Project Title: Relative Population Densities of Bigheaded Carp in the Tennessee River and Cumberland River, Tributaries of the Ohio River

Geographic Location: Tennessee and Cumberland rivers including Kentucky, Barkley, Cheatham, and Pickwick reservoirs (see Figure 1)

Lead Agency: Tennessee Wildlife Resources Agency (Cole Harty; cole.r.harty@tn.gov)

Participating Agencies: Kentucky Department of Fish and Wildlife Resources (KDFWR), Mississippi Department of Wildlife, Fisheries, and Parks (MDWFP), Alabama Department of Conservation and Natural Resources (ADCNR), Tennessee Technological University (TTU)

Statement of Need:

Adult bigheaded carp including Silver Carp (*Hypophthalmichthys moltrix*) and Bighead Carp (*H. nobilis*) have invaded the Ohio River Basin including the Tennessee and Cumberland rivers (USFWS 2016; Ridgway 2016). Silver Carp were first reported in the state of Tennessee in 1989, and Bighead Carp were reported in 1994 (Kolar et al. 2007). Despite occupancy data suggesting bigheaded carp presence in Tennessee for over three decades, the invasion may still be in early stages as evidenced by skewed sex ratios, high growth rates, and robustness (Ridgway 2016). Bigheaded carp are highly effective planktivores that can impose considerable ecosystem alterations by altering zooplankton communities (Sass et al. 2014). Therefore, monitoring and management of bigheaded carp species are required to prevent or ameliorate deleterious effects on natural resources, including current fish assemblages. Furthermore, surveillance and detections of changes in the leading edge of invasion will inform prioritization of management actions.

Tennessee Tech University began systematic sampling for bigheaded carp in 2017 to evaluate relative densities and monitor population expansion in the Tennessee and Cumberland rivers. Systematic sampling in the Tennessee and Cumberland rivers consisted of standard gill net sampling along longitudinal gradients on four reservoirs — the two most downstream reservoirs on each river including Barkley and Cheatham on the Cumberland River and Kentucky and Pickwick on the Tennessee River. The continuation of this work in 2022 aimed to increase sample sizes of data relating to the characterization of populations including age, growth, and population density and to provide an additional year of temporal data, which can be used to evaluate changes in the invasion over time. This project directly supports goals of the Ohio River Basin Asian Carp Control Strategy Framework including annual monitoring of bigheaded carp in tributaries of the Ohio River.

Project Objectives:

1) Conduct systematic sampling for the purpose of surveillance, early detection, distribution, and relative population characteristics of bigheaded carp in the Tennessee and Cumberland rivers.

2) Bigheaded carp surveillance and directed sampling in the Tennessee and Cumberland rivers that includes larval sampling and collaboration for controls and monitoring.

Project Highlights:

- Recruitment of bigheaded carp within the Tennessee and Cumberland rivers appears to remain low (i.e., young of year bigheaded carp are undetectable). Therefore, population growth may be more sensitive to immigration than local recruitment.
- Bigheaded carp populations in Cheatham and Pickwick reservoirs appear to have relatively low abundances, individuals are in good condition, and few young bigheaded carp are present.

Methods:

Tennessee Wildlife Resource Agency/Tennessee Tech University

Kentucky, Pickwick, Cheatham, and Barkley reservoirs on the Tennessee and Cumberland rivers were systematically sampled to account for and assess spatial variation in relative densities of bigheaded carp across longitudinal gradients of reservoirs. Sampling reaches were chosen at approximately equally spaced intervals throughout each reservoir and based on sampling gear constraints (e.g., depth, barge traffic) and the advice of biologists familiar with the study systems (e.g., TWRA and USGS). Three strata were sampled in Kentucky and Barkley reservoirs — the lacustrine (i.e., downstream), the transition, and the riverine (i.e., upstream). In Kentucky Reservoir, the downstream reach was located near Kentucky Dam, transition reach near Big Sandy embayment, and upstream reach near the Duck River (Figure 1). In Barkley Reservoir, the downstream reach was located near Barkley Dam, transition reach near the Little River embayment, and upstream reach near the Saline Creek embayment (Figure 1). Two strata were sampled in Pickwick Reservoir and Cheatham Reservoir — one upstream and one downstream reach in each reservoir. In Pickwick Reservoir, the downstream reach was located near Pickwick Dam and the upstream reach near Bear Creek embayment (Figure 1). In Cheatham Reservoir, the downstream reach was located near Cheatham Dam and the upstream reach near Sycamore Creek (Figure 1). During each sampling event, water temperature and geographic coordinates of sample locations were recorded.

Experimental monofilament gill nets consisted of two 45.7 m panels of either 76 mm and 89 mm square meshes (Type-I net) or 101 mm and 108 mm square meshes (Type-II net). All nets were 3.7 m in height, hobbled down to 2.4 m, and had a lead core bottom line and an 8 mm diameter foam core top line. Nets were set as floating sets and in gangs, with one of each net type deployed at a sampling site (i.e., one gang of two nets per sampling reach). Three sites were fished per sampling reach in all reservoirs using overnight gill-net sets. Sampling occurred three times at each reach across spring, summer, and fall seasons. Overnight sets were limited to the fall, spring, and early summer to minimize bycatch mortality. Net sets were placed in areas of low water velocity at depth ranges of 1.8-6 m. Catch per unit effort (CPUE) was calculated as

mean catch per overnight net set. Additional sampling used an electrified dozer trawl to capture fish and surveil for young-of-year. Dozer trawl efforts took place in summer and fall at each sampling site on Kentucky and Barkley reservoirs. All electrofishing used pulsed-DC current (5-8 Amps, 535 Volts, 120 pulses per second). Catch per unit effort for dozer trawl transects were calculated as mean catch per transect.

Morphological metrics of all bigheaded carp captured were recorded. Bighead and Silver Carp were identified based on characteristics described by Kolar et al. (2007) and sex, total length (TL; mm), and weight (W; g) were recorded. Sex of fish was used to determine male to female ratios, and length and weight data were used to produce length-frequency histograms for each reservoir and to calculate condition for comparisons among reservoirs and years. Condition was calculated as relative weight using standard weight (W_s) equations developed by Lamer (2015; Silver Carp: $\log_{10} W_s = -5.15756 + 3.06842 * (\log_{10} TL)$; Bighead Carp: $\log_{10} W_s = -4.65006 + 2.88934 * (\log_{10} TL)$). Relative weight ($W_r$) of each fish was calculated as $W_r = W / W_s * 100$, and the standard weight equations were developed using the 50th regression line percentile technique (Wege and Anderson 1978). Therefore, fish with W_r of 100 would be considered average. Otoliths were taken from a subsample of collected fish to allow later extrapolation to an age-length key. Target otolith sample sizes were 5-10 fish per two-inch length group per reservoir. The left gonad of female bigheaded carp were removed and weighed (g) to allow for gonadosomatic index (GSI) to be calculated. To calculate GSI, the left gonad weight was multiplied by two, divided by the total body weight, and multiplied by 100.

Results and Discussion:

Tennessee Wildlife Resources Agency/Tennessee Tech University

Effort and Catch

One hundred-eighty overnight-gill net sets were completed during 2022 on the Tennessee and Cumberland rivers — 54 on each Kentucky and Barkley reservoirs and 36 on each Pickwick and Cheatham reservoirs. Additionaly, 169 dozer trawls were completed — 82 on Kentucky Lake and 87 on Barkley Lake. In total, 979 bigheaded carp were captured — 968 Silver Carp and 11 Bighead Carp. Catch per unit effort has remained low (range = 0.0–0.8 fish per gang) for Bighead Carp in all reservoirs among all years (Table 1). For Silver Carp, catch per unit effort was lower in all reservoirs in 2022 than in 2021, excluding Kentucky Lake where CPUE increased from 2021 but remained low (10.7 fish per gang; Table 2, Figure 2). The highest CPUE in 2022 was in Barkley Lake at 15.1 fish per gang.

Length Distribution By Reservoir and Year

Mean length of fish captured by gill netting has increased over time in all reservoirs. Using ANCOVA, we found significant effects on total length among reservoirs, among years, and an interaction between reservoir and years. Post-hoc simple linear regression analysis for each lake indicated the relationship between total length and year had a positive slope for each lake. The

flatest slope was Cheatham Lake (slope = 8.557, 95CI = 5.989-11.125) and the steepest slope was Pickwick Lake (slope = 26.775, 95CI = 23.378-30.173; Figure 3). Thus, average length continues to increase across years in all reservoirs. This indicates that smaller, younger individuals have not recently recruited to the population. Visual inspection of length-frequency histograms (Figures 4–7) further demonstrates the temporal shift in fish length and the lack of replacement of smaller, younger fish.

Condition of Silver Carp by Reservoir and Year

Using an ANCOVA, we found significant effects between total length among years ($p < 0.001$), but there was not a significant effect among reservoirs ($p = 0.202$) and an interaction between reservoir and years was not significant ($p = 0.207$). Post-hoc simple linear regression analysis done with lakes grouped indicated the relationship between relative weight and year had a positive slope (slope = 1.189, 95CI = 0.993-1.386, $p = < 0.001$). Therefore, mean condition of the grouped Silver Carp populations was positively correlated with sampling year. An increase in condition across years could suggest a decrease in competition has allowed fish of the same size to achive higher condition, or it could be the result of fish continuing to grow in mass despite nearing asymtotic length. Measures of condition that compare length and weight—including relative weight (Table 3)—may experience increased variation as length asymptotes and weight continues to increase. Therefore, higher weight to length ratios (i.e., higher condition) could be the result of younger, smaller fish not recruiting to the system and older larger fish gaining mass quicker than length.

Gear Selectivity and Young of Year Detection

Sampling methods, including dozer trawling, did not capture any young-of-year Silver Carp. The shortest Silver Carp captured by dozer trawl in 2022 was 650 mm. The shortest Silver Carp captured by gill netting in 2022 was 579 mm.

Length-frequency histograms of Silver Carp captured using dozer trawls and gill nets are similar (Figures 8 & 9), and bootstraped-Kolomogorov-Smirnov tests failed to detect a difference in length distributions of Silver Carp captured by the two sampling methods in Kentucky Lake ($D = 0.063$; $p < 0.289$). However, a difference was detected in Barkley Lake ($D = 0.107$; $p = 0.014$). Furthermore, Welche's t-tests were conducted to evaluate the difference between the mean total length of fish sampled using these methods. No difference was detected in Barkley Lake ($t(284) = 0.169$; $p = 0.866$), but a statistically significant difference ($t(268) = 4.01$; $p < 0.0001$) was detected in Kentucky Lake with the mean total length of fish captured by dozer trawling (mean = 701; SE = 5.18) being larger than the mean total length of fish captured by gill netting (mean = 678; SE = 2.60). These results indicate that dozer trawl and gill netting yielded similar selectivity related to length of fish in Barkley Lake. However, there does appear to be differences in gear selectivity in Kentucky Lake. Nonetheless, gear selectivity does not appear to be related to the lack of sampled fish less than 500 mm because neither gear captured fish less

than 579 mm. This indicates that fish less than about 500 mm are not present in this population. Therefore, it is unlikely that any detectable local reproduction or immigration of young-of-year fish from the Ohio River or tributaries has occurred in recent years.

Fisheries Independent Catch

From 2017–2022, 27,347 kg of Silver Carp have been removed from the Tennessee and Cumberland rivers during gill-net sampling events for this study (Figure 10, Table 4). The largest mass of Silver Carp removed has most often been from Barkley Lake. However, the mass of fish removed has widely varied among sampling events and ANCOVA analysis failed to detect a difference among lakes ($p = 0.450$) and years ($p = 0.240$) and did not detect any interaction between lakes and years ($p = 0.450$). Trends in catch per unit effort data may be less pronounced when comparing mass of fish captured because fish captured in locations with lower density may be heavier on average than fish in higher density locations. An important distinction between mass of fish removed during this research and mass of carp removed by commericial fishers is that we use standardized sampling, while commercial fishers target their sampling areas to maximize catch for profit.

Weight of Fish (e.g., when do fish reach 8 pounds?)

The weight-length regression for Silver Carp in the Tennessee and Cumberland rivers with all lakes and years pooled is $\log_{10}(WT) = -5.3442 + 3.12919 \times \log_{10}(TL)$ where WT = mass in grams and TL = total length in mm. Therefore, a Silver Carp of 3,629 g (8 pounds) is estimated to be 711 mm in total length. In 2022, greater than half of fish sampled were over 3,629 g and all fish captured in Pickwick Lake since 2019 have been over 3,629 g (Table 5).

Sex Ratios and GSI

In 2022, sex ratios (females per male) were close to balanced (i.e., one female per male) in Barkley and Cheatham Reserviors, but slightly over balanced in Kentucky and Pickwick Reservoirs (Table 6). Sex ratios in this population have historically varied widely from 1:1, possibly due to early stages of invasion (see Fernholz 2018 and Ridgway 2016).

Gonadosomatic index of fish captured by gill netting has increased over time in all reservoirs. Using ANCOVA, we found significant effects on GSI among reservoirs, among years, and an interaction between reservoir and years (Figure 11). Post-hoc simple linear regression analysis done seperately for each lake indicated the relationship between GSI and year had a positive slope for each lake (Figure 11) ranging from 0.971 at Kentucky Lake (95CI = 0.803–1.139) to 1.522 at Pickwick Lake (95CI = 1.155–1.890). Increases in GSI over time, may be the result of the population consisting of older fish than during previous samples. Gonadosomatic index typically increases as fish become more fecund with age.

Ongoing Work

Otoliths were collected from 128 bigheaded carp in 2022. Funding for work in 2023 was secured and sampling plans to continue time series data are being developed.

Recommendation:

We recommend continuation of systematic sampling of bigheaded carp on the Tennessee and Cumberland rivers, which will allow for detection of changes in population trends, range expansions, or both. Furthermore, dozer trawling should be continued for the purpose of detecting annual variation in recruitment – these data can provide information that will help to ellucidate what environmental conditions result in strong year classes of bigheaded carp in the Tennessee and Cumberland rivers.

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Tables and Figures:

Table 1. Catch per unit effort (CPUE; mean fish per gang) of bighead carp in overnight gillnet sets during 2017–2022 by reservoir and year. Standard error (SE) expressed in parentheses.

Year	Barkley	Cheatham	Kentucky	Pickwick
2017	0.2(0.1)	0	0.8(0.6)	0
2018	0.1(0.1)	0.2(0.1)	0.1(0.1)	0
2019	0.5(0.2)	0.8(0.6)	0.1(0.1)	0
2020	0.7(0.2)	0.1(0.1)	0.1(0.1)	0.2(0.1)
2021	0.1(0.1)	0.6(0.3)	0.1(0.1)	0.1(0.1)
2022	0.1(0.1)	0(0)	0.3(0.2)	0.1(0.1)

Table 2. Catch per unit effort (CPUE; mean fish per gang) of silver carp in overnight gillnet sets during 2017–2022 by reservoir and year. Standard error (SE) expressed in parentheses.

Year	Barkley	Cheatham	Kentucky	Pickwick
2017	30(8.8)	16.7(4.4)	3.9(1.1)	13.3(5.7)
2018	27.8(6.7)	8.8(2.8)	13.4(2.5)	9.4(2.9)
2019	33.7(5.1)	13.4(3.5)	19.3(3.3)	22(10.8)
2020	32.7(3.4)	15.8(4)	12.3(2.7)	1.5(0.5)
2021	18.3(2.2)	11(2.8)	6.4(1.2)	2.2(0.9)
2022	15.1(2.5)	7.2(2.5)	10.7(2.4)	2.1(0.7)

Table 3. Mean relative weight of silver carp captured in overnight gill nets in each reservoir by year with standard error denoted in parentheses.

Year	Barkley	Cheatham	Kentucky	Pickwick
2017	94.2 (0.5)	105.0 (1.2)	93.9 (1.4)	102.8 (0.9)
2018	93.5 (0.3)	102.8 (0.8)	92.6 (0.4)	107.0 (0.8)
2019	96.6 (0.6)	103.7 (0.8)	92.6 (0.4)	108.6 (0.7)
2020	95.5 (0.5)	108.0 (0.9)	93.7 (0.6)	105.4 (3.2)
2021	98.4 (0.6)	107.8 (1.1)	98.3 (0.8)	117.4 (2.4)
2022	100.2(0.6)	109(0.9)	100.2(0.8)	108(2.5)

Table 5. Kilograms of silver carp removed using overnight gill nets by lake and year.

Year	Barkley	Cheatham	Kentucky	Pickwick
2017	938	553	157	363
2018	2,732	936	1,139	825
2019	2,124	892	728	927
2020	2,287	1,073	793	116
2021	2,239	1,187	743	297
2022	2,153	867	1,306	282

Table 6. Percent of Silver Carp over 3,629 g (8 pounds) among years and by lake.

Lake	2017	2018	2019	2020	2021	2022
Barkley	24	22	34	49	78	85
Cheatham	93	90	93	96	99	100
Kentucky	46	20	8	21	57	76
Pickwick	87	85	100	100	100	100

Table 7. Sex ratio (i.e., females per male) of silver carp captured in overnight gill nets in each reservoir by year.

	Year					
Lake	2017	2018	2019	2020	2021	2022
Barkley	0.93	0.83	0.81	0.72	1.12	0.87
Cheatham	0.59	0.95	0.70	1.02	1.09	0.74
Kentucky	0.43	0.77	1.10	1.07	1.02	1.06
Pickwick	1.03	2.07	1.19	0.64	1.06	1.06

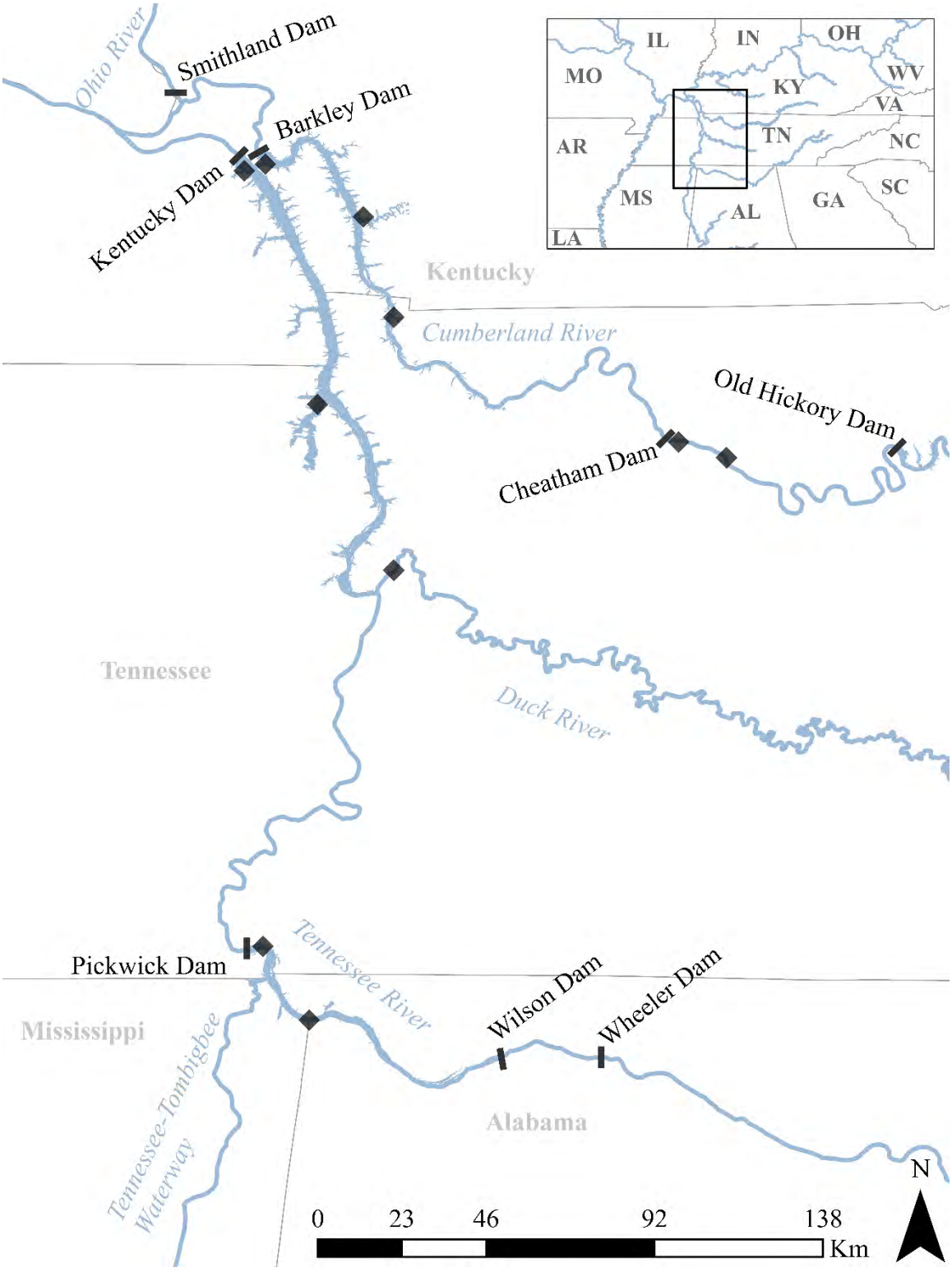

Figure 1. Map of the study area with systematic sampling sites denoted. Lock and dam locations are denoted by | and sampling sites are denoted by black diamonds.

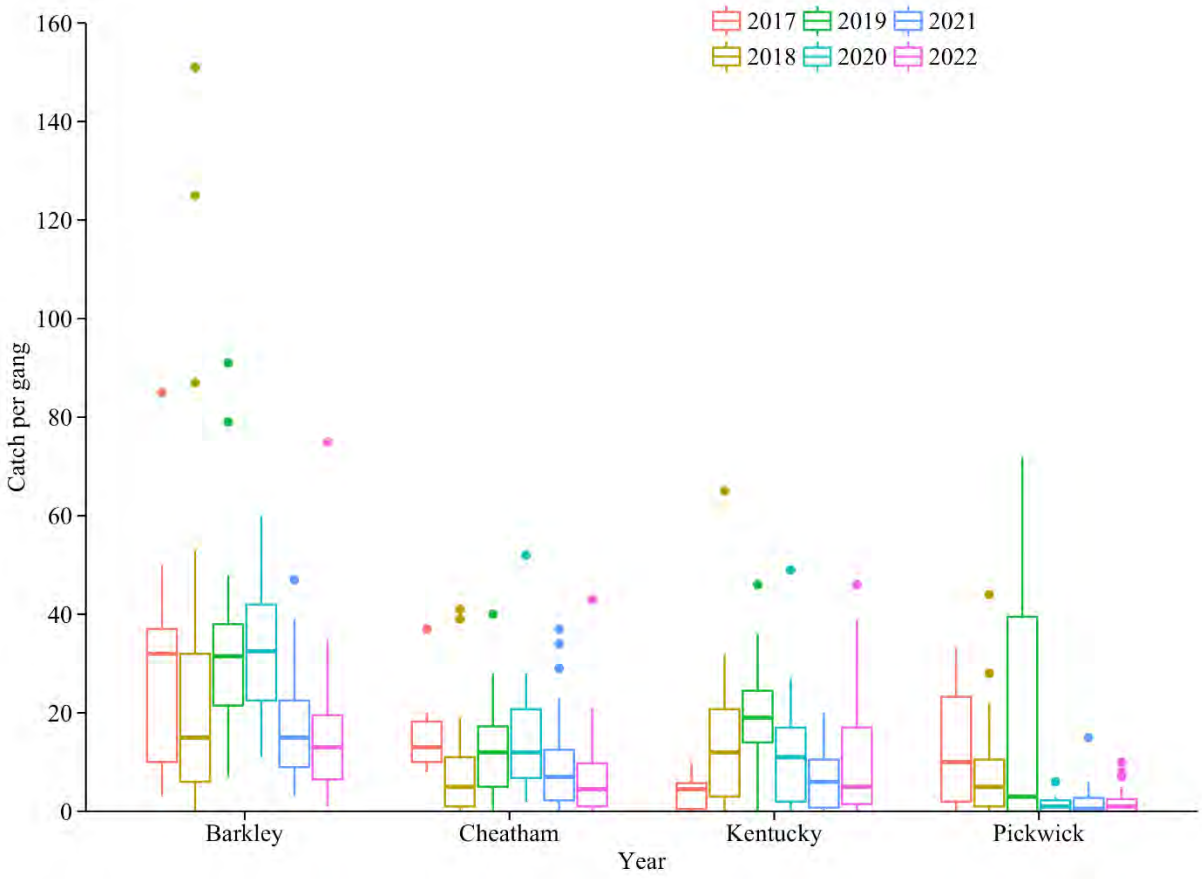

Figure 2. Boxplot of silver carp captured per overnight gill net set in Barkley, Cheatham, Kentucky, and Pickwick reservoirs during 2017–2022. Box ends represent the 25th and 75th quantiles, horizontal lines are the median, the upper whisker extends to the largest observation no further than 1.5 x interquartile range (IQR) from the 75th quantile, and the lower whisker extends to the smallest observation no further than 1.5 x IQR from the 25th quantile.

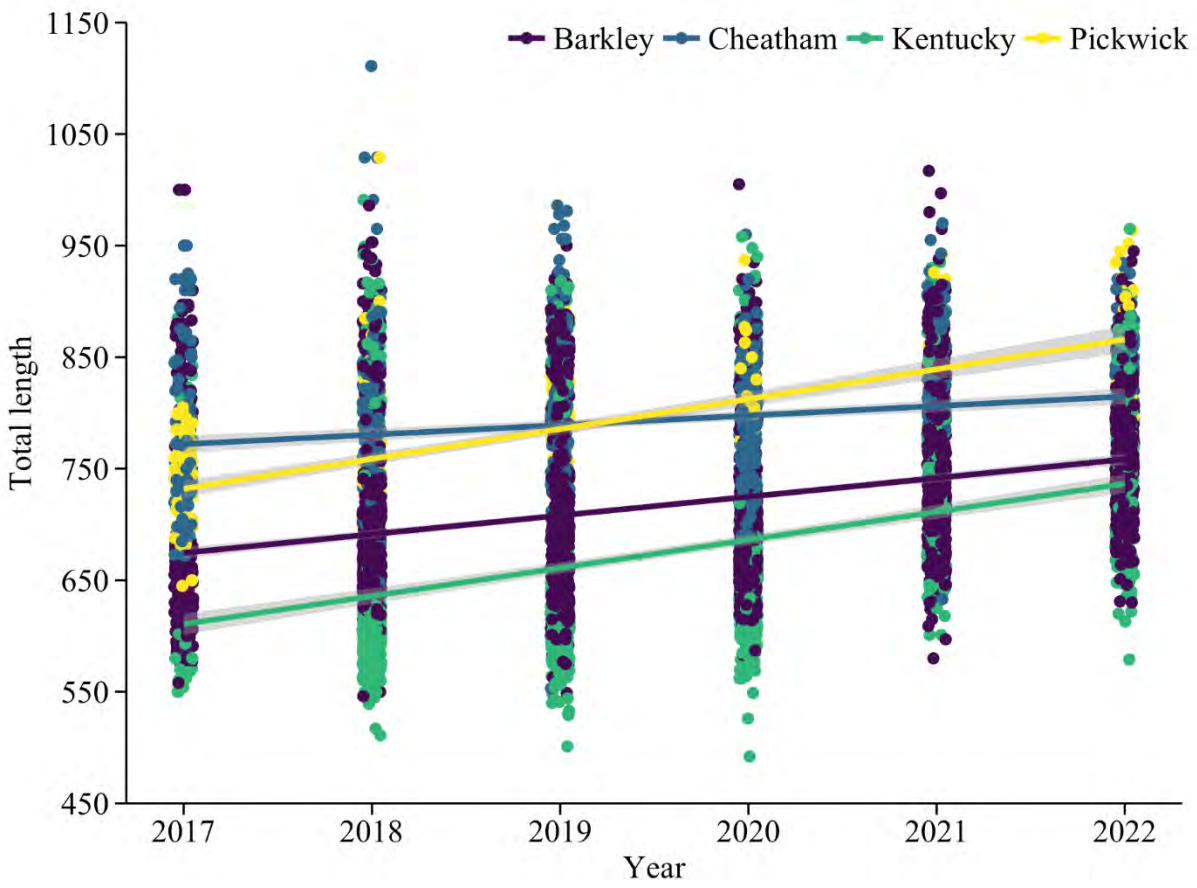

Figure 3. Regression of total length (mm) of silver carp by year. Data are grouped by reservoir. Area around each line indicates the 95% confidence interval.

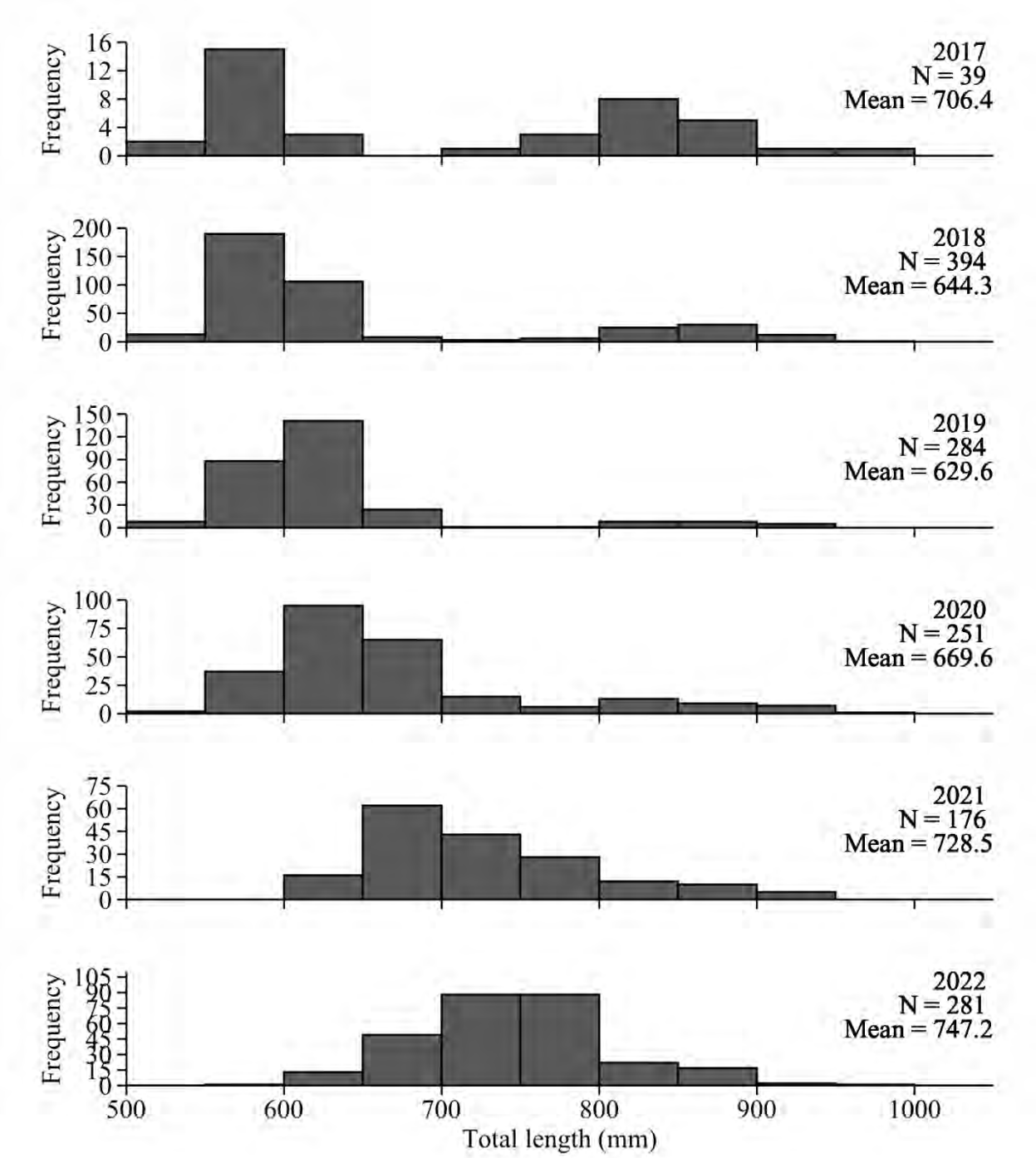

Figure 4. Length frequency histograms of silver carp captured in overnight gill net sets (dark grey) over six years—2017–2022— in Kentucky Reservoir.

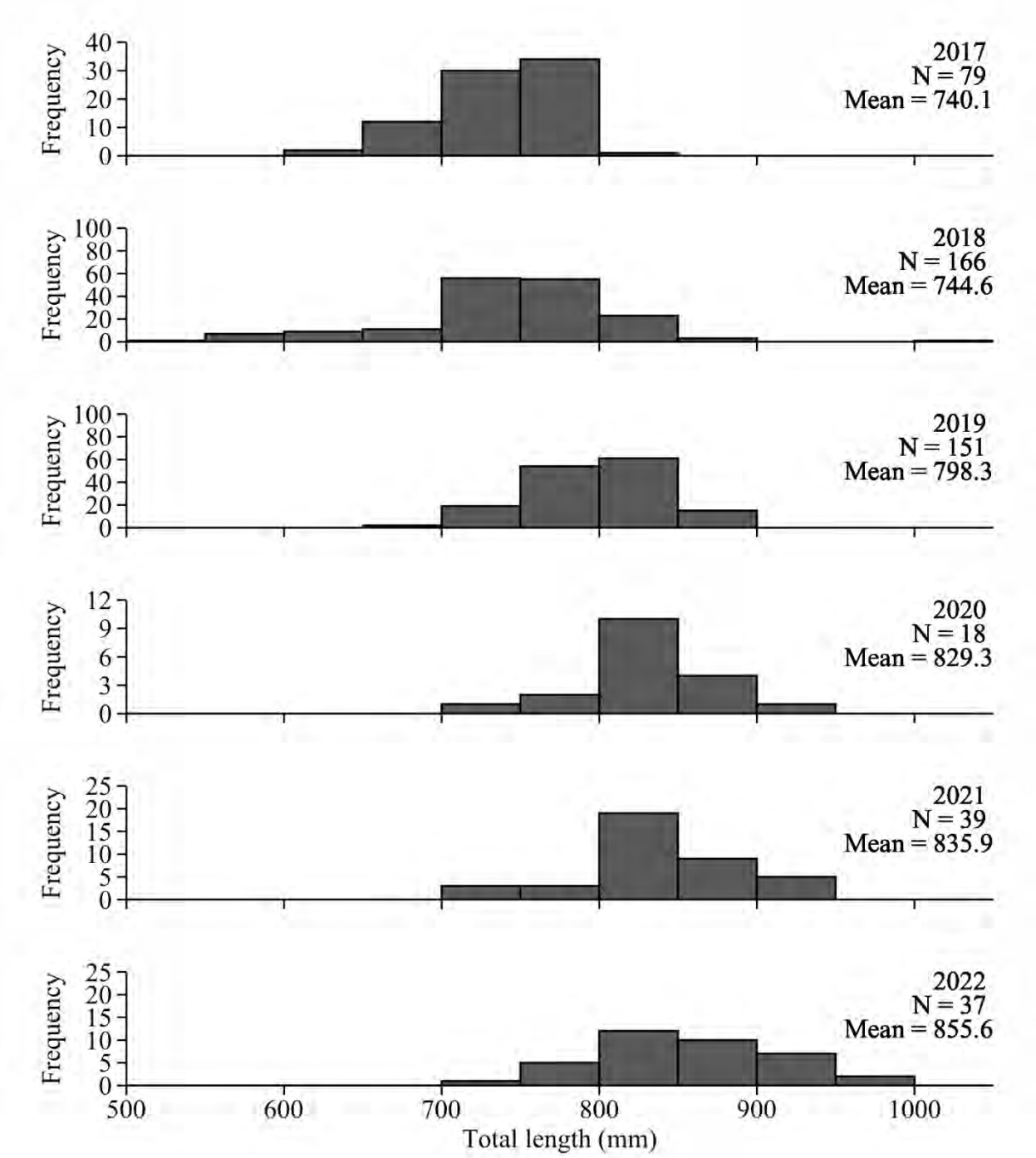

Figure 5. Length frequency histograms of silver carp captured in overnight gill net sets (dark grey) over six years—2017–2022— in Pickwick Reservoir.

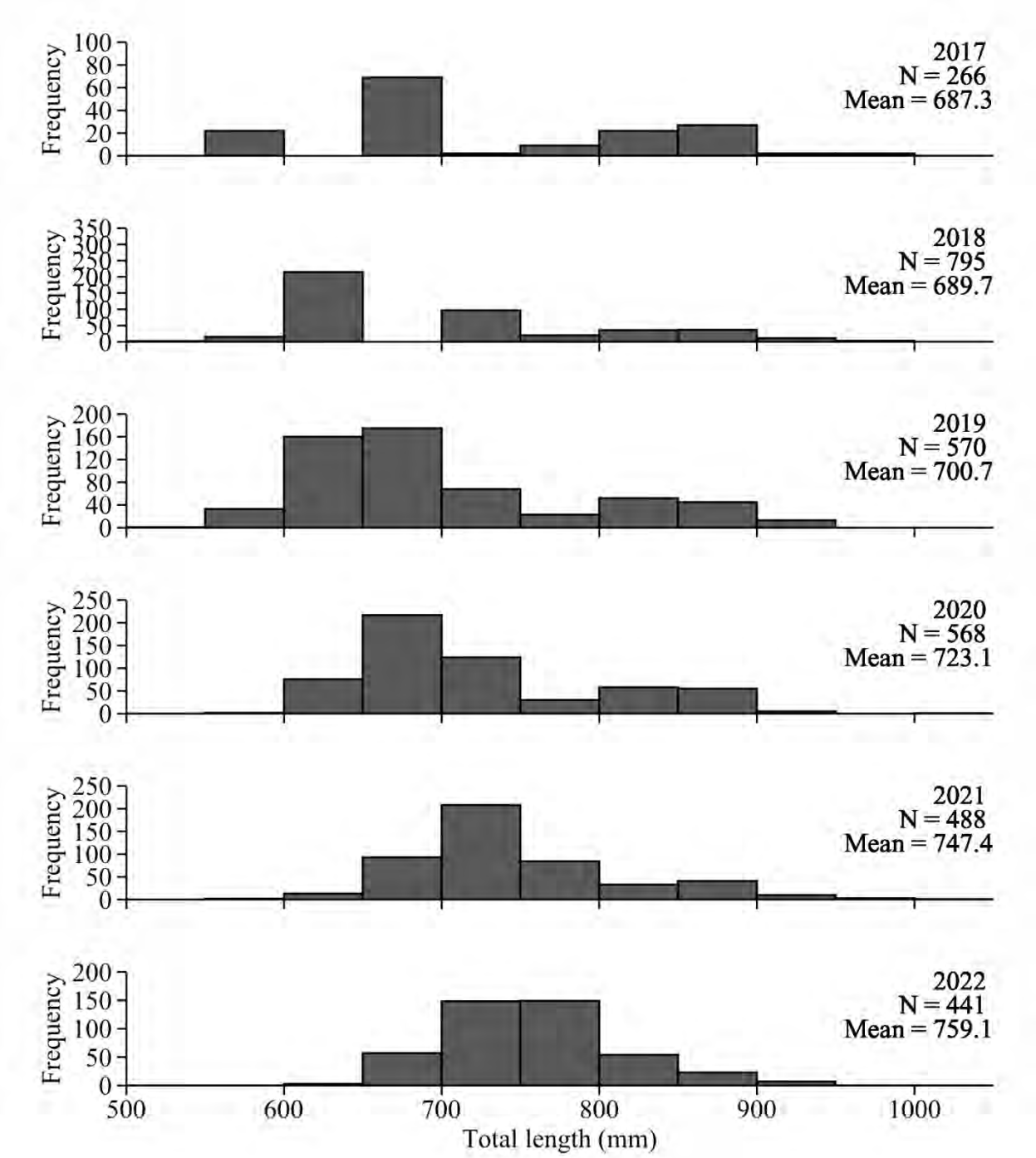

Figure 6. Length frequency histograms of silver carp captured in overnight gill net sets (dark grey) over six years—2017–2022— in Barkley Reservoir.

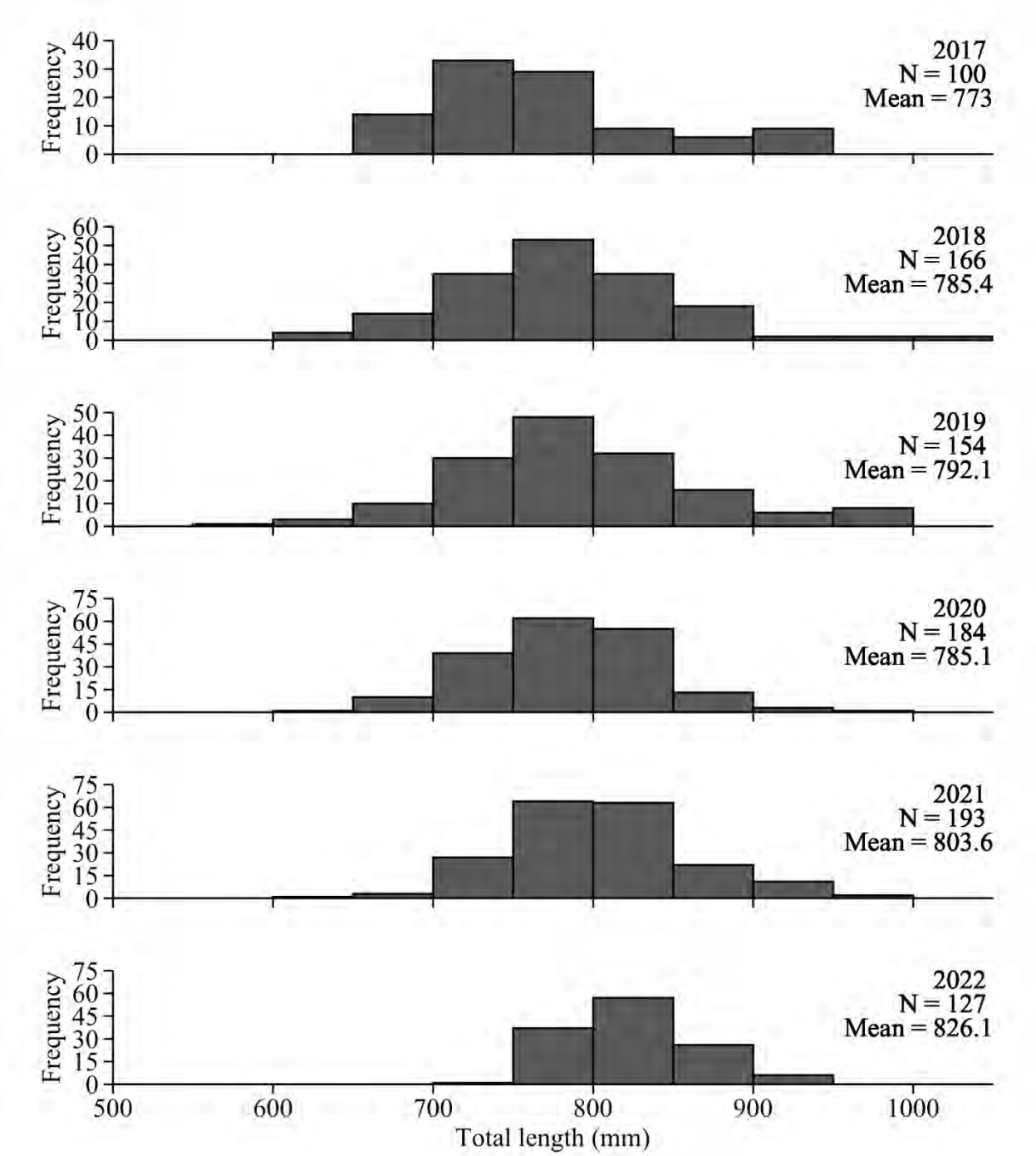

Figure 7. Length frequency histograms of silver carp captured in overnight gill net sets (dark grey) over six years—2017–2022— in Cheatham Reservoir.

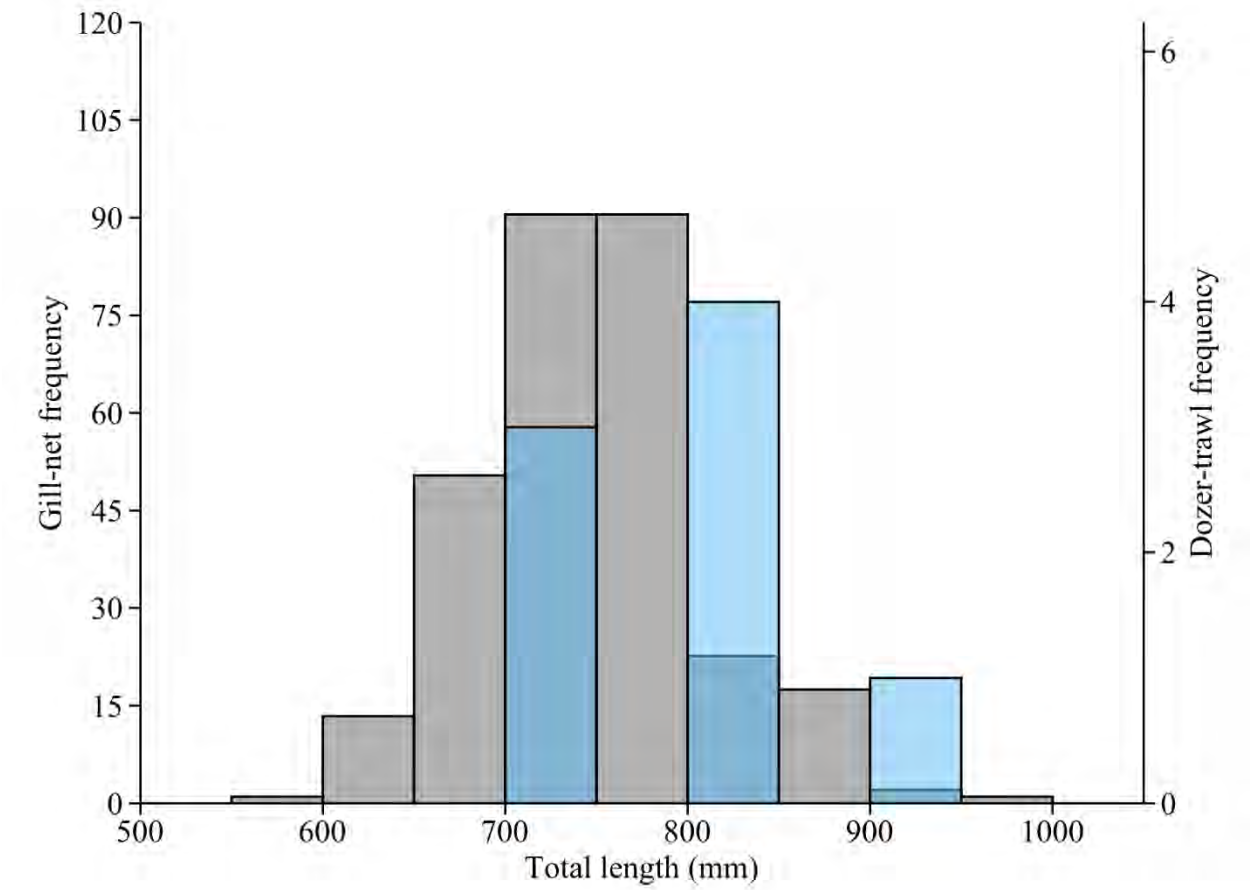

Figure 8. Length frequency distributions of dozer trawls (light blue) and gill nets (grey) in Kentucky Lake during 2022. Bars are translucent to allow overlap to be identified. Note: frequencies of gears are plotted on different scales to allow easier visual comparison of distributions.

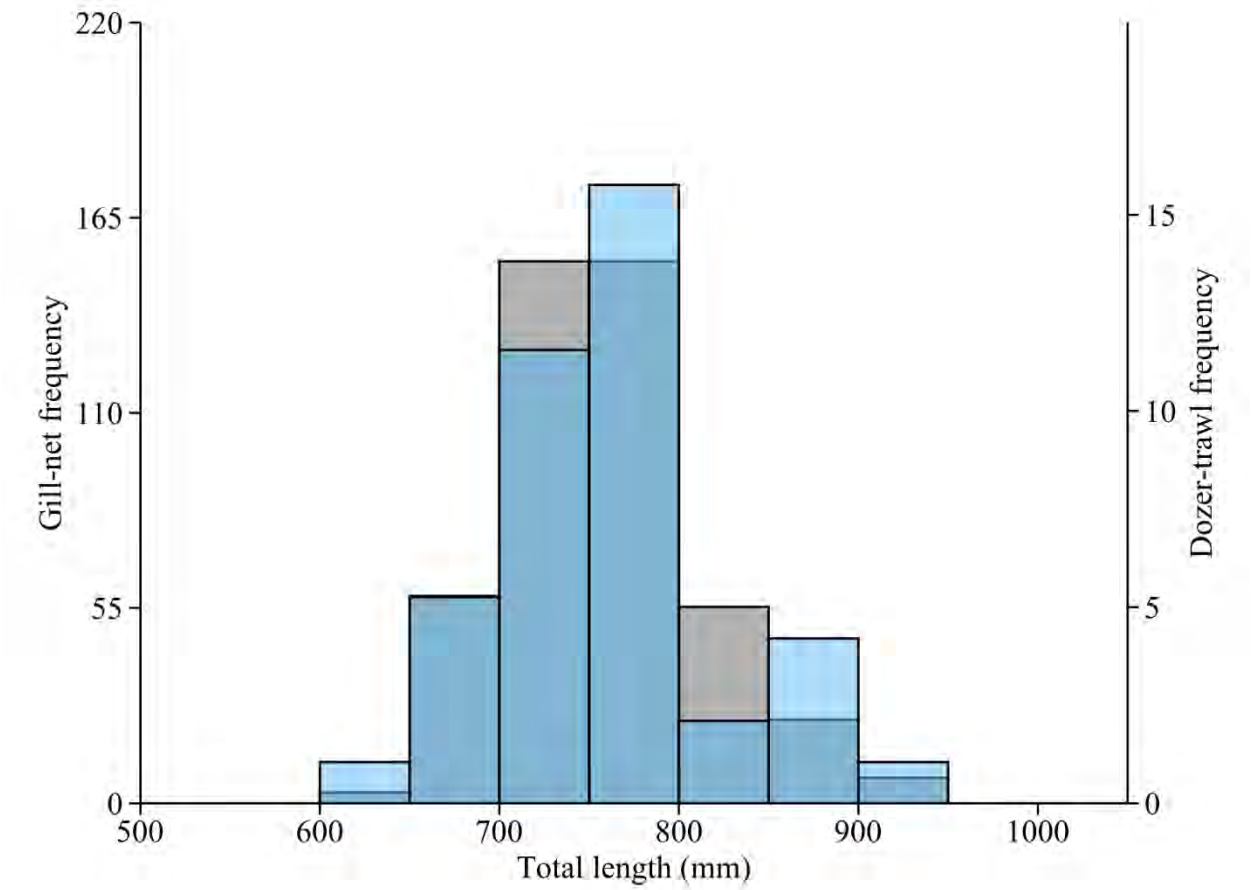

Figure 9. Length frequency distributions of dozer trawls (light blue) and gill nets (grey) in Barkley Lake during 2022. Bars are translucent to allow overlap to be identified. Note: frequencies of gears are plotted on different scales to allow easier visual comparison of distributions.

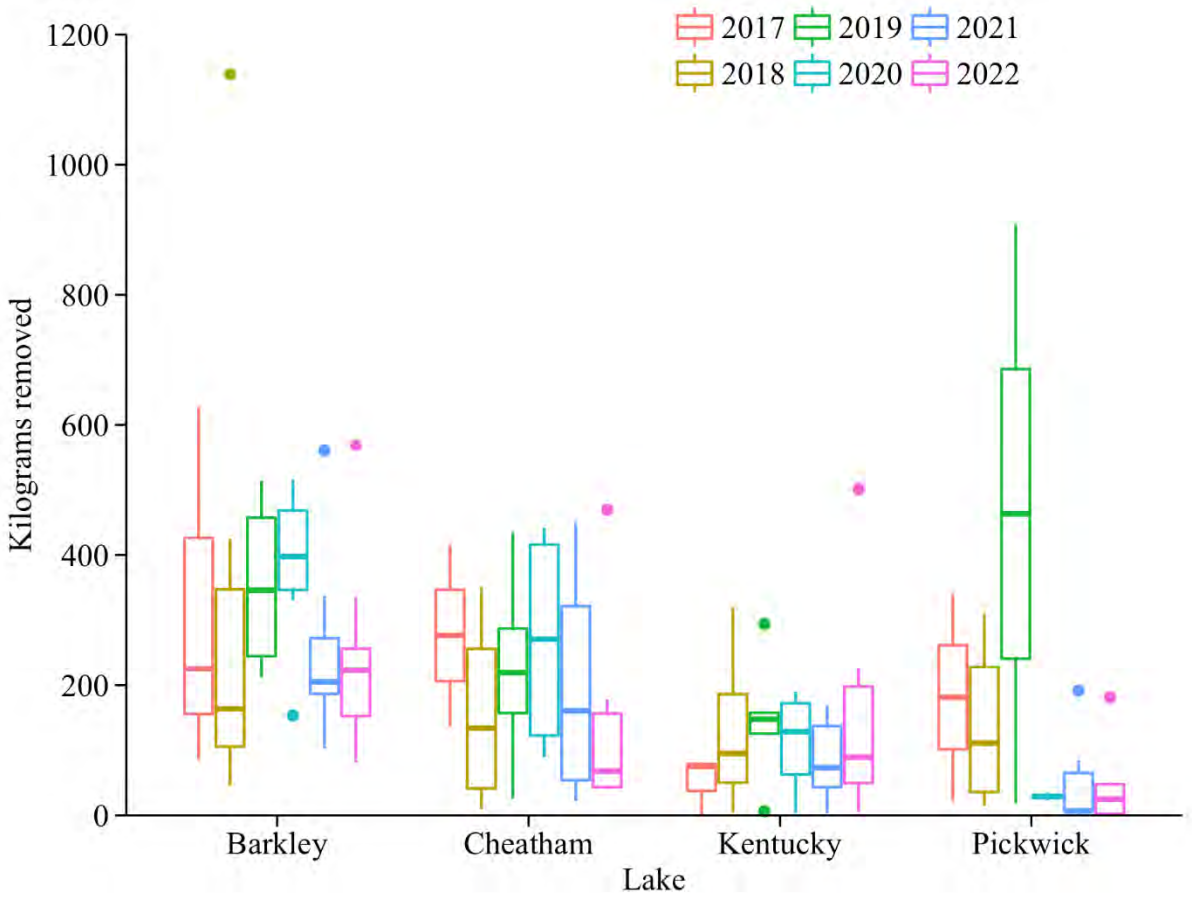

Figure 10. Kilograms of Silver Carp removed per sampling event by year and reservoir. Analysis of covariance found no significant differences among reservoirs, years, nor an interaction between lakes and years.

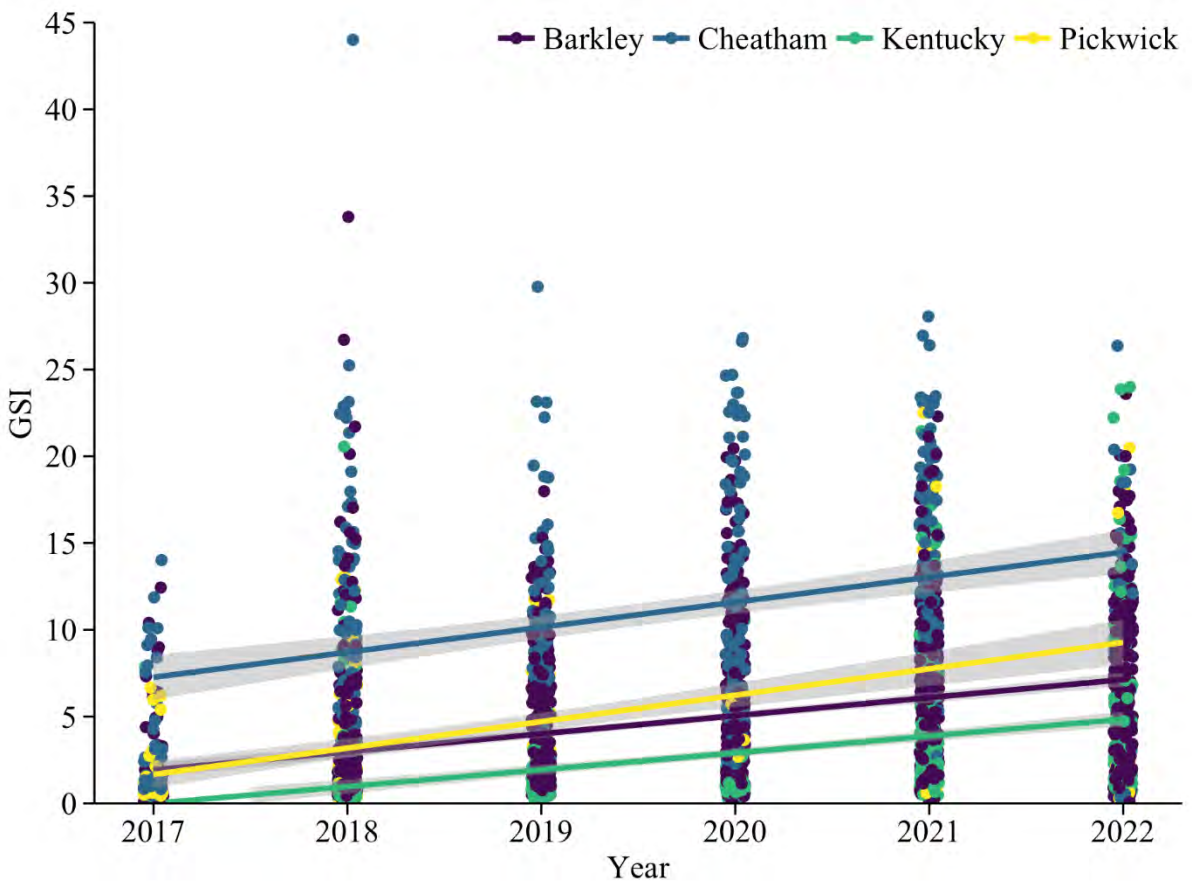

Figure 11. Regression of gonatosomatic index (GSI) of silver carp by year. Data are grouped by reservoir. Area around each line indicates the 95% confidence interval.