Development and implementation of a sustainable strategy to control common carp in the Purgatory Creek Chain of Lakes

Final report to the managers of the Riley Purgatory Bluff Creek Watershed District
for the project extension of "Developing and implementing a sustainable program to control common carp in Riley Purgatory Bluff Creek Watershed District Step 1: Developing control techniques in three model lakes"

December 31, 2015

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Synopsis

A final year of applied research in Lake Staring and the Purgatory Creek Conservation Area (PCCA) has reduced the population of adult common carp in this inter-connected system to less than 3,000 with a biomass below 100kg/ha. The project is now complete and this report summarizes all data for the entire Purgatory sub-watershed (Chain of lakes). Lake Staring responded very well to carp removal and control by showing substantial increases in water clarity as well as increases in plant cover and diversity as well as some apparent reduction in total phosphorus since monitoring started in 2010. While most of the recovery in plants was with native species, some exotic plant species are also now present. In addition to the 3000 adult carp present in Lake Staring, we estimate that nearly 3000 juvenile carp are also now present in this lake (and more in the PCCA from which they came). Winter seining was the most effective way to remove adult carp in Staring but its efficacy decreased rapidly with effort, seemingly because the carp learned to avoid nets. While the carp is presently not a problem to the ecology of this system, it will be in few years as the young carp continue to grow and possibly reproduce. Future control effort could focus on preventing more juvenile carp from moving downstream from PCCA to Staring, preventing new spawning by controlling adult movement into the PCCA by using the existing barrier in Purgatory Creek and also removing adults. Removal might be achieved by modifying barrier design and perhaps seining but efforts in 2015 showed that yield might be low, especially with repeat seining attempts throughout a season.

Foreword:

The document is the final report of a 5 year project funded by Riley Purgatory Bluff Creek Watershed District (RPBCWD) "Developing and implementing a sustainable program to control common carp in Riley Purgatory Bluff Creek Watershed District Step 1: Developing control techniques in three model lakes." The main phase of the project took place in 2011-2014 and the project was extended in December 2014 as a one year no-cost project to focus on a final year of carp control in Purgatory sub-watershed (i.e. primarily Lake Staring). The extension used a new permanent carp barrier that the RPBCWD had installed in Purgatory Creek with the assistance of its engineers. The present report summarizes all findings in the Purgatory sub-watershed (Chain of lakes) since 2011 and efforts at carp control. It was accompanied by a data report which was submitted in early December and its acceptance will signify acceptance of the terms of the contract and the no-cost extension under which the work was conducted. In this report we present the results of our efforts to assess and manage carp within the Purgatory Creek Chain of Lakes (PCCL) between 2011 -2015. It is comprised of eight sections. Following an introduction (Part 1) and a brief description of the study area (Part 2) we present initial assessments of carp abundance throughout PCCL (Part 3). We then focus on lakes that contained detectable carp populations and explain processes that drove their abundance and present strategies we tested to control those carp populations (Part 4). We also include a section on the use of the physical carp barrier that was installed in the final (extension) phase of the project to further suppress carp abundance (Section 5). We present a short section on the current status of carp abundance and achieved population control (Section 6) and resulting from it improvements in water quality, aquatic vegetation and native fish (Section 7). We finish with a section on management recommendations that includes several plausible management scenarios whose efficiency we evaluated using a model developed specifically for the purpose of this project (Section 8). The report also includes an appendix on the statistical model we developed to explain and manage carp abundance in this system.

1. Introduction

The common carp (*Cyprinus carpio*) is among the world's most invasive fishes. It was introduced to North America in late 1800s and is now widely distributed across the continent. Currently, the common carp (hereafter, "carp') is present in most lakes in central and southern Minnesota and are especially abundant in productive lakes of the Twin Cities area as well as the prairie lakes of southern Minnesota. In these areas, carp populations commonly reach 300-500 kg/ha, which substantially exceeds the ecological threshold of 100 kg/ha. Above this threshold, studies have shown carp to reduce submerged vegetation and water clarity. The carp is known for degrading water quality in lakes as it roots in the bottom while looking for food. It uproots aquatic vegetation, increases water turbidity and liberates nutrients from the sediments promoting algal blooms. Managing overly abundant populations of common carp is often necessary to restore and preserve lake ecosystems.

Although the effects of carp on lakes are relatively well understood, it is not known how to control carp populations in ways other than poisoning them with rotenone which is nonspecific. Over the last decade, our group has conducted several studies (including some funded by the RPBCWD) which have shown that controlling carp populations without the use of toxins is possible; our approach is based on exploiting several weaknesses in carp's life history including its unique behaviors such as forming tight winter aggregations that can be removed with nets (see our previous report for details). We have also documented that recruitment (production of young) in many carp populations is controlled by native fishes that forage on carp eggs and larvae. Further, many carp nurseries are winterkill-prone lakes that lack native predators. Using funding provided by RPBCWD (2008-2014) we demonstrated and implemented a successful carp management strategy in the Riley Chain of Lakes. This effort was subsequently extended for one more year (2015) as a no-cost extension using money remaining from the original contract to develop similar strategies of the Purgatory Chain of Lakes.

2. Study Area

The Purgatory Creek Chain of Lakes (PCCL) is comprised of eight lakes, of which four are directly connected via Purgatory Creek and the remaining systems are connected only intermittently (Figure 1). Lake productivity, depth and size vary substantially among these systems (Table 1). Several artificial and natural barriers restrict carp and fish movement and thus separate the PCCL into sub-units: 1) Lake Lotus, 2) Lake Staring-Purgatory Creek Conservation Area (PCCA) – which functions as one unit and has one population of carp, 3) the other lakes that are only connected occasionally and then only indirectly through underground pipes (Figure 1). Lake Lotus is located at the top of the Chain and is separated from other lakes because of elevation drop and a physical fish barrier at its outflow. Lake Staring and PCCA comprise a single ecological unit that is separated from other bodies of water by an old dam located downstream of Staring and multiple culverts and elevation differences upstream of PCCA. Notably, PCCA is comprised of two sections: the upper pool, which is relatively small and deep, and the lower pool which is much larger and shallow (max depth 1m; Figure 2). In this report, we focus primarily on the lower pool of PCCA because while it is connected with Lake Staring, few carp and fish appear to move between it and the Upper Pool in which we have detected only few adult carp. The Lower Pool plays a key role in carp population dynamics and management where Upper Pool does not. For brevity, we will use "PCCA" to refer to the lower pool of PCCA throughout the report, unless we specifically refer to the Upper Pool of PCCA.

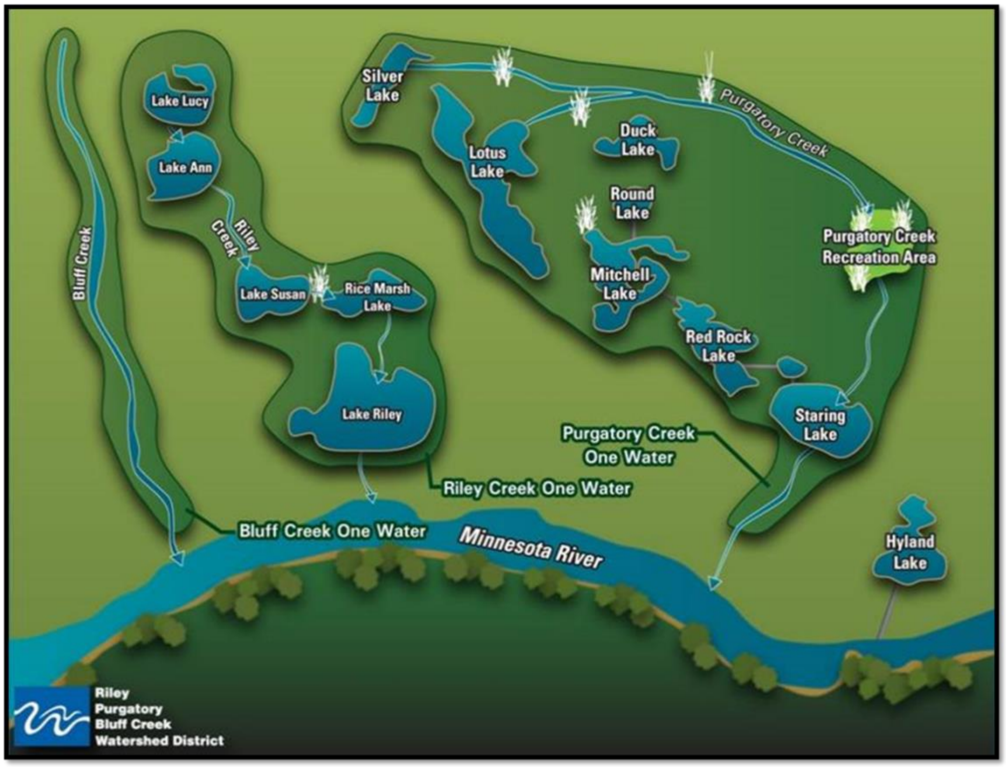

Figure 1. The study area.

Figure 2. Aerial photograph of the Upper and Lower pools of PCCA.

Table 1. Lake area, maximum depth and total phosphorus (TP) levels; * from MN PCA: http://www.pca.state.mn.us/

Lake	Area (ha)	Maximum depth (m)	Mean summertime Total Phosphorus (mg/L)
Duck	15.4	3.1	*.052
Lotus	99.1	8.8	.050
Mitchell	46.1	5.8	*.063
PCCA – Lower	~60	1	.132
PCCA – Upper	~10	3	.110
Red Rock	39.2	4.9	*.082
Round	12.4	11.2	*.046
Silver	34.0	4.0	.067
Staring	66.4	4.9	.095

3. STEP 1 (2011): Assessment of common carp abundance throughout Purgatory Creek Chain of Lakes

The first step in developing sustainable management strategies for invasive fish including the common carp is to estimate their abundance throughout the area of concern. To determine how many lakes in the Purgatory Chain of Lakes might have adult carp and where their biomass might exceed the ecologically-damaging threshold of 100 kg/ha we used standard boat-electrofishing and trapnetting surveys in all lakes. These estimates were then verified using mark-recapture to focus subsequent management efforts.

Our assessments of adult carp abundance and biomass began in 2011. First, we used boat electrofishing to conduct three 20-min surveys in each lake, with the exception of both the upper and lower PCCA and Silver Lake, where the boat could not be launched. The number of carp captured per hour of electrofishing was then used to produce a preliminary estimate of carp number and biomass using an equation developed by Bajer and Sorensen (2012). Second, we conducted late summer lake surveys with small-mesh (3/8 inch bar) trapnets, which are particularly effective at capturing small carp to determine which lakes in the chain were functioning as carp nurseries. Finally, in lakes where carp were found (Lotus and Staring) we conducted mark-recapture estimates to validate boat electrofishing estimates.

Boat electrofishing surveys conducted in 2011 suggested that adult carp were very abundant in Lake Staring (51 carp/h, Table 2), moderately abundant in Lake Lotus (6 carp/h; Table 2) and absent (not detected) in Duck, Mitchell, Round and Red Rock (PCCA and Silver could not be sampled using this method). Using the observed catch rates we estimated that the density of carp in Lake Staring was ~ 250 individuals per hectare while the density in Lotus was only ~ 30 per hectare (Bajer and Sorensen 2012). These estimates were confirmed and improved by conducting mark-recapture analyses in Staring (2011) and Lotus (2012). Both of these estimates involved the use of different sampling gear to mark and recapture the carp to reduce gear avoidance. In Lake Staring, 331 carp were captured in a baited trap (70 x 70 feet box trap), marked and released of which 71 were then recaptured in a winter seine in January 2011. This allowed us to estimate that Lake Staring was inhabited by ~ 26,000 carp whose biomass was close to 500 kg/ha (Table 4). In Lake Lotus, 286 carp were marked and released in winter 2012 of which 4 were recaptured (among 28) while conducting electrofishing surveys next summer. These numbers suggested that lake Lotus was inhabited by ~1,700 carp whose biomass was ~ 60 kg/ha (Table 4).

Trapnet surveys conducted in 2011 (and also 2010) showed that YOY carp were present in large numbers in the lower PCCA but only in small numbers in Lake Staring (Table 3). This provided the first indication that lower PCCA might be functioning as a carp nursery for Lake Staring. No YOY carp (or carp of any other age) were captured in trapnets in any other lakes (Table 3). Trapnet surveys continued annually (2012 – 2015) confirming trends observed during the initial years of the project (Table 3).

Table 2. Mean catch rates of common carp using boat electrofishing (EF; catch per hour). * Silver lake was sampled with gillnets instead of electrofishing since boat could not be launched. "-"no survey conducted.

Lake	2011	2012	2013	2014	2015
Duck	0	0	-	-	-
Lotus	6	7	8	4	-
Mitchell	0	0	-	-	-
PCCA – Upper	-	9	-	13	9
Red Rock	0	0	-	-	-
Silver	-	*0	-	-	-
Round	0	0	-	-	-
Staring	51	11	-	20	14.5

Table 3. Mean catch rates of young of year (YOY) common carp in small mesh trapnets. Surveys were conducted in all lakes only in 2011 because electrofishing surveys, which were conducted in all lakes both in 2011 and 2012 showed absence of any carp (YOY or adult) in Duck, Mitchell, Red Rock, Round, and Silver (Table 2); 2010 was a pilot year ahead of schedule; "-" no survey conducted.

Lake	2010	2011	2012	2013	2014	2015
Duck	-	0	-	-	-	-
Lotus	-	0	0	0	0	-
Mitchell	-	0	-	-	-	-
PCCA – Lower	210	0	1	9.2	.2	23.8
PCCA – Upper	-	0	0	0	0	0
Red Rock	-	0	-	-	-	-
Round	-	0	-	-	-	-
Silver	-	0	-	-	-	-
Staring	1	.2	0	0	0	0

Table 4. Mark-recapture estimates of carp number and biomass in lakes Lotus and Staring at the beginning of the study (2011).

Lake	Number of carp in the lake Mean ± SD	Biomass (kg/ha)
Lotus	1829 ± 612	64
Staring	26,228 ± 5,290	489

4. STEP 2 (2012-2014): Developing a sustainable strategy to reduce the number of carp and their biomass in Lotus Lake and the Lake Staring-PCCA System

Because our initial assessments showed that carp were present in only two systems within PCCL (Lotus Lake and the Staring-PCCA system), we focused our efforts on these systems. In each system we conducted a range of studies to document key attributes of carp behavior and population dynamics needed to develop sustainable management schemes. To do so, we documented the patterns of carp movement and seasonal aggregations, recruitment (survival of young), dispersal of young from nurseries to lakes, and we also tested several removal strategies including winter seining of carp aggregations. Our findings are described separately for each system. We focus on work conducted through 2014 but some 2015 data on carp movement are included.

Lotus Lake

Initial evaluations showed that Lotus Lake was inhabited by a relatively low number of old adult carp (Tables 2, 3, 4). This is relatively typical for deep, ecologically stable lakes of central Minnesota with abundant native fish populations (Bajer et al. 2012). Even though the carp spawn in such lakes annually, their eggs larvae and fry are then consumed by native fishes such as bluegills, which dominate those systems. Because carp in Lotus appeared to be controlled by native predators (i.e. there was no recruitment) and because the barrier at the outflow of the lake seems to prevent carp immigration from other lakes (i.e. Staring), we concluded that this population could be managed by simply removing adults using winter seining. Furthermore, because the initial population was relatively small, even a modest removal would ensure that the biomass of carp in the lake would remain well below the threshold that is considered to be ecologically damaging to temperate lakes (100 kg/ha). To do so, we implanted 12 carp with radiotransmitters in the fall of 2011 and tracked their movement within the lake during the winter of 2011-2012. An aggregation of carp was found in the northeast bay area of the lake and was targeted with an under ice seine net on Feb. 17, 2012. A total of 166 adult carp were captured and removed. This technique was difficult to apply in this lake because of its many plants. Adult carp biomass was reduced to 58.5 kg/ha. An additional reduction of biomass was conducted in the September of 2013 when 196 adult carp were caught and removed with a baited box net further reducing carp biomass to 51.7 kg/ha. Although further reductions of carp biomass might be considered in the future by using winter seining or baited box net but they are not essential to improving water quality in Lotus because the existing carp biomass is already quite low.

More recently, to confirm that our management strategy in Lotus Lake was sustainable (e.g. that carp removal did not trigger a population rebound), we conducted trapnet and electrofishing surveys in the fall of 2012, 2013, and 2014 (Tables 2, 3). These surveys showed an absence of young carp (Table 3) further reinforcing our initial conclusion that native fish are able to control carp reproduction in Lotus and that this population of carp is unlikely to increase.

Lake Staring - PCCA System

Processes driving the high abundance of carp in Lake Staring were found to be much more complex than those in Lotus Lake. Briefly, they appear to be attributable to a combination of the ecology and physical conditions in PCCA (the lower pool), which our initial studies suggested to function as a very productive carp nursery for Lake Staring (Table 3). The size and continuity of Purgatory Creek permits extensive movement of both adult and juvenile carp between the PCCA and Lake Staring, complicating the situation. To address these issues we: i) studied the movement of adult carp between Staring and PCCA; ii) investigated the possibility of using temporary instream barrier to block movement and perhaps remove adult carp that we had observed moving; iii) investigated the number and fates of juvenile carp; and iv) developed winter under-the ice seining to remove adult carp from Lake Staring.

i). Movement of adult carp between Staring and the lower pool of PCCA

To document movement patterns of adult carp which we suspected to be spawning in PCCA we implanted 10 adult carp with radiotransmitters (ATS, Model F1850) in Lake Staring in the fall of 2010. The number of radiotagged carp in the system was subsequently increased to be between 15 and 30 at any given time throughout 2012-2015. Telemetry showed that each year, up to 90% of carp left Lake Staring and migrated to the lower pool of PCCA to spawn (Figure 3). The migration occurred over 1-3 day periods and although its exact timing varied, it usually occurred in May when water temperatures are above 10°C and there was a sudden increase in water level (Figure 3). However, in 2013 and 2014, the first (usually smaller) spike in carp migration occurred in early April when water temperatures were only ~ 5°C (Figure 3).

Once in PCCA, adult carp typically remained for a period of time that ranged from just few days to over 2 months after which time they nearly always moved back to Lake Staring with a few (between 0 and 30% depending on a year) occasionally spending the winter in PCCA. Movement between the Lower and Upper PCCA was extremely rare but did occur when water levels remained high connecting both basins. Telemetry showed that the adults that remained in PCCA (lower pool) for the winter were able to find a small refuge near the inlet where the water scoured a depression in lake-bottom, while the rest of PCCA was frozen to the bottom (Figure 4). Water drawdowns and elimination of the winter refuge near the inlet could be used as a management strategy in the future both for adult and juvenile carp that overwinter in PCCA (see management section). The refuge near the inlet to PCCA could (and should) be filled in.

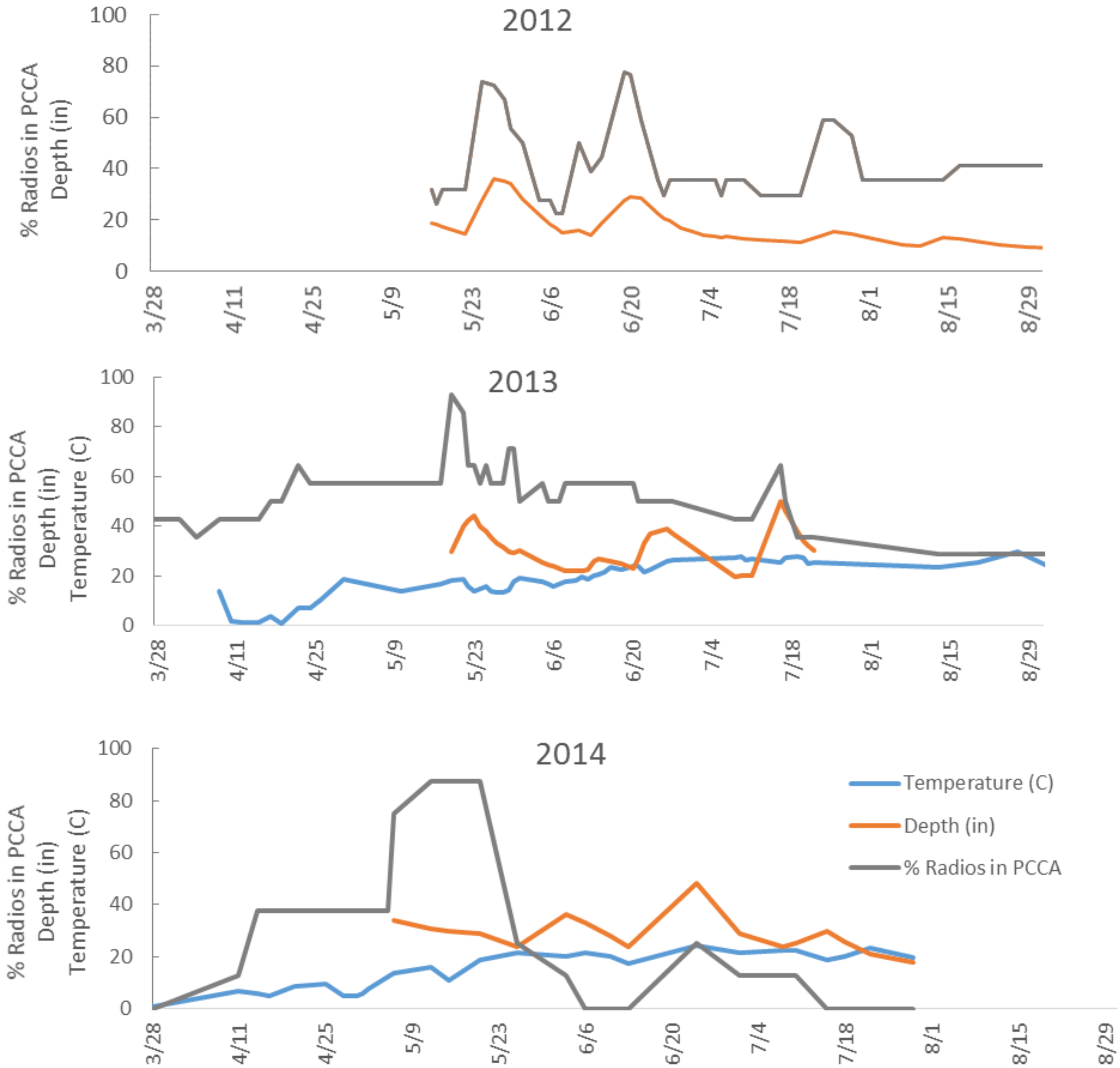

Figure 3: Movement of radiotagged adult common carp between Staring and the lower pool of PCCA in 2012, 2013, and 2014. An increase in the percentage of radiotagged carp in PCCA represents a movement of carp from Staring to PCCA, while a decrease represents carp out-migration back to Staring.

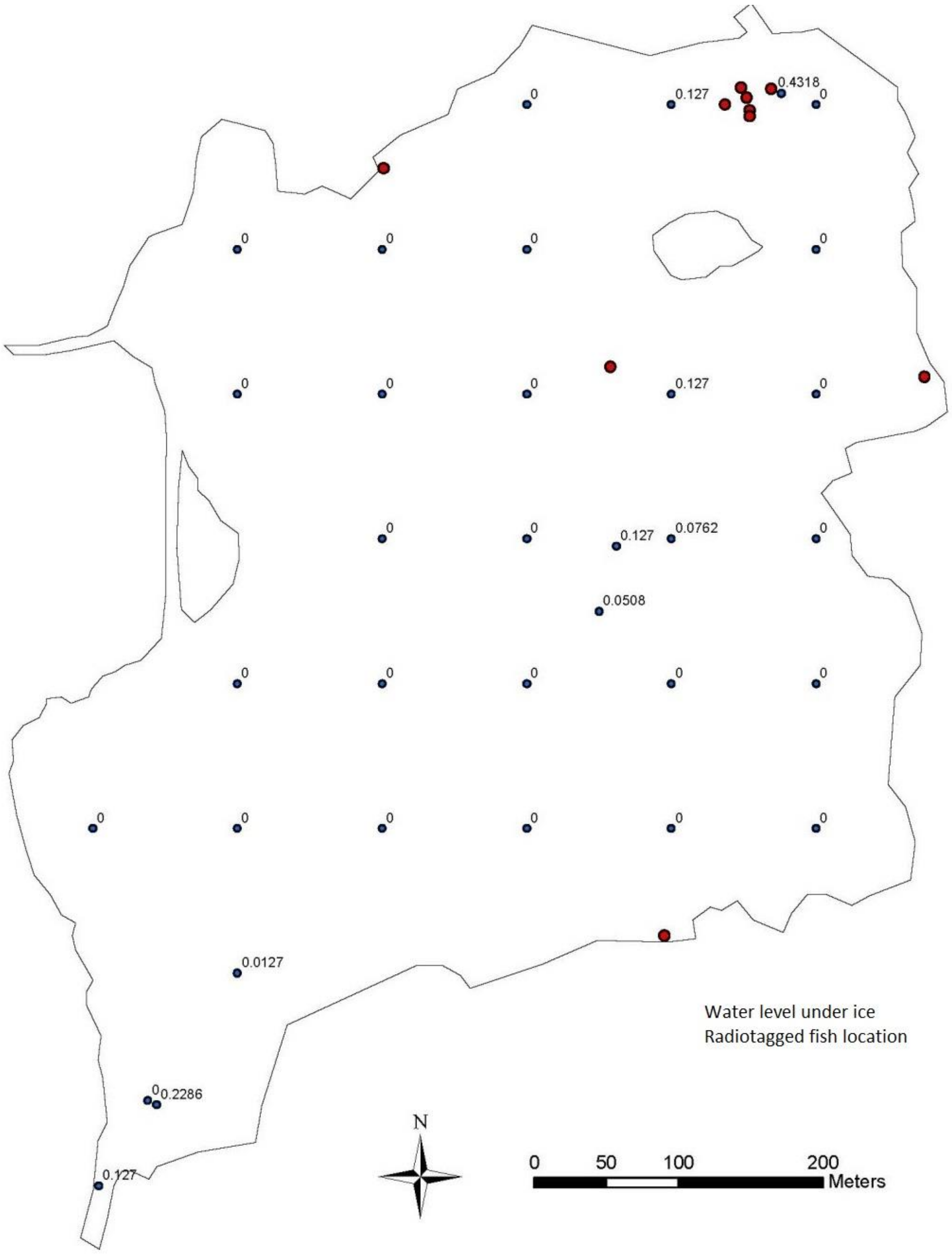

Figure 4: Map of the lower pool of PCCA in January 2013 with water depths under ice (blue circles) and aggregation of carp (red circles) in the "refuge" near the inlet. The three red circles near the edges of the lake represent carp that perished in the freeze-out.

iii) Using a physical instream barrier to block the movement of adult carp and remove them

Because nearly all adult carp migrated from Staring to PCCA to spawn each year, and usually in a relatively synchronized fashion (a 1-2 day migration might have thousands of carp), we hypothesized that blocking those fish with a temporary barrier and removing them when they aggregate below the barrier might be used as an effective management strategy. Most importantly this could also stop them from spawning in PCCA. We tested several approaches and temporary barrier designs to assess the feasibility of such a strategy. First, we built a PVC-pipe barrier in Purgatory Creek upstream of Staring in the spring of 2012, following our success with similar structure in Lake Susan. This barrier was maintained daily and several thousands of carp (including most radiotagged fish) aggregated downstream of the barrier over the course of 1-2 days in April 2012. We used backpack electrofishing to remove those fish (Figure 5) but only 400 could be removed in one day as the fish scared easily. Finally, a storm caused a sudden increase in stream water level, which scoured a hole underneath the barrier, allowing these fish to pass. Still, the approach of deploying temporary structures in the creek at the specific times that fish were moving seemed to have good promise if we could secure the bottom to prevent scour.

The temporary instream barrier design was improved in 2013 by reinforcing its bottom edge with landscaping fabric and pavers, but a new problem emerged. First, the carp staged in Lake Staring near the mouth of the creek but would not attempt the upstream migration in large numbers and did not aggregate below the barrier as before– they seemed to learn the barrier was present. Second, DNR stream regulations prevent us from constructing a pad on the bottom of the stream so we had to remove pavers. Thus, when water level came up after another large spring-time storm, a hole scoured under the pavers and a floating tree hit the barrier itself, which the carp detected and migrated to PCCA. This stream is extremely prone to floods and debris. Given these experiences, and also given the fact that adult carp in the system can be removed using means other than a barrier (winter seining; see below), we abandoned the barrier approach in 2014 when the watershed district started planning for a new barrier.

Figure 5. Removing carp from Purgatory Creek using backpack electrofishing in the spring of 2012. The carp aggregated below a temporary PVC barrier.

iv) Determining the production of young carp in Staring-PCCA and their fate

Young of year (YOY) carp were never observed in significant numbers in Lake Staring (Table 3), suggesting that nearly all carp in that lake originate from external nurseries, and very likely the Lower PCCA. Annual trapnet surveys conducted in PCCA in late summer (approximately three months after spawning) confirmed a high abundance of young-of-year (YOY) carp in PCCA (lower pool) approximately every-other year (Table 3) suggesting that this systems functions as the carp nursery for Lake Staring. This was in line with the observed annual spawning migrations of adult carp from Staring to PCCA.

The high abundance of YOY carp in PCCA, which occurs approximately every other year (Table 3) is likely attributable to low abundance of native predators in PCCA due to winter freeze-outs and hypoxia, and exasperated by high productivity of this system (nigh nutrient concentrations stimulate zooplankton which larval carp consume). The frequently occurring winter hypoxia is attributable to a very shallow depth of the lower pool of PCCA, which functions as storm water retention basin with highly variable water levels that tend to be lowest in the winter. Whereas winter hypoxia can sometimes be averted by installing winter aeration, which then allows native fish to rebound and control carp eggs and larvae, winter hypoxia cannot be prevented in PCCA by using winter aeration because this system is too shallow. Filling in the refuge in this area, as suggested above and as recommended in our reports at the time, might work to control carp because it would cause the entire basin to go anoxic.

It is essential to develop a good understanding of the number and fate of the juvenile carp in the nursery to develop a control strategy. To accomplish this, we attempted to conduct mark-recapture analyses of YOY carp in lower PCCA to estimate their abundance in 2013 and 2015. However, in both years, none of the 500+ individuals that were marked were recaptured suggesting that the population was very large (inestimable). Using data from similar systems, which show that 2,000 to 6,000 YOY carp can be produced per hectare in carp nursery lakes (Osborne 2012), we estimate that between 130,000 and 390,000 YOY carp (late summer fry ~ 10-15 cm in length) might have been present in PCCA in those years. Although these numbers are high, they are not necessarily unmanageable for the following reasons: 1) few YOY appear to move from PCCA to Staring during the first year (see below), 2) YOY face high natural mortality rates in PCCA in the summer and their abundance often declines by > 90% between July and October possibly due to high predation by birds, and 3) those YOY that do not migrate to Staring likely to perish due to winter hypoxia (see below).

We also studied the fate of YOY carp in PCCA and how many of them moved to Staring. In both 2013 and 2015 we implanted over 400 YOY carp in PCCA with PIT tags and tracked their movement to Staring by placing two PIT antennas in Purgatory Creek just upstream of Lake Staring. This effort showed that fewer than 10% of YOY carp leave PCCA in the first year of life. In 2013 only one carp was detected by the antennas out of 468 tagged. In 2015, 37 carp were detected by the antenna out of 663 marked. Most of these YOY carp crossed the antenna in July (Fig. 7). The movement occurred at a time when the water level in PCCA and in the stream was declining (Figure 3). It is possible that those fish were escaping bird predation as they were very vulnerable in PCCA during low water periods where only 2-3 deeper areas exist. We also conducted repeated trapnet surveys in PCCA to estimate the mortality rates of YOY carp between July and October of 2013 and 2015. These surveys documented declines in catch rates and suggested that YOY carp experience ~ 4% daily mortality in PCCA, which would suggest that their abundance declined by over 90% between July and October (Fig. 6). However, this would still leave many thousands of juvenile carp in the PCCA at summer's end. Analysis of trapnet data in spring described variable overwinter survival. These surveys showed that while both the 2011 and 2013 year classes did not survive over the winter. In contrast, the 2010 year class of YOY carp survived in PCCA the winter of 2010/2011 and then left the system in May 2012. We later estimated that approximately 8,000 age-2 carp moved from PCCA to Staring in 2012 (Figure 8).

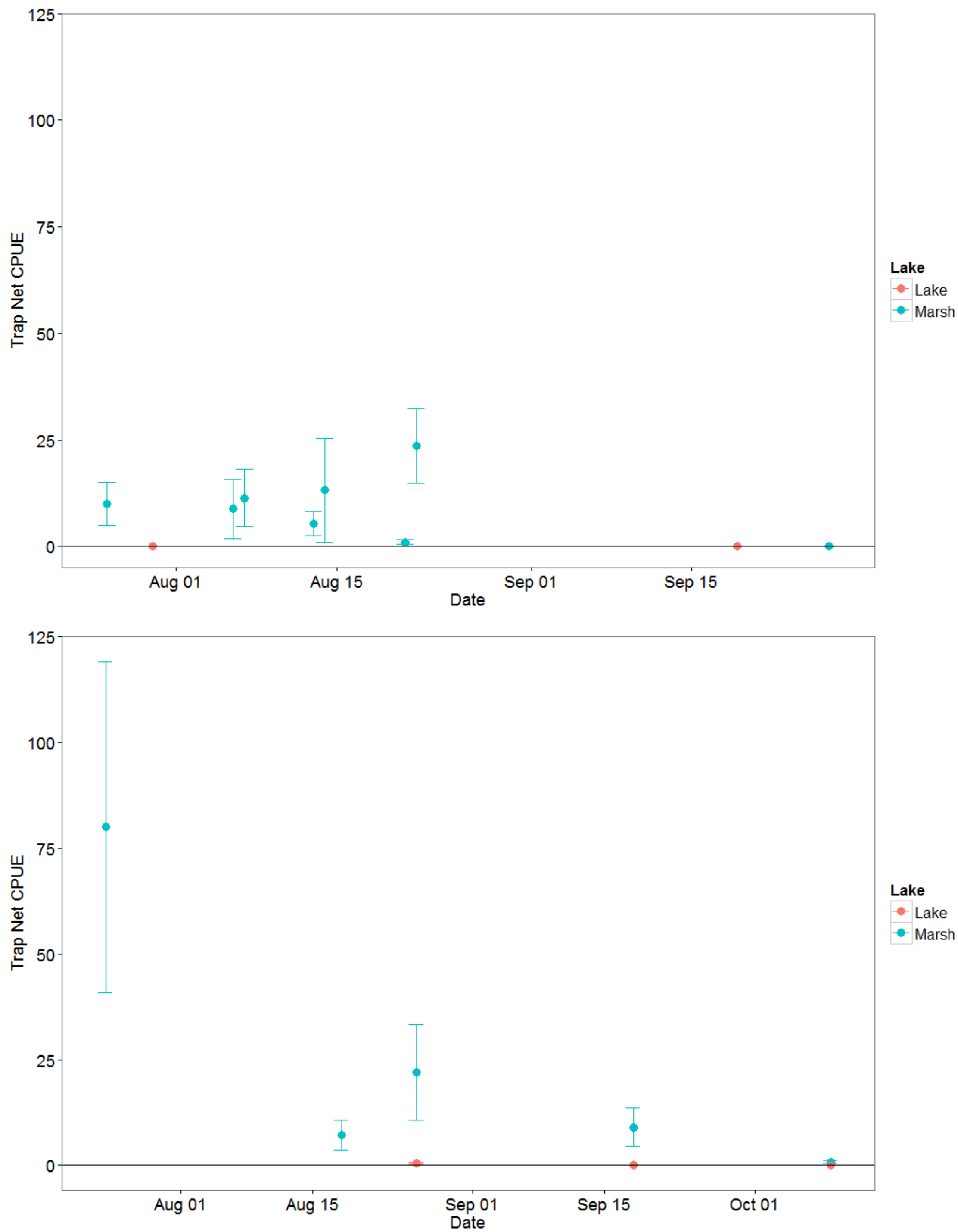

Figure 6: The average trap net catch rate (CPUE) of young of year common carp in the lower pool of PCCA (marsh; blue) and Lake Staring (lake; red) in 2014 and 2015. The error bars represent the standard error.

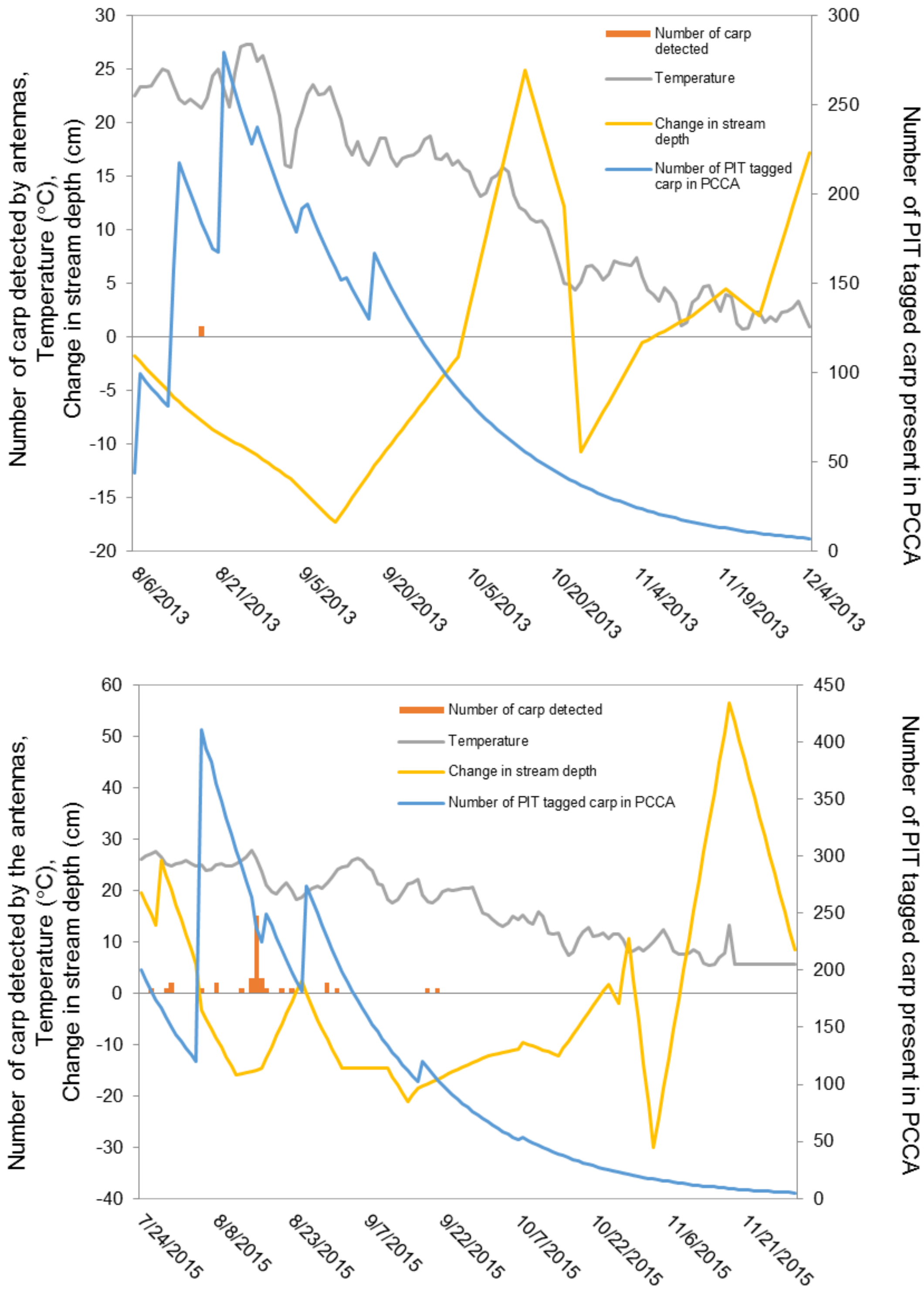

Figure 7: The number of PIT tagged YOY carp present in PCCA (blue line), number of PIT tagged carp detected by the antennas downstream of PCCA (orange bars), change in stream water level (in relation to annual mean; yellow line), stream temperature (gray line) in 2013 (top) and 2015 (bottom). The decline in the number of PIT tagged YOY carp in PCCA (blue line) represents natural mortality that was estimated from trapnet catch rates (Figure 6).

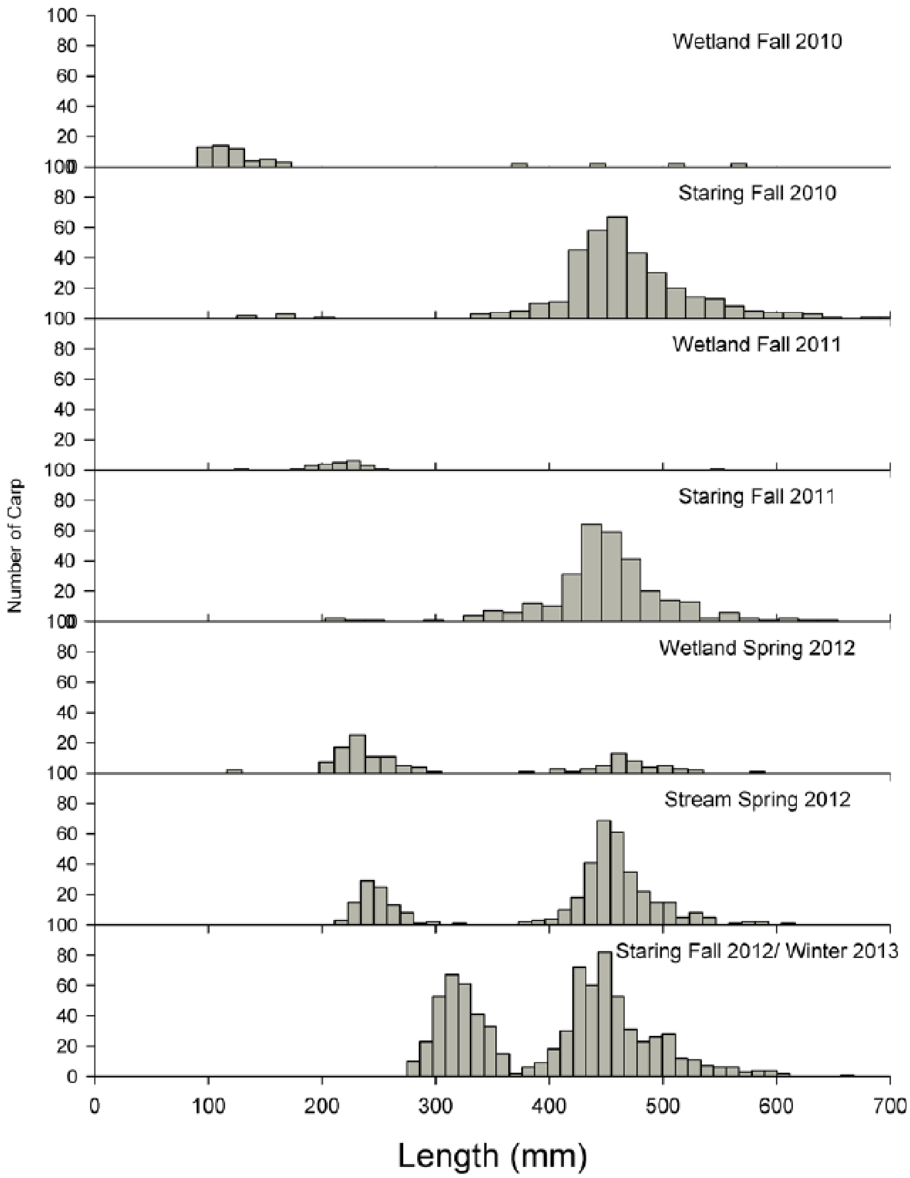

Figure 8. Length structure of common carp in lower pool of PCCA ("Wetland") and Staring during 2010-2013. Note the appearance of "small" carp (~280-350 mm) in Lake Staring in Fall 2012. These fish represent approximately 8,000 age-2 carp that moved down from PCCA in the spring of 2012.

v) Removal of adult carp in Lake Staring using winter seining

Adult carp are known to form winter aggregations that can be located using radiotagged adults and subsequently removed with seine nets (Figure 9). This strategy was fundamental in our successful carp management in the Riley Chain of lakes (our previous report) and we applied the same approach in Lake Staring. This started in 2011 when we implanted 10 carp with radiotransmitters to follow their winter aggregations. An aggregation was located and over 10,000 carp were captured in the seine (Table 5). Similar efforts were repeated in every subsequent winter, often several times. Overall, more than 20,000 carp were removed using winter seining, reducing the population in Staring from 26,000 to less than 3,000 carp (Table 5). Overall, winter seining in Lake Staring is feasible, effective and has been proven to be the most effective and practical strategy to remove excessive numbers of carp.

Although seining worked well, several limitations were noted. First, it became apparent carp can learn how to avoid the net if targeted repeatedly, especially within one season. This was evidenced by higher escape rates of radiotagged carp from the net over time (Table 5); the difference between radiotags that were in the area and those that were captured in the net. This could be minimized in the future by carefully planning each seine and conducting it in an organized and swift manner to minimize the opportunities for the carp to escape the net after which event they become much more difficult to catch. A better understanding of bottom topography to place the net, combined with GPS to lay out the corners of the net in relation to the location of carp school, pre-lining the area with twine should be used to improve seining efficiency in all future seining. Further, while the ‘old’ carp may learn how to avoid the seine, younger fish that recruit from PCCA should be much more susceptible after a year and we recommend that winter seining remain an important tool in managing carp in Lake Staring (see management section).

Table 5. Results of winter seining in Lake Staring. After the initial population estimates in 2011, all captured carp were removed from the lake. *released back into the lake to complete mark-recapture estimates; ** does not include ~3,000 YOY carp that moved from PCCA in 2015.

Date	Seine #	Captured	Population Remaining in lake	Radiotags in area	Radiotags in net
2011					
January 26	1	251*		3	2
January 27	2	11,684*	26,200	6	5
2012					
February 8	3	890	25,308	7	1
2013					
January 16	4	1688		6	1
January 17	5	0		8	0
February 4	6	92		0	0
February 6	7	2486		5	0
February 7	8	4017		6	2
February 25	9	1931		3	2
February 26	10	3507		5	2
February 27	11	147	11,440	unknown	1
2014					
January 13	12	4149		7	2
January 24	13	859		2	0
February 12	14	396		7	0
February 19	15	5		8	4
March 19	16	699	5,719	10	1
2015					
January 30	17	803		unknown	unknown
January 31	18	28		3	0
February 16	19	33		6	0
February 20	20	27		4	0
March 10	21	5	2,977	11	0

Figure 9. Winter seining for common carp in Lake Staring – final phase, fish are “landed” in the bag of the net. Photo Jake Osborne.

5. STEP 3 (2015) Carp control after the installation of the carp barrier in Purgatory Creek

In late 2014 Riley Purgatory Bluff Creek Watershed District decided to install a permanent carp barrier in Purgatory Creek within the existing concrete channel under the walking trail bridge just downstream of PCCA (Figure 10). A one year no-cost extension of our contract also went into place allowing us to monitor the barrier, and to remove adult carp. This section reports on: i) The barrier; ii) Tracking YOY and juveniles leaving PCCA; iii) Removing adult carp from Lake Staring system.

i) The Barrier. A barrier was installed by the RPBCWD engineer in March 2015 following designs provided by Barr Engineering after discussions in which we suggested that the new barrier be capable of being shut quickly so it could serve to both trap/ remove adult carp migrating to PCCA and (if necessary) to trap them in the PCCA where they might die because of a winter drawdown and freeze-out. We worked with the City of Eden Prairie in 2015 to maintain the new barrier. This partnership was necessary because the screening is very heavy and large machinery is/ was required to lift it to remove debris. The design of the barrier also required small change in plan. Instead of blocking the carp on the way to PCCA (this proved difficult to predict and it was not easy to trap below the new barrier), we decided that the barrier should be opened in early spring to allow the carp to swim into PCCA and then immediately closed behind them to trap them. The barrier might then be kept closed through the end of the year and a freeze-out used in the winter. We also hoped that carp might try to return to Lake Staring after spawning and aggregate on the upstream side of the barrier where they might then be removed. In May 2015, as expected, adult carp swam from Staring to PCCA and the barrier was closed behind them by the City. Some carp attempted to return to Staring approximately a week later when we used backpack electrofishing in combination with large mesh gill nets (to target carp; special DNR permit) and a block net to remove them. In between trapping, the City would often lift the screen to clean it. This scenario occurred four times and we removed a total of 633 adult carp (Figure 11) by mid-July when after one cleaning, the City inadvertently left the screening partially up and several thousand carp escaped. It is extremely difficult to lift the barrier, gauge when how it is positioned in the groves and then be sure it is completely down. This problem could be rectified in 2016 with modifications to the barrier (see management section).

Figure 10. Carp barrier below PCCA. The barrier (metal grid) is placed behind a debris rack located upstream.

Figure 11. Removal of carp near the barrier using backpack electrofishing and gillnets.

ii) YOY carp. The adult carp that entered the PCCA in 2015 and could not be effectively removed, spawned and produced many young which are described in Section iv. These YOY carp (as described above in Section 4) numbered in the hundreds of thousands but had experienced 90% mortality by the end of the summer. Unfortunately, our PIT tagging also showed that they were leaving the PCCA by mid-summer at rate of few percent per month. They were able to pass through the barrier. Ideally, the barrier design should be modified in the future either prevent adults from entering PCCA and/or preventing YOY from leaving (a bubble curtain might help to accomplish this).

iii) Adult carp removal continued in Lake Staring and PCCA throughout 2015. This complimented removal at the barrier site (described above). We employed: 1) under-ice seining (described in Section 4); 2) gill nets; 3) open water seining; and 4) baited box nets. A total of 1704 adult carp were removed from the system, including 633 (reported above) from the barrier site and another 155 from gill nets set around observed aggregations in PCCA (Table 6). In Lake Staring, 834 of these fish were removed by winter seining, 12 removed using gill nets set around observed aggregations, 66 removed in an open water seine in front of Purgatory Creek where carp were aggregating to migrate, and 14 were removed using baited box nets that were deployed twice in the littoral area of Lake Staring.

Table 6. Result of removal techniques used in Winter-Fall of 2015. All 1704 fish captured were removed from the system.

Lake	Winter Seine	Barrier Site*	Gill Net	Open Water Seine	Baited Box Net
Staring	834	-	12	66	14
PCCA	-	633	155	-	-

Part 6. The state of carp population in Lake Staring in late 2015

As a result of winter seining and systematic removal of carp (see above; Table 5), their abundance was reduced from 26,000 to ~ 3,000 between 2011-2015, while the biomass was reduced from ~ 500 kg/ha to ~ 100 kg/ha (Figure 12). This reduction met our management goal (100 kg/ha) and resulted in improvements in water quality (see Section 7). However, while the numbers of adult carp were low by late 2015, and likely causing little ecological harm, approximately 3000 YOY carp had entered Lake Staring from Lower PCCA (see Section 5), and started to grow rapidly, Their presence was apparent in an electrofishing survey conducted in late October 2015 (Figure 13).

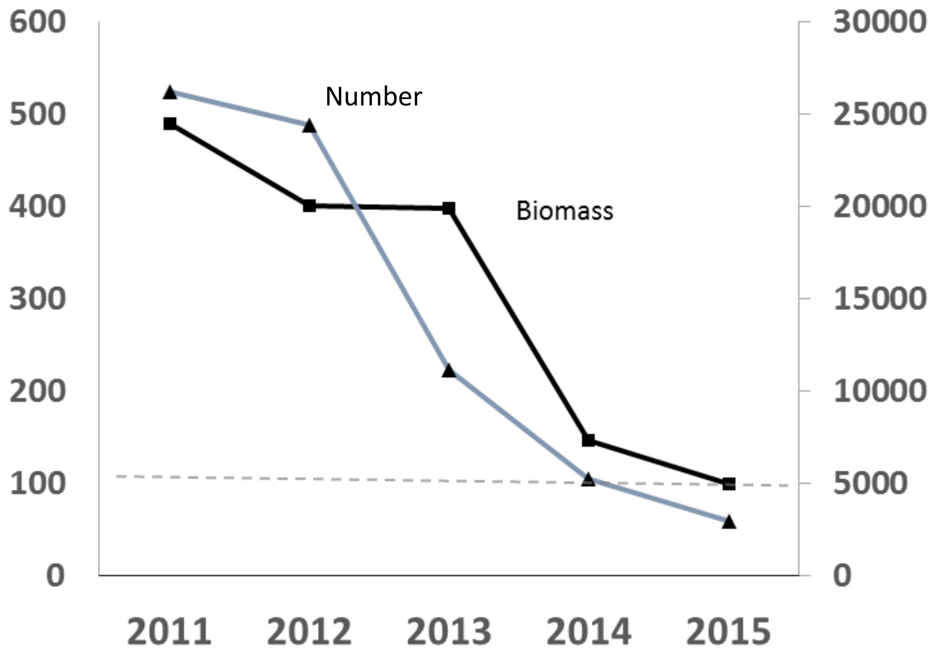

Figure 12. Biomass and abundance of common carp in Lake Staring. Dashed line shows a management goal of 100 kg/ha.

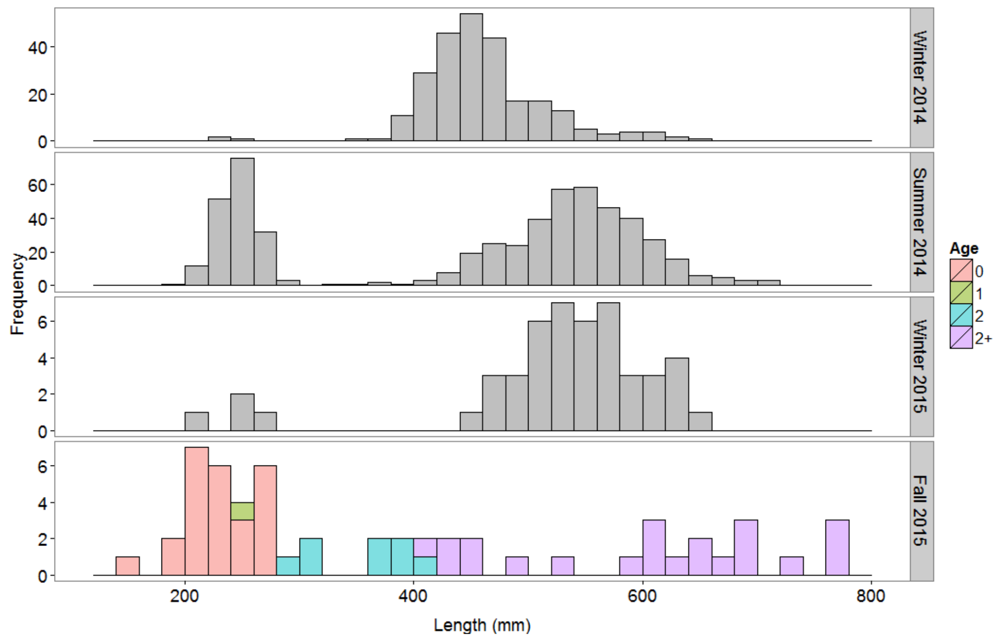

Figure 13. Size structure of Carp in Lake Staring. The last panel demonstrates the age structure of these carp using otoliths. Note age to the right.

Part 7. Improvements in habitat and water quality in Lake Staring as a result of carp management

We monitored water quality (Secchi, TP, ChlA, TSS), zooplankton (species composition), vegetation density and species richness, and native species richness and catch rate in Lake Staring between 2011-2015. Water quality and zooplankton samples were collected every two weeks during May-September of each year from two locations in the lake following identical methods as described in our previous report for the Riley Chain (integrated epilimnetic samples). Water quality samples (TP, TSS, ChlA) were then analyzed by Instrumental Research LLC, following standard methods (as described in the Riley Report). Zooplankton samples were counted under the microscope using a 1 ml well with 50 x 20 mm grid. Vegetation density and species richness were documented annually by conducting vegetation surveys along 10 transects delineated around the perimeter of the lake. The transects were perpendicular to shore and vegetation was visually assessed (% cover over a $4m^2$, species present) along each transect at water depths of 0.5, 1, 1.5 and 2 m. Native fish were surveyed by conducting annual trapnet surveys in late summer or fall of each year. Five trapnets were used and all fish were counted and a sample of up to 30 was measured for length for each species.

Water clarity increased from 2011 to 2015 exceeding 2 m and reaching the bottom of the lake on many occasions in the spring of 2013 and then also in the spring of 2014 and 2015. The improvement in water clarity in the summer was more modest but water clarity in September 2015 was approximately twice as high as during the high carp biomass years of 2011-2012 (Figure 14). ChlA concentrations declined during 2013-2015 with summertime concentrations dropping from approximately 50-60 ug/L before carp removal to 30-40 ug/L after carp removal (Figure 15). TSS followed a similar pattern (Figure 16). TP concentration declined in 2015 and for the first time, summertime TP did not exceed 100 ug/L (Figure 17). Notably, TP in September 2015 was only 40 ug/L, whereas it had exceeded 100 ug/L in all previous years. We suspect that the drop in TP in 2015 was largely attributable to the increased density of aquatic vegetation (and associated with it periphyton) which finally rebounded in 2015 after carp biomass was reduced to ~ 100 kg/ha but the presence of fewer carp may had a role too.

Aquatic vegetation increased in density and species richness following carp removal, with the biggest increases occurring in 2015 when carp biomass was reduced to approximately 100 kg/ha, which we proposed before to be a desired threshold in carp management. Vegetation cover increased from only 6% in 2011 to 40% in 2015. The number of species also increased from 5 to 10 (Table 7).

Catch rates of native fish remained relatively stable throughout 2011-2015 (Table 8), however the status of native fishery might not be accurately portrayed by our fine-mesh trapnet surveys that target predominantly YOY carp (Table 8). DNR conducted comprehensive gillnet surveys in Lake Staring in 2015 and will also conduct native fish growth rate analyses and those surveys will be more informative about the status of native fishery once they become available. Anecdotally, the number of northern pike and black crappies has increased in lake Staring over the last 5 years.

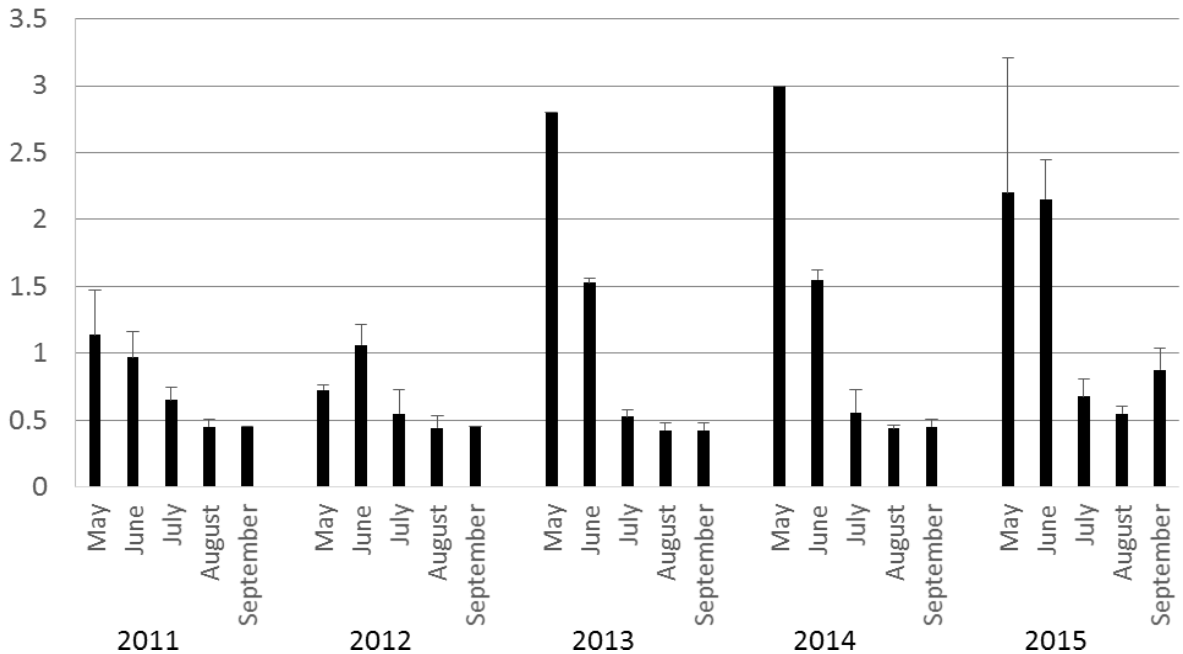

Figure 14. Mean +- SD Secchi depth in Lake Staring

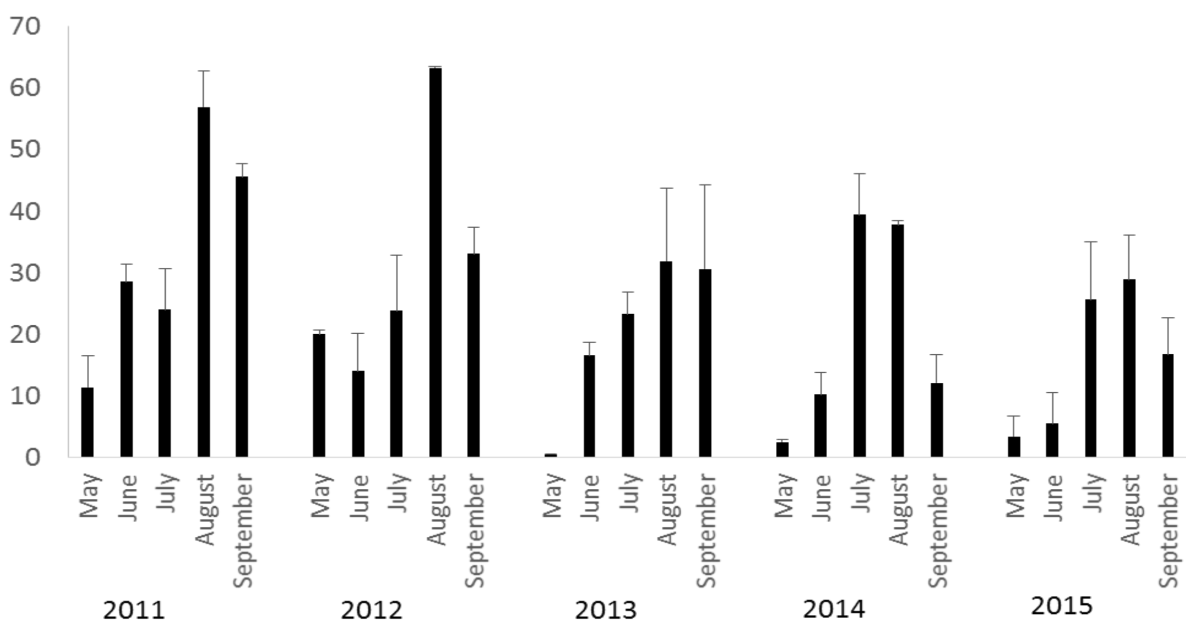

Figure 15. Mean +- SD chlorophyll A in Lake Staring.

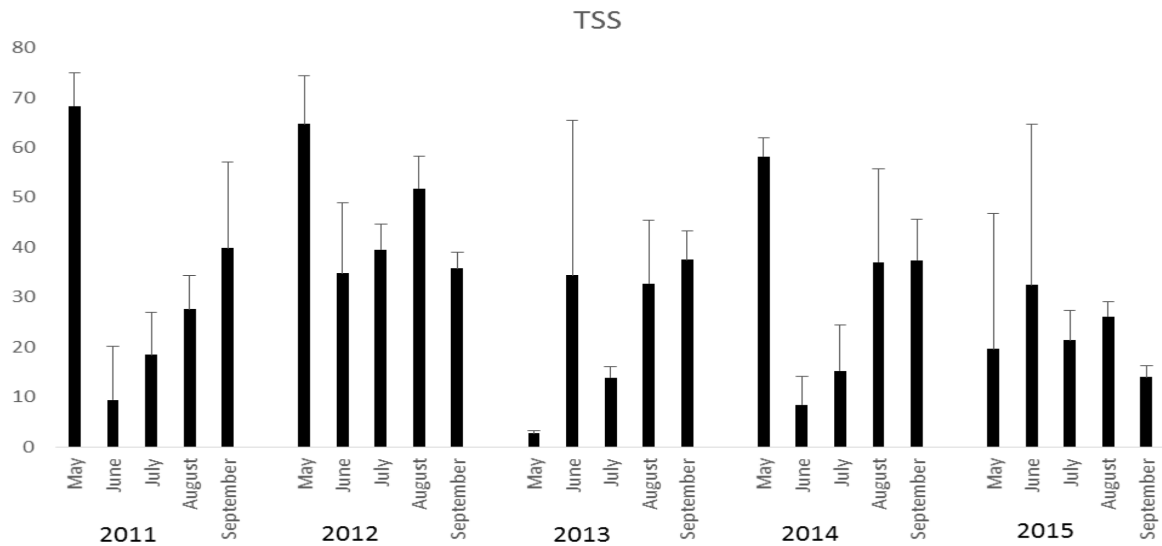

Figure 16. Mean +- SD total suspended solids concentrations in Lake Staring.

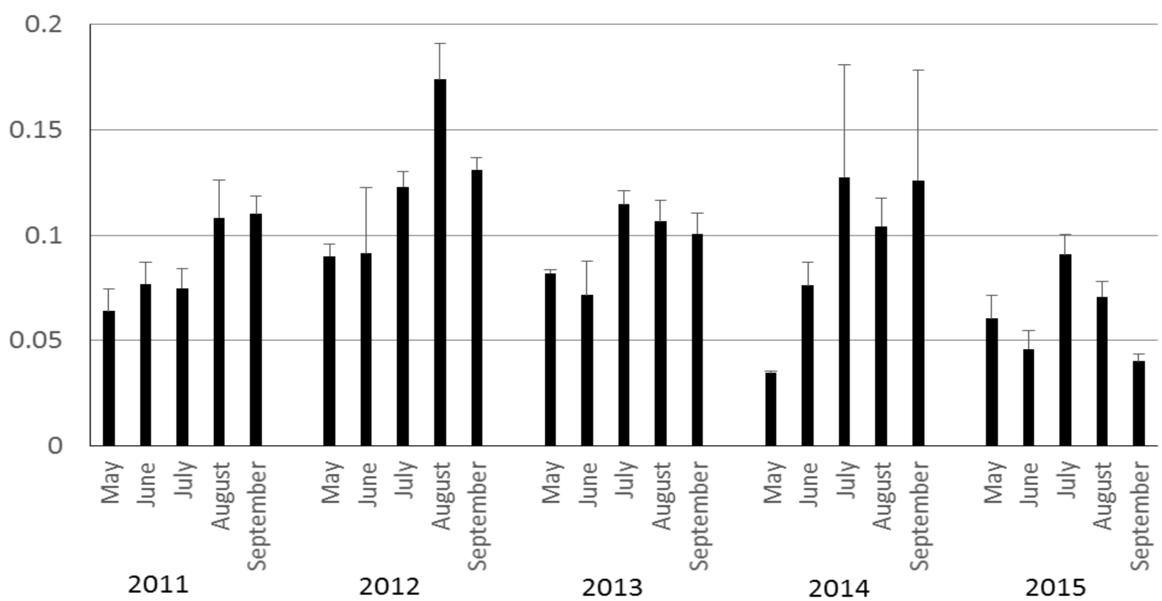

Figure 17. Mean +- SD total phosphorus concentrations in Lake Staring.

Table 7. Vegetation density and species richness in Lake Staring. % cover represents % bottom cover in lake areas shallower than 2 m. Species present in 2015 survey: Curly Leaf Pondweed (P*otamogeton crispus)*, White Water Lily (*Nymphaea ororata*), Spatterdock (*Nuphar variegatum*), Flat Stem Pondweed (*Potamogeton zosteriformes*), Coontail (*Ceratophyllum demersum*), Sago (*Potamogeton pectinatus*), Canada Waterweed (*Elodea canadensis*), Narrow-leaf Pondweed (*Potamogeton foliosus*), Muskgrass (*Chara*), exotic plant species: Bushy Pondweed (*Najas spp.*). Note: Eurasian water milfoil was also detected in Staring in 2015 but was not found in our standard survey.

Year	% bottom cover	# of Species	Carp Biomass (kg/ha)
2015	40 %	10.0	95
2014	9 %	8.0	
2013	N/A	N/A	
2012	0.7 %	3.0	
2011	6 %	5.0	498

Table 8. Native fish (ad carp) mean trapnet catch rates in Lake Staring during 2011-2015. LMB = largemouth bass, BLG = bluegill, CAP = carp, CRP = black crappie, BBHD = black bullhead, YEP = yellow perch, NOP = northern pike, GSF = green sunfish, PKS = pumpkinseed sunfish, WSF = white sucker, DRM = freshwater drum, BUF = bigmouth buffalo.

Year	LMB	BLG	CAP	CRP	BBHD	YEP	NOP	GSF	PKS	WSF	DRM	BUF
2010	0.4	36.4	1.2	2	2.6	9.2	0	0.8	4	0.8	0.8	0
2011	0.4	35.4	0.2	0.2	0	2.4	0	0.2	0	0.2	0	0
2012	0.4	18.6	0	12.6	0.4	1.8	0.2	0.4	0.4	1.2	0.6	0
2013	0.4	3.4	0	20.8	38.6	0.6	0.6	0	0.2	0	0	0
2014	0.8	7.6	0	0.6	0.2	0.2	0	0	0.4	0	0	0
2015	1.2	4	0.6	2.4	5.2	0.4	0	0.2	0.8	0	0	0

8. Management recommendations

We provide separate recommendations for Lotus Lake and the Staring-PCCA System as these two systems differ in their carp abundance and management needs.

Lotus Lake

This population of carp is presently at a level that is not damaging the native ecosystem, and is under control; no management is needed. Nevertheless, monitoring is advised on intermittent basis. We recommend conducting boat electrofishing surveys (3 transects 20 min each repeated on 3 separate days in mid to late summer) every other year to assess the status of carp population paying particular attention to the presence of small carp (< 30 cm). If an increase in catch rates is observed, we recommend using winter seining to remove excessive number of carp.

Staring-PCCA System

The population of adult carp in Staring-PCCA is currently at a level slightly below our management threshold of 100 kg/ha and does not appear to be causing a problem to the native ecosystem at present. However, active management is required to maintain the population at this level because Lake Staring contains over 3000 YOY carp which in 2-3 years will be large enough to likely cause problems. Further, because a small number of YOY still reside in the PCCA and the problems of recruitment suppression using the barrier are not yet solved, there is threat of the population increasing rapidly. The production of young carp in PCCA and their subsequent movement to Staring is the primary problem that needs to be addressed. While it might be difficult to eliminate the production of young carp in PCCA (which would require a complete elimination of adult carp in that system), the survival of young and their spread to Staring probably could be controlled using winter drawdowns and changes to barrier design. Control of recruitment and additional adult removal, even if modest, should be able to control carp as shown by a statistical model we have created (see Appendix). Maintenance of the barrier is presently managed by the City of Eden Prairie and the RPBCWD is advised to speak with them about possible maintenance issues.

Management recommendations for Staring-PCCA

1. Control the production, survival and dispersal of young carp from PCCA to Staring
    a. Fill-in the deep winter refuge located by the inlet to the Lower PCCA so that winter freeze-outs can occur more effectively.

b. Consider modifying the barrier so that it can reduce the outmigration of young carp from PCCA to Lake Staring. Even a 50% reduction in outmigration would make a difference (Model; Figure 18). This might be accomplished with bubble or sound curtains or perhaps better screening.

c. Prevent adult carp from entering PCCA to spawn. This might be achieved by keeping the present physical barrier at PCCA outlet in place continuously and achieving a 100% winter freeze in PCCA to kill all adults. However, this strategy may not succeed since even a low number of adult carp in PCCA (which can enter both from downstream and upstream – upper PCCA) is likely to produce high numbers if age-0.

d. Prevent young carp from recruiting in Lake Staring. Although we have not witnessed production of young carp in Lake Staring, this lake has winter-killed in the past and could produce carp. Installation of an aeration system in Lake Staring is recommended.

2. Monitor and remove adult carp from Lake Staring

   a. Use telemetry-guided winter seining when biomass exceeds 100 kg/ha based on electrofishing surveys). Seining might be needed every other winter (see Appendix) and removal of at least 50% adults might be a reasonable goal. Note that (Section 4) that carp learn to avoid nets quickly so the first attempt each season is especially important. Because of the large number of YOY in Lake Staring this year and fact that they are just now becoming catchable by net, a seine in 2016 is advised.

   b. Use the existing barrier to remove adults, if possible. At the very least, the barrier design should be modified so that it functions in a predictable manner (i.e. so that it can be closed properly and maintained in closed position – twice in 2015 it failed to close properly and many carp escaped (see Section 5 above). Another option would be to invest a trapping system. Carp removal at the barrier is not essential for carp management because adults can also be removed using winter seining, but would accelerate it. If this could be pursued, a few options are plausible:

      b.i. If the managers decide to use the existing physical barrier, one could let the carp swim into PCCA, close the barrier behind them and control them using winter freeze-out. This is especially reasonable if chances of winterkill can be improved and the chances of movement of any young that might be spawned reduced (see above).

b.ii. Alternatively, if the present barrier is not going to be modified, conduct removal in the stream during spawning migration – this is possible but labor intensive due to the need for daily telemetry surveys in the spring, precise timing of the barrier operation, and maintenance of the barrier.

b.iii. Retrofit the existing barrier – The barrier neither keeps YOY carp in, nor reliably blocks adults at present. These critical deficiencies could be addressed through modifications that could add bubble curtains and new gate structures, or perhaps an entirely new structure should be considered if the budget permits. This new structure might incorporate both a bubble curtain to stop downstream moving young, rotating self-cleaning screens and perhaps a trap to automatically trap and remove adults while perhaps leaving native fish. A custom (new) design would be required but structures with automated carp traps are found in Oregon while air curtains have been designed by the University and Fish Guidance Systems Ltd. (UK).

3. Conduct annual boat electrofishing surveys to monitor the abundance of carp in Lake Staring. At least three 20 min electrofishing transects should be conducted and mean catch rate per hour calculated and used to estimate carp biomass (for details see our Riley report).

4. Conduct annual trapnet surveys in both Lake Staring and Lower PCCA to monitor carp recruitment: 5 small-mesh trapnets set overnight in August –September each year. The presence of carp < 200 mm characterizes a recruitment event. If it occurs, special attention should be placed on conducting effective freeze-outs in PCCA during the following winter.

5. Use our statistical model and data to adjust strategies as needed; use adaptive management (see below).

9. APPENDIX: Carp population dynamics model for Staring-PCCA and its use in management recommendations

We developed an individual-based population dynamics model for carp in the Staring-PCCA system, which can be used for management purposes. The model simulates a sequence of events that is repeated each year and which includes springtime migrations of adults to PCCA, return from PCCA to Staring, recruitment of young in PCCA, survival of young in PCCA and their dispersal to Staring, overwintering either in PCCA or Staring, winter aggregations in Staring and their potential removal with nets. In addition, the model also simulates natural mortality, growth and aging. All model parameters (for example the movement from Staring to PCCA in the spring) are defined by certain probability values which we derived from empirical observations. These values are allowed to range within a certain limit to incorporate variability from one year to the next.

The model can be used to test several management scenarios such as winter seining, a barrier to stop and remove certain numbers of adults or an acoustic deterrent system to reduce the outmigration of juvenile carp from PCCA to Staring. These options can be used singly or in combination and different levels of winter seining or barrier efficiency can be applied (see management recommendations below). A computer file containing a version of the model that RPBCWD managers might use is also included on a flash drive.

Modeled management scenarios:

We model four management scenarios for Staring-PCCA that might be both effective and practical. Each model run starts with the existing population in Lake Staring: 2,500 adults, 1000 age-2, and 3,000 YOY (age-0) carp. Each scenario was run for 30 years and repeated 10 times. The goal is to maintain the biomass in Staring at <= 100 kg/ha. Other important assumptions include: adult carp perform annual spawn migrations to PCCA and then return, recruitment occurs in PCCA every other year (on average), winter draw-downs are performed in PCCA every other year and, whenever applied, result in eliminating 95% - 100% carp that overwinter in PCCA. Modeled management scenarios are:

1. Do nothing – this represents what would happen if the existing population in Lake Staring was not managed at all.

2. Deploy a Juvenile deterrent systems (bubble barrier) – the model assumes that the only management approach used is a new acoustic bubble barrier that reduces the migration of age-0 carp from PCCA to Staring by 50% of their normal values.

3. Winter-seining – the model assumes that the only management option is winter seining in Lake Staring that is conducted <u>every other</u> year and each time <u>50% carp > 360 mm (mesh size) are removed</u>.

4. Seine and juvenile bubble barrier – combination of scenario 3 and 4.

Results

1. Do nothing – carp exceed 100 kg/ha within 5 years and returned to pre-management biomass level ~ 500 kg/ha (Figure 18)

2. Juvenile bubble barrier – overall biomass increases to levels above 100kg/ha within 5 years and was slightly lower than the "do nothing" scenario (Figure 18).

3. Winter seining of adults – if 50% of all adult carp could be removed every other year (something we were not always able to achieve), then population would remain at ~ 200 kg/ha (Figure 18).

4. Seining + Juvenile bubble barrier – If 50% of all adults can be removed and the YOY blocked by 50% then the population should oscillate ~ 100 kg/ha, occasionally exceeding it. This could be improved further by, for example, intensifying winter seining during particular years (Figure 18).

It should be noted, however, that it is extremely difficult to simulate exact biomass levels 30 years into the future given carps enormous reproductive potential, varying levels of natural mortality, winter freeze-outs, and the complex nature of processes that drive their abundance in Staring-PCCA. However, our results suggest that a synergistic strategy that combines a modest level of adult removal with a moderately effective juvenile dispersal barrier is most likely to be effective in this system (Figure 18).

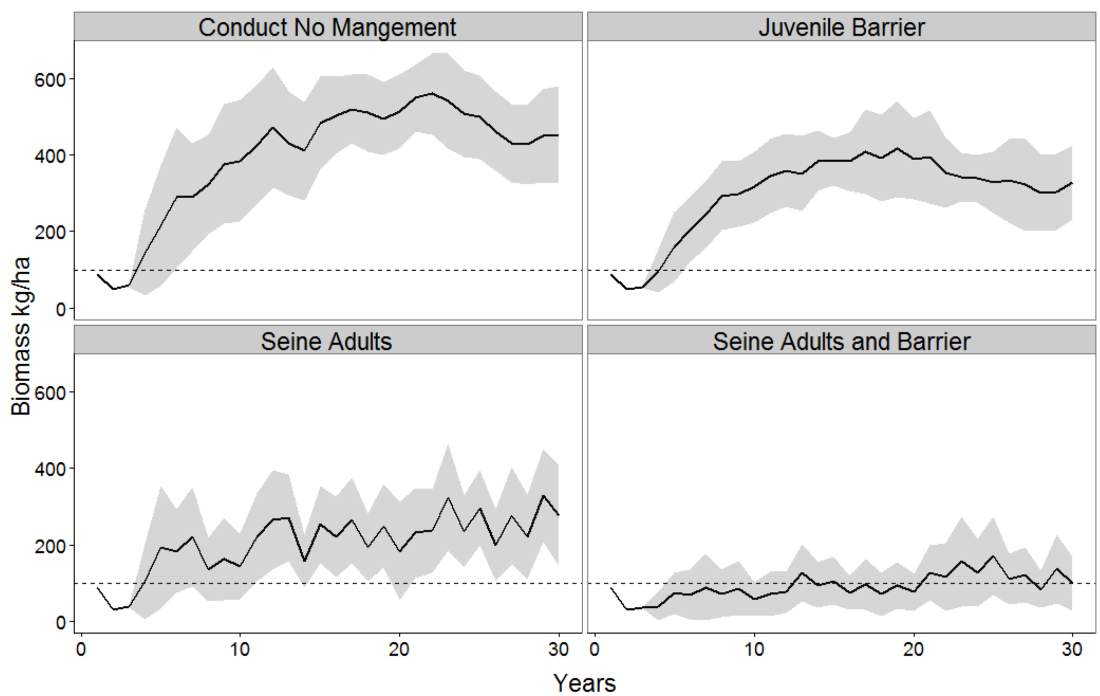

Figure 18. Results of four potential management scenarios in Staring-PCCA. Shown is carp biomass in Lake Staring over 30 years. Each scenario was repeated 10 times and the mean

response is plotted. Shaded areas show +- 1 SE. Dashed line represents the management goal of 100 kg/ha.

10. References

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