Project: Relative Population Densities of Asian 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 (TWRA; Cole Harty, cole.r.harty@tn.gov).

Participating Agencies: TWRA, 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)

Introduction:

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 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 ecosystems alterations by altering zooplankton communities (Sass et al. 2014). Therfore, monitoring and management of bigheaded carp species are required in order to prevent or ameliorate deleterious affects on natural resources including current fish assembalages. Furthermore, surveillance and detections of changes in the leading edge of invasion will inform prioritization of management actions.

Systematic sampling for bigheaded carp commenced in 2017 to evaluate relative densities and monitor population expansion in the Tennessee and Cumberland rivers. Systematic sampling in the Tennessee and Cumberland rivers consited 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 2020 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 monitoring 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 Asian carp in the Tennessee and Cumberland rivers.
2) Asian 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. 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 have relative weights exceeding 1.0, and no small carp are present. Density-dependence can not be determined, but those charactertics suggest that these reservoirs could accrue higher abundances of bigheaded carp if recruitment or immigration increased.

Methods:

Agency: TWRA/TTU

Kentucky, Pickwick, Cheatham, and Barkley reservoirs on the Tennessee and Cumberland rivers were systematically sampled to assess spatial variation in relative densities of bigheaded carp across longitudinal gradients of reservoirs and within reservoir productivity. 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, KDFWR, MDWFP, 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 dowstream 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.

The sampling design and procedure was similar to protocols used by commercial fishers in Kentucky and Tennessee and the methods described by Welker and Drobish (2010) and Ridgway (2016). Experimental monofilament gill nets consisting of two 45.7 m panels of either 76 and 89 mm square meshes (Type-I net) or 101 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. Target sampling seasons included spring (May through June), summer (July through September), and fall (October through December 4) of 2020 (but, see below). 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 dozier trawl to capture fish and surveil for young-of-year. Dozier 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 efforts for dozier 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 was 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 50^{th} 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. Targeted lapilli otolith sample sizes were from 10 fish per two-inch length group. The left gonad of female bigheaded carp was removed and weighed (g) to allow for gonadosomatic index (GSI) to be evaluated. To calculate GSI, the left gonad weight was multiplied by two, divided by the total body weight, and multiplied by 100.

Results and Discussion:

One hundred twenty-six overnight gill net sets were completed during 2020 on the Tennessee and Cumberland rivers — 36 on Barkley, 24 on Cheatham, 42 on Kentucky, and 24 on Pickwick reservoirs. In total, 1,061 bigheaded carp were captured in gill nets including 19 Bighead Carp and 1,042 Silver Carp. The more downstream reservoirs in the Tennessee and the Cumberland rivers (i.e., Kentucky and Barkley) had higher CPUE than the upstream reservoirs (i.e., Pickwick and Cheatham; Table 1; Figure 2) in 2020. The trend of upstream reservoirs having lower CPUE has remained consistent since 2017 in the Cumberland River, but has alternated each year in the Tennessee River (Table 1, Figure 3). Catch per unit effort on Pickwick Reservoir was low in 2020 in comparison to other years and in comparison to other reservoirs (Table 1). Systematic sampling in reservoirs during 2020 indicated a general trend of higher densities in upstream portions of reservoirs except for in Barkley Reservoir where the highest relative densities were in the transition site (CPUE = 19.2, SE = 4.0) and the most downstream site (CPUE 17.9, SE = 3.5)

and the most upstream site had the lowest CPUE of 11.9 (SE = 2.7; Table 2). Dozier trawl sampling captured 250 Silver Carp at Barkley or Kentucky reservoirs, and no Bighead Carp were captured. The smallest bigheaded carp captured in a dozier trawl was 553 mm, and no young-of-year bigheaded carp were detected. A lack of small fish captured using dozier trawling methods is probably relective of low recruitment numbers, not poor gear-efficacy. Therfore, dozier trawling should be continued for the purpose of surveillance and detection of new recruits to younger year classes.

Length frequency distributions including dozier trawl and overnight gill net captures for each reservoir show few fish under 600mm (Figure 4) indicating that few young fish have recently recruited in the Tennessee or Cumberland rivers either from natural reproduction or immigration. The peak of length frequency distributions is higher in more upstream reservoirs (Figure 4), and relative weight (Table 4) and GSI values (Figure 5) were higher for the upstream reservoirs than the downstream reservoirs on the same rivers in 2020. High relative weight, high GSI, and low CPUE in Cheatham and Pickwick reservoirs are indicators of expanding populations, likely not exhibiting density-dependent characteristics to population increases, growth, or fish condition. Sex ratios in 2020 were between 0.8 and 1.4 males per female for all reservoirs (Table 5). Male to female sex ratio has decreased since 2017 in Cheatham and Kentucky reservoirs but has increased since 2017 in Pickwick and Barkley reservoirs (Table 5).

In 2020, an additional 298 otolith samples were collected including samples from 141 female, 139 male, and 2 unknown-sex Silver Carp and samples from 9 female and 7 male Bighead Carp. Otolith samples will be processed and used to further evaluate growth curves of bigheaded carp within the Tennessee and Cumberland rivers. Analysis using otolith data will also help to inform total mortality estimates and stock assessment modeling.

In 2020, two major events occurred that interefered with data collection. First, record floods in the Tennessee and Cumberland rivers. Second, Covid-19 and travel restrictions for personal health and safety. By the time the rivers receded in the spring, we were only able to sample the Kentucky Dam before travel restrictions were enforced due to Covid-19. After quaranting protocols and guidance on personal protective equipment were provided by the U.S. Center for Disease Control, all sites were able to sampled during summer and fall 2020.

Recommendation: TWRA recommends continuation of systematic sampling of bigheaded carp on the Tennessee and Cumberland rivers, which may allow for detection of changes in population trends, range expansions, or both. Furthermore, dozier trawling should be continued for the purpose of detecting annual variation in recruitment; these data can provide information that will help to determine 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 net) of overnight gillnet sets during 2017–2020 by reservoir and year. Standard error (SE) expressed in parentheses and number of nets expressed as N.

	Barkley		Cheatham		Kentucky		Pickwick	
Year	N	CPUE (SE)	N	CPUE (SE)	N	CPUE (SE)	N	CPUE (SE)
2017	18	15.0 (4.2)	12	8.5 (1.9)	20	2.3 (0.6)	12	6.7 (2.2)
2018	51	15.8 (3.8)	33	5.2 (1.3)	52	7.7 (1.4)	36	4.7 (1.1)
2019	36	17.0 (2.8)	24	6.8 (1.6)	30	9.5 (2.1)	12	12.7 (5.1)
2020	36	16.3 (2.0)	24	7.9 (1.6)	42	6.1 (1.4)	24	0.9 (0.3)
Total	141	16.1 (1.7)	93	6.7 (0.8)	144	6.8 (0.8)	84	5.0 (1.0)

Table 2. Catch per unit effort (CPUE; mean fish per net) of overnight gillnet sets in 2020 by systematic-sampling site. Standard error (SE) expressed in parentheses and number of nets expressed as N. Entries are in order of downstream sites to upstream sites for each river and reservoir.

River	Reservoir	Site	N	CPUE (SE)
Tennessee	Kentucky	Kentucky Dam	18	8.6 (2.5)
Tennessee	Kentucky	Big Sandy	12	8.1 (2.6)
Tennessee	Kentucky	Duck River	12	0.2 (0.1)
Tennessee	Pickwick	Pickwick Dam	12	1 (0.4)
Tennessee	Pickwick	Bear Creek	12	0.8 (0.3)
Cumberland	Barkley	Barkley Dam	12	11.9 (2.7)
Cumberland	Barkley	Little River	12	19.2 (4.0)
Cumberland	Barkley	Saline Creek	12	17.9 (3.5)
Cumberland	Cheatham	Cheatham Dam	12	12.3 (2.6)
Cumberland	Cheatham	Sycamore Creek	12	3.5 (0.8)

Table 3. Catch per unit effort (CPUE; mean fish per net) of overnight gillnet sets in 2020 by systematic-sampling site and season. Standard error expressed in parentheses. Spring included May through June, Summer July through September, and Fall October through December 4.

	Kentucky			Pickwick		Barkley			Cheatham	
Season	Big Sandy	Duck River	Kentucky Dam	Bear Creek	Pickwick Dam	Barkley Dam	Saline Creek	Little River	Cheatham Dam	Sycamore Creek
Spring	11.2 (5)		11.7 (6.8)			9.8 (3.7)	20.8 (4.9)	21.8 (7.2)	12.8 (4.7)	2.5 (0.8)
Summer		0.3 (0.2)	7.2 (2.7)	0.5 (0.3)	1 (0.5)	14 (4.2)		16.5 (3.8)		
Fall	5 (1.3)	0.2 (0.2)	7 (2.9)	1 (0.5)	1 (0.7)		15 (5.1)		11.8 (3)	4.5 (1.2)

Table 4. Mean relative weight of bigheaded carp captured in overnight gill nets in each reservoir by year with standard error denoted in parentheses.

Year	Barkley	Cheatham	Kentucky	Pickwick
2017	94.3 (0.5)	106.3 (1.7)	92.8 (1.2)	101.7 (1.5)
2018	93.7 (0.4)	103.7 (0.8)	92.6 (0.4)	107.0 (0.8)
2019	96.5 (0.6)	103.8 (0.8)	93.3 (0.8)	108.9 (0.7)
2020	95.3 (0.5)	108.3 (1.0)	93.0 (0.7)	105.9 (3.5)

Table 5. Sex ratio (male:female) of bigheaded carp captured in overnight gill nets in each reservoir by year.

Year	Barkley	Cheatham	Kentucky	Pickwick
2017	1.1:1.0	1.7:1.0	2.1:1.0	1.0:1.0
2018	1.2:1.0	1.1:1.0	1.3:1.0	0.5:1.0
2019	1.2:1.0	1.4:1.0	0.9:1.0	0.9:1.0
2020	1.4:1.0	1.0:1.0	0.9:1.0	1.4:1.0

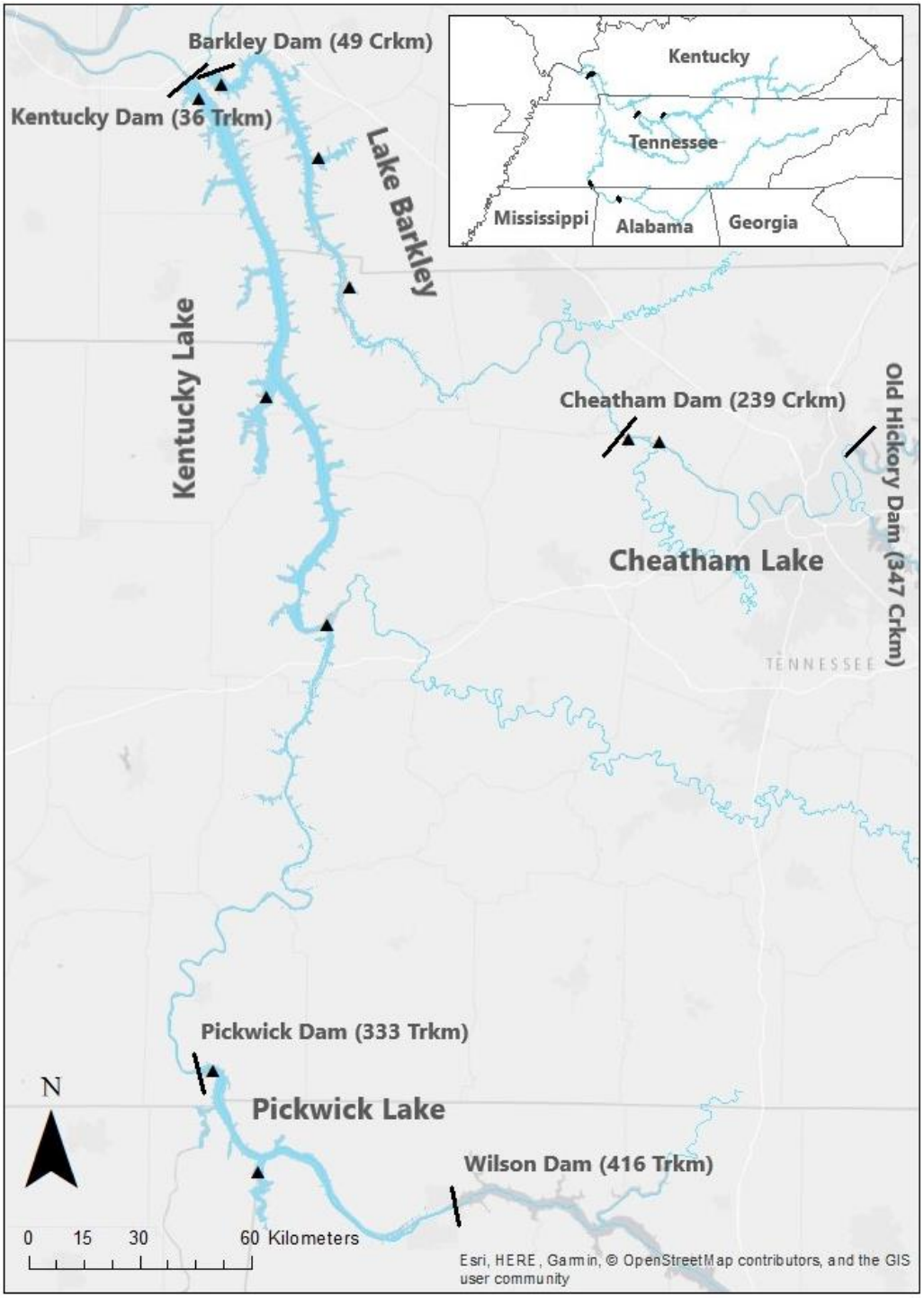

Figure 1. Map of the study area with systematic sampling sites denoted. Lock and dam locations are denoted by | and sampling sites are denoted by ▲.

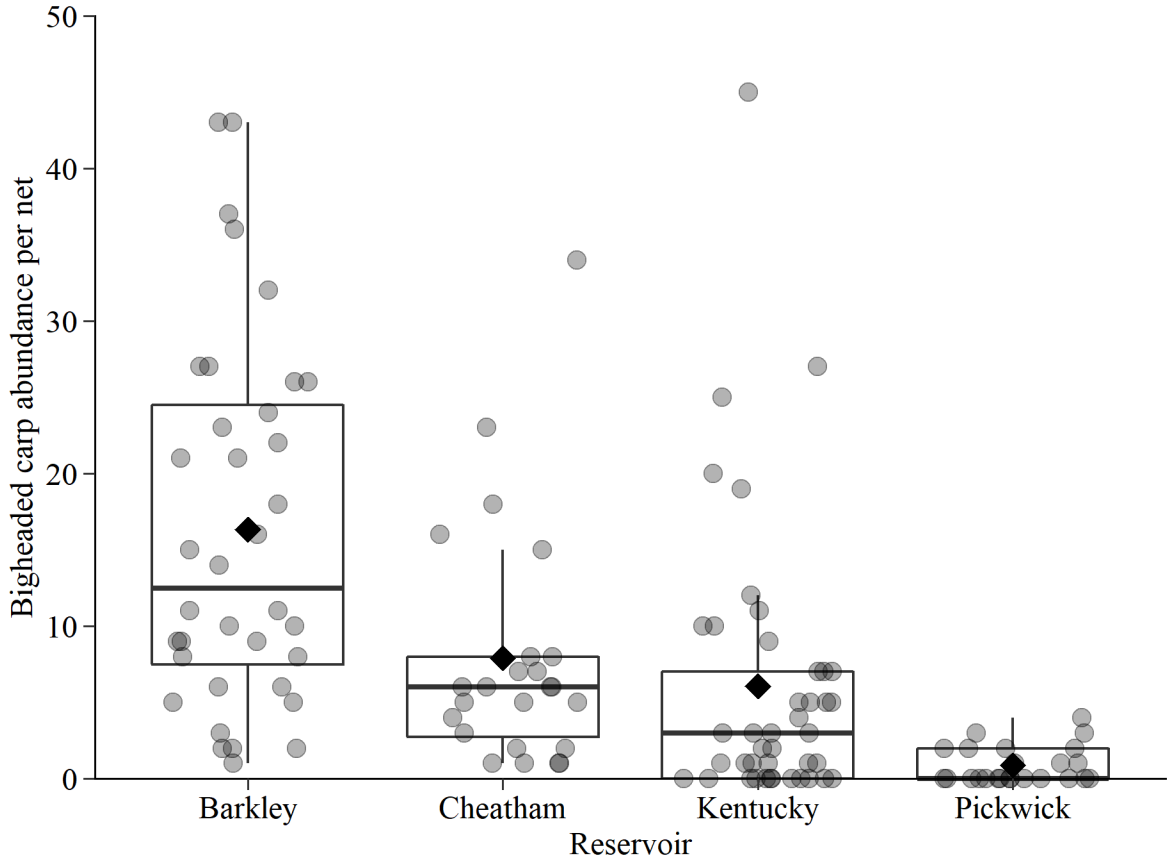

Figure 2. Boxplot of bigheaded carp captured per overnight gill net set in Barkley, Cheatham, Kentucky, and Pickwick reservoirs during 2020. Box ends represent the 25th and 75th quantiles, horizontal lines are the median, the upper whisker extends to the largest observation no further than 1.5 * interquartile range (IQR) from the 75th quantile, the lower whisker extends to the smallest observation no further than 1.5 * IQR from the 25th quantile, and black diamond represents the mean.

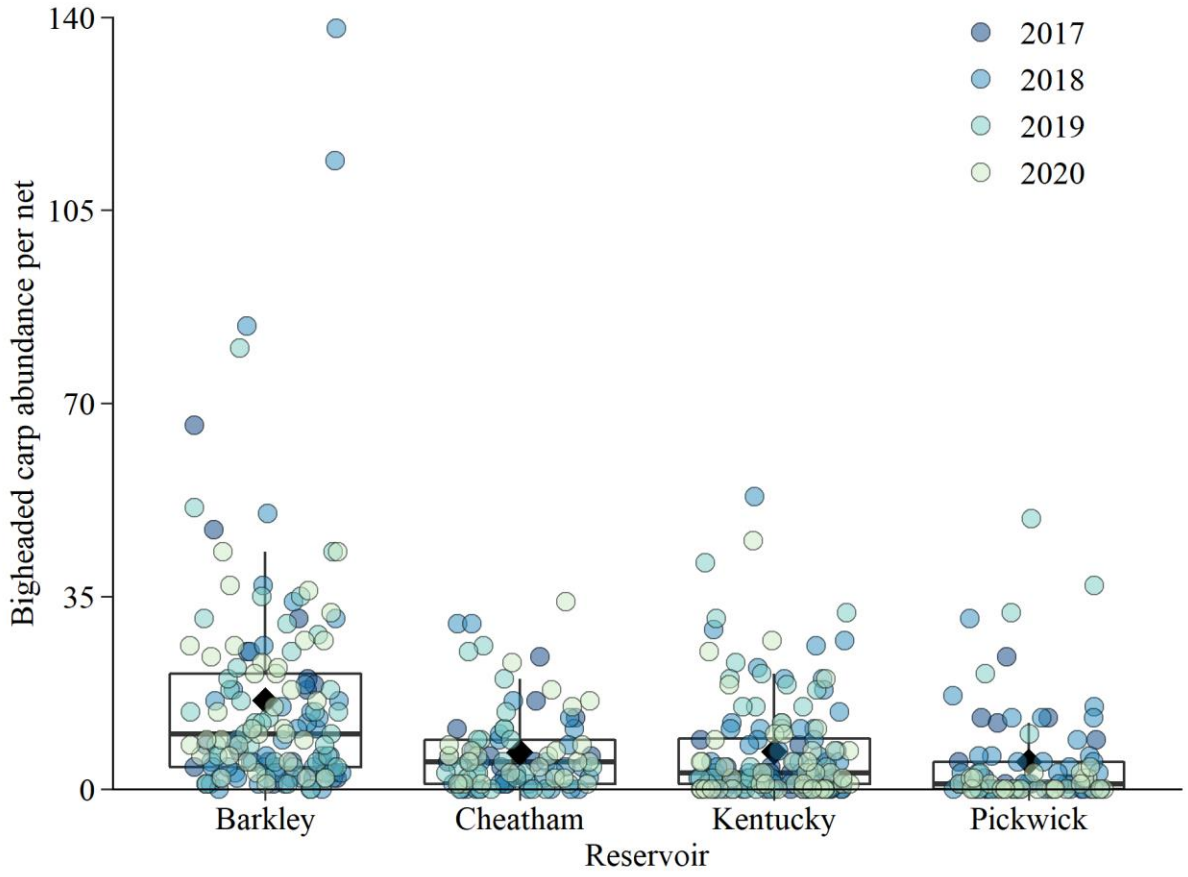

Figure 3. Boxplot of bigheaded carp captured per overnight gill net set in Barkley, Cheatham, Kentucky, and Pickwick reservoirs from 2017 – 2020 (year of net set represented by color). Box ends represent the 25th and 75th quantiles, horizontal lines are the median, the upper whisker extends to the largest observation no further than 1.5 * interquartile range (IQR) from the 75th quantile, the lower whisker extends to the smallest observation no further than 1.5 * IQR from the 25th quantile, and black diamond represents the mean.

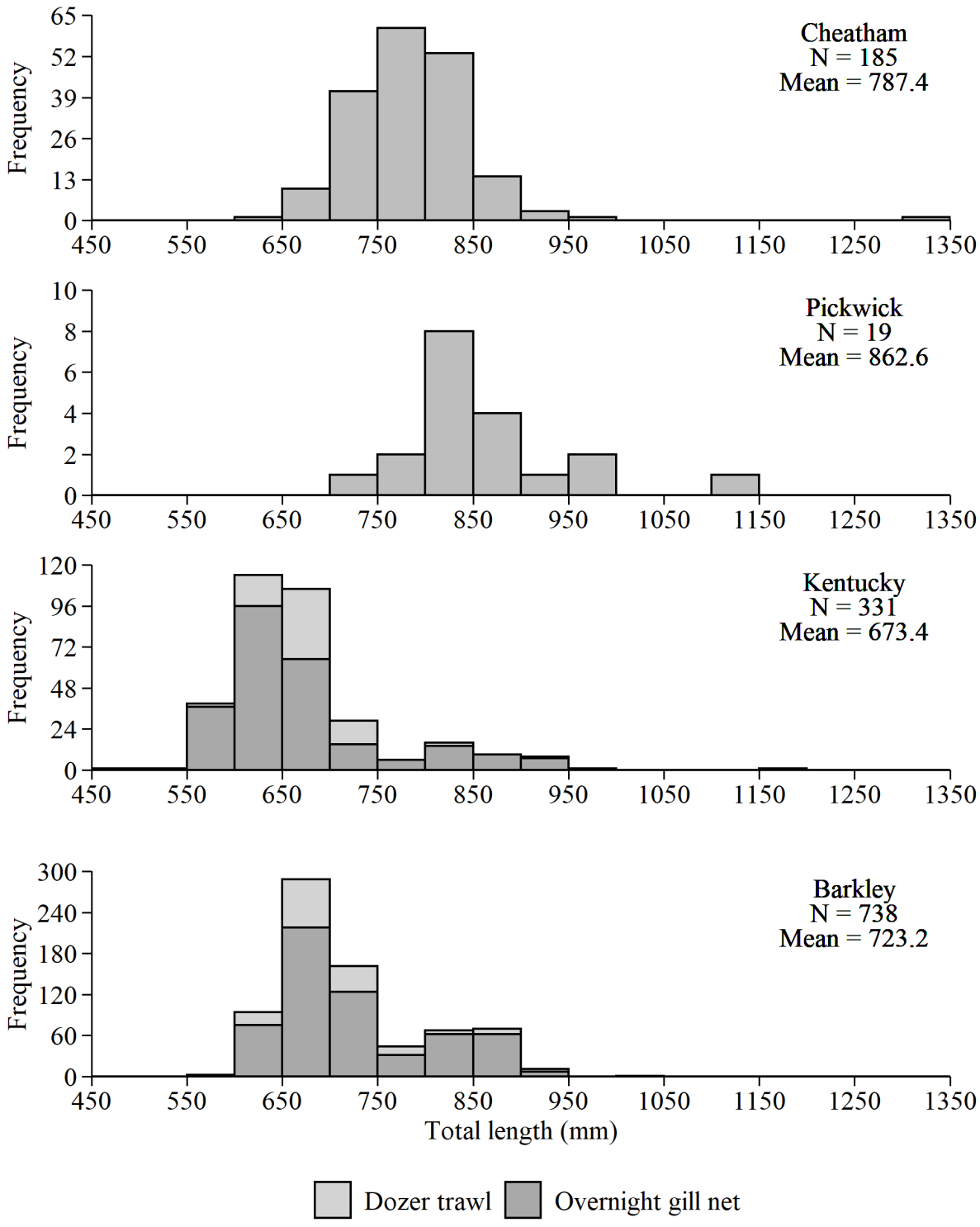

Figure 4. Length frequency histograms of bigheaded carp captured in overnight gill nets (dark grey) and dozier trawls (light grey) in four Tennessee River and Cumberland River reservoirs.

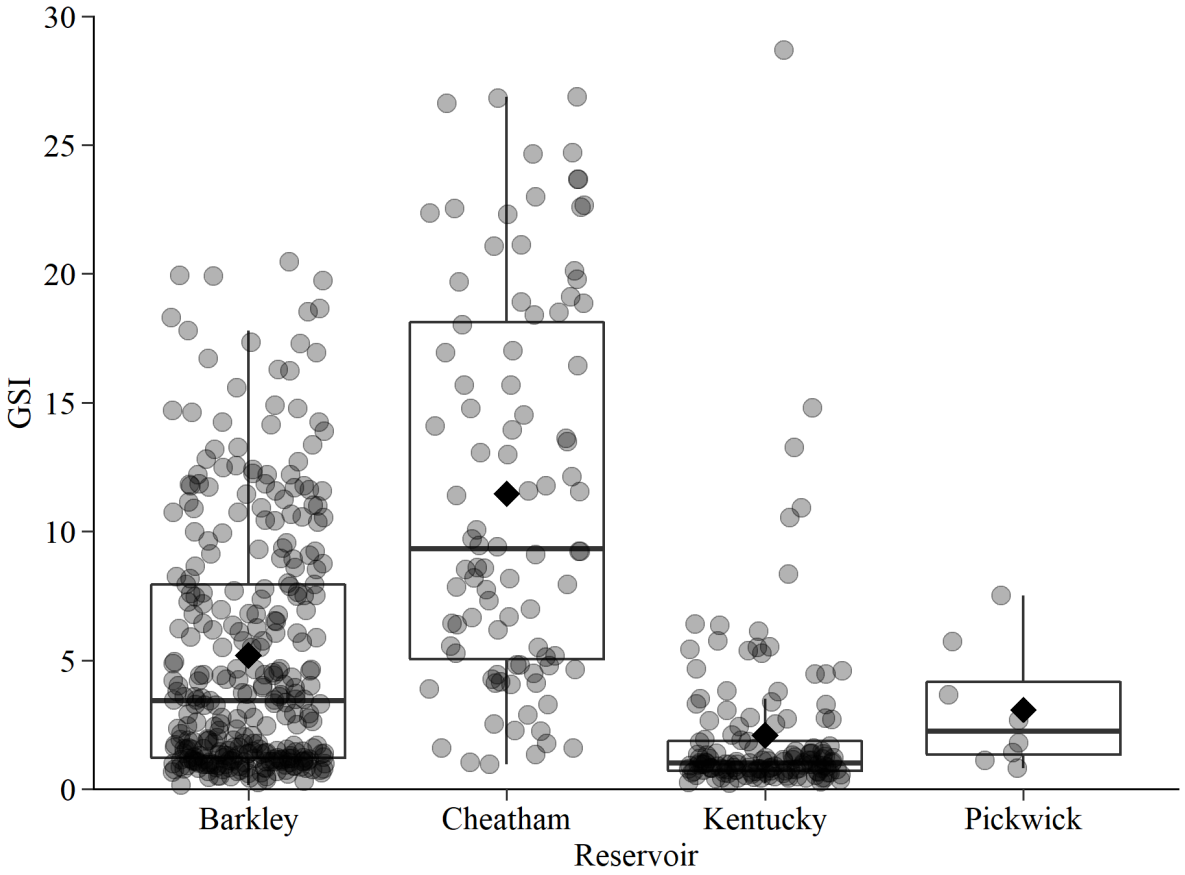

Figure 5. Boxplot of gonadosomatic index (GSI; GSI = left gonad weight * 2 / weight * 100) of individual bigheaded carp captured in overnight gill nets or dozier trawls in Barkley, Cheatham, Kentucky, and Pickwick reservoirs during 2020. Box ends represent the 25th and 75th quantiles, horizontal lines are the median, the upper whisker extends to the largest observation no further than 1.5 * interquartile range (IQR) from the 75th quantile, the lower whisker extends to the smallest observation no further than 1.5 * IQR from the 25th quantile, and black diamond represents the mean.