annual PIT data analysis.
    d. Strategically tag carp with PIT tags throughout chain; especially important after a recruitment event in Lino Lakes.

5. Maintain EGS systems in Rice Creek to block adult spawning migrations and juvenile recruitment into Long Lake from Lino Lakes
    a. Clear debris and maintain cathodes and anodes in creeks
    b. Maintain PIT antennas associated with mock trap

6. Update the population model using current data and use it to guide future management.

Literature cited

Banet, Nathan. "Partial migration, homing, diel activity, and distribution of adult common carp across a large, model watershed in the North American Midwest." M.S. Thesis. University of Minnesota (2016).

Bajer, P. G., Sullivan, G., & Sorensen, P. W. (2009). Effects of a rapidly increasing population of common carp on vegetative cover and waterfowl in a recently restored Midwestern shallow lake. *Hydrobiologia*, *632*(1), 235-245.

Bajer, P. G., & Sorensen, P. W. (2010). Recruitment and abundance of an invasive fish, the common carp, is driven by its propensity to invade and reproduce in basins that experience winter-time hypoxia in interconnected lakes. *Biological Invasions*, *12*(5), 1101-1112.

Bajer, P. G., Chizinski, C. J., & Sorensen, P. W. (2011). Using the Judas technique to locate and remove wintertime aggregations of invasive common carp. *Fisheries Management and Ecology*, *18*(6), 497-505.

Bajer, P. G., & Sorensen, P. W. (2012). Using boat electrofishing to estimate the abundance of invasive common carp in small Midwestern lakes. *North American Journal of Fisheries Management*, *32*(5), 817-822.

Bajer, P. G., & Sorensen, P. W. (2015). Effects of common carp on phosphorus concentrations, water clarity, and vegetation density: a whole system experiment in a thermally stratified lake. *Hydrobiologia*, 746(1), 303-311.

Lechelt, Joseph D. et al. "Low downstream dispersal of young-of-year common carp from marshes into lakes in the Upper Mississippi River region and its implications for integrated pest management strategies." (2017).

Johnsen, P. B., & Hasler, A. D. (1977). Winter aggregations of carp (Cyprinus carpio) as revealed by ultrasonic tracking. *Transactions of the American Fisheries Society*, *106*(6), 556-559.

Vilizzi, L., Tarkan, A. S., & Copp, G. H. (2015). Experimental evidence from causal criteria analysis for the effects of common carp Cyprinus carpio on freshwater ecosystems: a global perspective. *Reviews in Fisheries Science & Aquaculture*, *23*(3), 253-290.