Report on Carp Management Activities in the Clearwater Chain of Lakes in 2023
January 31, 2024
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Summary

During the summer and fall of 2023, Carp Solutions conducted assessments of common carp (*Cyprinus carpio*) populations in lakes Betsy, Caroline, Louisa, Marie, Union, Clear and Scott in the Clearwater Chain of Lakes. Using the mark-recapture method, the population in Lake Betsy was estimated at 2,099 carp (90% CI: 753-3,444) with an estimated biomass density of 182.7 kg/ha (90% CI: 66-300 kg/ha). Boat electrofishing was used to estimate carp abundance and biomass in the remaining lakes and these estimates were: Lake Caroline, population of 2,418 carp (90% CI: 1,125-3,711), biomass density 212 kg/ha (90% CI: 89-335 kg/ha); Lake Louisa, population of 2,457 carp (90% CI: 795-4,119), biomass density 183 kg/ha (90% CI: 63-302 kg/ha); Lake Marie, population of 2,921 carp (90% CI: 1,812-4,031), biomass density 286 kg/ha (90% CI: 167-405 kg/ha); Scott Lake, population of 880 carp (90% CI: 263-1,497), biomass density: 133 kg/ha (90% CI: 28-238 kg/ha); Lake Union, population of 860 carp (90% CI: 114-1,606), biomass density 125 kg/ha (90% CI: 48-203 kg/ha). No carp were captured in Clear Lake. Other than in Clear Lake, carp populations exceeded the 100 kg/ha management threshold in all surveyed lakes. Carp aging analyses were conducted in all lakes, except Clear. The average carp ages were: Lake Betsy 30.7 years (max: 44, min: 8); Lake Caroline 23.8 years (max: 58, min: 4); Lake Louisa 29.1 years (max: 57, min: 4); Lake Marie 28.7 years (max: 45, min: 7); Scott Lake 28.5 years (max: 40, min: 8); Lake Union 29.6 years (max: 44, min: 2). Observed age structures showed that carp populations were dominated by relatively old individuals (10-40 years old), which suggests limited recruitment rates in recent years. A pilot test of carp removal with baited box nets was conducted in Lake Betsy. Using two nets pulled three times, resulting in the removal of approximately 25% of the carp population.

Methods and Results

Boat Electrofishing surveys

Three electrofishing surveys were conducted on Betsy, Clear, Caroline, Louisa, Marie, Scott, and Union Lakes during the summer and fall of 2023. Electrofishing surveys consisted of four to six transects, with each transect including approximately 20 minutes of effective electrofishing time. The purpose of these surveys was to generate population and biomass estimates of common carp in each lake using the mean catch per hour (CPUE) (Bajer and Sorensen 2012). When current was passed through the water, stunned fish floated to the surface where carp were collected using dip nets. Other species were noted, but not collected during this process. Collected carp were measured for length, had their left pelvic fin clipped, and were inserted with a PIT tag before they were released back into the water.

Carp were captured in electrofishing surveys in all lakes, except in Clear Lake where no carp were captured or seen. In Lake Betsy, a total of 16 carp were collected, with an average length of 29.6 inches (Figure 1). The CPUE suggested that population estimate for this lake was 1,130 carp (90% CI: 558-1,702) with an estimated biomass density of 96 kg/ha (90% CI: 53-139 kg/ha) (Table 1); we also determined carp abundance and biomass in Lake Betsy using mark-recapture analyses, which are generally considered more accurate and those values are reported below. Lake Caroline electrofishing surveys yielded 35 carp with an average length of 28.5 inches (Figure 2). The CPUE derived population estimate was 2,418 carp (90% CI: 1,125-3,711) and the biomass density of 212 kg/ha (90% CI: 89-335 kg/ha) (Table 2). As for Lake Louisa, a collection of 25 carp with an average length of 30.4 inches (Figure 3) lead to a population estimate of 2,457 carp (90% CI: 795-4,119) and an estimated biomass density of 183 kg/ha (90% CI: 63-302 kg/ha) (Table 3). In Lake Marie, 42 carp were captured with an average length of 30.5 inches (Figure 4). The population estimate was calculated to be 2,921 carp (90% CI: 1,812-4,031) and a biomass density estimate of 286 kg/ha (90% CI: 167-405 kg/ha) (Table 4). A total of 20 carp with an average length of 29.1 inches (Figure 5) were collected during the surveys in Scott Lake. The population estimate for Scott Lake was 880 carp (90% CI: 263-1,497) with a biomass density estimation of 133 kg/ha (90% CI: 28-238 kg/ha) (Table 5). Lastly, Lake Union yielded 16 carp with an average length of 30.0 inches (Figure 6) during surveys. Lake Union had a population estimate of 860 carp (90% CI: 114-1,606) and biomass density of 125 kg/ha (90% CI: 48-203 kg/ha) (Table 6).

During all of these surveys, fish species other than carp were also noted, but not counted, netted, or measured. On Lake Betsy, black crappie, bluegill, black and yellow bullheads, channel catfish, largemouth bass, northern pike, walleye, white sucker, and yellow perch were observed. During the Lake Caroline surveys, black and white crappies, bluegill, bowfin, channel catfish, golden shiner, largemouth bass, northern

pike, pumpkinseed, spotted shiner, white sucker, and yellow perch. Species observed in the Clear Lake surveys include black crappie, bluegill, golden shiner, northern pike, pumpkinseed, largemouth bass, walleye, white sucker, and yellow perch. In Lake Louisa, bluegill, bowfin, brown bullhead, channel catfish, black crappie, largemouth bass, northern pike, walleye, white sucker, yellow bullhead, and yellow perch were observed. For Lake Marie, black bullhead, black crappie, bluegill, bowfin, largemouth bass, northern pike, pumpkinseed, spottail shiner, walleye, white crappie, white sucker, and yellow perch were seen. On Scott Lake, black crappie, bluegill, bowfin, channel catfish, largemouth bass, northern pike, walleye, white sucker, and yellow perch were observed. Lastly, black crappie, bluegill, bowfin, green sunfish, golden shiner, largemouth bass, pumpkinseed, walleye, white crappie, white sucker, yellow bullhead, and yellow perch were all observed while surveying Union Lake.

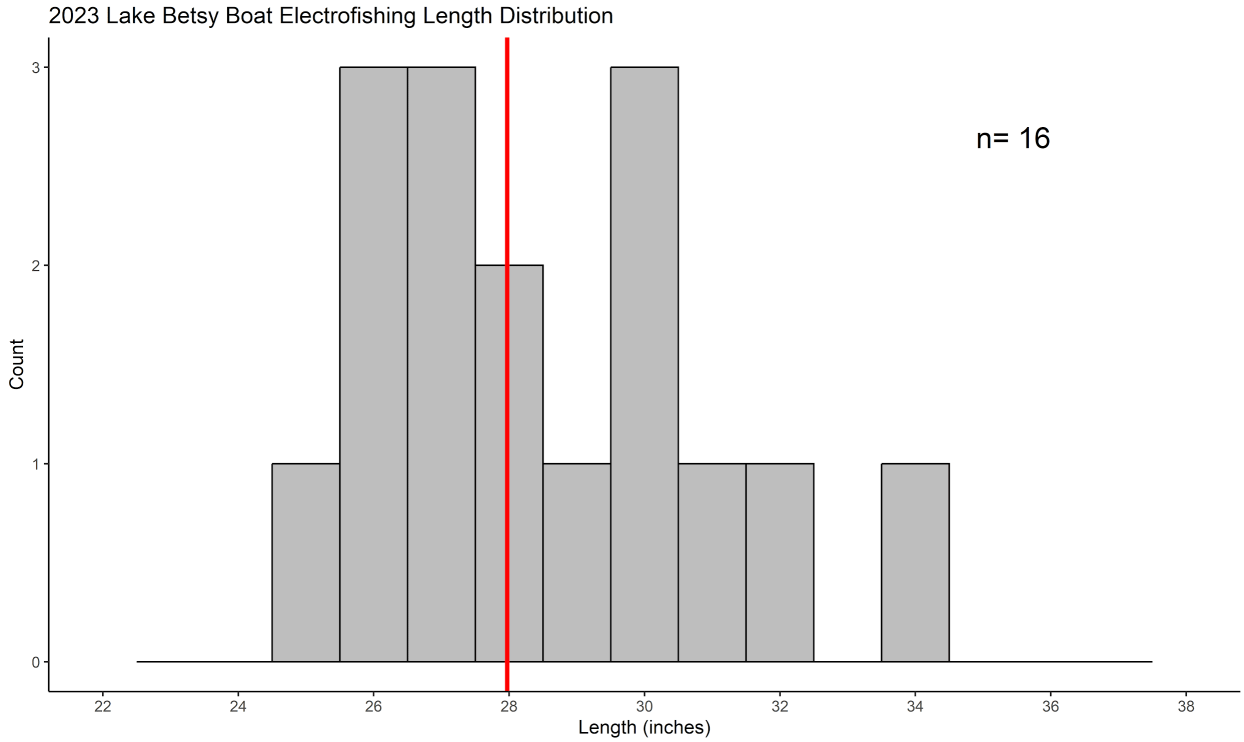


Figure 1: Length distribution of carp (n=16) captured in Lake Betsy boat electrofishing surveys. The red line represents the median length.

Table 1: Lake Betsy electrofishing survey data for carp by date. CPUE stands for Catch Per Unit Effort, in units of carp per hour of shock time.

Date	Transects	Carp caught	Time shocking (min)	CPUE	Average Length (inches)	Population Estimate	Biomass Density Estimate (kg/ha)
7/19/2023	6	10	112	5.35	28.3	1,756	132.1
7/24/2023	4	2	86	1.40	27.6	600	42.0
7/27/2023	5	4	101	2.38	29.4	885	74.3
Average	5.00	5	100	3.21	29.6	1,130	96
Total	15	16	299				
SE				1.19	0.52	348	26
Lower 90%				1	29	558	53
Upper 90%				5	30	1,702	139

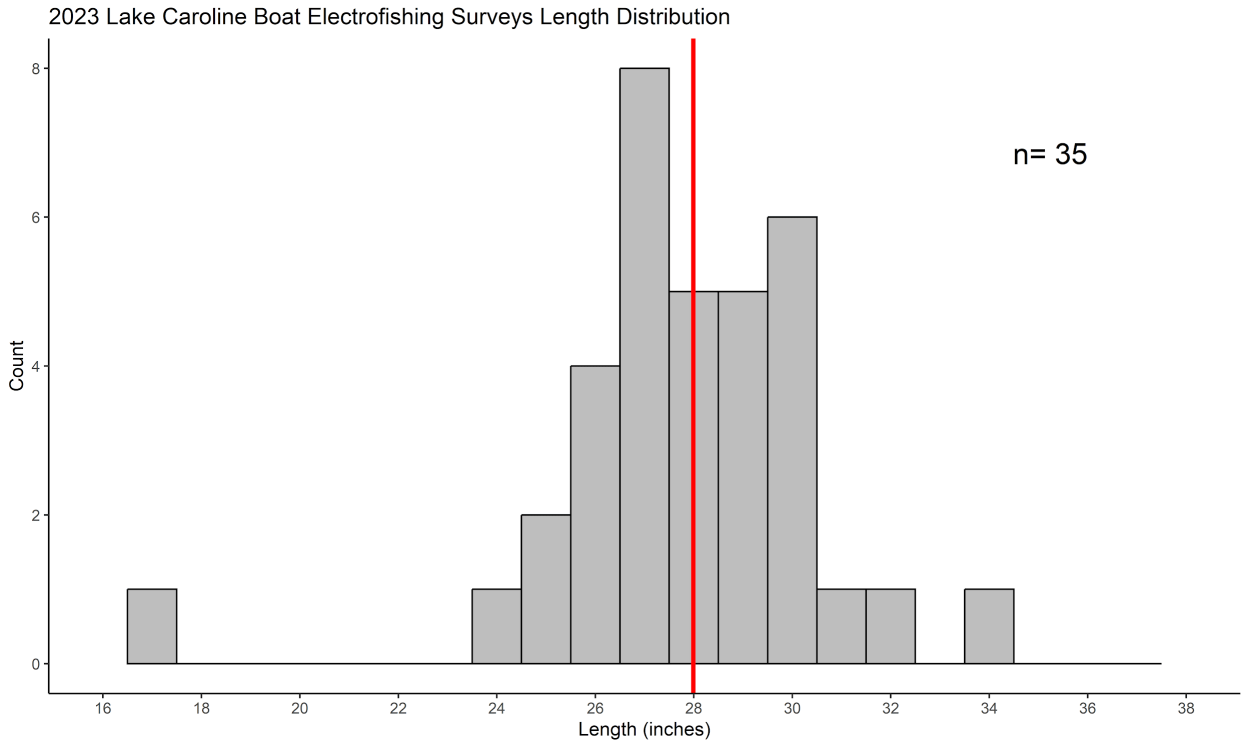


Figure 2: Length distribution of carp (n=35) captured in Lake Caroline boat electrofishing surveys. The red line represents the median length.

Table 2: Lake Caroline electrofishing survey data for carp by date. CPUE stands for Catch Per Unit Effort, in units of carp per hour of shock time.

Date	Transects	Carp caught	Time shocking (min)	CPUE	Average Length (inches)	Population Estimate	Biomass Density Estimate (kg/ha)
7/13/2023	4	19	80	14.27	28.1	3,842	322.4
8/4/2023	4	5	80	3.73	24.5	1,128	64.6
8/8/2023	4	11	80	8.25	29.0	2,292	211.0
Average	4.00	12	80	8.74	28.5	2,418	212
Total	12	35	240				
SE				3.05	1.40	786	75
Lower 90%				4	26	1,125	89
Upper 90%				14	31	3,711	335

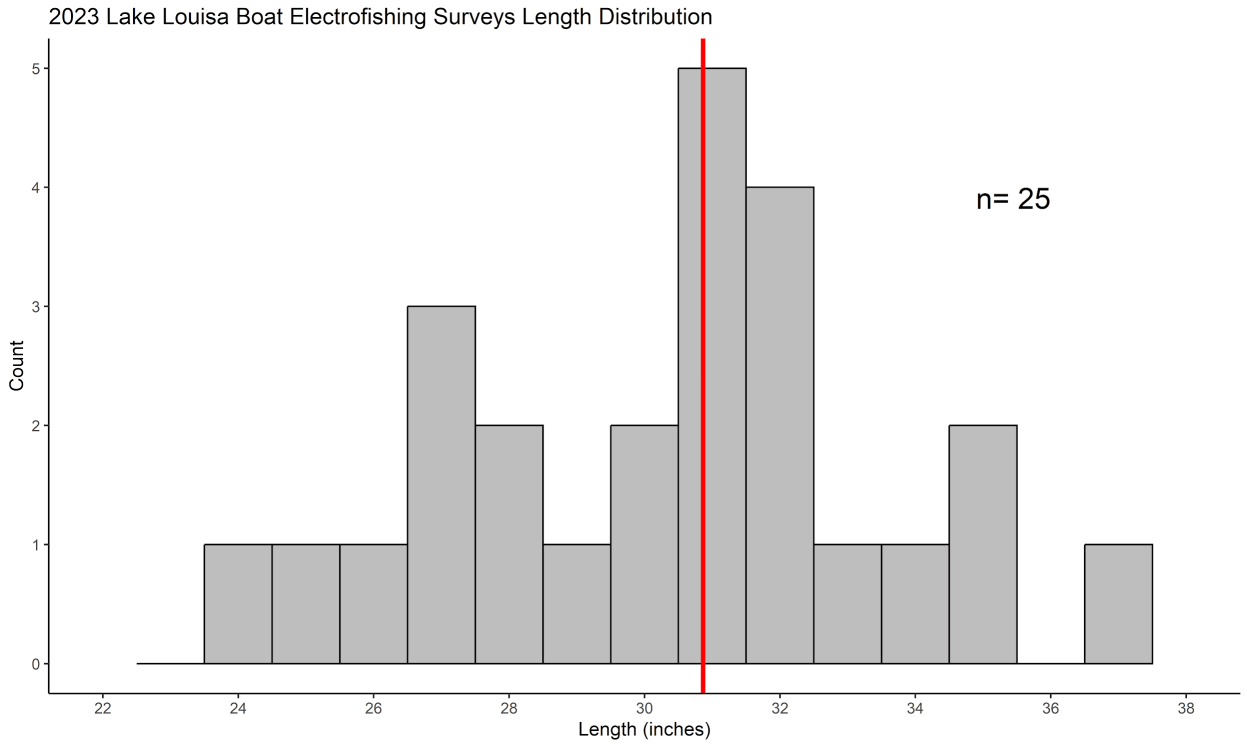


Figure 3: Length distribution of carp (n=25) captured in Lake Louisa boat electrofishing surveys. The red line represents the median length.

Table 3: Lake Louisa electrofishing survey data for carp by date. CPUE stands for Catch Per Unit Effort, in units of carp per hour of shock time.

Date	Transects	Carp caught	Time shocking (min)	CPUE	Average Length (inches)	Population Estimate	Biomass Density Estimate (kg/ha)
7/12/2023	4	15	81	11.17	30.1	4,266	308.7
7/25/2023	5	8	83	5.81	30.8	2,332	179.9
8/7/2023	4	2	80	1.49	30.4	772	57.4
Average	4.33	8	81	6.16	30.4	2,457	183
Total	13	25	243				
SE				2.80	0.20	1,010	73
Lower 90%				2	30	795	63
Upper 90%				11	31	4,119	302

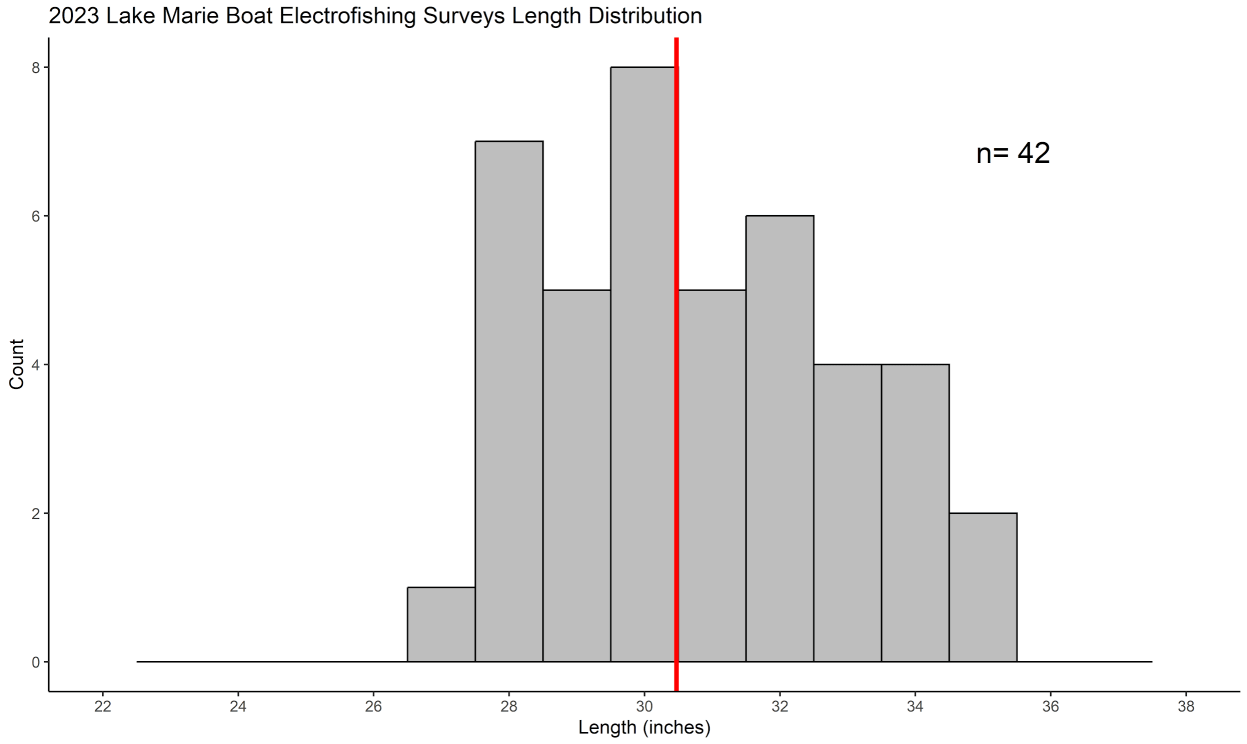


Figure 4: Length distribution of carp (n=42) captured in Lake Marie boat electrofishing surveys. The red line represents the median length.

Table 4: Lake Marie electrofishing survey data for carp by date. CPUE stands for Catch Per Unit Effort, in units of carp per hour of shock time.

Date	Transects	Carp caught	Time shocking (min)	CPUE	Average Length (inches)	Population Estimate	Biomass Density Estimate (kg/ha)
7/12/2023	1	2	12	9.93	28.9	2,939	247.0
7/25/2023	4	12	81	8.84	30.1	2,636	247.3
8/3/2023	4	6	81	4.47	31.2	1,421	147.3
8/14/2023	4	22	81	16.23	31.2	4,691	487.0
Average	4.00	13	81	9.87	30.5	2,921	286
Total	13	42	255				
SE				2.43	0.55	675	72
Lower 90%				6	30	1,812	167
Upper 90%				14	31	4,031	405

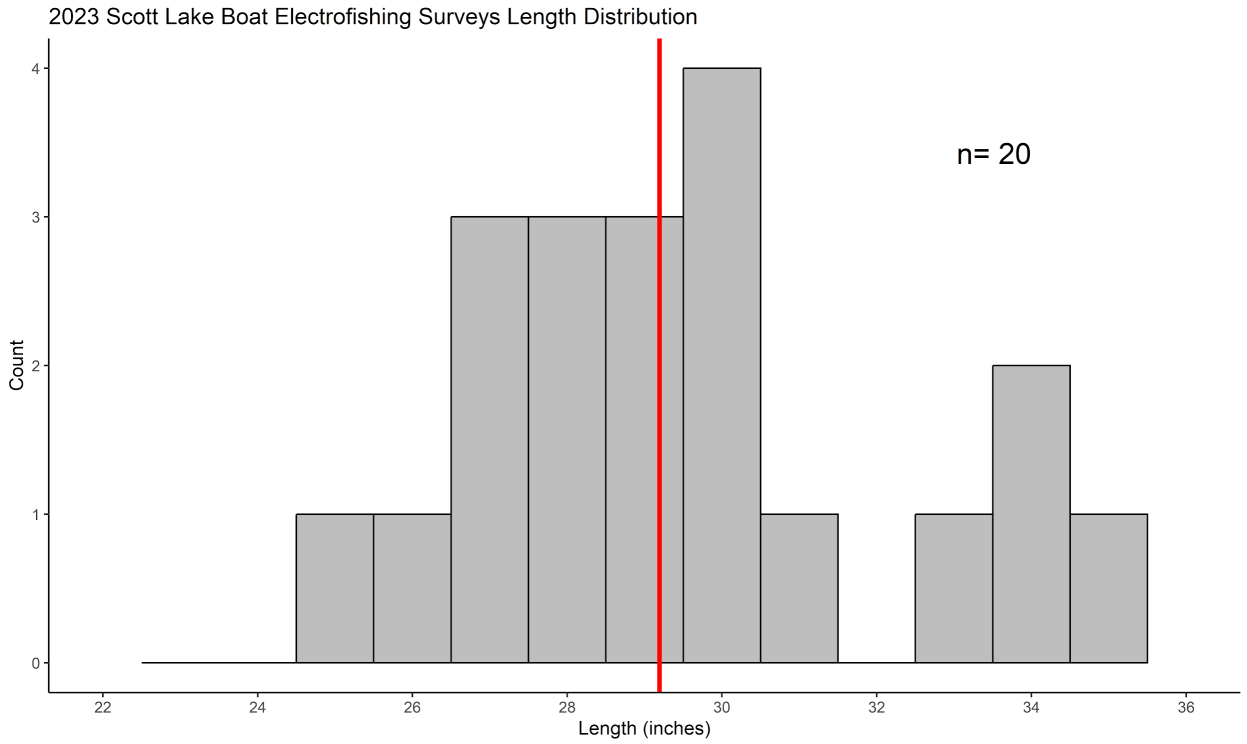


Figure 5: Length distribution of carp (n=20) captured in Scott Lake boat electrofishing surveys. The red line represents the median length.

Table 5: Scott Lake electrofishing survey data for carp by date. CPUE stands for Catch Per Unit Effort, in units of carp per hour of shock time.

Date	Transects	Carp caught	Time shocking (min)	CPUE	Average Length (inches)	Population Estimate	Biomass Density Estimate (kg/ha)
7/28/2023	4	3	83	2.18	28.3	445	62.5
8/9/2023	4	4	80	3.00	29.1	575	87.0
8/14/2023	4	13	81	9.69	29.9	1,629	265.4
Average	4.00	7	81	4.94	29.1	880	133
Total	12	20	243				
SE				2.38	0.45	375	64
Lower 90%				1	28	263	28
Upper 90%				9	30	1,497	238

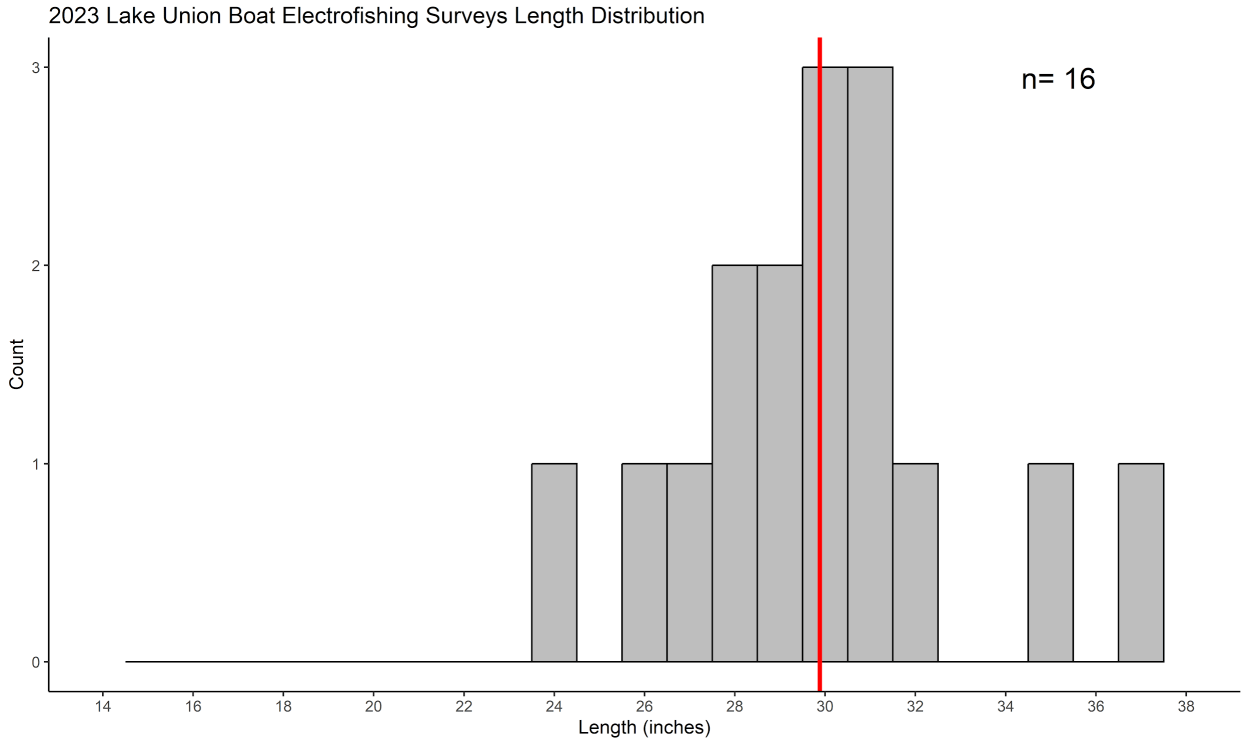


Figure 6: Length distribution of carp (n=16) captured in Union Lake boat electrofishing surveys. The red line represents the median length.

Table 6: Union Lake electrofishing survey data for carp by date. CPUE stands for Catch Per Unit Effort, in units of carp per hour of shock time.

Date	Transects	Carp caught	Time shocking (min)	CPUE	Average Length (inches)	Population Estimate	Biomass Density Estimate (kg/ha)
7/7/2023	2	5	27	11.02	28.0	2,066	250.2
7/18/2023	4	5	80	3.75	29.4	779	107.8
7/31/2023	6	6	121	2.98	31.9	642	111.1
Average	4.00	5	76	4.21	30.0	860	125
Total	12	16	228				
SE				2.56	1.13	454	47
Lower 90%				0	28	114	48
Upper 90%				8	32	1,606	203

Pilot Box Netting

Two box nets, one PIT antenna, and an experimental automated feeder were installed on Lake Betsy on August 3-4 (see map in Figure 7). The box nets were then baited with cracked corn to attract carp to the traps. The automatic feeder was placed at Net 1 over the PIT antenna to test the effectiveness of a low-maintenance feeding system in a box net. The nets were checked regularly to ensure the carp were consuming the bait. Three pulls from both box nets were conducted. The first took place on August 18, when it was planned to implant PIT tags and release a portion of the carp caught in order to provide better data on the PIT antennas for future pulls. A total of 108 carp were caught from the two nets, of which 68 were removed. The remaining 40 carp (20 from each net) were measured for length, marked with a PIT tag, had their right pelvic fins clipped, and were released. The second and third pulls occurred on August 31 (175 carp captured and removed) and September 20 (250 carp captured and removed). All carp in both of these pulls were euthanized and removed from the lake. The first 50 carp from each pull were measured for length, while all carp collected were scanned for PIT tags, to allow for the detection of recaptured carp. Otoliths were also removed from 60 of the carp from the second pull. A distribution of the lengths of all measured carp from box netting is on display in Figure 8. The data from box netting by date are shown in Table 7. Overall, 533 carp were captured in box nets, of which 493 were removed (Table 1).

Of the 40 carp released back into the lake, 12 (30%) were later removed during the two following box netting efforts. Of the 16 carp implanted with PIT tags using boat electrofishing, 3 (18.8%) were recaptured in box nets. Using the recaptures of carp tagged while boat electrofishing among carp captured in box netting a preliminary population estimate was derived using the Chapman estimator. This resulted in a mark-recapture carp population estimate of 2,099 individuals (90% CI: 753-3,444) with an estimated biomass density of 182.7 kg/ha (90% CI: 66-300 kg/ha). Following box netting these estimates dropped to a population of 1,606 and a biomass of 139.8 kg/ha. The pilot box netting removed approximately 25% of the carp population.

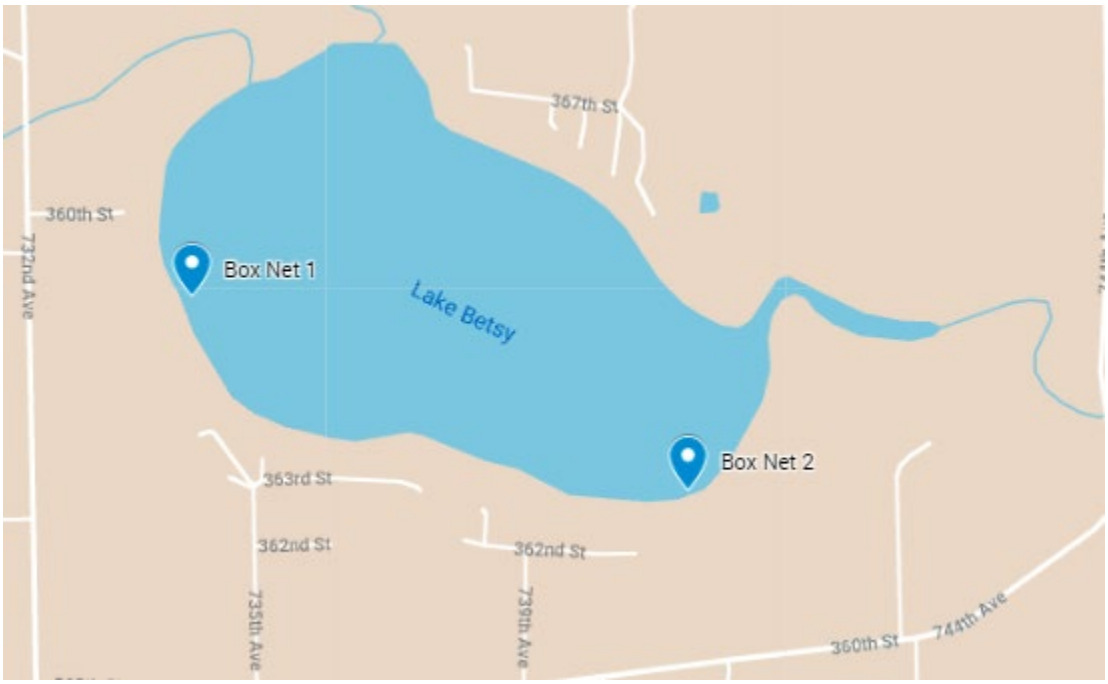


Figure 7: Box net locations on Lake Betsy.

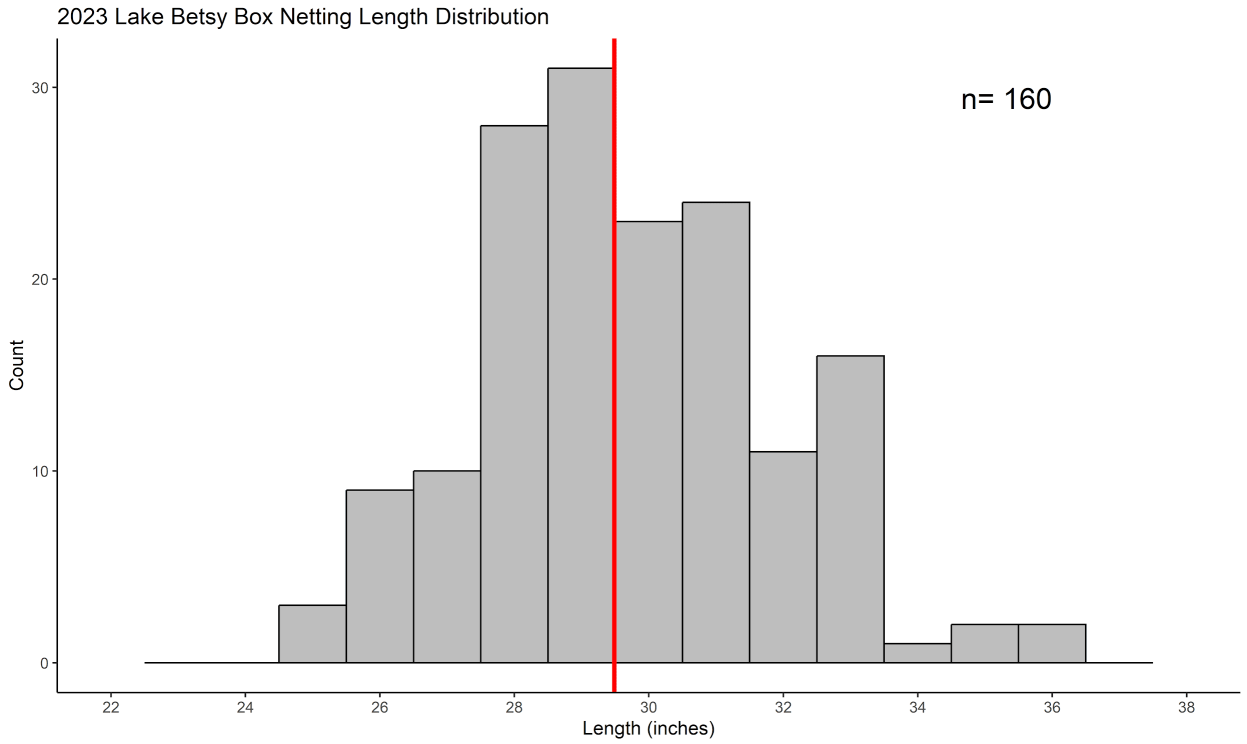


Figure 8: Length distribution of carp (n=160) captured in Lake Betsy box netting removals. The red line represents the median length.

Table 7: Data collected from box net removals on Lake Betsy. LPC stands for Left Pelvic Clip, while RPC stands for Right Pelvic Clip. 40 carp from the first pull were marked and released

Date	Catch	PIT Recaps	LPC Recaps	RPC Recaps	Total New Recaps	Average Length
8/18/2023	68+40	0	0	0	0	782
8/31/2023	175	6	0	7	7	750
9/20/2023	250	8	3	5	8	761
Average	164	5	1	4	5	764
Total	493+40	14	3	12	15	

Trap Netting

A trap netting survey was conducted on September 18 in Little Mud Lake. The purpose of this survey was to determine whether or not juvenile carp are present in the lake as a potential nursery site and to evaluate the native micropredators present in the waterbody. During this survey, five nets were placed around the perimeter of the water (see Figure 9) and left overnight. The following day, the contents of each net were collected, analyzed, and the fish species within them were identified before being released. Species observed during this survey and their abundance is shown in Table 8. The first 50 individuals of each species in each net were measured, counted, and

released. Any individuals of a species that surpassed 50 per net were counted and released without measuring. The lengths recorded are shown in Figure 10. No carp of any size were found during this survey (Table 8). The catch was dominated by black bullheads, black crappies and golden shiners.

Figure 9: Trap net locations for the trap net survey on Little Mud Lake.

Table 8: Little Mud Lake trap net survey data.

Trap Net #	Black bullhead	Black crappie	Golden shiner	Rainbow trout	Total
1	0	1	0	0	1
2	114	13	14	0	141
3	37	3	4	0	44
4	1	5	11	0	17
5	40	11	3	2	56
Total	192	33	32	2	259
CPUE (Fish per Net)	38.4	6.6	6.4	0.4	
Average Length (mm)	89	115	94	341	

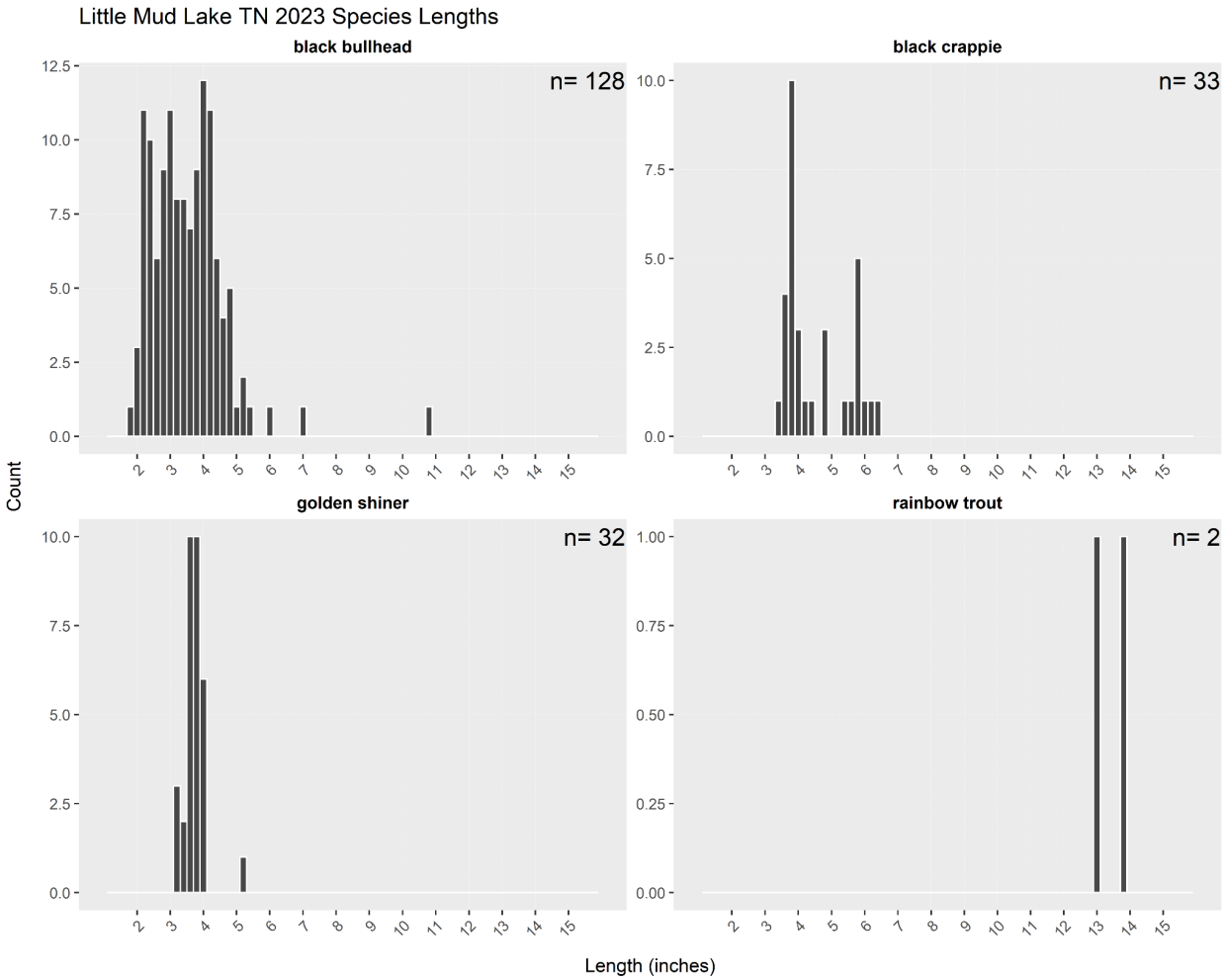


Figure 10: Distribution of lengths of sampled species from Little Mud Lake trap net survey.

Aging

In order to examine the longevity of carp and the history of carp recruitment in lakes where carp biomass estimates exceeded 100 kg/ha (all lakes except Clear), we conducted additional electrofishing surveys to collect and age up to 50 carp from each lake; in Betsy, carp for aging were collected from box nets. These surveys were conducted in late summer and fall of 2023. After being captured, the carp were euthanized, measured for length and weight before their otoliths (inner ear bones) were extracted. Later, these otoliths were embedded in epoxy and sectioned using an isomet. These sections were then read under a microscope to count the annuli of the otolith and determine their age.

The aging analysis revealed that the carp in this chain of lakes were generally quite old but varied greatly in age. Across the six lakes, ages ranged from 2-58 years, with an overall average of 28 years (Table 9; Figs 11-16). Across all the lakes, only one carp under 4 years old was found (in Union Lake). In all lakes, between 69% and 93% of all carp aged were older than 10 (Table 9). Lake Louisa had the youngest carp

population, but even in that lake only 31% of carp were younger than 10. The aging data suggest that while some carp recruitment occurred in the lakes in the last decade, these lakes had much higher carp recruitment rates 30-50 years ago.

Table 9: Age data collected from the 2023 Clearwater Chain surveys.

Lake	Betsy	Caroline	Louisa	Marie	Scott	Union
Number of carp	56	54	24	26	11	27
Minimum	8	4	4	7	8	2
Maximum	44	58	57	45	40	44
Average	30.7	23.8	29.1	28.1	28.5	29.6
Median	33.5	21.0	36.5	38.5	30.0	31.0
Juvenile count (age 0-3)	0	0	0	0	0	1
Number under age 10	5	17	6	5	1	2
Percentage Juvenile	0.00%	0.00%	0.00%	0.00%	0.00%	3.70%
Percentage under age 10	8.93%	31.48%	25.00%	19.23%	9.09%	7.41%

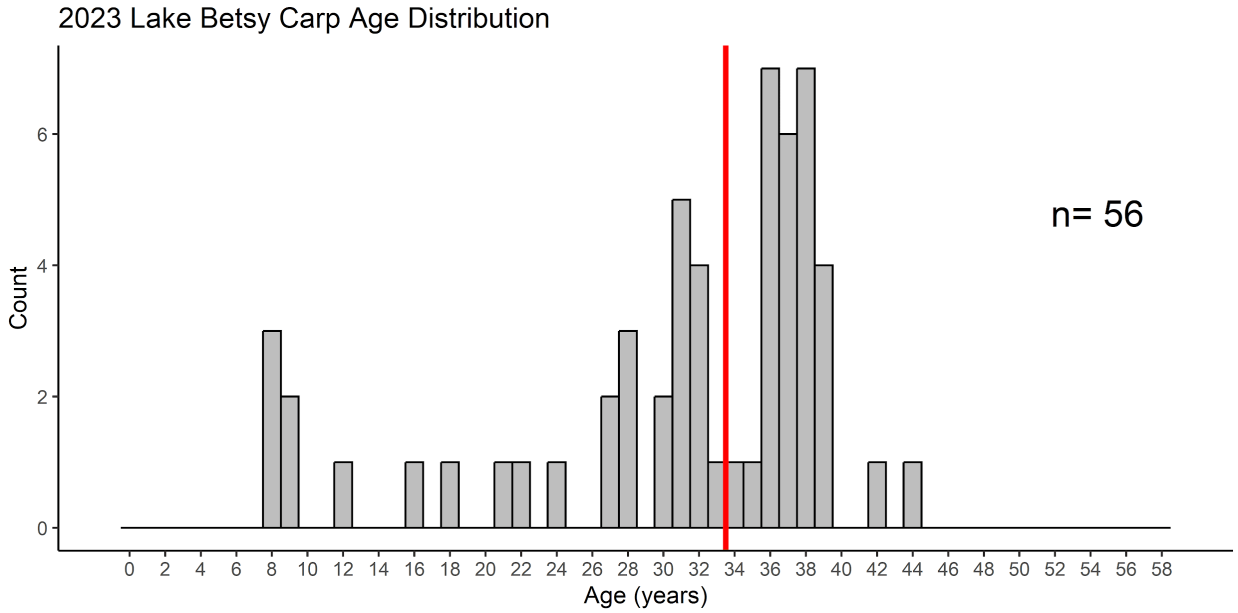


Figure 11: Histogram of the determined ages of carp collected in Lake Betsy.

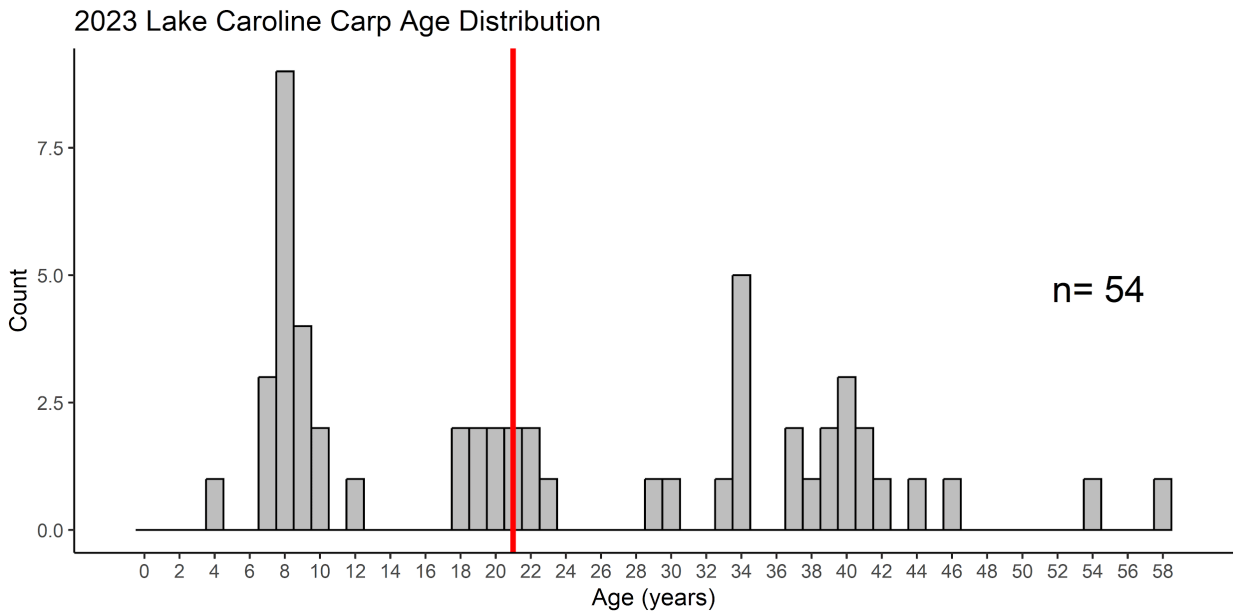


Figure 12: Histogram of the determined ages of carp collected in Lake Caroline.

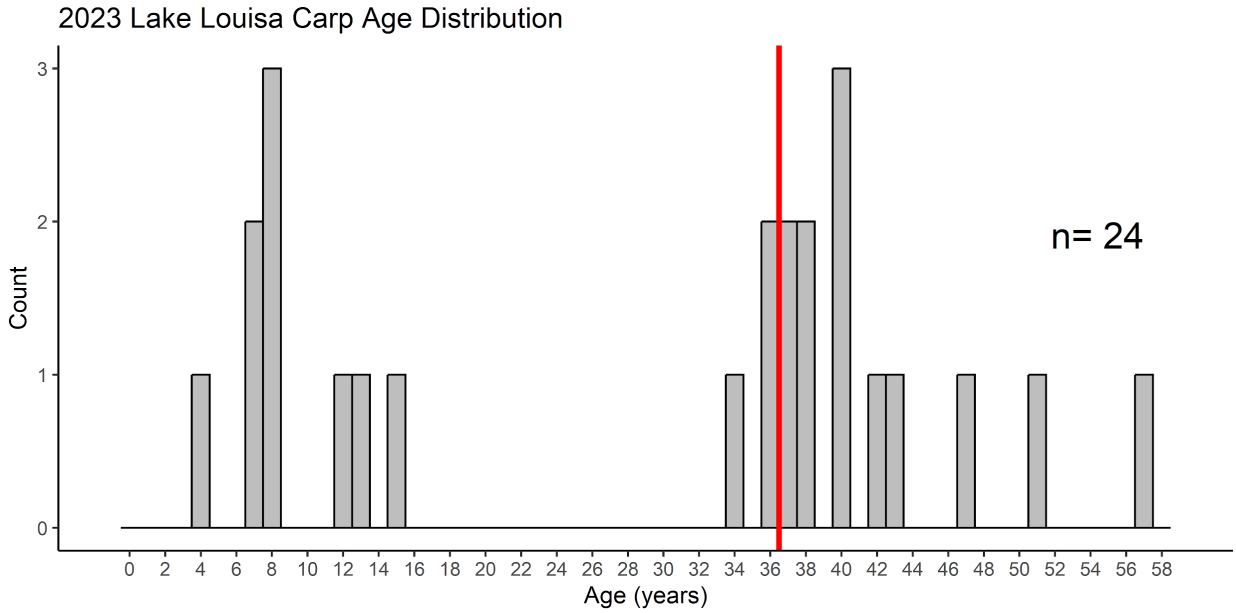


Figure 13: Histogram of the determined ages of carp collected in Lake Louisa.

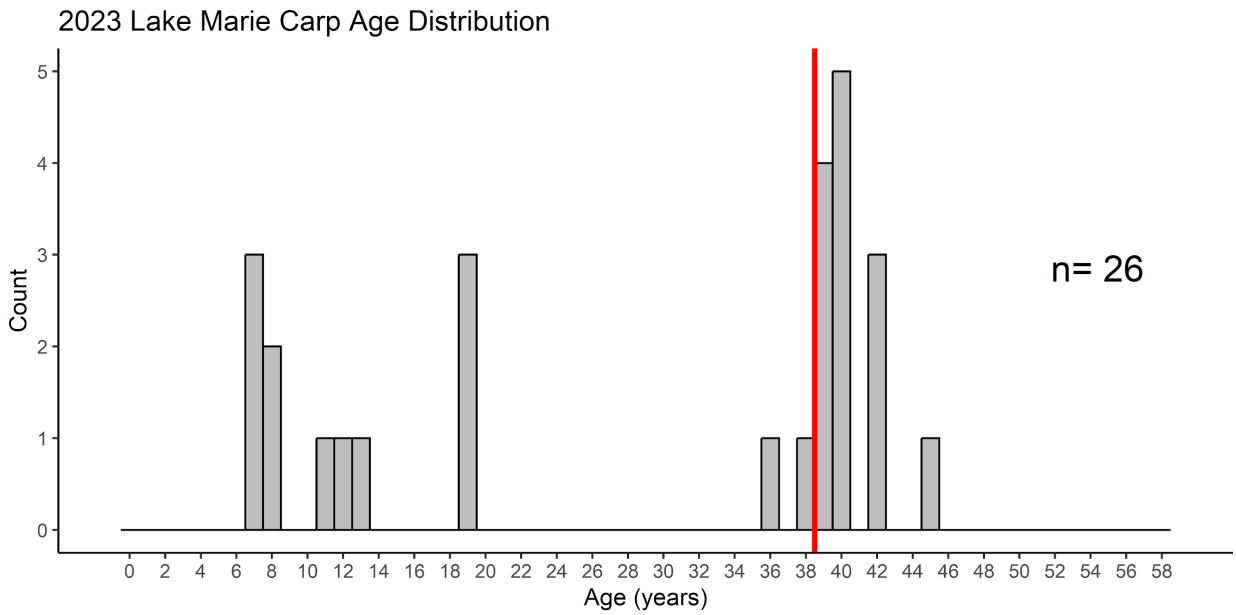


Figure 14: Histogram of the determined ages of carp collected in Lake Marie.

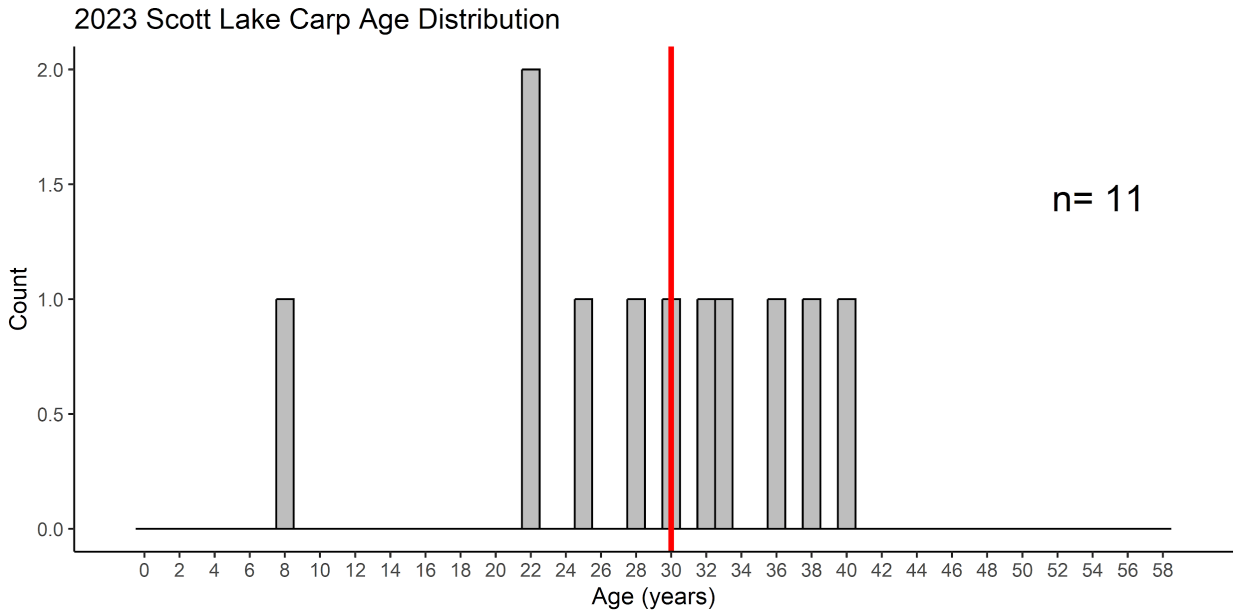


Figure 15: Histogram of the determined ages of carp collected in Scott Lake.

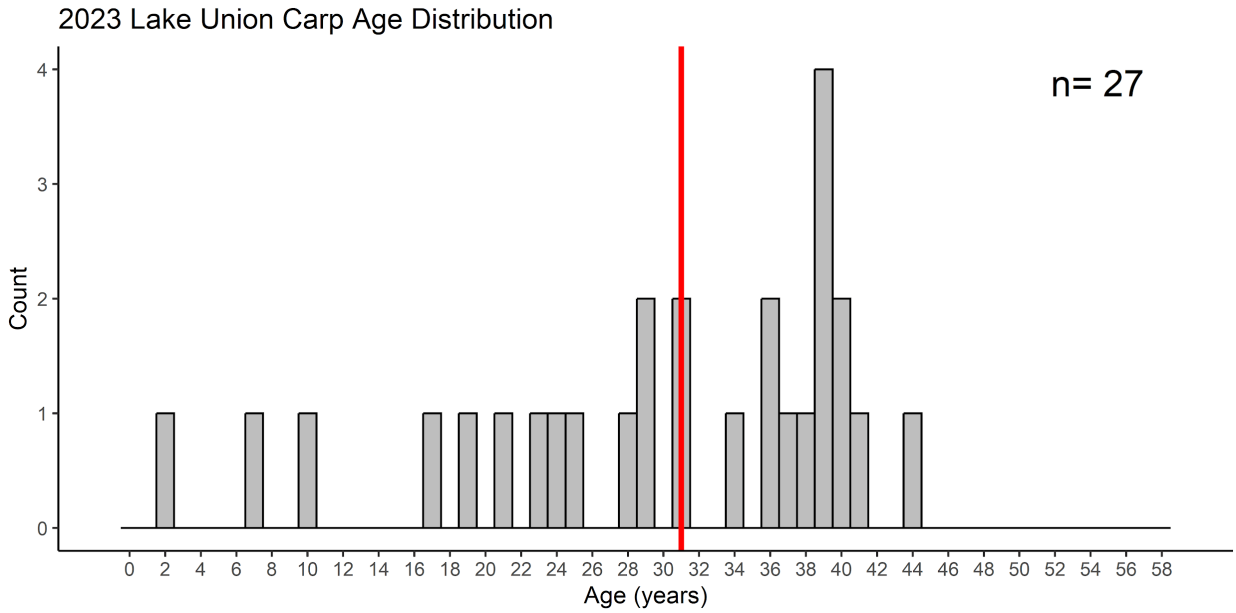


Figure 16: Histogram of the determined ages of carp collected in Union Lake.

Discussion

Carp Population Size and Structure

Carp biomass densities in excess of 200 kg/ha typically have strong, negative effects on lake habitat and water quality (Figure 17), while biomass densities below 100 kg/ha have only negligible effect on lake habitats. For management purposes, 100 kg/ha is often used as an acceptable level of carp biomass. Our results suggest that carp biomass in lakes Betsy, Louse, Marie, Caroline, Union and Scott (Table 10) exceed this biomass threshold. Thus, carp management is recommended in those lakes.

The lakes all had relatively similar sized carp, with median lengths between 28-31 inches (Fig 18). While Betsy, Louisa, and Marie Lakes had fairly tight length distributions between 24-36 inches, Marie, Scott, and Union Lakes had more dispersed length distributions with carp as small as 16 inches. Of particular note, Louisa and Marie Lakes showed significant crossover in carp populations. During boat electrofishing surveys there were several instances of recapture of carp from one of the lakes in the other. The size structure of these lakes were also not significantly different (Student's t-test, p-value = 0.77); Fig. 19. The age differences between the two lakes also showed no significant difference (t-test; p-value = 0.83). We suspect that carp populations in Lake Louisa and Marie travel frequently between the two lakes. This should be considered in future carp removal and management.

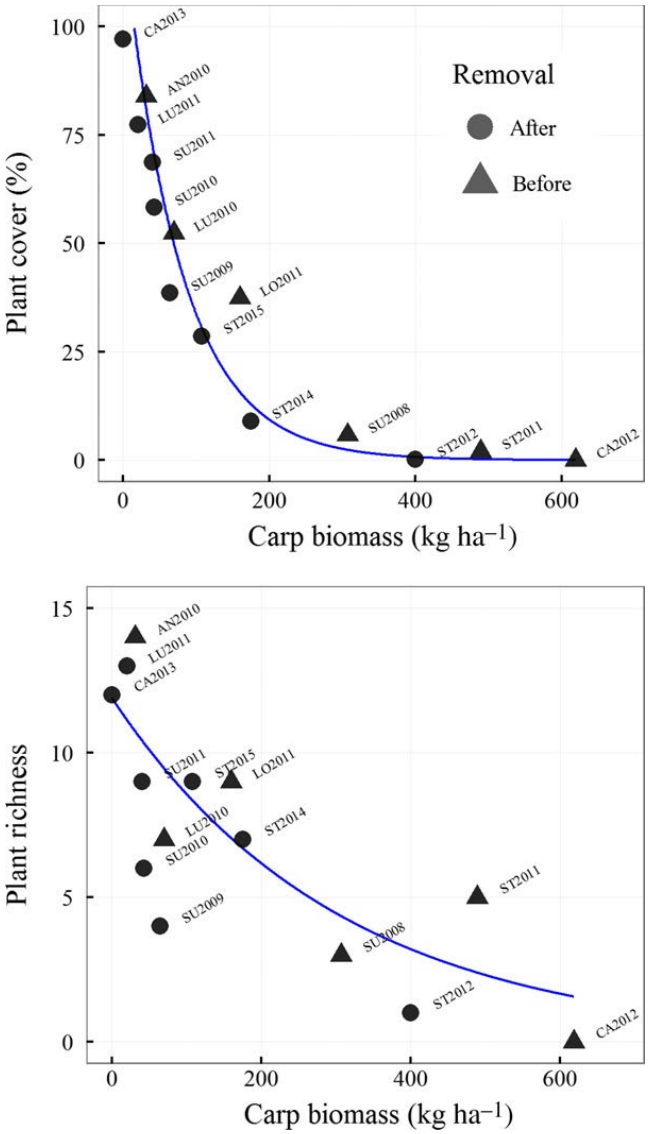
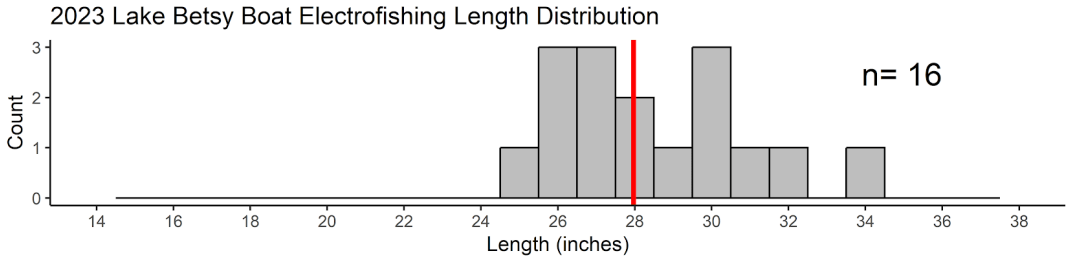
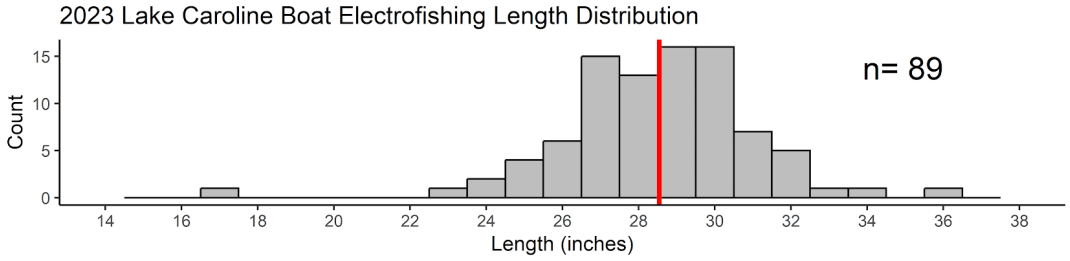


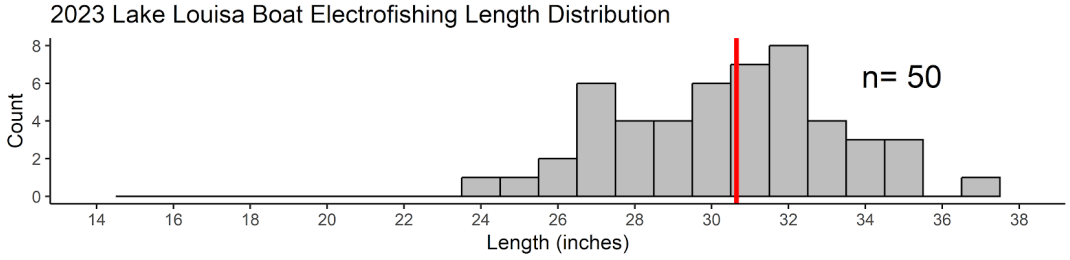
Figure 17: Relationship between common carp biomass and aquatic macrophyte cover in the littoral (top) and plant richness (bottom) in small Minnesota lakes. From Bajer et al. 2016.

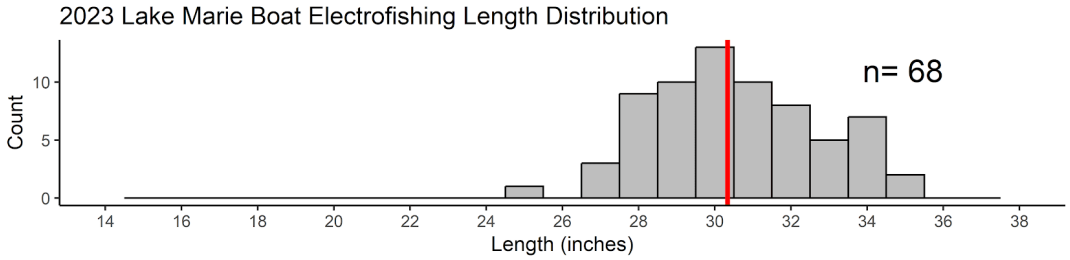
Table 10: Lake areas, carp biomass density estimates, and population estimates for Clearwater Lakes surveyed by 2023 electrofishing surveys.

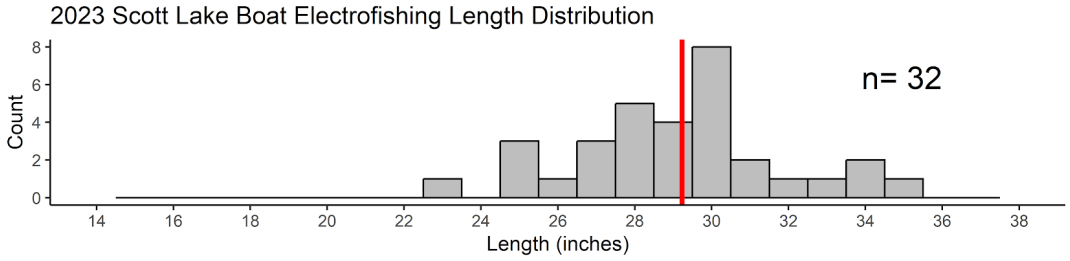
Lake	Clear	Betsy	Caroline	Louisa	Marie	Scott	Union
Lake Area (acres)	529.07	153.66	135.16	189.43	145.81	82.7	92.94
Biomass Density Estimate (kg/ha)	0	139.8	198.6	181.9	293.4	138.2	124.6
Population Estimate	0	1,606	2418	2457	2921	880	860


2023 Lake Betsy Boat Electrofishing Length Distribution
n= 16
Count
Length (inches)


2023 Lake Caroline Boat Electrofishing Length Distribution
n= 89
Count
Length (inches)


2023 Lake Louisa Boat Electrofishing Length Distribution
n= 50
Count
Length (inches)


2023 Lake Marie Boat Electrofishing Length Distribution
n= 68
Count
Length (inches)


2023 Scott Lake Boat Electrofishing Length Distribution
n= 32
Count
Length (inches)

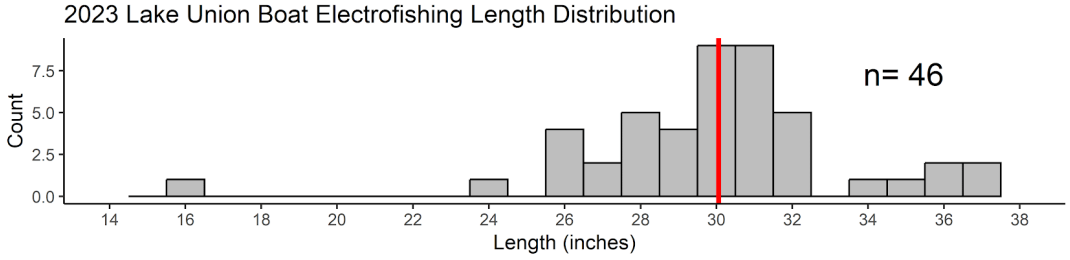
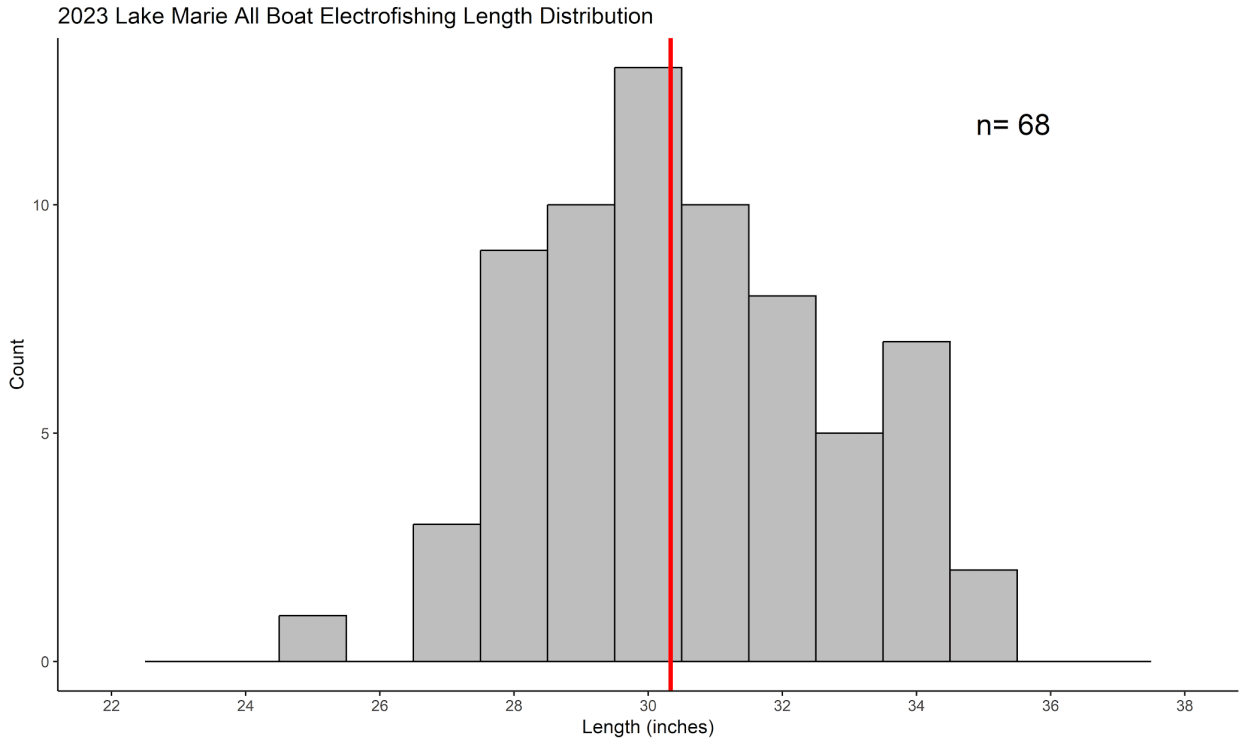

2023 Lake Union Boat Electrofishing Length Distribution
n= 46
Count
Length (inches)

Figure 18: Comparison of length distributions of carp between Betsy (n=16), Caroline (n=89), Louisa (n=50), Marie (n=68), Scott (n=32), and Union (n=46) lakes. The red lines represent median lengths.



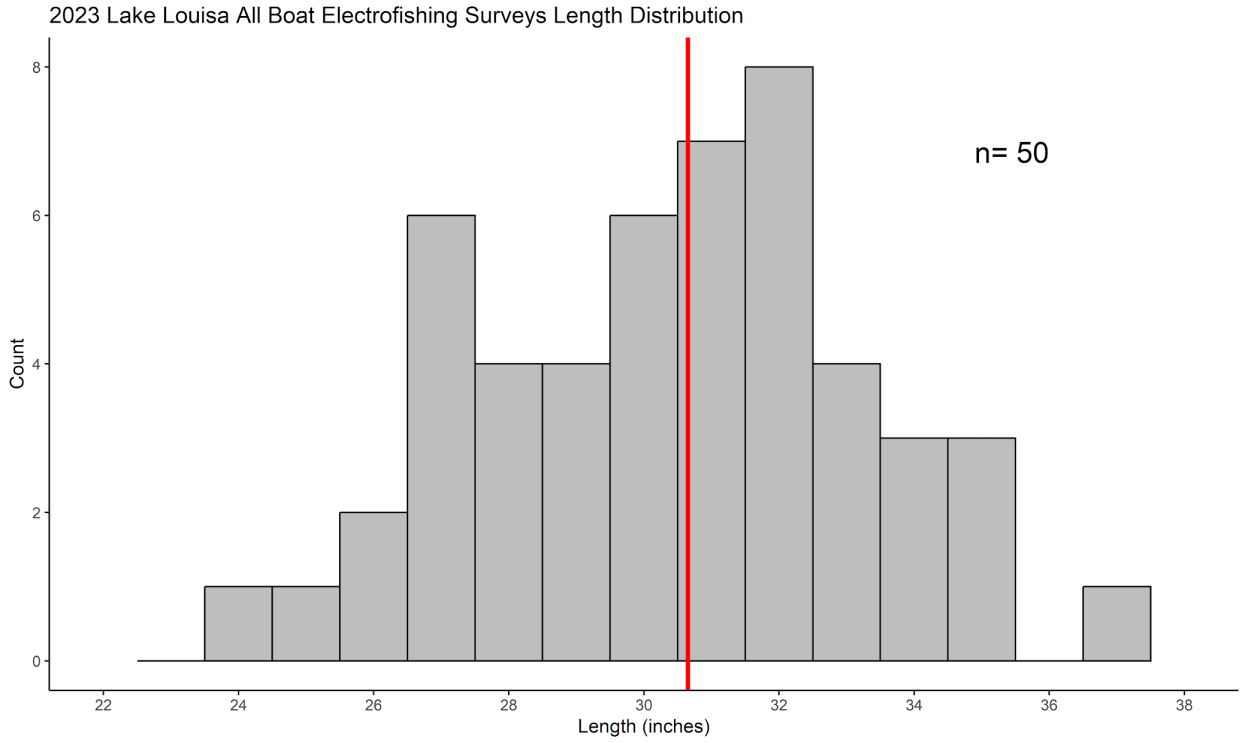


Figure 19: Comparison of length distributions of all carp caught in Lake Louisa (n=50) and Lake Marie (n=68). The red lines represent median length.

Carp Removal Measures

Box netting has been shown to be an effective method of carp removal in Lake Betsy where approximately 25% of the carp population was removed in just three removal events. Box netting could be continued and scaled up in the future to reduce carp biomass below the 100 kg/ha threshold. This method might also be successful in other lakes in the system, where carp biomass is currently excessive.

The newly implemented automated feeding device worked well to concentrate the carp feeding window. With the use of the feeder in conjunction with the PIT antenna system, box netting efforts were able to effectively capture significant portions of the carp population. Introducing the additional tagged carp from the first box net removal effort also proved valuable. These carp increased the amount of data that was collected from the PIT systems by making peak feeding activity visible with multiple carp visiting the bait per hour.

Carp Aging

The aging analysis revealed generally older populations of adult carp with only one juvenile carp found in Union Lake. The average age of carp in these lakes was in the 28-30 year range, with the exception of Lake Caroline where the average age was 23.8 years old. Although the carp were mostly older, there were still populations of carp under ten years old in all of the lakes. In Betsy, Scott, and Union Lakes, less than 10% of the total population was under 10 years compared to 19-31% in Caroline, Louisa, and Marie.

Overall, while the aging data showed that some recruitment occurred in these lakes in the past 10 years (especially in Caroline), carp recruitment rates were much higher 20-50 years ago. This bodes well for carp management via physical removal because removed carp are unlikely to be rapidly replaced by new recruits. The aging data also shows that the carp are long-lived in these lakes and are unlikely to decline due to natural mortality unless they are removed.

Management Recommendations

Clear Lake

No carp were observed during the series of surveys conducted during the 2023 season. Based on the lack of carp and the in place carp barrier we recommend only periodic surveys on a roughly biennial basis. However, the planned PIT antennas for the spring of 2024 may change this if it is found that there is significant movement towards the lake from the Lake Betsy population.

Little Mud Lake

No carp were observed during the trap netting survey conducted in Little Mud Lake. Unless carp are found in Clear Lake or evidence of movement into Clear Lake from Lake Betsy is found there is no need for further carp management.

Lakes Over 100 kg/ha (Betsy, Caroline, Louisa, Marie, Scott, Union)

In the spring of 2024, we plan to install PIT antenna systems at all potential carp migration routes and existing carp barriers within this chain of lakes to monitor carp spawning migrations. The planned locations of PIT systems are between Marie and Caroline, between Louisa and Scott, between Betsy and Scott, and two systems between Clear and Betsy. Additionally, it is recommended to place another PIT system in the creek south of Lake Union which connects to Judicial Ditch Number 2 and hence Widmark Lake. Widmark Lake could be used by carp as a nursery lake. This PIT antenna data will reveal the intensity and timing of carp spawning migrations. If significant migrations are found, barriers to prevent them in the future are recommended. These barriers would help in controlling carp recruitment in the system as well as provide for opportunistic spring removal efforts. Data collected in the spring of 2024 will determine if spring removals of migrating carp are a viable management option.

Removals of carp in all of the lakes with biomass density in excess of 100 kg/ha should be conducted. Box netting proved successful in Betsy Lake, and this method could be potentially applied in other lakes. Our population estimates suggest that an additional 450 carp would need to be removed in Betsy to reach 100 kg/ha and 1,200 carp would need to be removed in Caroline to reach the same goal. Lakes Louisa and Marie (treated as one unit) would require approximately 3,000 carp to be removed in order to reach the management threshold. In Scott Lake and Union Lakes, approximately 250 carp would need to be removed (in each). These estimates are preliminary (based on one season of data), and more accurate estimates would be generated as removal occurs in those lakes.

In addition to carp removal and tracking their spawning migrations, we also recommend periodic boat electrofishing surveys every two to three years to monitor carp populations in the lakes. These surveys would allow us to evaluate the current management strategies for their effectiveness. These would also give us an opportunity to implant more PIT tags to help aid PIT detections for the purpose of spring tracking or removal efforts.

Citations

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, 13 817-822.

Bajer, P.G., Beck, M.W., Cross, T.K., Koch, J.D., Bartodziej, W.M. and Sorensen, P.W., 2016. Biological invasion by a benthivorous fish reduced the cover and species richness of aquatic plants in most lakes of a large North American ecoregion. Global Change Biology, 22(12), pp.3937-3947.

Supplement: Estimated weight from measured length equations for each lake

Using the lengths and weights measured when the carp were collected for aging, an equation to estimate the weight of a carp based on its length was determined for each lake. The log-transformed scatterplots for each lake with the linear fit are shown in Figure 20-25. The equations determined from these graphs for each lake are:

- Lake Betsy: weight (lbs)=$10^{-3.695}$ x inches$^{3.254}$
- Lake Caroline: weight (lbs)=$10^{-3.544}$ x inches$^{3.147}$
- Lake Marie: weight (lbs)=$10^{-3.544}$ x inches$^{3.147}$
- Lake Louisa: weight (lbs)=$10^{-3.654}$ x inches$^{3.265}$
- Scott Lake: weight (lbs)=$10^{-3.916}$ x inches$^{3.434}$.
- Union Lake: weight (lbs)=$10^{-3.332}$ x inches$^{3.029}$

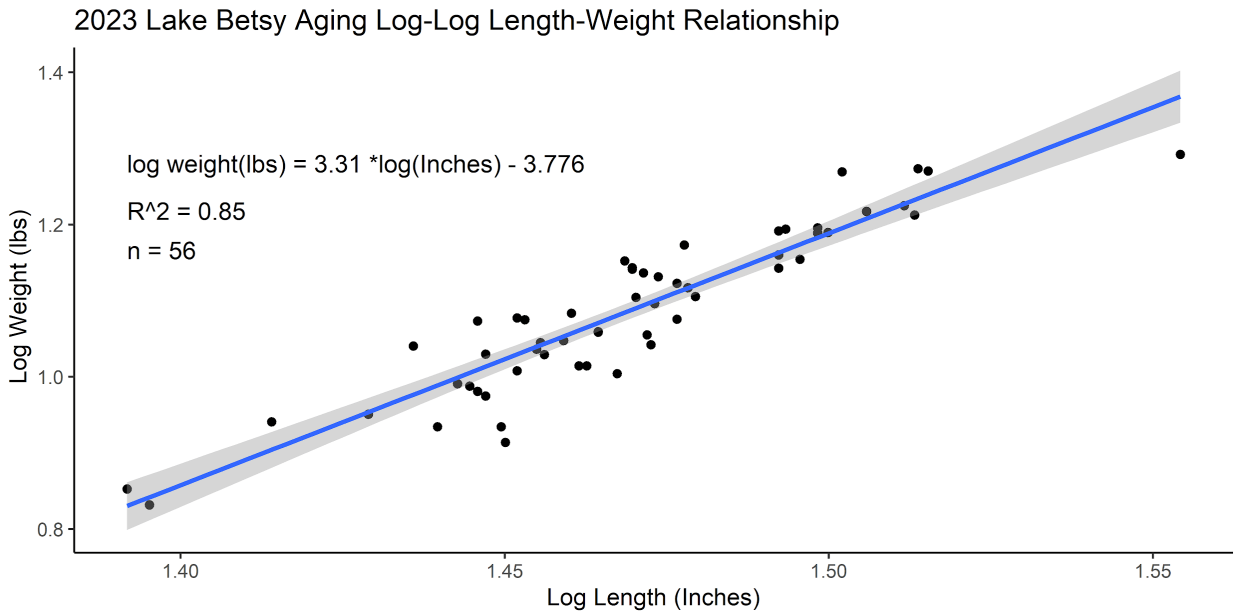


Figure 20: Log-transformed length-weight scatterplot for the carp collected for aging in Lake Betsy. The equation can be used to estimate carp weights from this lake using the equation: weight (lbs)=$10^{-3.695}$ x inches$^{3.254}$

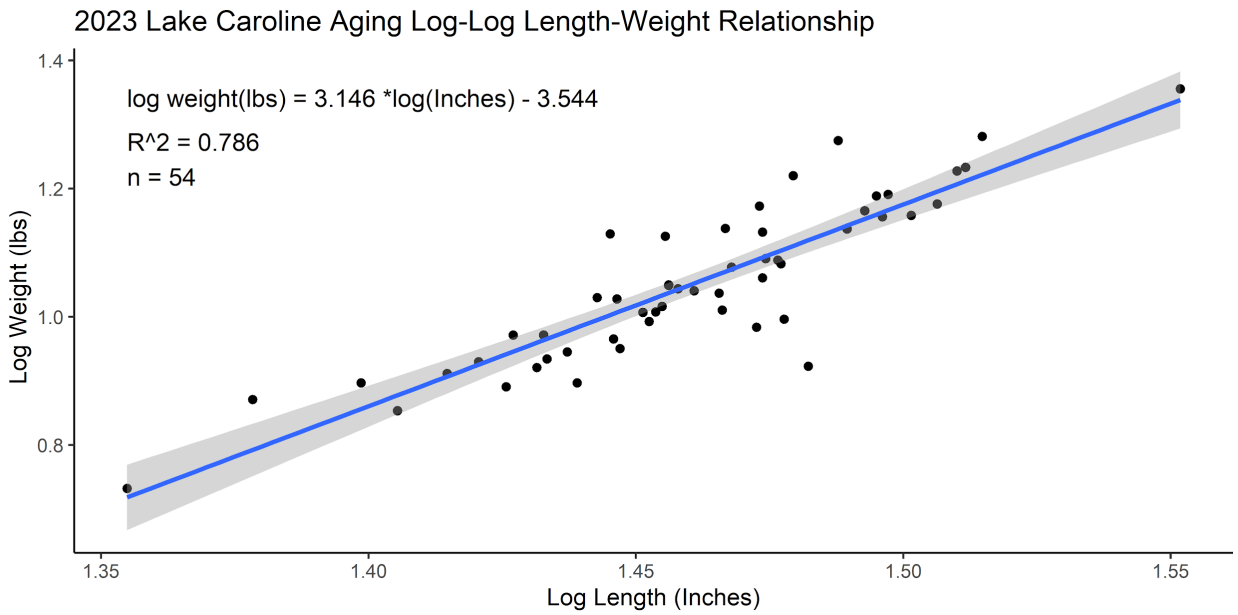


Figure 21: Log-transformed length-weight scatterplot for the carp collected for aging in Lake Caroline. The equation can be used to estimate carp weights from this lake using the equation: weight (lbs)=$10^{-3.544}$ x inches$^{3.147}$

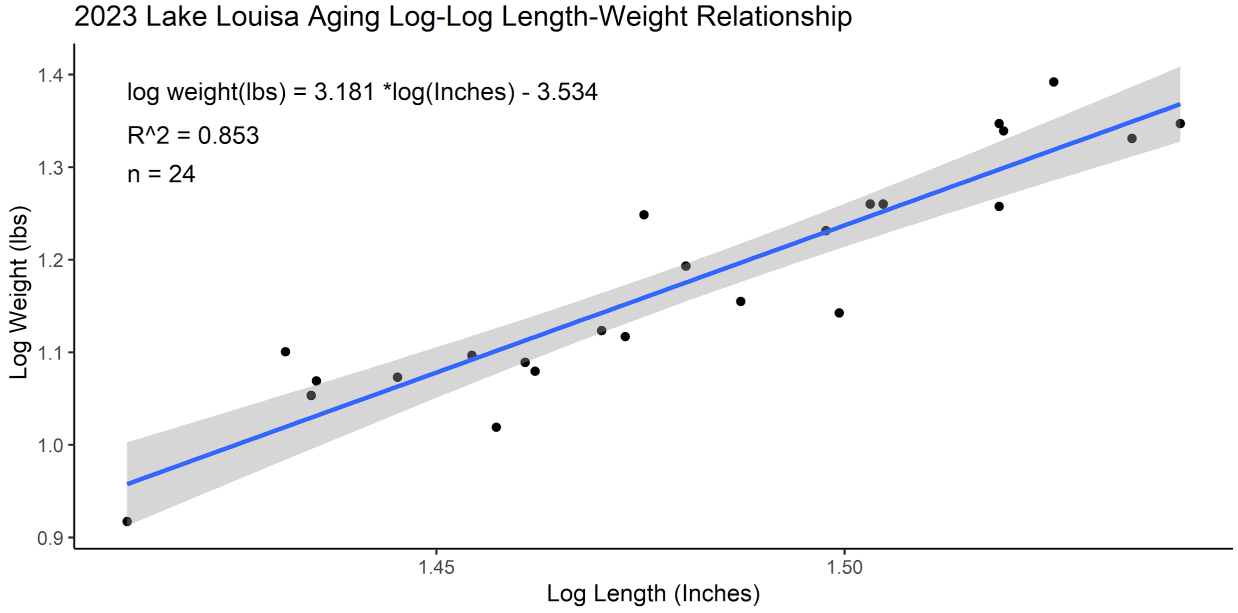


Figure 22: Log-transformed length-weight scatterplot for the carp collected for aging in Lake Louisa. The equation can be used to estimate carp weights from this lake using the equation: weight (lbs)=$10^{-3.654}$ x inches$^{3.265}$

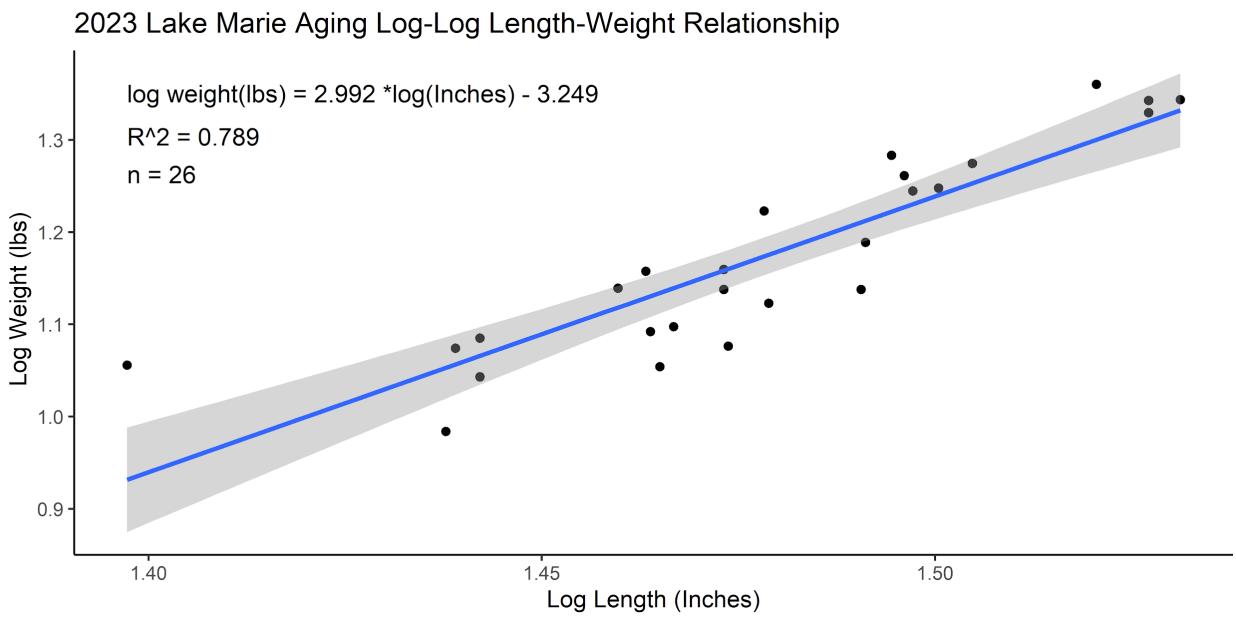


Figure 23: Log-transformed length-weight scatterplot for the carp collected for aging in Lake Marie. The equation can be used to estimate carp weights from this lake using the equation: weight (lbs)=$10^{-3.249}$ x inches$^{2.992}$

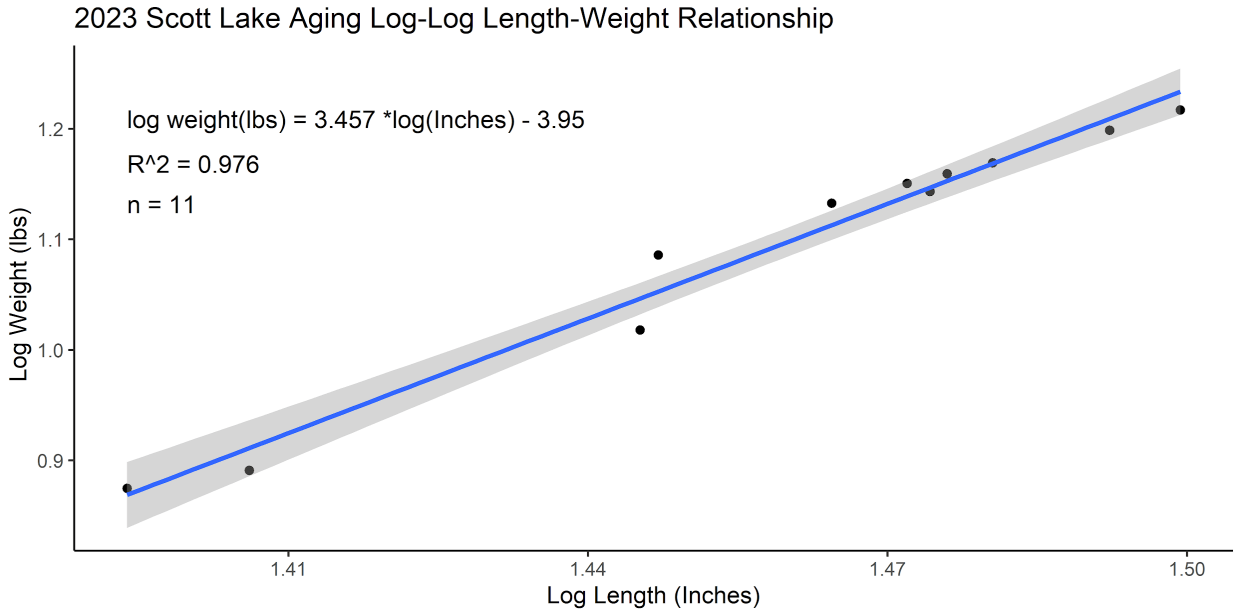


Figure 24: Log-transformed length-weight scatterplot for the carp collected for aging in Scott Lake. The equation can be used to estimate carp weights from this lake using the equation: weight (lbs)=$10^{-3.916}$ x inches$^{3.434}$

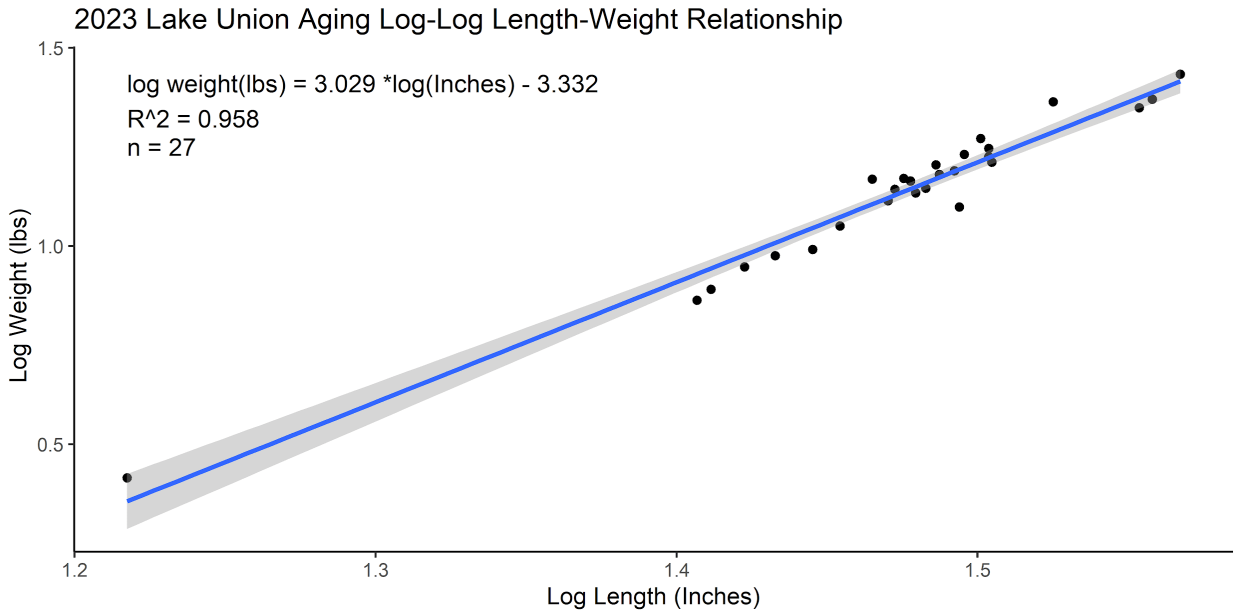


Figure 25: Log-transformed length-weight scatterplot for the carp collected for aging in Union Lake. The equation can be used to estimate carp weights from this lake using the equation: weight (lbs)=$10^{-3.332}$ x inches$^{3.029}$