Early detection and evaluation of Asian carp removal in the Ohio River

Geographic Location: Ohio River basin, extending from the Cannelton pool (RM 720.7) to the R.C. Byrd pool (RM 279.2) along with the Dashields (RM 13.3), Montgomery Island (RM 31.7), and New Cumberland (RM 54.4) pools of the Ohio River in addition to the Allegheny and Monongahela rivers.

Participating Agencies: Indiana Department of Natural Resources (INDNR), Kentucky Department of Fish and Wildlife Resources (KDFWR), Pennsylvania Fish and Boat Commission (PFBC), Unites States Fish and Wildlife Service (USFWS), West Virginia Division of Natural Resources (WVDNR)

Statement of Need:
Invasive species are responsible for undesirable economic and environmental impacts across the nation (Lovell and Stone 2005; Pimentel et al. 2005; Jelks et al. 2008). Considerable effort towards the management and monitoring of Asian carp has been implemented since their introduction in the early 1980's (Kolar et al. 2005). However, because of their tolerance for a wide range of environmental conditions, carp have successfully established invasive populations the Ohio River basin (ORB).

This project provides an ongoing, coordinated approach to monitor Asian carp and fish communities in the ORB. Assembling information on distribution and habitat use of Asian carp provides an assessment tool that informs Asian carp prevention, removal, and response efforts. In addition, this information is used in an effort to determine impacts of carp on native fish assemblages and provides incremental assessments of removal efforts.

Objectives:
1. Evaluate management actions using changes in the population structure, distribution, and relative densities of Asian carp in the Ohio River through standardized targeted sampling.
2. Evaluate influence of Asian carp management actions on native fish communities in the Ohio River.
3. Monitor and survey for Asian carp presence in upstream areas where carp are rarely detected to inform response and containment efforts.

Methods:
Clarification of Terminology Referenced in This Document
With the current rate of Asian carp expansion and the massive effort to study and adaptively manage carp impacts across a broad range of Mississippi River sub-basins, it is important to clarify terminology used in technical documentation and annual reports. Therefore, a list of terms used in this report are provided.

Bigheaded Carps – Silver (Hypophthalmichthys molitrix), Bighead (Hypophthalmichthys nobilis), and their hybrids.
Establishment Front – the furthest upriver range of Asian carp populations that demonstrates natural recruitment.
Invasion Front – the furthest upriver extent where reproduction has been observed (eggs, embryos, or larvae), but recruitment to young-of-year fish has not been observed.
Invasive Carp – one of four species (i.e. Silver Carp, Bighead Carp, feral Grass Carp, and Black Carp) originating from the continent of Asia.
Presence Front – The furthest upstream extent where invasive carp occur, but reproduction is not likely.
Targeted Sampling – Gear and/or techniques used to specifically target invasive carp and exclude native species.

Spring Standardized Targeted Sampling (Cannelton – R.C. Byrd)

To the extent of the effort expended in the Ohio River, annual targeted sampling provides Asian carp relative abundances within each pool. It is recognized that more effort is warranted, and increased funding expected in 2020 will provide resources to increase this measure's accuracy. Targeted sampling was conducted 09 April – 16 May in 2019. Six concurrent pools (Cannelton – R.C. Byrd) were targeted (Figure 1), but due to unseasonably high water levels, gill netting effort was limited. All fixed sampling sites were selected from a previous stratified-random design completed in 2015. Although this previous experimental design is considered ideal, it became clear that it was logistically prohibitive without additional increases in funding and available personnel. Thus, sampling structure was adjusted in an attempt to offset logistic limitations while maintaining adequate pool coverage. Pools were segmented with fixed electrofishing and gill netting sites (~24 electrofishing runs and 8-12 gill net sets per pool). To ensure coverage within each pool, sites were divided between main-stem, island back-channels, tributaries/embayments, and dam tailwaters. Tributary or embayment sites comprised the majority of sampling locations (~ 62%) due to their size and sampling manageability. Movement data also indicates that bigheaded carp spend much of their time in these locations. The main-stem was obviously the most abundant habitat available for sampling, but because of its width, depth, and lack of quality carp habitat, fisheries gears were limited in their ability to target invasive carp species.

Electrofishing transects were conducted during 0800 – 2100 hours and standardized at 900 seconds in a general downstream direction with one dipper. In most cases, a power goal, intended to transfer a minimum of 3000 Watts from water to fish, was implemented (Gutreuter et al. 1995). Asian carp were specifically targeted using increased driving speeds and allowable pursuit of fish upon sightings. During active sampling, all non-target fish species were ignored; however, all small, shad-like species were collected and examined thoroughly before being released to avoid mis-identification of juvenile Asian carps. Catch rates for Silver Carp species were used for comparison with previous sampling seasons.

Gill nets used in targeted sampling were primarily 45m (150ft) in length, 3m (14ft hobbled to 10ft) in depth, and constructed of large mesh (either 10cm or 12.5cm bar mesh) with a foam core float line to keep them suspended at top water. An additional 45-m net with 7.6cm mesh (3" bar mesh) was included in KDFWR sampling where flow and debris allowed. Gill nets were set perpendicular from the shoreline and fished for two hours, during which we created noise and water disturbances every 30 minutes within 300 meters of the sets. Regular disturbance was intended to drive bigheaded carps into the entanglement gear. Catch rates (fish/set) were compared to previous sampling seasons.

Bigheaded carps were identified to species and examined for jaw tags and transmitters, surgically implanted during 2013 – 2018. Harvest locations were geo-located, and the fish were weighed, and measured. Unless the fish contained transmitters, all invasive carps were euthanized. A subsample of otoliths and spines were collected for aging following established protocols (Beamish 1981; Schrank and Guy 2002; Williamson and Garvey 2005; Seibert and Phelps 2013). Bigheaded carp not euthanized were tagged with a distinct jaw tag and a 95-mm,VEMCO 69 kHz – V16 acoustic-coded transmitter. Tagged fish were released at their point of capture. All fish tagged during the monitoring project activities are reported in the telemetry project report: *Quantifying lock and dam passage, habitat use, and survival rates of Asian carp in the Ohio River.*

Fall Standardized Community Monitoring (Cannelton – R.C. Byrd)
During 05 October – 20 November, fish community surveys were repeated along standardized sites in the middle Ohio River (for explanation, see above). Lengths and a subsample of weights were taken on all fish captured and identified to the lowest taxonomic level possible. All fish were released in the same location as their capture (excluding Asian carps). Invasive carps were either euthanized or tagged using the same procedures described above.

Electrofishing transects were standardized by time using one dipper as described above. A power goal, intended to transfer a minimum of 3000 Watts from water to fish, was implemented (Gutreuter et al. 1995) at a 25% duty-cycle and 60 pulses per second (pulsed DC). All fish entrained during a 15-minute transect were collected. All small individuals, with morphometric characteristics similar to Asian carp, were examined thoroughly. When large schools of Clupeids or Cyprinids were encountered, fish were dipped at a constant rate while maintaining a consistent, straight-line speed.

Gill nets were also fished as described above where flow and debris allowed. Gill nets were set perpendicular from the shoreline and fished for two hours while creating noise and water disturbance every 30 minutes, within 300 meters of the set.

Additional community data was collected using seining conducted in October at four boat ramps in the R.C. Byrd Pool of the Ohio River. One seine haul was conducted at each of the four locations using a 30-foot seine with 3/16" mesh and a 6-foot bag (1/8" mesh). Species readily identifiable in the field were enumerated and released; all other species were retained for identification and enumeration in the laboratory. Size ranges and biomass data were collected where possible.

Hydroacoustics Analysis
Hydroacoustic work was conducted in December of 2019 and sites were based on previous years of hydroacoustics sampling in the Cannelton, McAlpine, and Greenup pools (Table 1). Each site consisted of a main channel section and an associated tributary, which were analyzed separately. For main channel scans, the transducers were shore facing. Tributaries were scanned with the transducers facing towards the middle of the channel, and were traversed as far as the channel was passable, or until 1-nmi.

Hydroacoustics analysis was conducted according to MacNamara et al. (2016) and the Large River Hydroacoustics Mobile Survey Standard Operating Procedure, Region 3 U.S. Fish and Wildlife Service in Echoview Version 10.0. Raw data was imported into a mobile survey template and calibrated for analysis. Pre-analysis processing included corrections for shifts in transducer frequency, 1-meter data exclusions to nearfield zones, bottom-line exclusions for accurate water volume calculations, and removal of bad data regions where wake disturbance or vegetation contributed to poor data quality. Targets were detected using parameters from Parker-Stetter et al. (2009) and the Echoview target detection algorithm. Echoview's fish tracking algorithm was used to group multiple targets from a single fish, reducing the potential for over counting. The mean acoustic target strength (dB) of each fish target was used to estimate total length (cm). The pool-specific community data was used to inform the hydroacoustics data. Size bins were created for each 1-cm length group from 10-120 cm TL for all fish (Silver Carp, Bighead Carp, Grass Carp, and other species). These length-specific proportions were then used to assign species to acoustically detected fish. Pool-specific length-weight regressions were used to estimate the length-specific biomass for each species. Species specific density and biomass density were calculated for each site, habitat type (main channel (MC), side channel (SC), or tributary (trib)), and pool.

Assessing Asian Carp Population Demographics
Lengths and weights of bigheaded carps collected in 2019 (August through December) were compiled and $\log_{10}$ transformed. A single regression line for each species was derived to compare length-weight relationships to previous years. Regressions were achieved with the general linear model (lm()) in base R (R Core Team 2016) with lengths being measured in millimeters and weight measured in grams. The equations are reported the form of (Table 2 and 3):

$$\log_{10}[\text{Weight}_{g}] = a + b * \log_{10}[\text{Length}_{mm}]$$

Body conditions were also evaluated using the standard weight equations developed by Lamer *et al.* (2015) to compare annual conditions of Silver Carp in the Cannelton Pool and among several pools for fish captured in 2019. The same temporal comparison was made for Bighead Carp captured in Cannelton Pool; however, there were not enough fish collected in 2019 to compare differences among pools.

During standardized, targeted monitoring, Bigheaded carp lapilliar otoliths were removed from subsamples for aging. Prior to aging, otoliths were prepared using one of two methods. They were glued to a glass slide using thermoplastic cement, ground to the nucleus, and examined using reflected light under a microscope (Beamish 1981; Schrank and Guy 2002; Williamson and Garvey 2005; Seibert and Phelps 2013); or thin-cross sections were cut using a low-speed, Isomet saw and the fish were aged with a microscope using transmitted or reflected light (Figure 2). Over 250 otoliths were collected in 2019 and we are still in the process of aging them. Age data will be used to calculate the mean length at age (range, 95% confidence interval) for Silver Carp and to use the von Bertalanffy growth equation:

$$L_t = L_\infty\,(1-e^{-K(t-t0)})$$

Where L_t = the estimated length at time t, L_∞ = the estimated maximum theoretical body length, K = Brody growth coefficient, t = time or the index of ages by year, and t_0 = is the time in years when fish length would theoretically be zero. The model will be fitted in R using non-linear modeling procedures (Ogle 2016) and used to estimate pool-specific mortality rates (Then et al. 2015).

Monitoring Ahead of the Invasion Front

Targeted sampling for Asian Carp was conducted using 24-hour gill net sets in December 2019 in the Montgomery Slough portion of the Ohio River (Montgomery Island Pool, RM 949.78 to 950.11) near where positive eDNA hits for Bighead Carp were found in 2017 and historically. Gill nets used in sampling were 90 meters (300 feet) in length, ~4 meters (12 feet) in depth, and constructed of 8 cm, 10 cm, or 13 cm (3”, 4”, or 5”, respectively) bar mesh.

Fish community monitoring was conducted using nighttime boat electrofishing in May and June 2019 in the Allegheny River at the LD 2 tailwater (Emsworth Pool) and LD 8 tailwater (Pool 7) and in the Monongahela River at the Braddock tailwater (Emsworth Pool) and Grays Landing tailwater (Maxwell Pool). Five consecutive, 10-minute electrofishing runs were conducted on each bank beginning either downstream of the lock chamber, or as close as possible to the dam wall for a total of 100 minutes of pedal time. Electrofishing was conducted using an ETS MBS 2D unit operated at 30% duty cycle, 60 pps, and between 250-550 V pulsed DC. All fish species were targeted and enumerated in the field, or retained for identification in the laboratory if field identification was not practical. Gamefish species were measured, weighed, and a scale sample was retained for age and growth analysis.

Fish community monitoring was also conducted in the Montgomery Island Pool of the Ohio River using beach seines in August 2019. Six fixed locations were sampled using a 30 m (100’) seine with 1-cm (3/8”) mesh. One seine haul was conducted at each of the six locations. Species readily identifiable in the field were enumerated and released; all other species were retained for identification and enumeration in the laboratory.

Incidental sampling for Asian Carp was conducted using baited tandem hoop nets and boat electrofishing. Baited tandem hoop nets (4’ diameter, 1.5” bar mesh, 3 nets in tandem) were set in all pools of the Monongahela River in June 2019 and were fished for three consecutive nights. All species were identified and enumerated before being released except for Channel and Flathead Catfish, which were retained for aging using otoliths.

Daytime boat electrofishing was conducted in July and August on four fixed sites in the Montgomery Island Pool of the Ohio River, four fixed sites on the Charleroi Pool of the Monongahela River, and six fixed sites on Pool 4 of the Allegheny River. Electrofishing was conducted using an ETS MBS 2D electrofishing system operated at 25% duty cycle and 60 pulses per second (pulsed DC) at variable voltages and amperages depending on river conditions. Transects were fixed length (100 – 300 m) and were sampled from 7 to 11 minutes. Black bass were measured and enumerated, and presence/absence of other species was recorded.

Nighttime boat electrofishing was conducted in October in New Cumberland Pool of the Ohio River and Pool 4 of the Allegheny River and in November; in Montgomery Island and Dashields pools of the Ohio River; Emsworth Pool and Pool 7 of the Allegheny River; and Emsworth and Maxwell pools of the Monongahela River. Sampling was conducted using an ETS MBS electrofishing system operated at 25% duty cycle and 60 pulses per second (pulsed DC) at variable voltages and amperages, depending on river conditions. Three, 15-minute transects were completed in the tailwater portion of the Montgomery Dam (Cumberland Pool) on each bank in October. All black bass and Moronidae were collected, and presence/absence of other species was recorded. On the Allegheny River in October, four fixed sites were sampled. Black bass and Sander species were collected, and presence/absence of other species was recorded. In the two pools each of the Ohio, Allegheny, and Monongahela Rivers in November, the same unit and settings were used. Transects consisted of four 10-minute runs in the tailwater portion of each pool. All Sander species were collected and presence/absence of other species were recorded.

Compilation and Incorporation of Other ORB Data Sources
Regional and national georeferenced databases were utilized to compile additional Asian carp records providing range data from reports by other entities or groups which conduct sampling or fisheries activities in the ORB. The Nonindigenous Aquatic Species (NAS) database, currently maintained by United States Geological Survey, was accessed in March 2020 and used to add records, captures, and sightings for the four Asian carp species of concern of these projects. The NAS database provides a unified reporting and referencing system where confirmed sightings from all basin partners can be added annually. It is encouraged that state and federal basin partners continue to report carp sightings to this database to promote a single reference location for records throughout the basin. In addition, data from the Ohio River Valley Water Sanitation Commission (ORSANCO) were downloaded and compiled to determine the additional occurrences of Asian carps in sampling data taken from 1957 – 2019. Data were sorted and mapped in order to supplement project records and additional upstream detections of Asian carp species in the Ohio River. Tributaries of the Ohio River are also included in this data, but are only referenced using their associated pools. Finally, data from carp captures during agency removal efforts and contract fishing were compiled to finalize ORB sighting by species.

Results:
Spring Targeted Sampling (Cannelton – R.C. Byrd)
Spring targeted electrofishing in 2019 yielded no Bighead and 104 Silver Carp from Cannelton, McAlpine, and Markland pools (Table 4). Grass carp were also collected in Cannelton, McAlpine, and Markland in greater numbers overall than in previous years. Silver Carp CPUE in the Cannelton Pool appears to have increased over time, but remained consistently low in McAlpine and Markland pools (Figure 3a). Catch rates in 2019 are the highest they have been in the Cannelton Pool since this project began, but are only slightly higher than 2017.

Spring gill netting in 2019 proved to be challenging due to high water conditions, limiting the total number of net sets to 78 (~ 35% of target effort). Sampling produced catches of Silver and Bighead carp in both Cannelton and McAlpine pools with Grass Carp also being captured in R.C. Byrd (Table 5). Seventy-three sets representing 3,338 meters (10,950ft) of net, yielded 254 fish and 13 taxa. Silver Carp made up 33% of the total catch by number while Bighead Carp and Grass Carp made up ~2% of the total each. Smallmouth Buffalo, as they have been in all previous sampling years, made up the largest portion of bycatch (~ 41% of total catch) with Paddlefish and Blue Catfish being the next most common species (~ 5% of total catch each). The remaining 12% of total catch from gill net efforts was made up of

Common Carp, Longnose Gar, Flathead Catfish, Freshwater Drum, Striped Bass, and Bigmouth Buffalo
6 5
the Cannelton Pool peaked in 2017 for both Silver and Bighead carp (Figure 3b and Figure 4); since then, rates have decreased, but continue to fluctuate within the range of our annual standard error. Pools upriver of Cannelton yield such low and sporadic occurrences of invasive carp species that it is difficult to determine if there are true differences in relative abundances. However, with catches being consistently low, it does not appear that relative abundances have increased in pools above McAlpine Locks and Dam.

Fall Standardized Community Monitoring (Cannelton – R.C. Byrd)
Fall electrofishing sampling in 2019 produced zero Bighead Carp captures, four Silver Carp captures in the Cannelton Pool, and one Grass Carp capture in Markland and Greenup. A total of 112 transects (27.5 hours) yielded 15,466 fish comprising 60 taxa (Table7). Emerald Shiners were the most commonly encountered species, 42% of the total catch by number throughout the sampling period (Table 8). Gizzard Shad (~37% total catch), Channel Shiner (~5% total catch), Bluegill Sunfish (~3% total catch), Smallmouth Buffalo (~2% total catch), and Largemouth Bass (~2% total catch) made the majority of the additional diversity seen during community monitoring. The remaining 9% of diversity varied widely by species and location. Accounts of all species captured during sampling can be found in Table 8 below.

During 2018 gill netting surveys, Silver Carp were captured only in the Cannelton Pool while Bighead carp were captured in the Cannelton and R.C. Byrd pools. In 2019, Bighead and Silver carp were both captured in Markland Pool, but not seen elsewhere. One hundred and thirty-six sets representing 6,195m (20,325ft), yielded a total catch of 144 fish and 15 taxa (Table 9). In 2019, Paddlefish replaced Smallmouth Buffalo as the most common species encountered (~51% of total catch) while Smallmouth Buffalo captures made up an additional 18% of total catch (Table 10). Blue Catfish (~6% of total catch), Common Carp (~5% of total catch), and Bigmouth Buffalo (~3% of total catch) made up the majority of the remaining diversity encountered during sampling efforts. The additional diversity making up the remaining 17% of total fish captured in 2019 (Table 10).

Beach seine hauls in the R.C. Byrd Pool captured seven different fish species, including the Eastern Mosquitofish, which has not been represented in community data previously. Emerald Shiners made up the majority of catch (~55% total catch) while Channel Shiner was the second most frequent species (~ 42% of total catch). The next most frequent species encountered were Eastern Mosquitofish, Bluntnose Minnow, and Bluegill Sunfish making up 2%, 0.46%, and 0.30% of total catch respectively. Finally, six Spotfin shiners and 1 Johnny Darter were also collected (Table 11).

Hydroacoustic Analysis
These results were informed by community monitoring data and catch data from removal programs. Cannelton Pool analysis was informed by community monitoring data (Oct. 2019) and catch data from removal programs for Grass Carp (Aug-Oct 2019), Bighead Carp (Oct 2019), and Silver Carp (Oct. 2019). This totaled 365 fish that were over 300 mm in length. McAlpine Pool analysis was informed by community monitoring data (Oct-Nov 2019) and catch data from removal programs for Grass Carp (April 2019), Bighead Carp (July 2019), and Silver Carp (Silver-Oct 2019). This totaled 265 that were over 300 mm in length. No weights were recorded for Bighead Carp in the McAlpine data. Cannelton length-weight data was used for this calculation. The sample size was small and the relationship was not as strong as desired. No community data was available for Greenup Pool in 2019. The 2018 community data (November) was combined with catch data from various removal projects. No Bighead Carp or Silver Carp were captured in Greenup Pool and only one Grass Carp was captured in May 2018. A total of 290 fish greater than 300 mm were used. Only one fish was captured and weighed in 2018 in Greenup Pool. To create length-weight relationships to estimate 2019 Greenup biomass density, Grass Carp length-weight data from Greenup was combined with Cannelton, McAlpine, and Markland. This totaled 18 individuals over 300 mm.

A total of 11 river locations were sampled, and were further broken down by habitat type during analysis resulting in 17 analysis sites (Table 1). Scans in Cannelton and McAlpine were performed by the Lacrosse, WI USFWS office from Dec. 2nd-6th, 2019. Scans in Greenup were performed by the Wilmington, IL USFWS substation from Dec. 9th-12th, 2019. Both offices followed the protocols laid out by the Carterville USFWS office in accordance with previous years of Ohio River hydroacoustics.

Cannelton pool had the greatest density when all carp species were averaged together (0.075 fish/1000m³) (Table 12 , Figure 6). Likewise, each individual species had the greatest site-averaged density in Cannelton: Silver Carp 0.191 fish/1000m³, Bighead Carp 0.014 fish/1000m³, and Grass Carp 0.019 fish/1000m³ (Table 125, Figure 6). The species-averaged density in McAlpine was 0.021 fish/1000m³ (Table 12). McAlpine's species-specific pool-averaged densities were 0.051 fish/1000m³ for Silver Carp, 0.007 fish/1000m³ for Bighead Carp, and 0.006 fish/1000m³ for Grass Carp ((Table 12 , Figure 6). Greenup Pool's average density was dictated by a large grass carp density (0.103 fish/1000m³) making the average 0.034 fish/1000m³ ((Table 12 , Figure 6). Silver Carp and Bighead Carp did not return a measurable density in Greenup Pool; the average value is not representative value for these species. This result is likely due to the lack of carp represented in the community data.

The biomass density of carp species followed a similar pattern to density values (Table 12 , Figure 7). Cannelton Pool had the greatest biomass density when all carp species were averaged together (0.390 kg/1000m³). However, only two of the three species had the greatest site-averaged biomass density in Cannelton (Silver Carp 0.858 kg/1000m³ and Grass Carp 0.019 kg/1000m³). McAlpine Pool had the greatest site-averaged biomass density of Bighead Carp (0.113 kg/1000m³), while Cannelton's biomass density was 0.009 kg/1000m³. The species-averaged biomass density in McAlpine was 0.140 kg/1000m³. The Silver Carp site-averaged biomass density in McAlpine was 0.252 kg/1000m³ and Grass Carp was 0.560 kg/1000m³. Greenup pool had the lowest average carp biomass density at 0.001 kg/1000m³. Silver Carp and Bighead Carp did not have a biomass density for Greenup Pool, but Grass Carp had a biomass density of 0.002 kg/1000m³. The highest recorded density (0.424 ± 0.2248 fish/1000m³) was Silver Carp in the main channel of the Ohio River near Clover Creek and in general the densities of Silver Carp in Cannelton Pool were the highest overall (Table 13 , Figure 8). Biomass densities in Cannelton mirrored this pattern (Table 14 7, Figure 9). The individual site and species-specific densities recorded in McAlpine Pool were generally lower than the densities in Cannelton (Table 13 , Figure 10). Biomass densities in McAlpine did show that Bighead Carp contributed a large proportion of biomass compared to Silver Carp (Table 14 , Figure 10-11 -25). Density and biomass density by site and species were all zero except for Grass Carp at the Guyandotte main channel site.

Assessing Asian Carp Population Demographics

In total, the number of Bighead Carp captured across all projects in 2019 was 50 fish; a slight decrease compared to the 57 fish caught in 2018. Males were most commonly encountered, making up 60% of fish captured during framework efforts in 2019. The majority of fish were captured in the Cannelton Pool with only four fish (two male and two female) being captured in McAlpine, two fish (both female) being captured in Markland. The mean total length for all fish captured, regardless of location, was slightly lower when compared to previous years. Males averaged 977mm (n = 26, SE = 26.2) while females averaged 933mm (n = 17, SE = 32.1). In the Cannelton Pool, male fish exhibited a wider range in total length than female fish (Figure 5). Both sexes fell within the same range of total lengths as seen in past years, but with a higher relative frequency of smaller fish compared to data from 2017 and 2018 (Figure 12). The weight-length regression for 2019 shows a gradual slope when compared to the established ORB regression and a higher y-intercept (Figure 13). Data points from 2019 cluster well with previous data, but the range of data did not span the same range of total lengths observed between 2016 – 2017. With no data available for fish <716mm in total length, it is likely that lack of smaller fish heavily influenced the regression. When considering only the Cannelton Pool, boxplot comparisons of relative weights (W_r) for Bighead Carp over the past four years indicate a general decline in body condition (Figure 14).

In 2019, 761 Silver Carp were captured across all framework projects; this is far less than previous years due to low water levels, and higher than normal temperatures. Males were the most common sex encountered, making up 69% of fish captured throughout the middle Ohio River basin. More specifically, males in the Cannelton Pool made up approximately 68% of the population and averaged 781mm (n = 387, SE = 4.2) in total length, while females averaged slightly larger at 797mm (n = 180, SE = 6.8). Silver Carp captured in the McAlpine Pool were 73% male, averaging 817mm (n = 126, SE = 6.2) in total length while females were 843mm on average (n = 47, SE = 10.2). The ranges in total length were comparable between the two sexes in the Cannelton and McAlpine pools (Figure 15 and Figure 16). Silver Carp caught in the Markland Pool were 71% male with an average total length of 917mm (n = 15, SE = 10.1) and females around 969mm (n = 6, SE = 37.7). As in the past, fish found farther up the system tend not only to be larger on average (Figure 17), but also in better condition, as seen using the relative weight (Wr) equation developed by Lamer *et al*. 2015 for Silver Carp (Figure 18). Within the Cannelton Pool, Silver Carp body condition has remained consistent. Fish captured in 2019 displayed decreases in both the median and range of relative weights compared to previous years (Figure 19). Fish caught in 2019 fit well to the previous regression established for fish in the ORB, and length to weight comparisons were similar to previous years (Figure 20).

Evidence of recent spawning activity, was seen over a much shorter duration in 2019 than in previous years. Seventy-three percent (73%) of female fish captured May 14 – June 12 displayed recent spawning patches. A spawning patch was considered present if it was actively hemorrhaging or the flesh was raw, with scales missing along the ventral keel of the body with little to no visible sign of healing (Figure 21). By the beginning of June most female fish were healing or displayed little sign of spawning activity on their ventral keel. After May 12th, only four fish captured exhibited what appeared to be recent spawning patches in 2019. In contrast, previous years have shown spawning patches beginning in mid-May and continuing throughout the summer into August, indicating a protracted spawning season.

In total, otoliths from 262 Silver or Bighead carp were harvested to track age distribution, growth, and estimate mortality. Otoliths taken from fish above McAlpine Locks and Dam provide a snapshot of age distributions above Cannelton so that managers can determine if populations are growing or aging over time. In 2017 and 2018 the majority of Silver Carp were between the ages of 4 and 6 years and were used to create the first ORB comparison between average total lengths and predicted lengths at age using a von Bertalanffy growth curve (Table 15). Otoliths are currently being processed and aged by KDFWR, but data to date suggests that the majority of Silver Carp captured in both the Cannelton and McAlpine pools are between 4 and 7 years old. Upon completion, otoliths taken in 2019 will be used to model and predict both length at age for Silver Carp in the ORB and estimate mortality in Cannelton and McAlpine pools so that it can be tracked annually.

Monitoring Asian Carps Ahead of the Invasion Front

Targeted gill net sampling for Asian carp in the Montgomery Slough of the Ohio River did not collect any Asian carp species. Common Carp, Smallmouth Buffalo, River Carpsucker, and Sauger were the only four species captured and comprised 55%, 34%, 10%, and 1% of the total catch on the Ohio River, respectively.

Fish community monitoring in the Emsworth Pool of the Allegheny and Monongahela Rivers, Pool 7 of the Allegheny River, and the Maxwell Pool of the Monongahela River was conducted in May and June 2019 and consisted of 1.67 hrs of effort per pool using pulsed DC night electrofishing. No Asian carp species were captured during fish community surveys. Twenty-seven species and 532 individuals, 37 species and 849 individuals, 24 species and 334 individuals, and 37 species and 1015 individuals were captured in the Emsworth Pool (Allegheny), Pool 7 (Allegheny), Emsworth Pool (Monongahela), and Maxwell Pool (Monongahela), respectively. Golden Redhorse, Smallmouth Bass, and Walleye comprised approximately 35% of the total catch between all pools (Table 16).

Beach seining on the Montgomery Island Pool in August 2019 collected no Asian carp species. A total of 2324 individuals of 15 different species were captured. Emerald Shiner comprised 91% of the total catch (Table 17)

The Pennsylvania Fish and Boat Commission tracks incidental captures of Asian carp through other various projects and has no new captures or reports of invasive carps resulting from those efforts. Efforts in 2019 included 24 baited tandem hoop nets that were fished for 72 net nights and captured no Asian carp species. Sixteen species and 480 individuals were captured, and Channel Catfish, Smallmouth Buffalo, and Flathead Catfish comprised 47%, 18%, and 14%, of the total catch, respectively. Daytime boat electrofishing on the Ohio River Montgomery Island Pool, Monongahela River Charleroi Pool, and Allegheny River Pool 4 was conducted for 2.13 hrs of effort and no Asian carp were captured. Similarly, night boat electrofishing on the Ohio River in the New Cumberland Pool at the Montgomery Dam tailwater for 1.5 hrs of effort and in Pool 4 of the Allegheny River for 1.98 hrs of effort captured no Asian Carp in October. No Asian carp were captured during night electrofishing surveys in November in the, Montgomery Island or Dashields Pools of the Ohio River, the Emsworth Pool and Pool 7 of the Allegheny River, and the Emsworth Pool and Maxwell Pool of the Monongahela River (1.33 hrs of effort per pool).

Compilation and Incorporation of Other ORB Data Sources

Data taken from ORSANCO records show a similar pattern in presence/absence of Asian carps as seen during standard monitoring sampling and removal efforts conducted between 2015-2019. The farthest up-river accounts of Silver Carp by ORSANCO were in the Markland Pool in 2012 and McAlpine Pool in 2014. The USGS NAS database expanded the known range of Silver Carp in 2016 after reports from OHDNR about an adult fish detection in Raccoon Creek, a tributary of the R.C. Byrd Pool (Figure 22). Recently, a Bighead Carp was captured in a tributary of the Pike Island Pool in 2016 with an additional account of a Bighead impinged against the water intake screen at WH Sammis Power Plant in the New Cumberland Pool in 2018 (Figure 23). Grass Carp records continue to be sporadic throughout the Ohio River and within all internal waters of the surrounding basin states (Figure 24). This is likely a reflection of Grass Carp establishment throughout the ORB. Reports of Black Carp within the lower part of the Ohio River and surrounding systems have increased in the past few years. In 2019 there were forty-two reports from verified captures in the lower Ohio River and surrounding tributaries, Barkley Lake/Cumberland River, Kentucky Lake/Tennessee River (Figure 25). With some recent captures as far up as the J.T. Meyers Pool, just below Newburgh, IN.

Discussion:

Work conducted in 2019 continues to support the hypothesis that the middle ORB is the current invasion front for Silver Carp expansion in the Ohio River. Thus, work conducted along this geographic range is significant because it provides a snapshot of the upper establishment front as it progresses into the lower end of the presence front for Silver Carp in the sub-basin (Figure 1). Bighead Carp continue to be difficult to capture along this range, but are encountered most frequently in the Cannelton Pool. This originally led to the assumption that their geographic distribution and invasion status followed a similar pattern as Silver Carp. However, evidence from records farther upriver are known to occur and additional knowledge gained from agency removal efforts above Cannelton indicate Bighead patterns of distribution likely differ from that of Silver Carp. With limited data on Bighead Carp, most management actions for the middle ORB utilize information based off of Silver Carp distributions and characteristics. Better sampling techniques and increases in successful captures are needed to determine long-term changes in Bighead Carp densities. Considering the lack of information on Bighead Carp in the basin, Cannelton still contains the highest observed densities of both species and is likely the farthest upriver pool with an established Silver Carp population. Anecdotal increases in sightings through removal effort, and progressively larger annual harvests indicate population crowding and suggest that agency-based removal efforts have not been sufficient to control population growth in the Cannelton Pool. Thus, Cannelton has been the focus for an additional control measure, implemented to suppress upriver Asian carp progression in the ORB: a contract fishing program established in 2019.

High percentages of zero-catches, non-normal data distributions, and infrequently large catches in annual sampling emphasize the aggregate nature of these fishes. This makes tracking trends of intra-pool relative abundance difficult over time. Silver Carp relative abundance has varied over the past four years, but average electrofishing catch rates in 2019 were the highest in the Cannelton Pool to date. Interestingly, average gill net catch rates exhibited a similar pattern in the Cannelton Pool over time. Electrofishing and netting efforts have been conducted independently, and occasionally, sampling may not have even occurred within the same week. This synchronicity has not been observed between gears above the Cannelton Pool, and densities of Silver Carp have continually appeared to drop as much as 75% – 82% when moving just one pool upriver. In pools above McAlpine, electrofishing efforts have not provided sufficient information about invasive carp abundances or demographics, and more effort would be necessary to subscribe management recommendations for controlling invasive carp abundances in Markland – R.C. Byrd pools. Additionally, standardized gill netting provides little to no information on populations above Cannelton, except that numbers of fish are so low that detection is unlikely using this particular gear type.

Most data from fish in low density pools is collected through population control efforts. While limited, it consistently indicates that Silver Carp located further upriver are larger and have better body conditions than fish in the Cannelton Pool. Increased frequency of larger length-classes of Silver Carp, in addition to narrower ranges of total lengths suggest that fish captured upriver are likely immigrants rather than indicating successful recruitment in those pools. Carp collections above the invasion front continue to be sporadic, and records above R.C. Byrd Pool were not observed in 2019 through either intentional or unintentional sampling efforts.

The hydroacoustics data show similar trends as indicated above, with overall carp densities being highest in Cannelton Pool, and decreasing as you move upstream. The density of total carp decreased by over half from Cannelton to McAlpine. Greenup Pools average density was dictated by a high Grass Carp density. Grass Carp were only detected at one site in Greenup Pool – Guyandotte Main Channel. This site registered a very high density of Grass Carp (0.7220 ± 0.3100 fish/1000m^3); the highest density of any species at any site. This value could have resulted from insufficient community data and should be investigated further. Individual species density also decreased when moving from Cannelton Pool upstream. Silver Carp had the greatest overall density in Cannelton, followed by McAlpine and then Greenup, which had an undetectable density. In McAlpine Pool, Bighead Carp had a high relative biomass when compared to Silver Carp and Grass Carp. This phenomenon has also been noted by Coulter et al 2018. The standard error associated with the 95% confidence intervals for density and biomass density need to be investigated further.

The results from hydroacoustics for the 2019 field season are limited by the absence of data from Markland, Meldahl, and R.C. Byrd. Markland and Meldahl were excluded from hydroacoustics scans due to a lack of community data to inform the results. R.C. Byrd Pool sites were attempted, but due to conditions and equipment failure, they could not be completed. This gap in the data limits our ability to tell where the carp populations begin to be undetectable with this method. Additionally, the community data that was used to inform this analysis was a combination of community monitoring data, various removal projects, and previous year's data. This could introduce error or skew the data. In the future, we hope to focus on a smaller range of sites (J.T. Meyers, Newbourgh, Cannelton, and McAlpine) where densities will make quality community data easier to obtain. Community monitoring efforts are continually being evaluated to improve efficacy and efficiency. In the future, new gear types, including the Dozer Trawl and Paupier, will be evaluated for use in the Ohio River to effectively capture Asian Carp populations.

Increases in CPUE appeared to be associated with spawning activity in 2017 – 2019, and carp appear more susceptible to traditional gears and techniques during May – August. In addition, fish appear to move into adjacent tributaries and embayments when river flows increase. These characteristics provide strategic periods when population control efforts can be prioritized by targeting fish entering or exiting tributaries and embayments. Catch rates tend to decrease as water temperatures decrease entering into fall making collections difficult and likely decreasing invasive carp representation in community monitoring efforts. However, as temperatures cool, contract anglers and agency crews have been successful in identifying and collecting fish using netting techniques because the fish are more sluggish and susceptible to entanglement. Winter target areas include many of the tributaries and embayments in the lower Cannelton Pool and some deeper tributaries in upper Cannelton and McAlpine pools. These observations lead us to recommend that regular removal targeting in these locations be incorporated annually to boost population control efforts.

Recommendations:
Targeted, standardized sampling should continue to increase our ability to observe changes in relative abundances of invasive carps along the invasion front. However, wide variations in annual sampling ranges indicate a need to expand efforts under the current protocol to increase confidence around mean catch rates. In addition, area or distance-based electrofishing sampling should be investigated due to its ability to better standardize sampling effort when considering differences in driver movement and responses when pursuing fish. Also, sampling units which incorporate both electrofishing and gill nets should be investigated to determine if the herding techniques used in removal efforts are able to be standardized to better target Bighead carp. This may also aid in defining standardized areas for sampling efforts. However, this may not address problems concerning large numbers of zero-data and infrequently large catches in annual sampling. Exploration into more sensitive measures of change are under consideration (e.g. annual probabilities of detection, changes in proportion of zero-catches, and occupancy modeling).

The effort it takes to perform the community sampling to inform hydroacoustics is time consuming and often unproductive due to low carp populations in the upper pools of the Ohio River. Without robust community data, hydroacoustics analysis has the potential to mis-represent the density of fish species. Moving forward with this project, we plan to focus hydroacoustics efforts in pools that can provide appropriate community data to assure accuracy in the hydroacoustics results. This will involve a continuation and potential expansion of hydroacoustics sites in Cannelton and McAlpine, and the addition of sites in J.T. Myers and Newburgh.

When considering sampling locations, the majority of zero-catch runs or net-sets come from the main-stem river, island back-channels, and dam tailwaters. Redirecting sampling efforts to only tributaries and embayments may increase CPUE averages and lower proportions of zero-catch data, but may not sufficiently represent trend changes in pools with less dense Asian carp numbers. However, telemetry data may allow basin states to investigate if there are periods of time where the majority of the invasive carp populations occupy tributaries or waters accessible to standard gears. Using this information, annual sampling may be adjusted to better target fish while still getting a representative sample of fish in each pool.

Finally, with little indication that agency-based removal is sufficient to control populations along the establishment front, the continuation of the contract angling program is recommended. More detail about this program is available in the control and containment report for the ORB, but in summary, contract anglers were able to remove over 100,000 lbs of invasive carp in just five – six months of fishing in the Cannelton Pool. Over half of harvests are verified through receipts of sale to the Kentucky Fish Center (KFC) or other processors and on-board observers are giving managers access to bycatch information in addition to subsamples of target landings data which will allow partners to consider additional recommendations concerning population control.

Project Highlights:

- In 2019, electrofishing catch rates for Silver Carp were the highest they have been since the evaluation project began. Gill net data has fluctuated in a similar fashion, mirroring changes in electrofishing catch rates over time. Few fish are successfully captured upriver of Cannelton Pool and more effort needs to be placed into tracking changes in those pools.
- High percentages of zero-catches, non-normal data distributions, and infrequently large catches in annual sampling emphasize the aggregated distributions of invasive carp and make trends in relative abundances difficult to track over time. It is recommended that effort be increased to strengthen confidence around annual estimates of relative abundance.
- Capture numbers continue to reflect that Cannelton and McAlpine have much higher densities of invasive bigheaded carp than the pools above them and relative abundances would suggest that the current geographic line for Silver Carp establishment likely falls in Cannelton Pool despite the absence of YOY fish found above J.T. Myers Pool.
- Hydroacoustics data indicated Asian Carp density and biomass density decrease as you move upstream from Cannelton into higher pools of the Ohio River Basin. The hydroacoustics program will benefit from more robust community data. Agency-based removal efforts do not appear to have slowed the growth of Silver Carp populations over the last four years, however, the newly established contract angling program was successful in applying large increases in pressure on invasive carp populations in the Cannelton Pool. It is recommended that this program continue and basin partners remain engaged with the program in order to make recommendations and encourage its success.
- With less information on Bighead Carp, little can be said to the extent of their establishment within the ORB; however, Bighead are able to be targeted at strategic locations, even in low density pools. Better sampling strategis need to be developed to aid in assessing changes in their densities over time.
- Telemetry may be a useful tool in helping to fine-tune monitoring efforts, especially if it can show that residency times for invasive carp increase during certain times when traditional fisheries gears can be utilized to monitor their abundance.
- No occurrences of invasive bigheaded carp were recorded in targeted or incidental sampling events ahead of Racine Locks and Dam for 2019. However, removal efforts in collaboration with USFWS did produce eight Bighead captures in the R.C. Byrd Pool indicating that larger scale removal efforts are warranted to lower numbers in that pool and decrease the likelihood of successful recruitment.

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Appendix A: Tables

Table 1 . 2019 Hydroacoustics Sites

Pool	Site	Habitat

Cannelton	Clover Creek	Main Channel
Cannelton	Clover Creek	Tributary
Cannelton	McAlpine Tailwater	Main Channel
Cannelton	Salt River	Main Channel
Cannelton	Salt River	Tributary
McAlpine	Harrods Creek	Tributary
McAlpine	Harrods Creek	Main Channel
McAlpine	Six Mile Island	Side Channel
McAlpine	Little KY	Main Channel
McAlpine	Little KY	Tributary
McAlpine	Patton	Main Channel
Greenup	Big Sandy	Main Channel
Greenup	Big Sandy	Tributary
Greenup	Guyan Creek	Main Channel
Greenup	Guyandotte	Main Channel
Greenup	Guyandotte	Tributary
Greenup	Little Sandy	Main Channel
Greenup	Little Sandy	Tributary

Table 2 . Estimated weights at two lengths for Silver Carp from published data collected throughout their range in the Mississippi River basin. Amended from Hayer et al. 2014.

System: Specific Locale	L-W Regression Equation (metric)	Predicted weight for 450mm (g)	Predicted weight for 800mm (g)	Reference
Ohio River	$\log_{10}$ weight = -5.13 + 3.05($\log_{10}$ length)	917	5302	ORB Technical Report 2017
Illinois River	$\log_{10}$ weight = -5.29 + 3.12($\log_{10}$ length)	972	5856	Irons et al. 2011
Middle Mississippi River	$\log_{10}$ weight = -5.29 + 3.11($\log_{10}$ length)	915	5477	Williamson and Garvey 2005
Missouri River: Gavins Point	$\log_{10}$ weight = -6.92 + 3.70($\log_{10}$ length)	788	6628	Wanner and Klumb 2009
Missouri River: Interior Highlands	$\log_{10}$ weight = -5.35 + 3.13($\log_{10}$ length)	900	5453	Wanner and Klumb 2009
Missouri River tributary: Big Sioux River	$\log_{10}$ weight = -5.53 + 3.21($\log_{10}$ length)	970	6150	Hayer et al. 2014
Missouri River tributary: James River	$\log_{10}$ weight = -5.26 + 3.11($\log_{10}$ length)	981	5869	Hayer et al. 2014
Missouri River tributary: Vermillion River	$\log_{10}$ weight = -4.82 + 2.90($\log_{10}$ length)	748	3971	Hayer et al. 2014

Table 3 . Estimated weights at two lengths for Bighead Carp from published data collected throughout their range in the Mississippi River basin.

System: Specific Locale	L-W Regression Equation (metric)	Predicted weight for 450mm (g)	Predicted weight for 800mm (g)	Reference
Ohio River	$\log_{10}$ weight = -5.05 + 3.03 ($\log_{10}$ length)	976	5577	ORB Technical Report 2017
Illinois River: La Grange	$\log_{10}$ weight = -4.84 + 2.95 ($\log_{10}$ length)	970	5298	Irons et al. 2010
Missouri River (Males)	$\log_{10}$ weight = -5.42 + 3.15 ($\log_{10}$ length)	866	5306	Schrank and Guy 2002
Missouri River (Females)	$\log_{10}$ weight = -5.40 + 3.13 ($\log_{10}$ length)	803	4860	Schrank and Guy 2002
Missouri River: Gavins Point	$\log_{10}$ weight = -4.86 + 2.96($\log_{10}$ length)	985	5409	Wanner and Klumb 2009
Missouri River: Interior Highlands	$\log_{10}$ weight = -4.30 + 2.75($\log_{10}$ length)	991	4825	Wanner and Klumb 2009

Table 4 Electrofishing effort and the resulting total catch by the number of fish, number of species, and catch per unit effort (fish per hour) of three species of Asian carp captured in six pools of the Ohio River from spring targeted sampling in 2019. Standard errors are in parentheses.

Spring Boat Electrofishing							
	Ohio River 2019						
	Cannelton	McAlpine	Markland	Meldahl	Greenup	RC Byrd	Total
Sampling Dates	09 April - 16 May						
Effort (Hours)	5.00	5.00	6.00	5.25	4.66	5.88	31.79
Sample Transects	20	20	24	21	19	26	130
All Fish (N)	87	17	8	0	0	0	112
Species (N)	2	1	2	0	0	0	2
Bighead Carp (N)	0	0	0	0	0	0	0
Silver Carp (N)	86	15	3	0	0	0	104
Grass Carp (N)	1	2	5	0	0	0	8
	CPUE (fish/hr)						
Bighead Carp	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00	0.00	
Silver Carp	17.2 (4.28)	3.00 (1.30)	0.5 (0.37)	0.00 (0.00)	0.00	0.00	
Grass Carp	0.20 (0.20)	0.40 (0.28)	0.83 (0.34)	0.00 (0.00)	0.00	0.00	

Table 5 . Gill netting effort and summaries of the resulting total catch by the number of fish, number of species, and catch per unit effort (fish per yard) of three species of Asian carp captured in six pools of the Ohio River from spring targeted sampling in 2019. Standard errors are in parentheses.

Spring Gill Netting							
	Ohio River 2019						
	Cannelton	McAlpine	Markland	Meldahl	Greenup	RC Byrd	Total
Sampling Dates	18 April - 29 May						
Effort (ft)	3900	2100	0	0	1500	3450	10950
Net Sets	26	14	0	0	10	23	73
All Fish (N)	120	113	0	0	0	21	254
Species (N)	11	8	0	0	0	8	13
Bighead Carp (N)	4	1	0	0	0	0	5
Silver Carp (N)	68	16	0	0	0	0	84
Grass Carp (N)	3	1	0	0	0	2	6
	CPUE (fish/yd)						
Bighead Carp	3.1e-3 (1.8e-3)	1.4e-3 (1.4e-3)	0.00	0.00	0.00	0.00	
Silver Carp	0.05 (0.02)	0.02 (0.02)	0.00	0.00	0.00	0.00	
Grass Carp	2.3e-3 (1.7e-3)	1.4e-3 (1.4e-3)	0.00	0.00	0.00	5.8e-4 (4.0e-4)	

Table 6 A bycatch table showing the catch of non-target species through the use of gill netting during 2019 targeted monitoring. (Ohio River Pools: Cann = Cannelton; McAlp = McAlpine; Mark = Markland; Meld = Meldahl; Green = Greenup; RCBy = R.C. Byrd)

Spring Gill Netting							
	Ohio River Pools in 2019						
By-Catch	Cann	McAlp	Mark	Meld	Green	RCBy	Total
Bigmouth Buffalo		1					1
Blue Catfish	8					5	13
Common Carp	7	2				1	10
Flathead Catfish	3					3	6
Freshwater Drum	1	1				2	4
Longnose Gar	4	2				2	8
Paddlefish	12	1					13
Smallmouth Buffalo	8	90				5	103
Striped Bass	2						2

Table 7 . Electrofishing effort and the resulting total catch by the number of fish, number of species, and catch per unit effort (fish per hour) of three species of Asian carp captured in six pools of the Ohio River from fall community sampling in 2019. Standard errors are in parentheses.

Fall Boat Electrofishing							
	Ohio River 2019						
	Cannelton	McAlpine	Markland	Meldahl	Greenup	RC Byrd	Total
Sampling Dates	15 October - 20 November						
Effort (Hours)	6.00	5.25	6.00	0.00	4.77	5.47	27.49
Sample Transects	24	21	24	0	19	24	112
All Fish (N)	1038	657	1542	0	2744	9485	15466
Species (N)	39	34	32	0	41	41	60
Bighead Carp (N)	0	0	0	0	0	0	0
Silver Carp (N)	4	0	0	0	0	0	4
Grass Carp (N)	0	0	1	0	1	0	2
	CPUE (fish/hr)						
Bighead Carp	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00	0.00	0.00	
Silver Carp	0.67 (0.39)	0.00 (0.00)	0.00 (0.00)	0.00	0.00	0.00	
Grass Carp	0.00 (0.00)	0.00 (0.00)	0.17 (0.17)	0.00	0.21 (0.21)	0.00	

Table 8 . The number of fish captured by species and percent of total catch during fish community surveys in six pools of the Ohio River with boat electrofishing at fixed monitoring sites in 2019. (Ohio River Pools: Cann = Cannelton; McAlp = McAlpine; Mark = Markland; Meld = Meldahl; Green = Greenup)

	Ohio River Pools in 2019							
Species Captured	Cann	McAlp	Mark	Meld	Green	RC Byrd	Total	Percent
Bigeye Chub						2	2	0.013%
Bigmouth Buffalo	2	3			1	3	9	0.058%
Black Crappie	3	1	2		3	8	17	0.110%
Black Redhorse		3	6				9	0.058%
Blue Catfish	1						1	0.006%
Bluegill Sunfish	117	56	89		150	82	494	3.194%
Blue Sucker	5						5	0.032%
Bluntnose Minnow	1				15	41	57	0.369%
Bowfin	1				3	1	5	0.032%
Brook Silverside	2						2	0.013%
Bullhead Minnow						3	3	0.019%
Central Stoneroller						11	11	0.071%
Channel Catfish	14	21	21		20	13	89	0.575%
Channel Shiner					10	708	718	4.642%
Common Carp	4	3	16		11	15	49	0.317%
Emerald Shiner	514	93	154		1399	4347	6507	42.073%
Flathead Catfish	3	1			2	4	10	0.065%
Freshwater Drum	14	25	14		128	58	239	1.545%
Gizzard Shad	75	189	964		577	3864	5669	36.655%
Golden Redhorse	16	11	16		38	11	92	0.595%
Goldfish						1	1	0.006%
Grass Carp			1		1		2	0.013%
Green Sunfish	1	5	2		6	29	43	0.278%
Highfin Carpsucker			3		2		5	0.032%
Johnny Darter					1	2	3	0.019%
Largemouth Bass	17	64	41		66	51	239	1.545%
Logperch	1						1	0.006%
Longear Sunfish	16	22	5		11	7	61	0.394%
Longnose Gar	20	16	11		14	6	67	0.433%
Mooneye	1						1	0.006%
Moxostoma Genus	1		1				2	0.013%
Muskellunge					2		2	0.013%
Northern Hogsucker		1	3			4	8	0.052%
Orangespotted Sunfish	5	3	1			28	37	0.239%
Quillback	1	1			1		3	0.019%

Table 8 (cont). The number of fish captured by species and percent of total catch during fish community surveys in six pools of the Ohio River with boat electrofishing at fixed monitoring sites in 2019. (Ohio River Pools: Cann = Cannelton; McAlp = McAlpine; Mark = Markland; Meld = Meldahl; Green = Greenup)

	Ohio River Pools in 2019							
Species Captured	Cann	McAlp	Mark	Meld	Green	RC Byrd	Total	Percent
Redear Sunfish	24	8	4		5	1	42	0.272%
River Carpsucker	6	12	23		43	5	89	0.575%
River Redhorse		7	2		3	2	14	0.091%
Rock Bass		1					1	0.006%
Sand Shiner	1						1	0.006%
Sauger	3	1	3		22	11	40	0.259%
Saugeye					2		2	0.013%
Smallmouth Redhorse	13	5			3	7	28	0.181%
Silver Carp	4						4	0.026%
Silver Chub			2		4		6	0.039%
Silver Lamprey					1		1	0.006%
Silver Redhorse					15	1	16	0.103%
Skipjack Herring	13	17	7		3	5	45	0.291%
Smallmouth Bass	7	8	6		11	19	51	0.330%
Smallmouth Buffalo	68	41	68		117	89	383	2.476%
Spotfin Shiner						5	5	0.032%
Spotted Bass	30	19	11		20	14	94	0.608%
Spotted Gar	11						11	0.071%
Spotted Sucker	7	2	14		5	8	36	0.233%
Striped Bass	5	10	2				17	0.110%
Walleye					3	2	5	0.032%
Warmouth		3	5			1	9	0.058%
Hybrid Striped Bass	1	1	1		14	3	20	0.129%
White Bass	1	1	14		5		21	0.136%
White Crappie	9	3	30		6	12	60	0.388%
Yellow Perch					1	1	2	0.013%
Totals	1038	657	1542	0	2744	9485	15466	

Table 9 Gill netting effort and summaries of the resulting total catch by number of fish, number of species, and catch per unit effort (fish per yard) of three species of Asian carp captured in six pools of the Ohio River from fall community sampling in 2019. Standard errors are in parentheses.

Fall Gill Netting							
	Ohio River 2019						
	Cannelton	McAlpine	Markland	Meldahl	Greenup	RC Byrd	Total
Sampling Dates	05 October - 20 November						
Effort (ft)	4800	4200	5850	0	2325	3150	20325
Net Sets	32	28	39	0	16	21	136
All Fish (N)	88	16	33	0	2	5	144
Species (N)	5	6	11	0	2	3	15
Bighead Carp (N)	0	0	2	0	0	0	2
Silver Carp (N)	0	0	2	0	0	0	2
Grass Carp (N)	2	0	0	0	0	1	3
	CPUE (fish/yd)						
Bighead Carp	0.00	0.00	1.0e-3 (1.0e-3)	0.00	0.00	0.00	
Silver Carp	0.00	0.00	1.0e-3 (7.2e-4)	0.00	0.00	0.00	
Grass Carp	1.3e-3 (8.7e-4)	0.00	0.00	0.00	0.00	0.00	

Table 10 . The number of fish captured by species and percent of total catch in six pools of the Ohio River with gill netting surveys at fixed monitoring sites in 2019. (Ohio River Pools: Cann = Cannelton; McAlp = McAlpine; Mark = Markland; Meld = Meldahl; Green = Greenup)

	2019 Fall Monitoring Gill Netting							
	River Pool							
Species Captured	Cann	McAlp	Mark	Meld	Green	RC Byrd	Total	Percent
Bighead Carp			2				2	1.389%
Bigmouth Buffalo			5				5	3.472%
Blue Catfish	4		5				9	6.250%
Common Carp	3		3		1		7	4.861%
FlatheadCatfish			1			3	4	2.778%
FreshwaterDrum		2					2	1.389%
Gizzard Shad			1				1	0.694%
Grass Carp	2					1	3	2.083%
Longnose Gar		1				1	2	1.389%
Paddlefish	71	3					74	######
Silver Carp			2				2	1.389%
Silver Redhorse		2	1				3	2.083%
Smallmouth Buffalo	8	7	10		1		26	######
Striped Bass			1				1	0.694%
Hybrid Striped Bass		1	2				3	2.083%
Totals	88	16	33	0	2	5	144	

Table 11 . The number of fish captured by species and percent total catch from four seine hauls in the RC Byrd Pool of the Ohio River

	RC Byrd Pool 2019	
Species Captured	N	% Catch
Bluegill	10	0.30
Bluntnose Minnow	15	0.46
Channel Shiner	1382	41.99
Eastern Mosquitofish	70	2.13
Emerald Shiner	1807	54.91
Johnny Darter	1	0.03
Spotfin Shiner	6	0.18
Total	3291	

Table 12 The average density and biomass density of carp species by pool.

Pool	Silver Carp (fish/1000m³)	Bighead Carp (fish/1000m³)	Grass Carp (fish/1000m³)	Total Carp (fish/1000m³)
Cannelton	0.191	0.014	0.019	0.075
McAlpine	0.051	0.007	0.006	0.021
Greenup	0.000	0.000	0.103	0.034
	Silver Carp (kg/1000m³)	**Bighead Carp (kg/1000m³)**	**Grass Carp (kg/1000m³)**	**Total Carp (kg/1000m³)**
Cannelton	0.858	0.099	0.213	0.390
McAlpine	0.252	0.113	0.056	0.140
Greenup	0.000	0.000	0.002	0.001

Table 13. The density of carp species per site and habitat type sampled.

Site	SVCP fish/1000m³ ± 95% CI	BHCP fish/1000m³ ± 95% CI	GSCP fish/1000m³ ± 95% CI
Clover Creek MC	0.424 ± 0.2248	0.0291 ± 0.0154	0.0450 ± 0.0239
Clover Creek Trib	0.2844 ± 0.0877	0.0225 ± 0.0069	0.0253 ± 0.0078
McAlpine Tailwater MC	0.0068 ± 0.0031	0.0006 ± 0.0003	0.0015 ± 0.0007
Salt River MC	0.2001 ± 0.2001	0.0157 ± 0.0157	0.0171 ± 0.0171
Salt River Trib	0.0383 ± 0.0070	0.0032 ± 0.0006	0.0067 ± 0.0012
Harrods Creek Trib	0.1545 ± 0.1494	0.0280 ± 0.0271	0.0213 ± 0.0206
Harrods Creek MC	0.0568 ± 0.0182	0.0025 ± 0.0008	0.0037 ± 0.0012
Six Mile Island SC	0.0356 ± 0.0281	0.0057 ± 0.0045	0.0029 ± 0.0022
Little KY MC	0.0203 ± 0.0203	0.0014 ± 0.0014	0.0017 ± 0.0017
Little KY Trib	0.0164 ± 0.0068	0.0024 ± 0.0010	0.0018 ± 0.0007
Patton MC	0.0237 ± 0.0224	0.0016 ± 0.0015	0.0045 ± 0.0042
Big Sandy MC	0.0000 ± 0.0000	0.0000 ± 0.0000	0.0000 ± 0.0000
Big Sandy Trib	0.0000 ± 0.0000	0.0000 ± 0.0000	0.0000 ± 0.0000
Guyan Creek MC	0.0000 ± 0.0000	0.0000 ± 0.0000	0.0000 ± 0.0000
Guyandotte MC	0.0000 ± 0.0000	0.0000 ± 0.0000	0.7220 ± 0.3100
Guyandotte Trib	0.0000 ± 0.0000	0.0000 ± 0.0000	0.0000 ± 0.0000
Little Sandy MC	0.0000 ± 0.0000	0.0000 ± 0.0000	0.0000 ± 0.0000
Little Sandy Trib	0.0000 ± 0.0000	0.0000 ± 0.0000	0.0000 ± 0.0000

Table 14 . The biomass density of carp species per site and habitat type sampled.

Site	SVCP kg/1000m³ ± 95% CI	BHCP kg/1000m³ ± 95% CI	GSCP kg/1000m³ ± 95% CI
Clover Creek MC	1.9124 ± 1.0138	0.1896 ± 0.1005	0.5042 ± 0.2673
Clover Creek Trib	1.2550 ± 0.3869	0.1659 ± 0.0512	0.2775 ± 0.0855
McAlpine Tailwater MC	0.0297 ± 0.0136	0.0037 ± 0.0017	0.0171 ± 0.0078
Salt River MC	0.9212 ± 0.9212	0.1139 ± 0.1139	0.1848 ± 0.1848
Salt River Trib	0.1738 ± 0.0317	0.0214 ± 0.0039	0.0791 ± 0.0144
Harrods Creek Trib	0.6719 ± 0.6500	0.4552 ± 0.4404	0.1976 ± 0.1911
Harrods Creek MC	0.3104 ± 0.0994	0.0394 ± 0.0126	0.0351 ± 0.0113
Six Mile Island SC	0.2036 ± 0.1606	0.0976 ± 0.0770	0.0283 ± 0.0223
Little KY MC	0.1115 ± 0.1115	0.0220 ± 0.0220	0.0153 ± 0.0153
Little KY Trib	0.0868 ± 0.0359	0.0383 ± 0.0158	0.0175 ± 0.0072
Patton MC	0.1255 ± 0.1182	0.0247 ± 0.0233	0.0434 ± 0.0409
Big Sandy MC	0.0000 ± 0.0000	0.0000 ± 0.0000	0.0000 ± 0.0000
Big Sandy Trib	0.0000 ± 0.0000	0.0000 ± 0.0000	0.0000 ± 0.0000
Guyan Creek MC	0.0000 ± 0.0000	0.0000 ± 0.0000	0.0000 ± 0.0000
Guyandotte MC	0.0000 ± 0.0000	0.0000 ± 0.0000	0.0135 ± 0.0058
Guyandotte Trib	0.0000 ± 0.0000	0.0000 ± 0.0000	0.0000 ± 0.0000
Little Sandy MC	0.0000 ± 0.0000	0.0000 ± 0.0000	0.0000 ± 0.0000
Little Sandy Trib	0.0000 ± 0.0000	0.0000 ± 0.0000	0.0000 ± 0.0000

Table 15 . Average length at age for Silver Carp captured in 2017 and 2018 and predicted length at age based on a von Bertalanffy growth model.

Age	n	Mean Length (mm)	Std Deviation (mm)	Predicted Length* (mm)
1	4	333	+/- 49	367
2	7	560	+/- 66	536
3	4	654	+/- 28	659
4	11	767	+/- 76	748
5	17	814	+/- 72	813
6	12	866	+/- 50	860
7	9	850	+/- 48	895
8	2	867	+/- 153	920
9	1	963		938
10	1	986		950

* Predictions are based on von Bertalanffy growth model derived using data from fish aged in 2017 and 2018.

Table 16 . Total number of fish captured per pool and percent of total captured at four pools combined in the Allegheny and Monongahela Rivers during spring night electrofishing surveys in 2019. (A=Allegheny, M=Monongahela)

Allegheny and Ohio River Pools in 2019						
Species Captured	Emsworth (A)	Pool 7 (A)	Emsworth (M)	Maxwell (M)	Total	Percent
Black Crappie		1		3	4	0.15%
Black Redhorse	23	141	5	64	233	8.53%
Bluegill	1	7	2	22	32	1.17%
Bluntnose Minnow	3			131	134	4.91%
Brook Silverside		2			2	0.07%
Channel Catfish	1	14	6	3	24	0.88%
Channel Darter				1	1	0.04%
Channel Shiner	6	1		34	41	1.50%
Common Carp	13	4		1	18	0.66%
Emerald Shiner	14	23		208	245	8.97%
Flathead Catfish			2	3	5	0.18%
Freshwater Drum	16		14	5	35	1.28%
Gizzard Shad	3	1	5	1	10	0.37%
Golden Redhorse	60	142	21	113	336	12.31%
Golden Shiner		1			1	0.04%
Green Sunfish				31	31	1.14%
Greenside Darter		1		4	5	0.18%
Johnny Darter				4	4	0.15%
Largemouth Bass		1	1	3	5	0.18%
Lepomis hybrids				1	1	0.04%
Logperch		2	5	6	13	0.48%
Longhead Darter	8	1			9	0.33%
Longnose Gar	16	1	33	10	60	2.20%
Mimic Shiner	13	4		80	97	3.55%
Mottled Sculpin		1			1	0.04%
Muskellunge				1	1	0.04%
Northern Hog Sucker	3	6	1	7	17	0.62%
Pumpkinseed		1			1	0.04%
Quillback	2	23	13	1	39	1.43%
Rainbow Trout - Hatchery			1		1	0.04%
River Carpsucker	2	3	4	5	14	0.51%
River Redhorse	6	22	10		38	1.39%
Rock Bass	17	33	5	16	71	2.60%
Sand Shiner	15	4		83	102	3.74%
Sauger	17		40	26	83	3.04%
Silver Redhorse	21	27	40	13	101	3.70%
Silver Shiner		1			1	0.04%

Table 16 (cont). Total number of fish captured per pool and percent of total captured at four pools combined in the Allegheny and Monongahela Rivers during spring night electrofishing surveys in 2019. (A=Allegheny, M=Monongahela)

Allegheny and Ohio River Pools in 2019						
Species Captured	Emsworth (A)	Pool 7 (A)	Emsworth (M)	Maxwell (M)	Total	Percent
Smallmouth Bass	96	94	41	68	299	10.95%
Smallmouth Buffalo	14	20	31		65	2.38%
Smallmouth Redhorse	37	124	5	15	181	6.63%
Spotfin Shiner	3	8	1	8	20	0.73%
Spotted Bass				5	5	0.18%
Streamline Chub		2			2	0.07%
Striped Shiner		2			2	0.07%
Trout Perch		2			2	0.07%
Walleye	117	124	46	29	316	11.58%
White Bass				3	3	0.11%
White Crappie	5	1	2		8	0.29%
White Sucker				1	1	0.04%
Yellow Perch		4		6	10	0.37%
Totals	532	849	334	1015	2730	

Table 17 . Total number of fish captured and percent of total captured during annual beach seine surveys in the Montgomery Island Pool from 2019.

Species Captured	2019	Percent Abundance
Bluntnose Minnow	44	1.89%
Central Stoneroller	2	0.09%
Channel Catfish	1	0.04%
Channel Shiner	7	0.30%
Emerald Shiner	2107	90.66%
Gizzard Shad	4	0.17%
Mimic Shiner	7	0.30%
Northern Hog Sucker	7	0.30%
Rainbow Darter	1	0.04%
Sand Shiner	17	0.73%
Silver Chub	4	0.17%
Silver Shiner	16	0.69%
Smallmouth Bass	2	0.09%
Spotfin Shiner	104	4.48%
Spotted Bass	1	0.04%
Totals	2324	

Appendix B: Figures

Figure 1. The Ohio River, from the Cannelton to R.C. Byrd Pool, with corresponding invasion statuses for Silver Carp. These are subject to change on an annual basis upon the receipt of new data and are currently developed using standard sampling and project data from the interagency efforts in Ohio River basin.

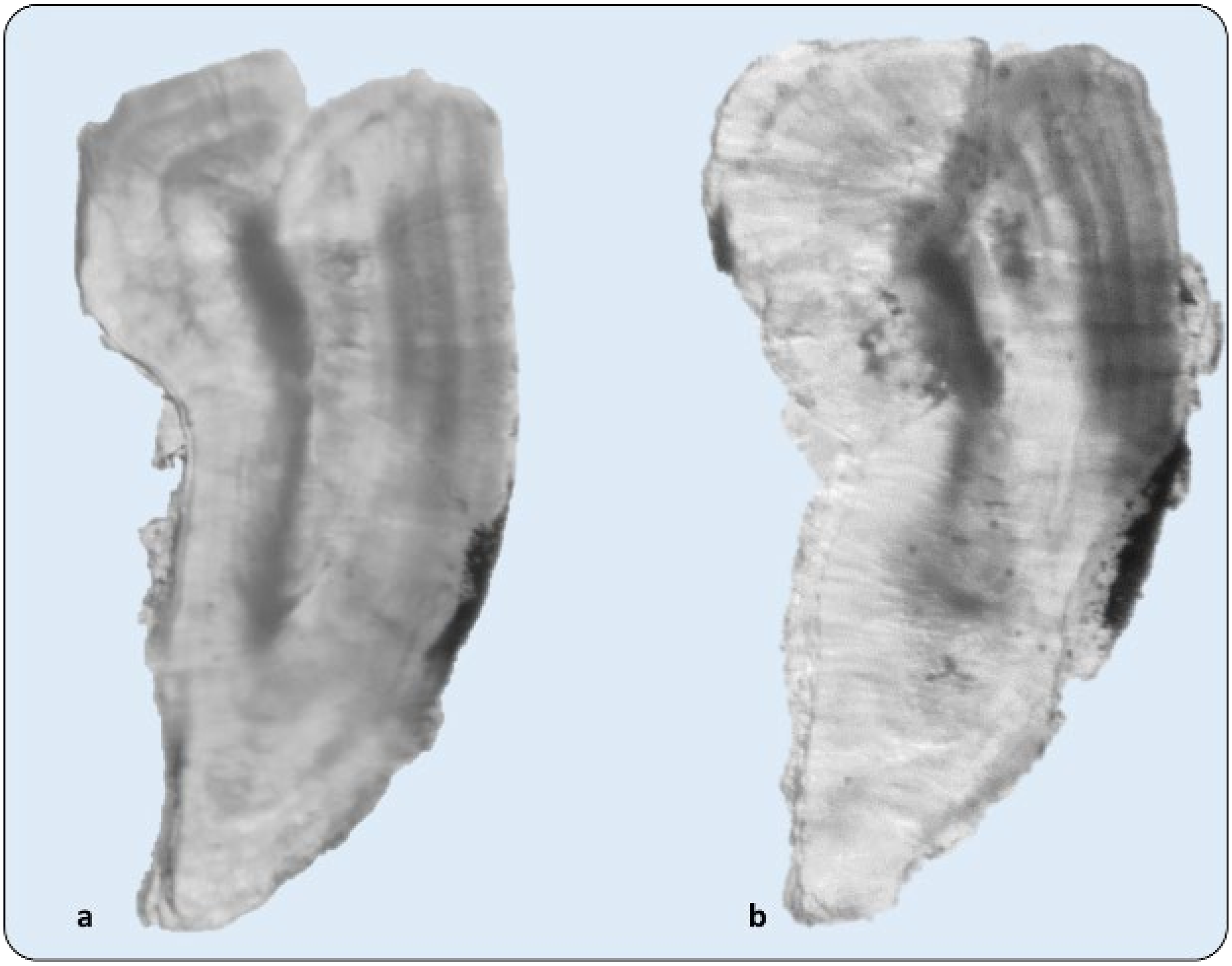
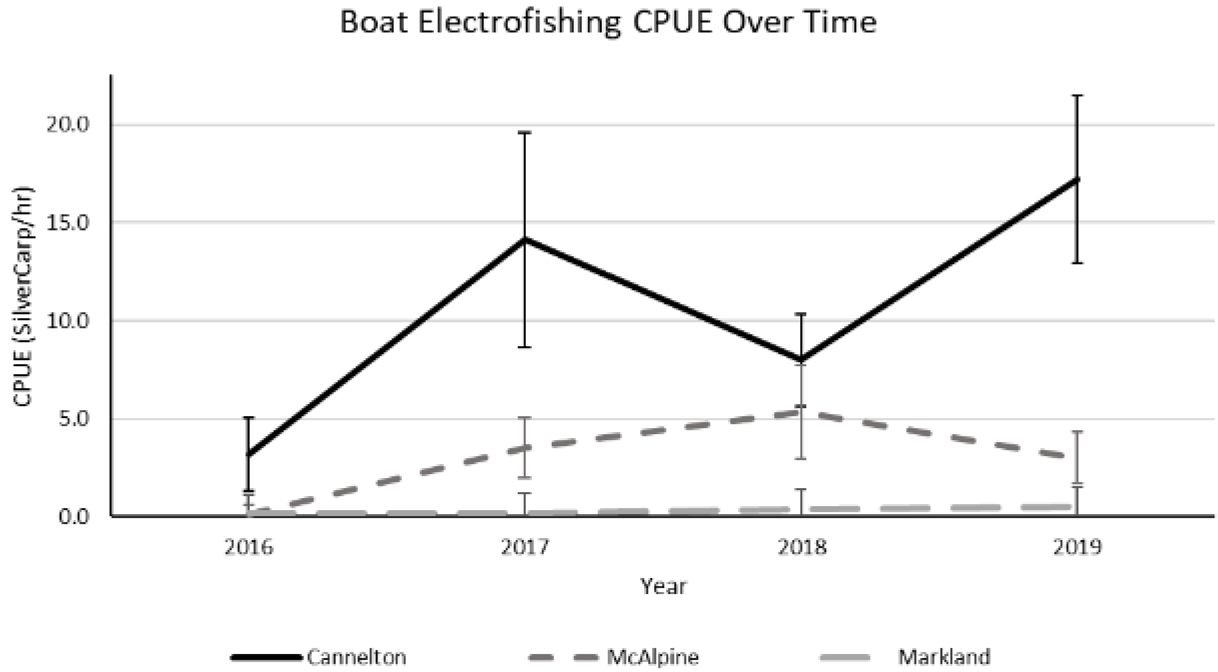


Figure 2. Examples of otoliths taken from fish removed from the ORB during spring standardized monitoring in the Cannelton Pool. Sizes are not to scale. Figure 2a. Otolith harvested from an assumed 4-year-old male Silver Carp at 780mm and 4.6kg. Figure 2b. Otolith harvested from an assumed 5-year-old male Silver Carp at 856mm and 6.1kg.



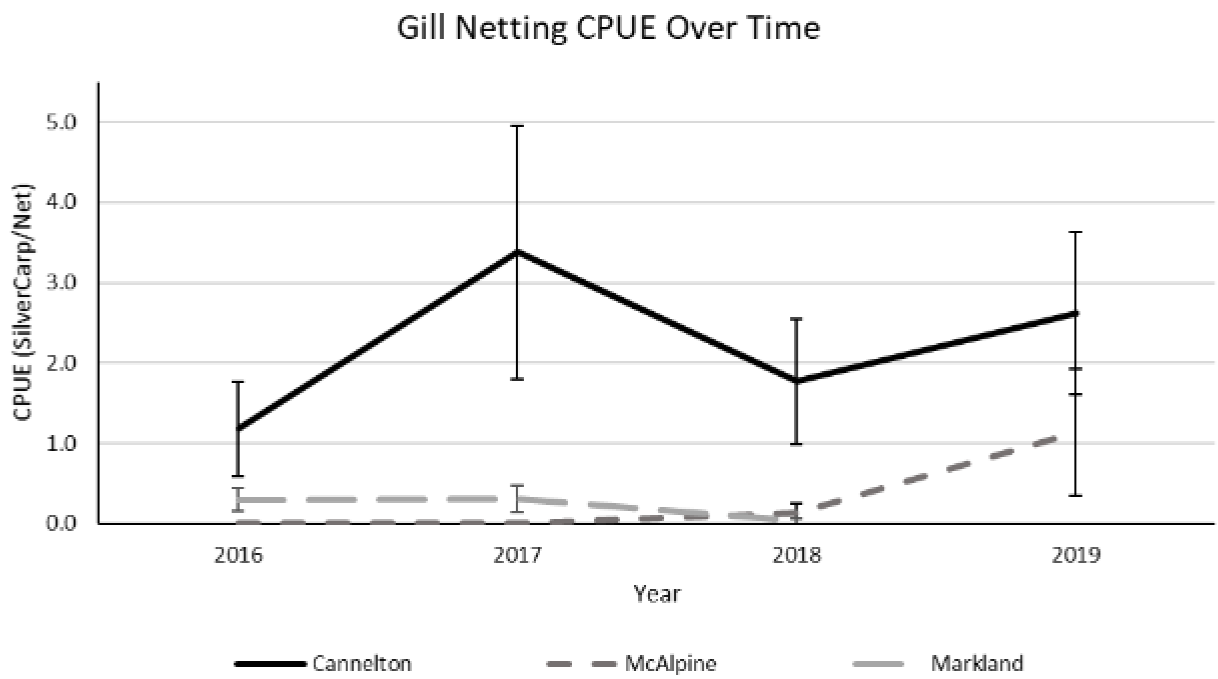


Figure 3. The change in catch per standard unit effort (CPUE) of Silver Carp in the middle Ohio River since 2016. Figure3a depicts the change in CPUE, measured in fish/hour, for Silver Carp captures using targeted boat electrofishing. Figure3b depicts the change in CPUE, measured in fish/net-set, for Silver Carp captured using gill netting. Error bars represent standard errors.

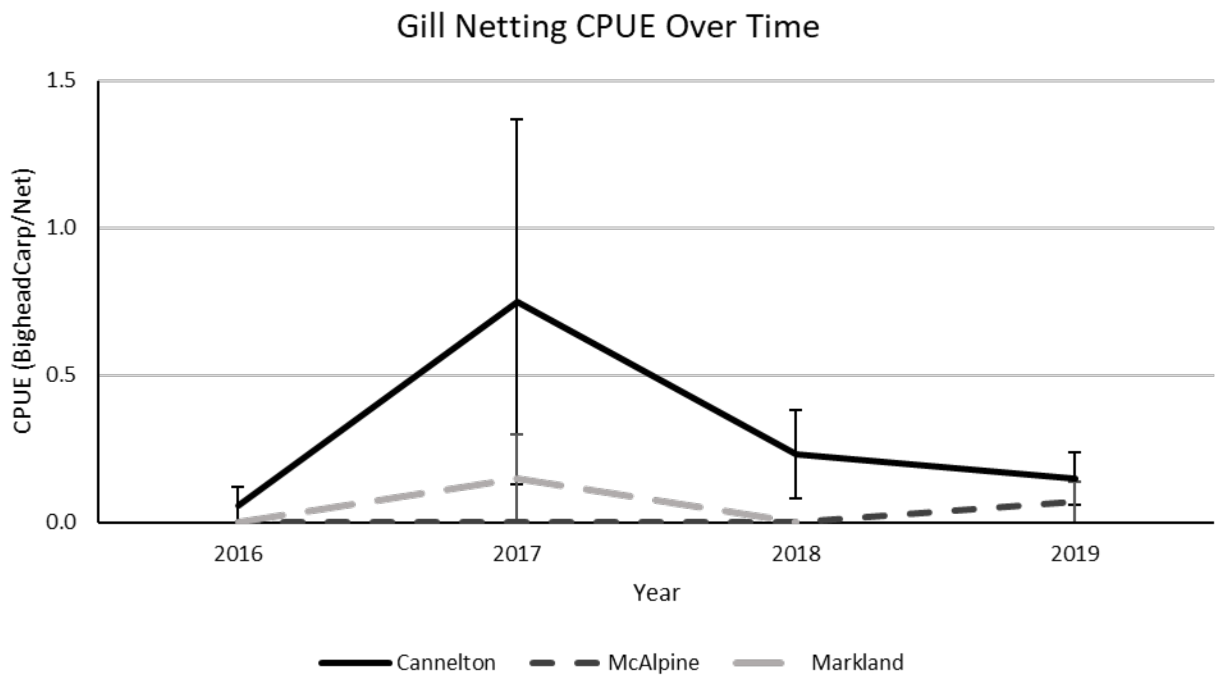


Figure 4. The change in catch per standard unit effort (CPUE) of Bighead Carp in the middle Ohio River since 2016. The CPUE is measured in fish/net-set for Bighead Carp captures using standardized gill netting protocol. Error bars represent standard errors.

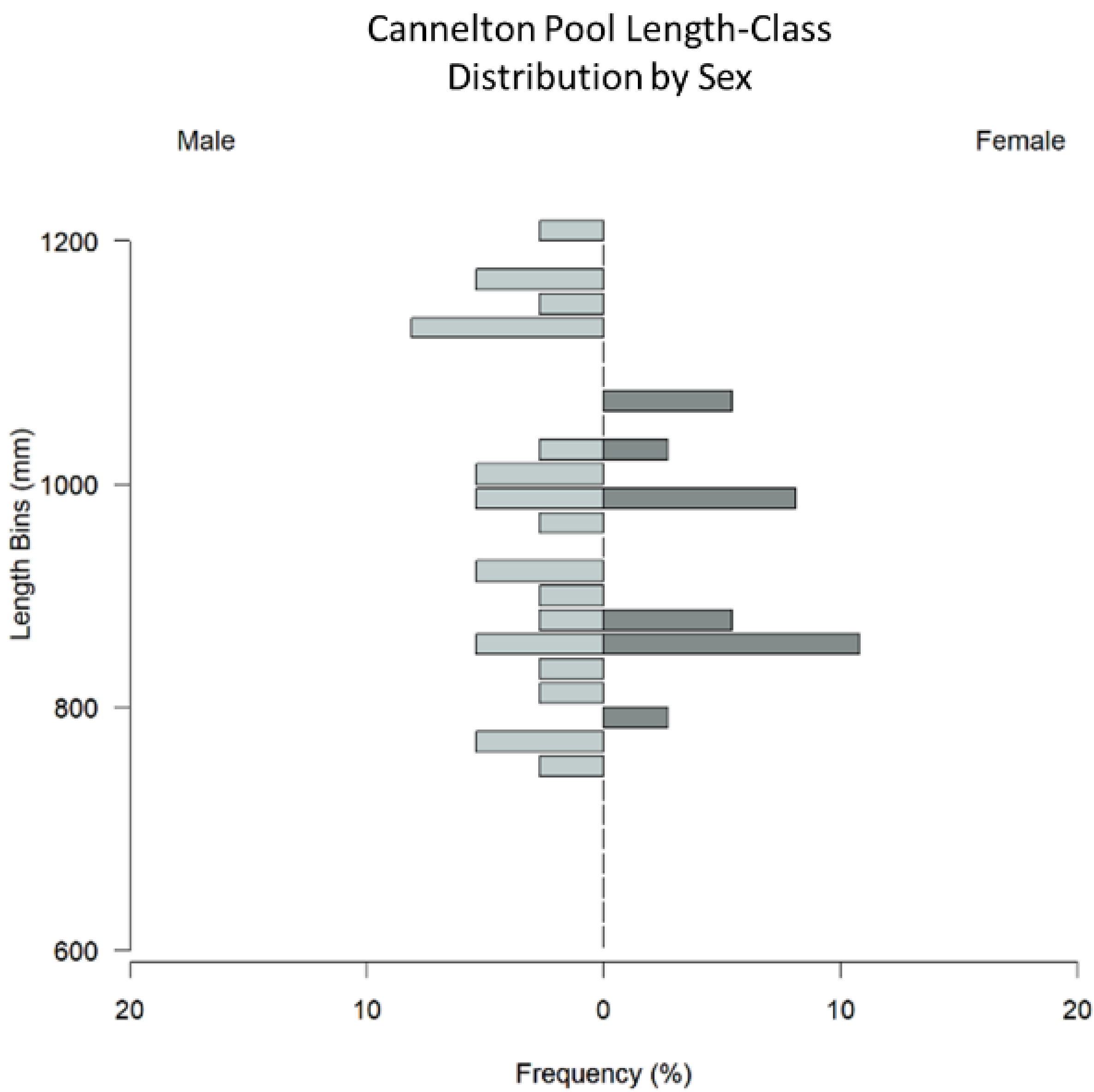


Figure 5. The percent frequency of both male and female Silver Carp, distributed by 20mm length-bins in the Cannelton Pool in 2019.

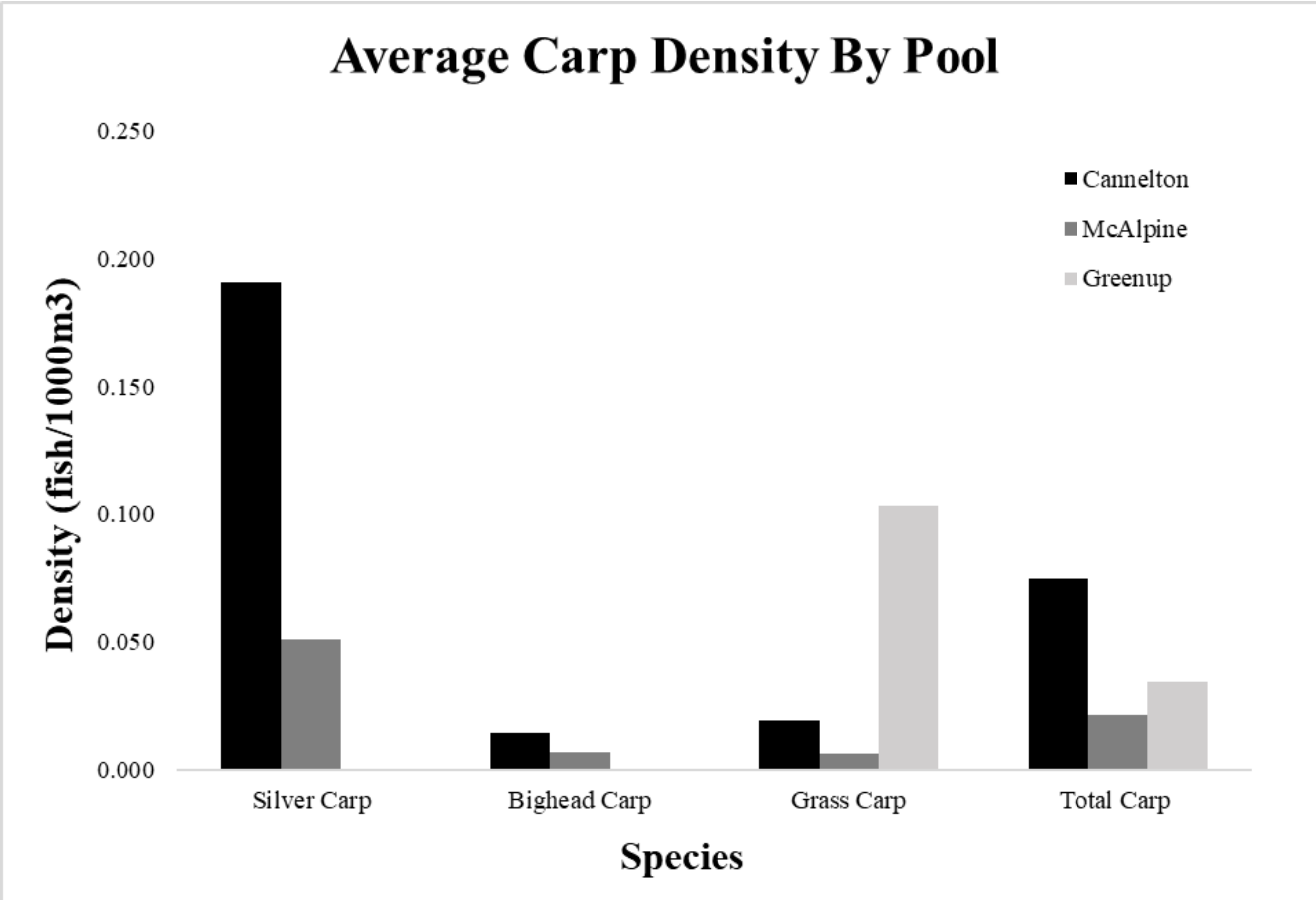


Figure 6. The pool-wide average of carp species densities.

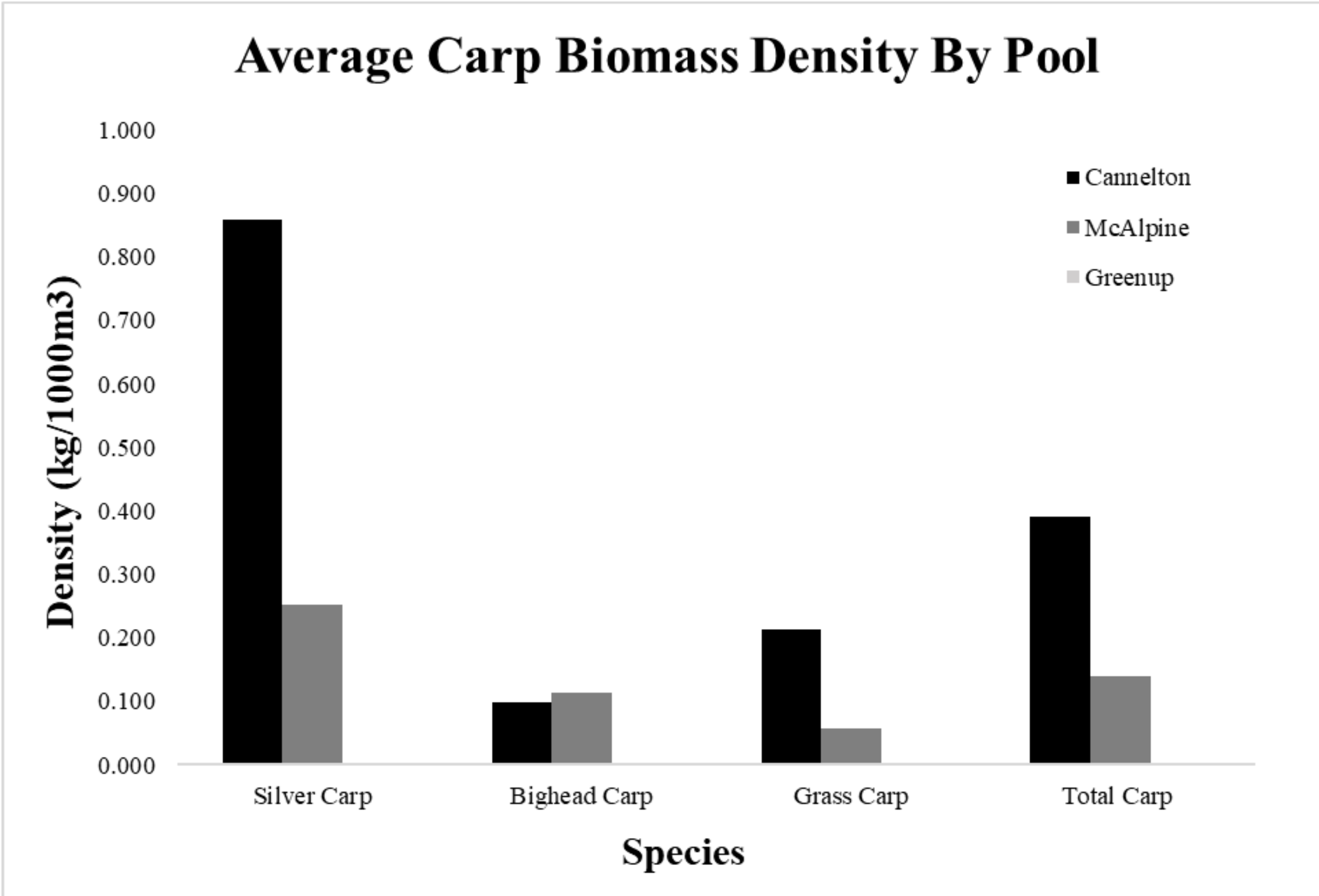


Figure 7. . The pool-wide average of carp species biomass densities.

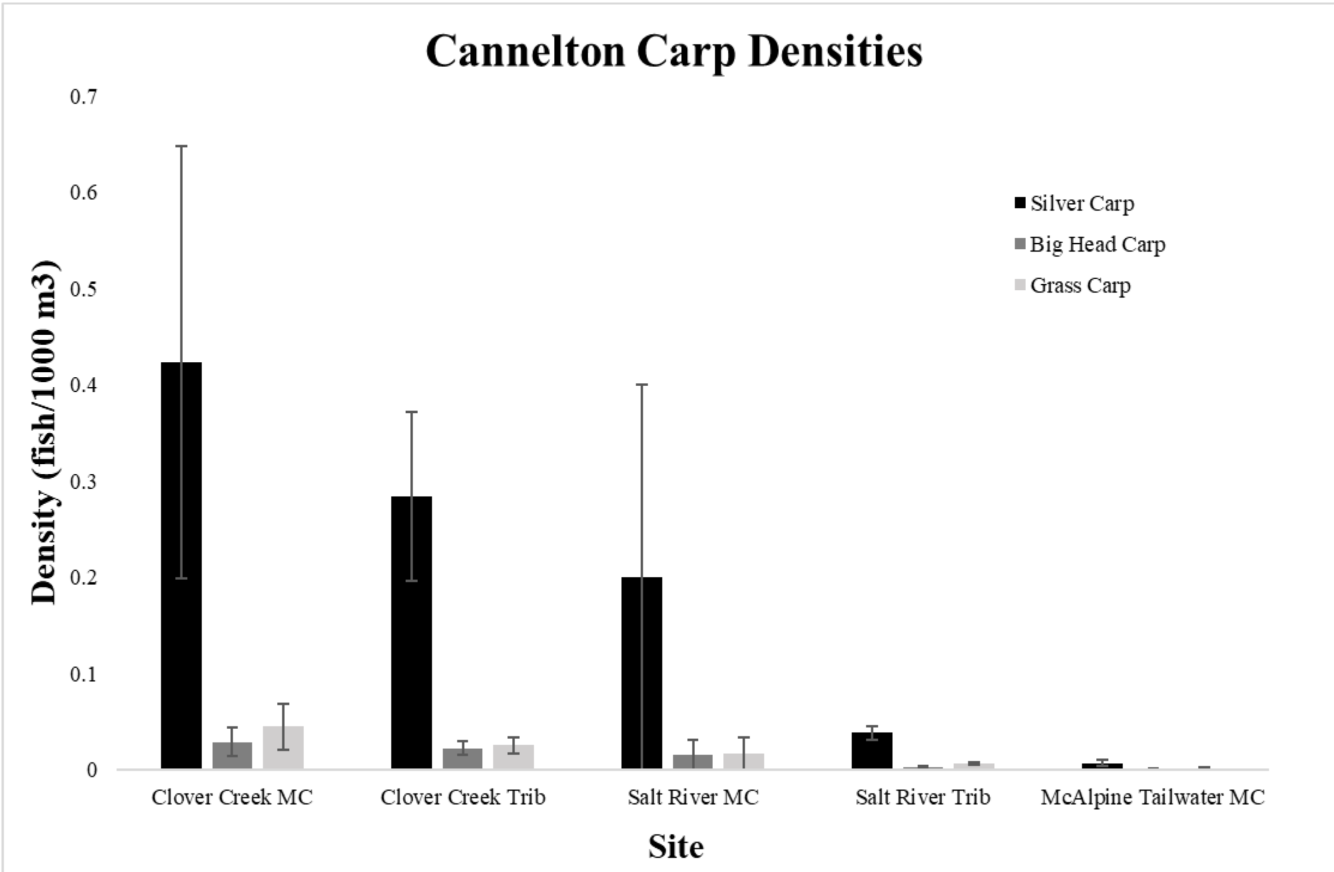


Figure 8. The species-specific carp densities by site in Cannelton Pool.

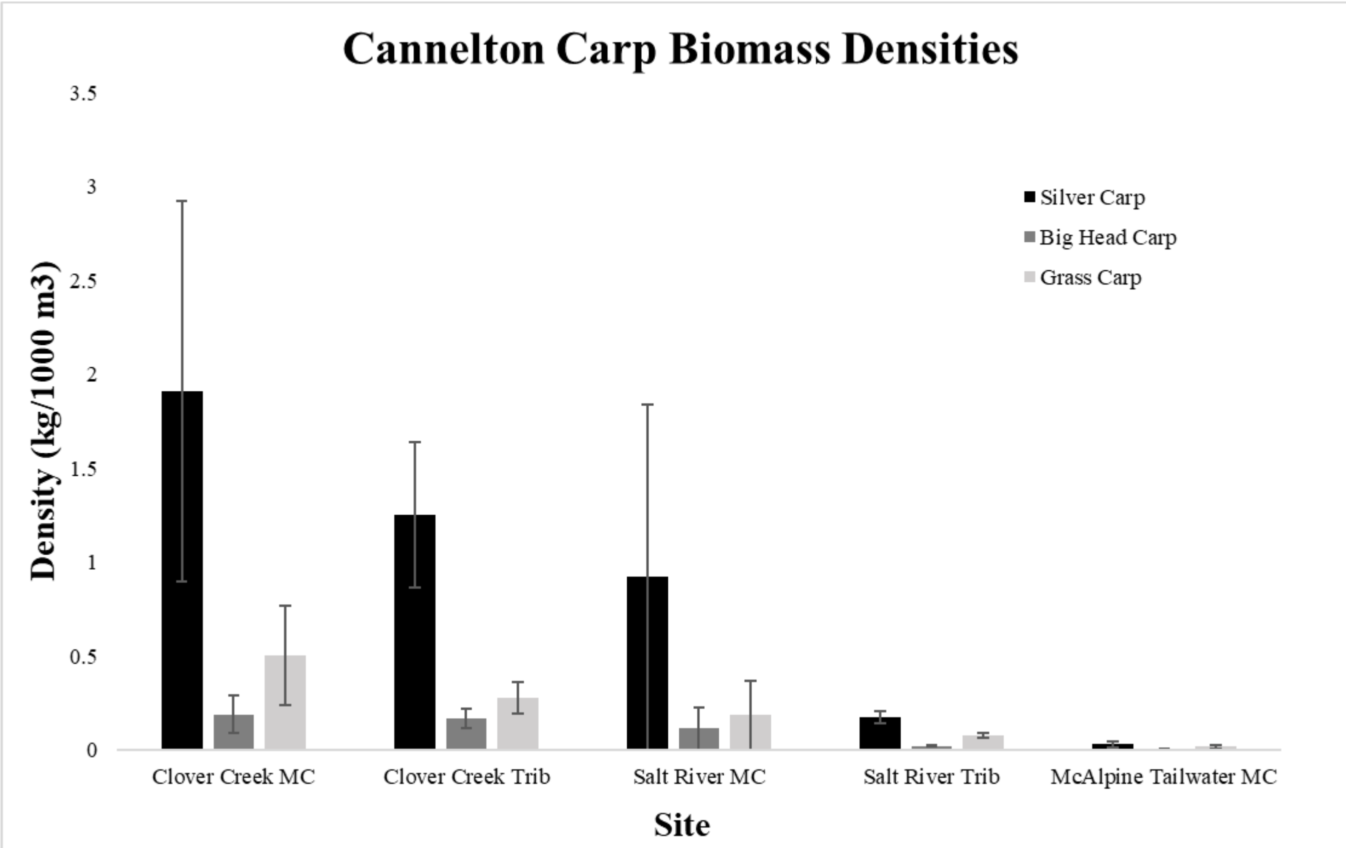


Figure 9. The species-specific carp biomass densities by site in Cannelton Pool.

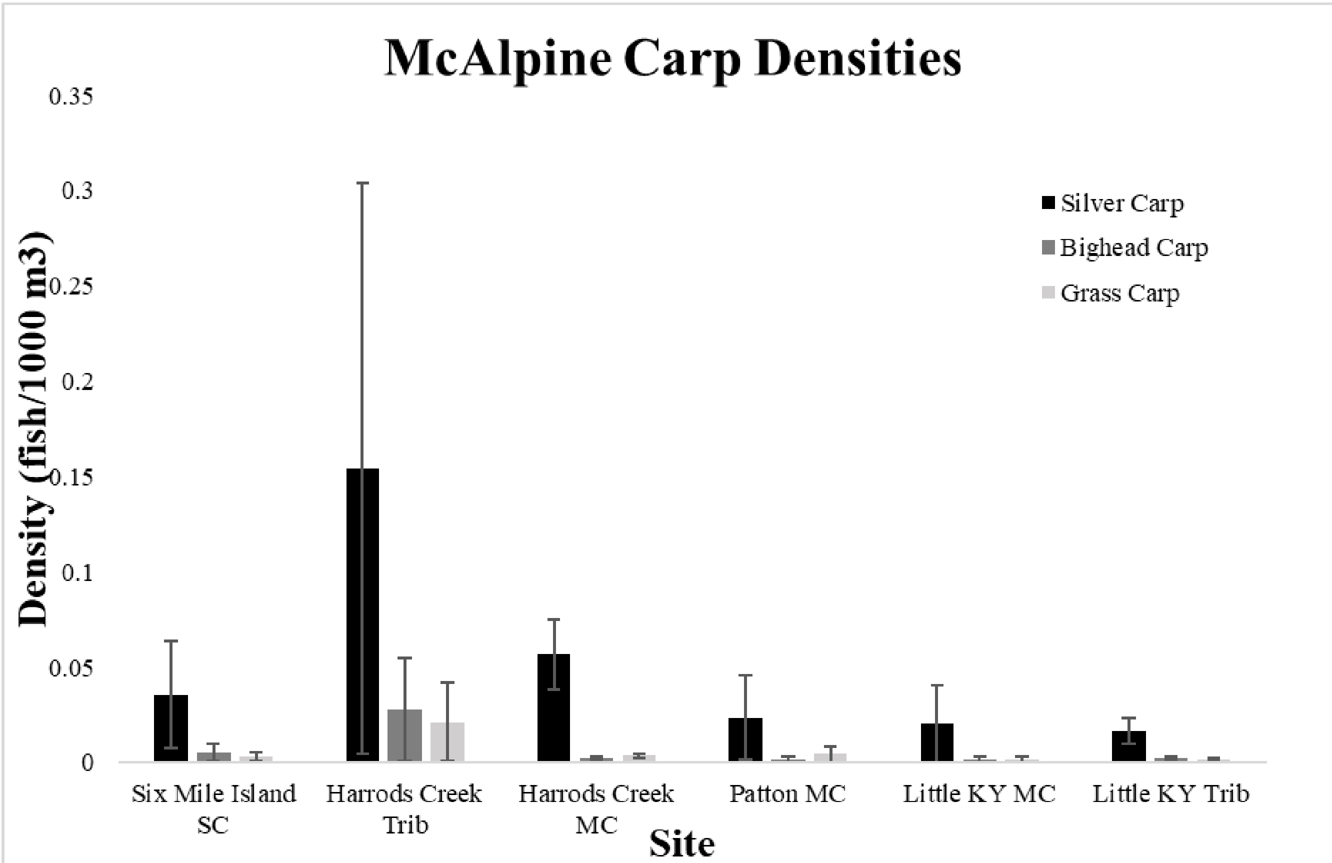


Figure 10. The species-specific carp densities by site in McAlpine Pool.

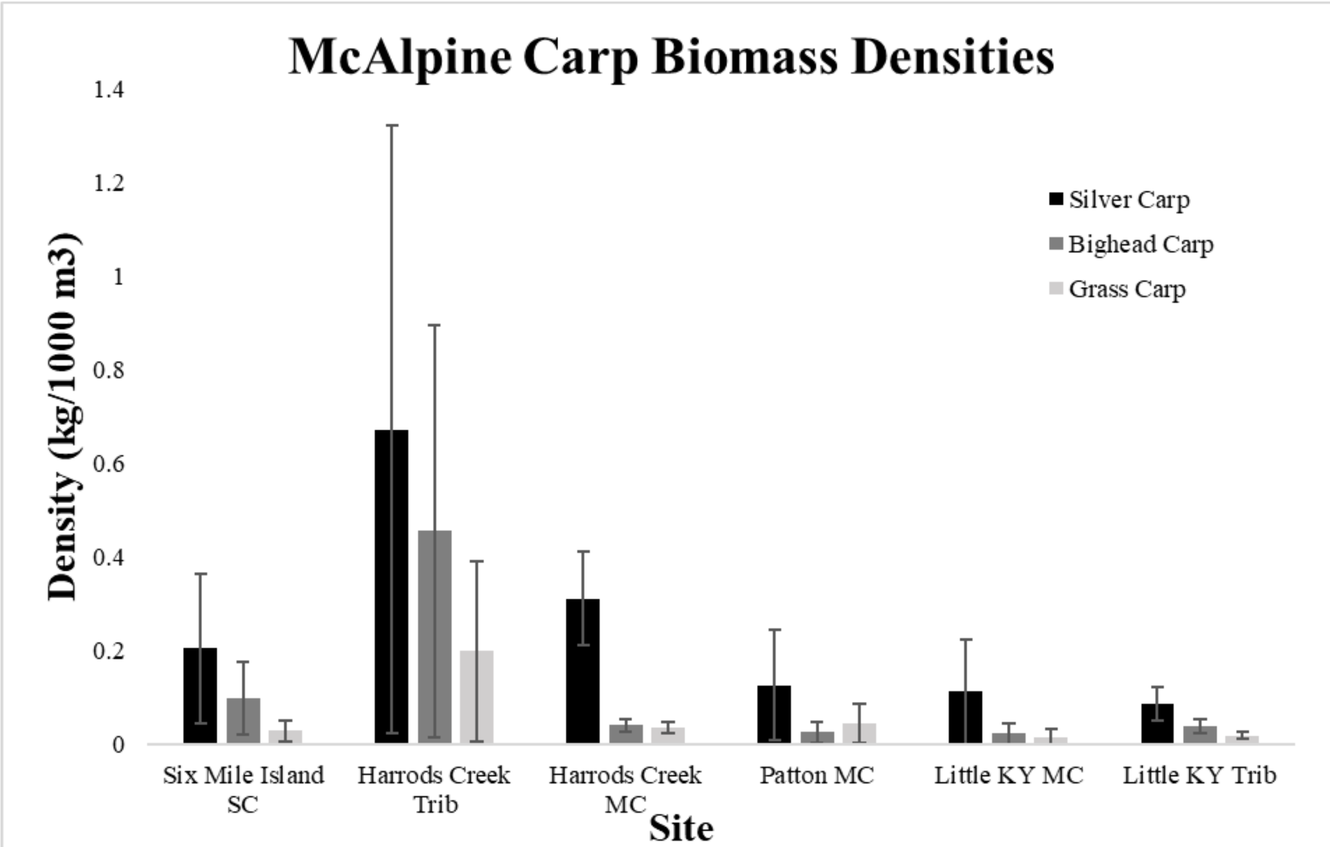


Figure 11. . The species-specific carp biomass densities by site in McAlpine Pool.

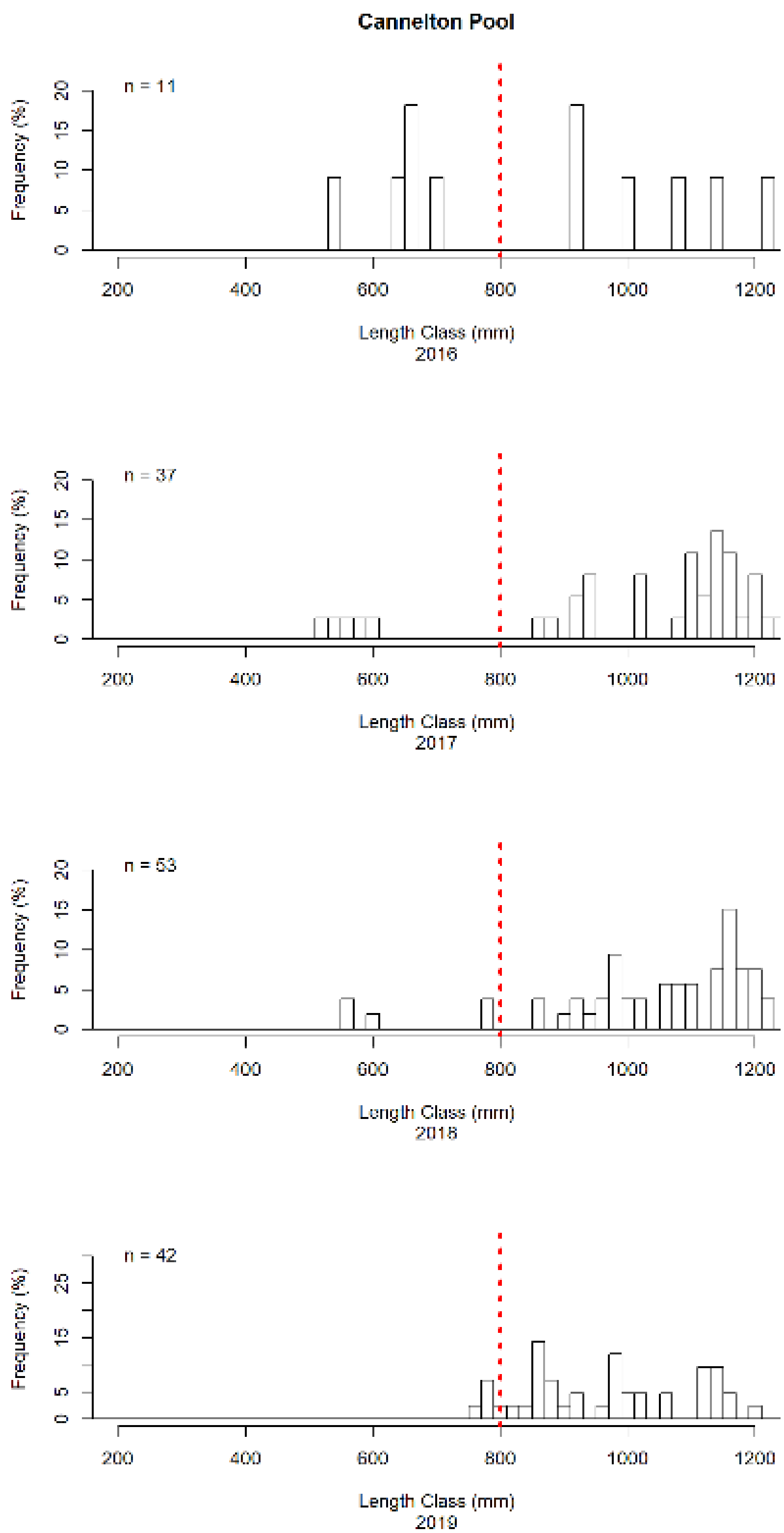


Figure 12. . The frequency of total lengths for Bighead Carp captured in Cannelton pool since 2016. The line at the 800mm length-class serves as a reference point when considering changes in length-class distributions through time.

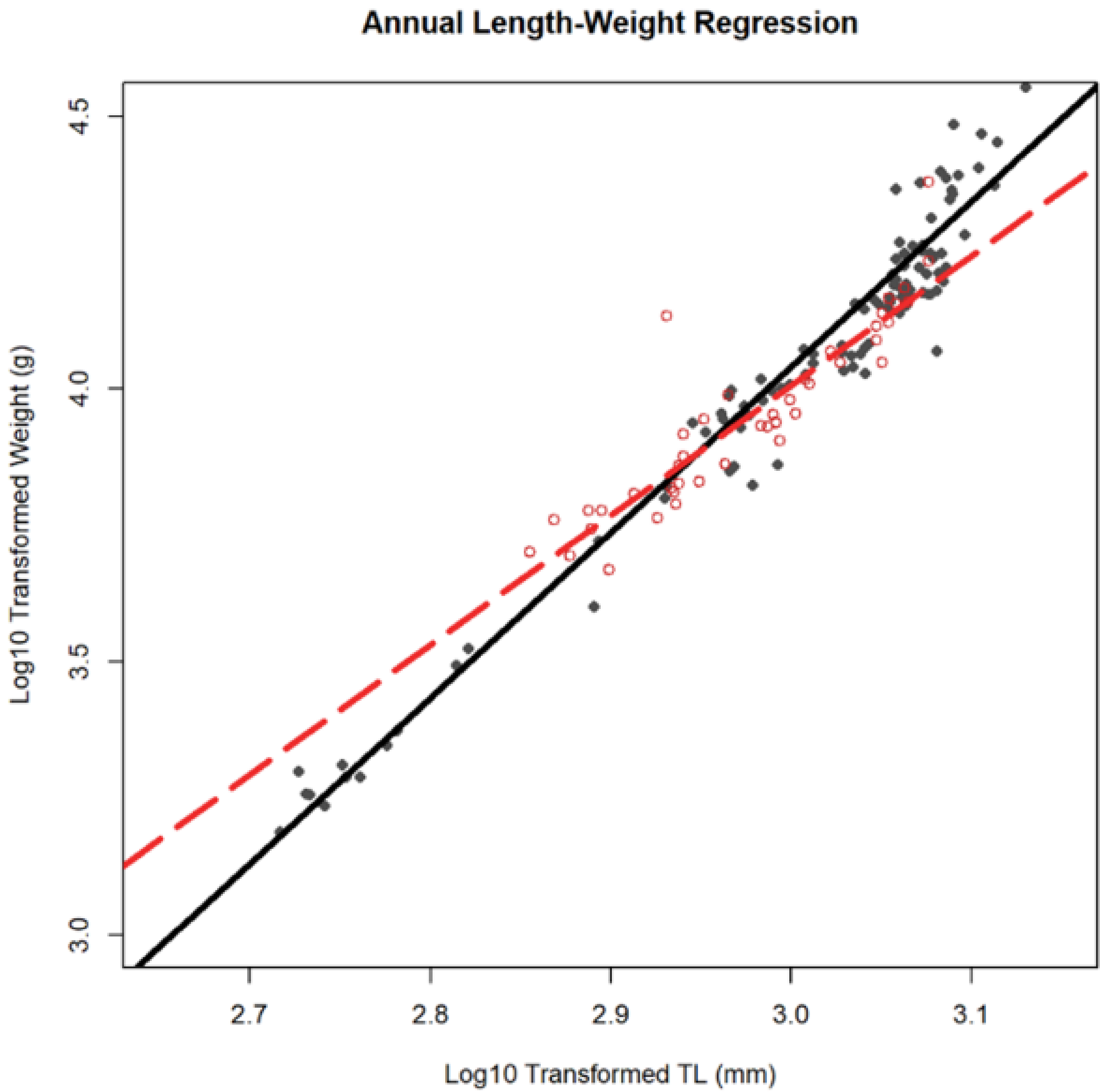


Figure 13. . The log-transformed relationship between total length (mm) and weight (g) for Bighead Carp in the ORB. The black line and scatterplot indicate previously observed length-weight relationships for Bighead Carp in the ORB using data collected 2015 – 2017 (regression equation found in Table 2). The red line and data points indicate the regression line and length-weight relationships for new data, collected in 2019.

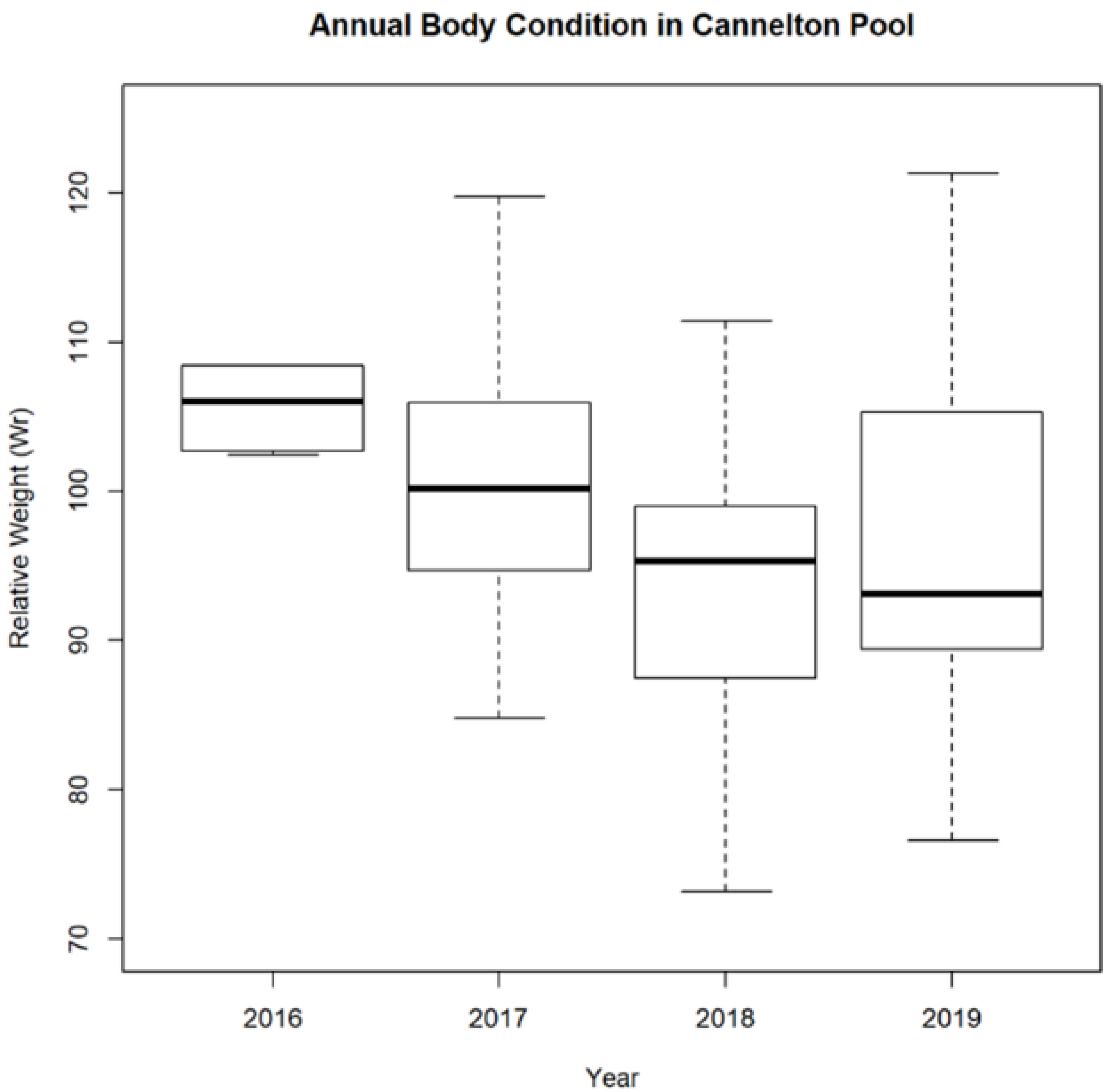


Figure 14. . A boxplot comparison of the relative weights (Wr) for Bighead Carp captured in the Cannelton pool from 2016 through 2019. Relative weights were calculated using the 50th regression percentile equation for Bighead Carp established by Lamer *et al*, 2015.

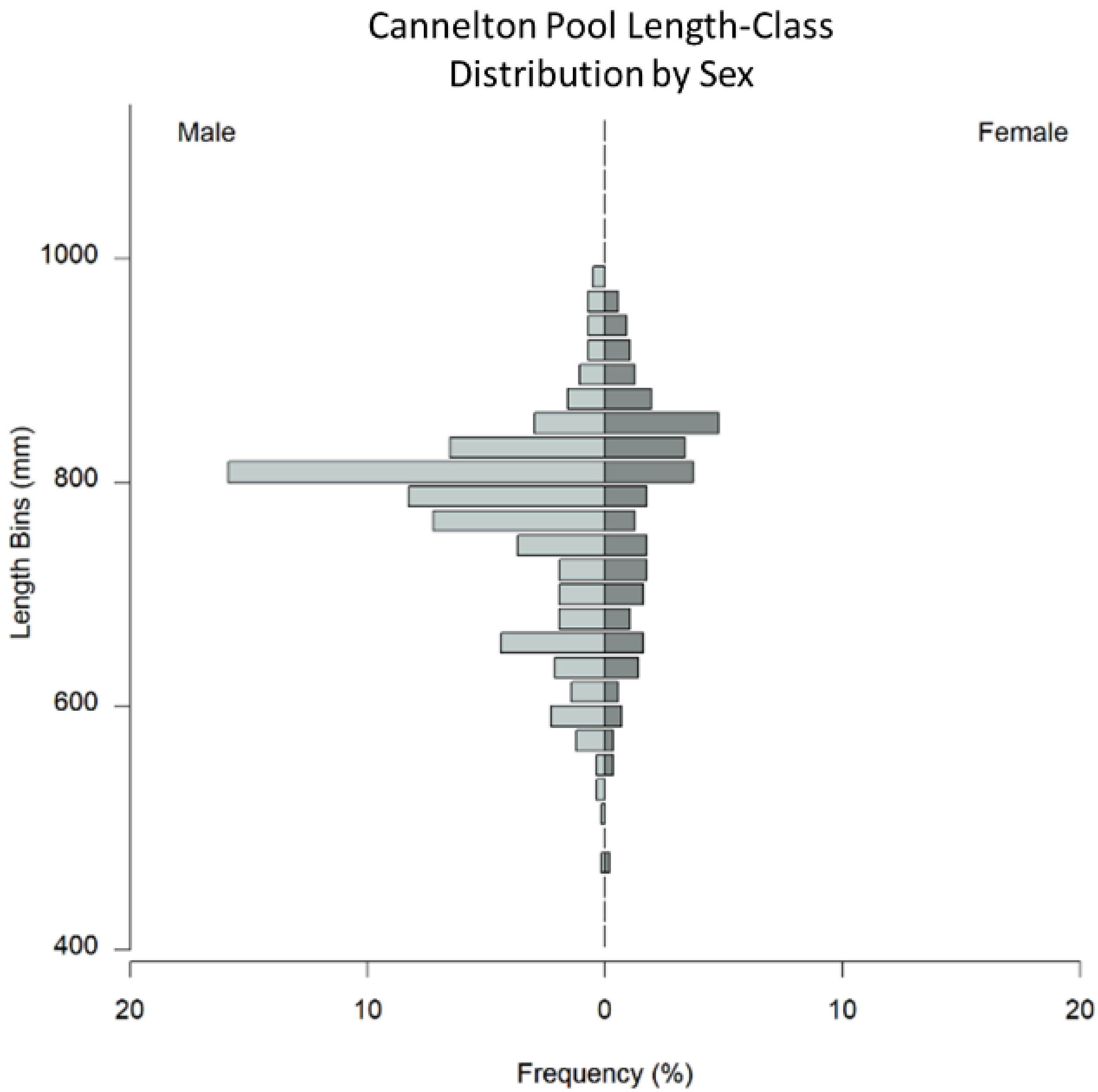


Figure 15. The percent frequency of both male and female Silver Carp, distributed by 20mm length-bins in the Cannelton Pool in 2019.

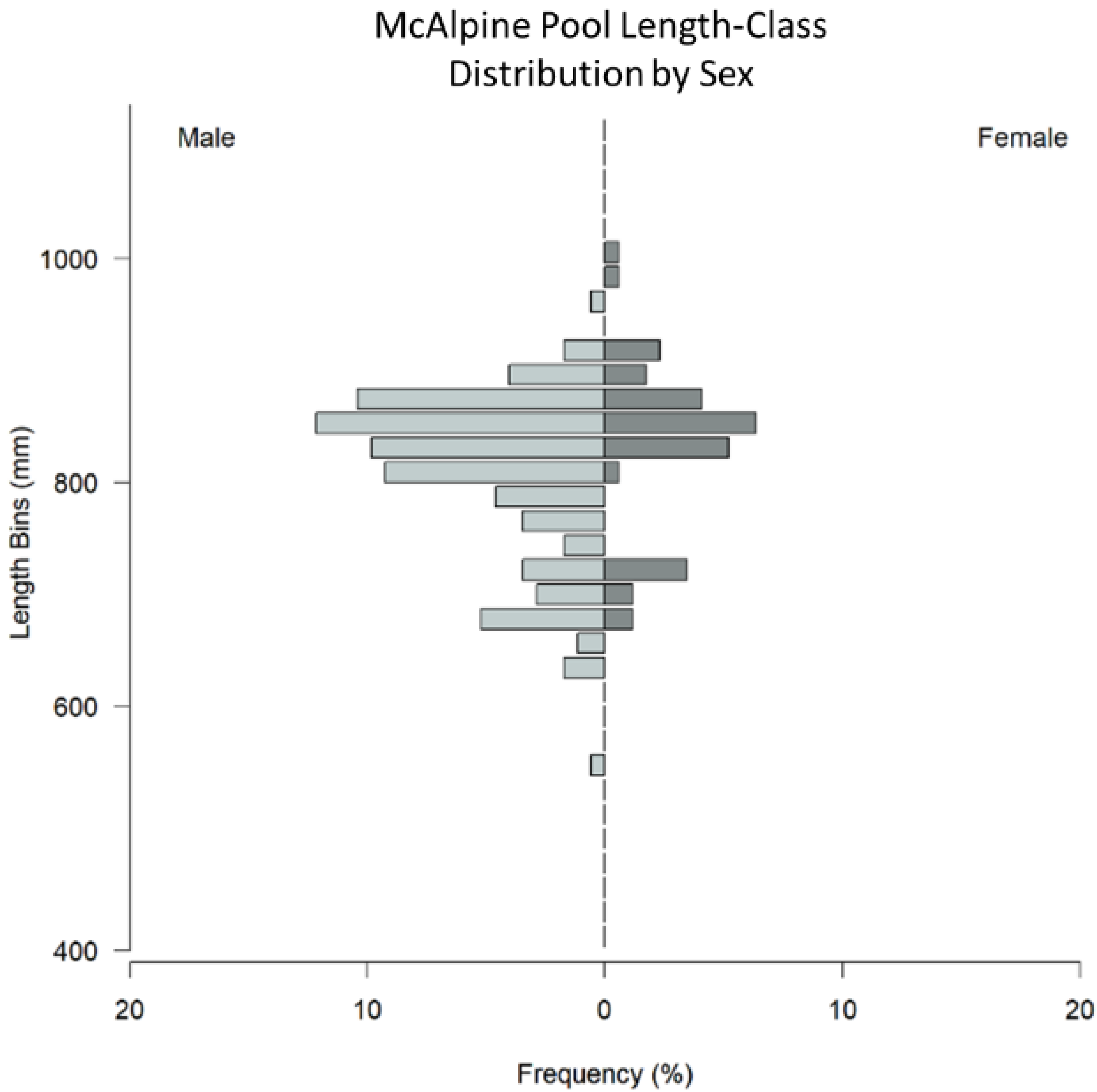


Figure 16. The percent frequency of both male and female Silver Carp, distributed by 20mm length-bins in the McAlpine Pool in 2019.

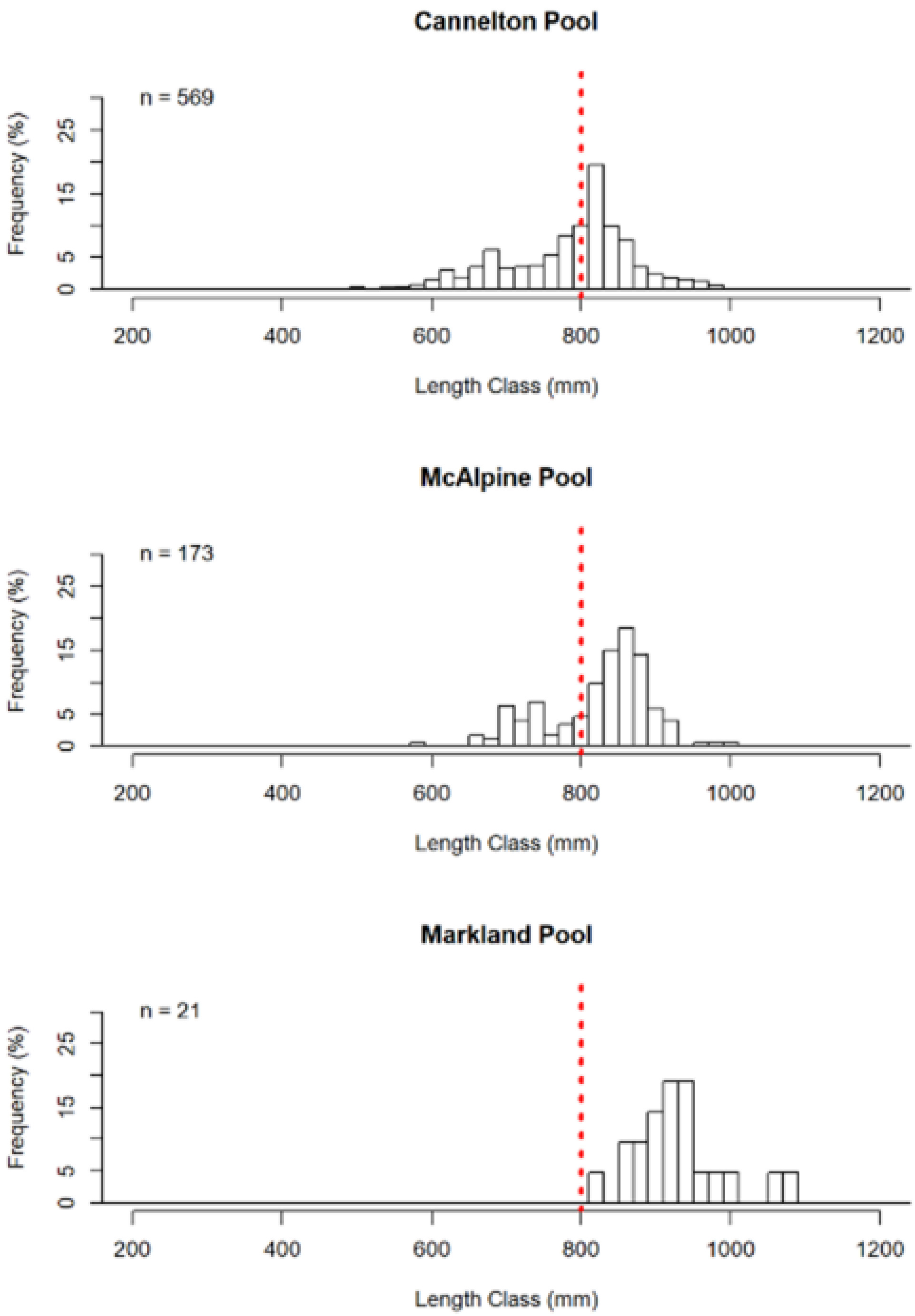


Figure 17. The frequency of total lengths for Silver Carp captured in the Cannelton, McAlpine, and Markland pools in 2019. The line at the 800mm serves as a reference point when considering changes in length-class distributions between pools.

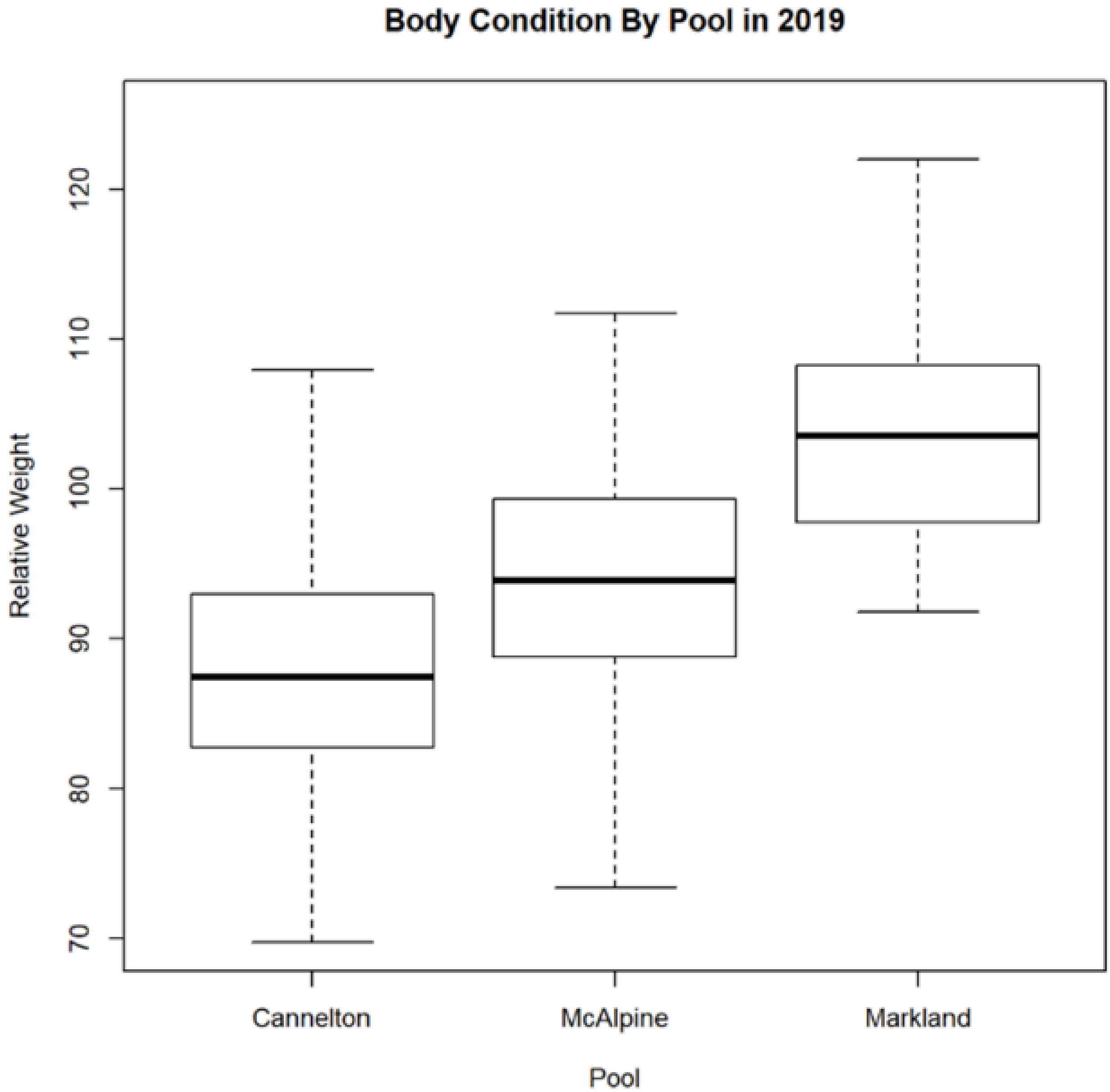


Figure 18. A boxplot comparison of the relative weights (Wr) of Silver Carp captured in the Cannelton, McAlpine, and Markland pools in 2019. Relative weights were calculated using the 50th regression percentile equation developed for Silver Carp by Lamer *et al.*, 2015.

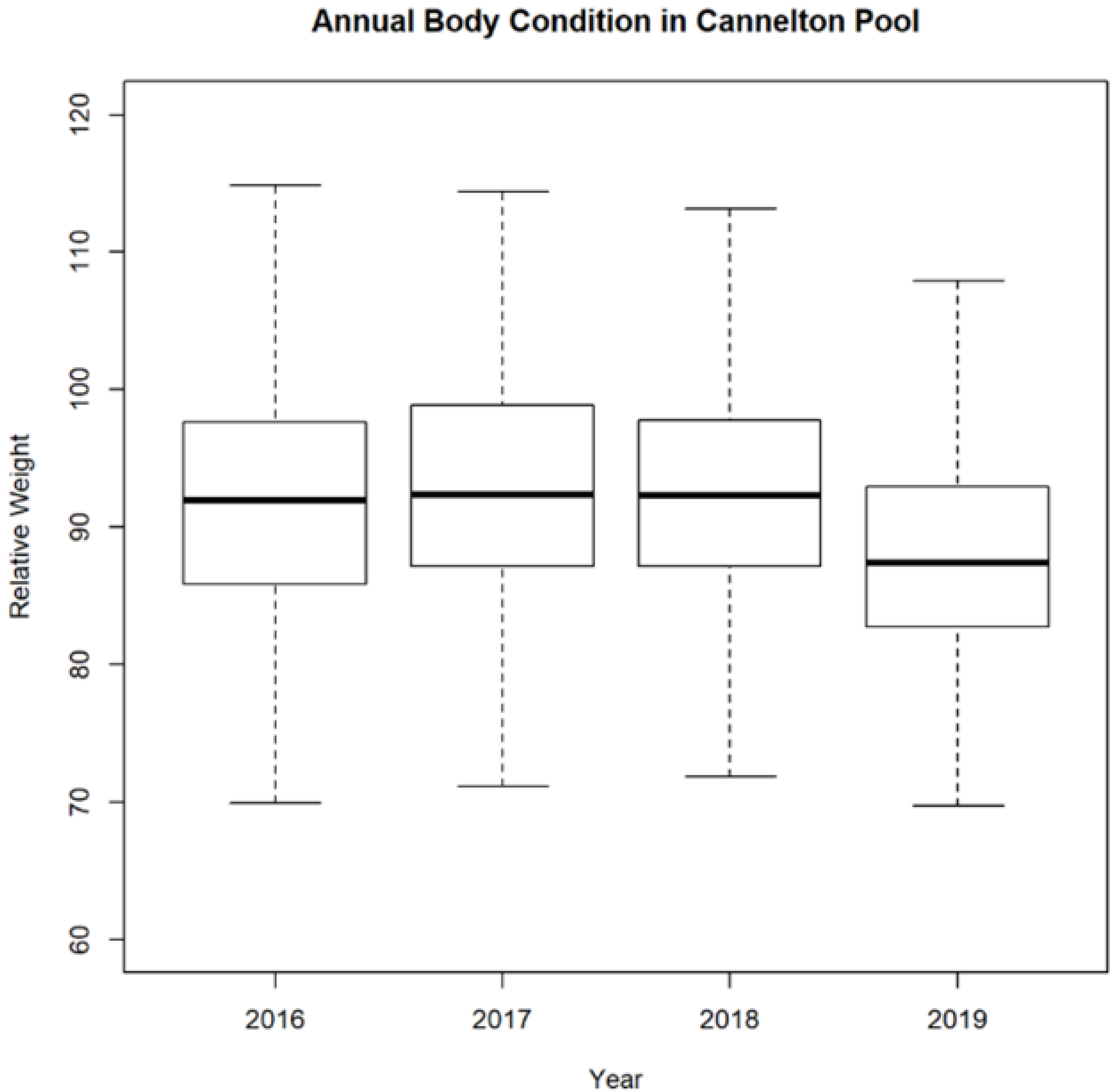


Figure 19. . A boxplot comparison of the relative weights (Wr) of Silver Carp captured in the Cannelton pool from 2016 through 2019. Relative weights were calculated using the 50th regression percentile equation for Silver Carp established by Lamer *et al*, 2015.

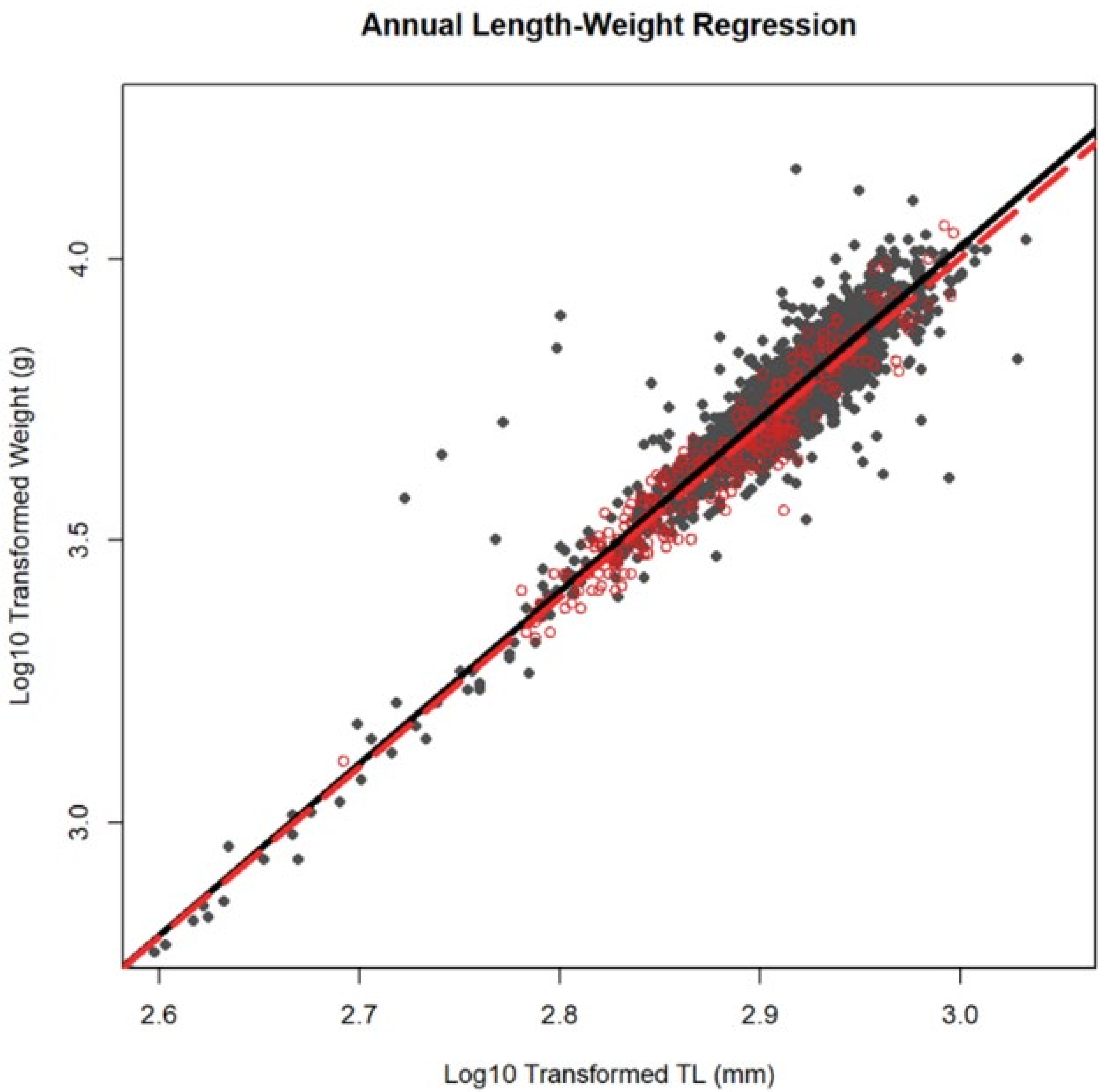


Figure 20. The log-transformed relationship between total length (mm) and weight (g) for Silver Carp in the ORB. The black line and scatterplot indicate the cumulative length-weight relationship for Silver Carp in the ORB using previous data since 2016 (regression equation found in Table 1). The red line and data points indicate the regression line and length-weight relationships for new data, collected in 2019.

Figure 21. An example of a female Silver Carp with a spawning patch in 2019. Spawning patches are evidence of recent spawning activity and are tracked annually to estimate the relative start date and duration of spawning.

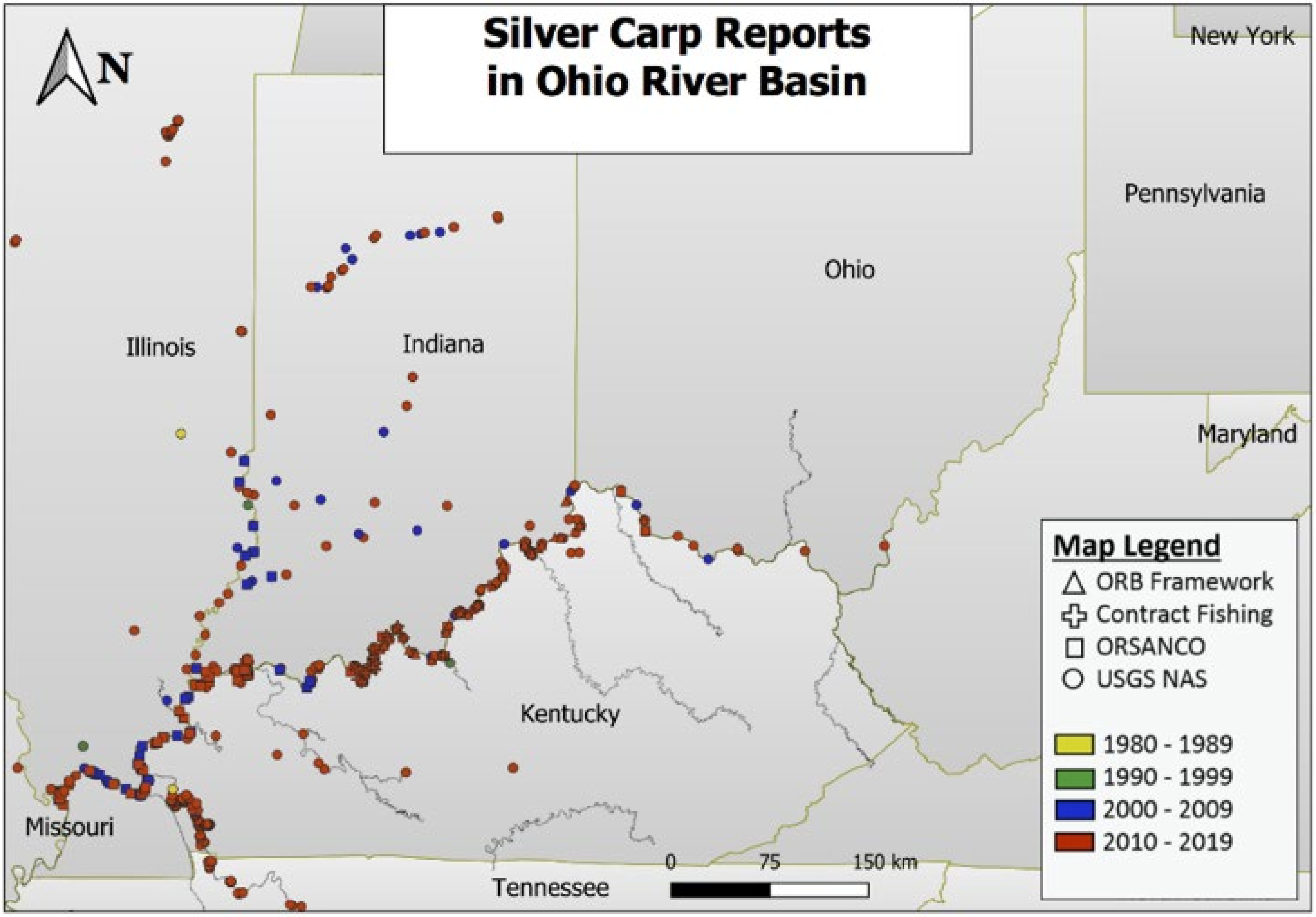


Figure 22. A map incorporating data on the geographic range and temporal proximity of Silver Carp records and reports in the ORB. Data compiled from contract fishing (implemented in 2019), the Framework projects, ORSANCO, and the USGS NAS database.

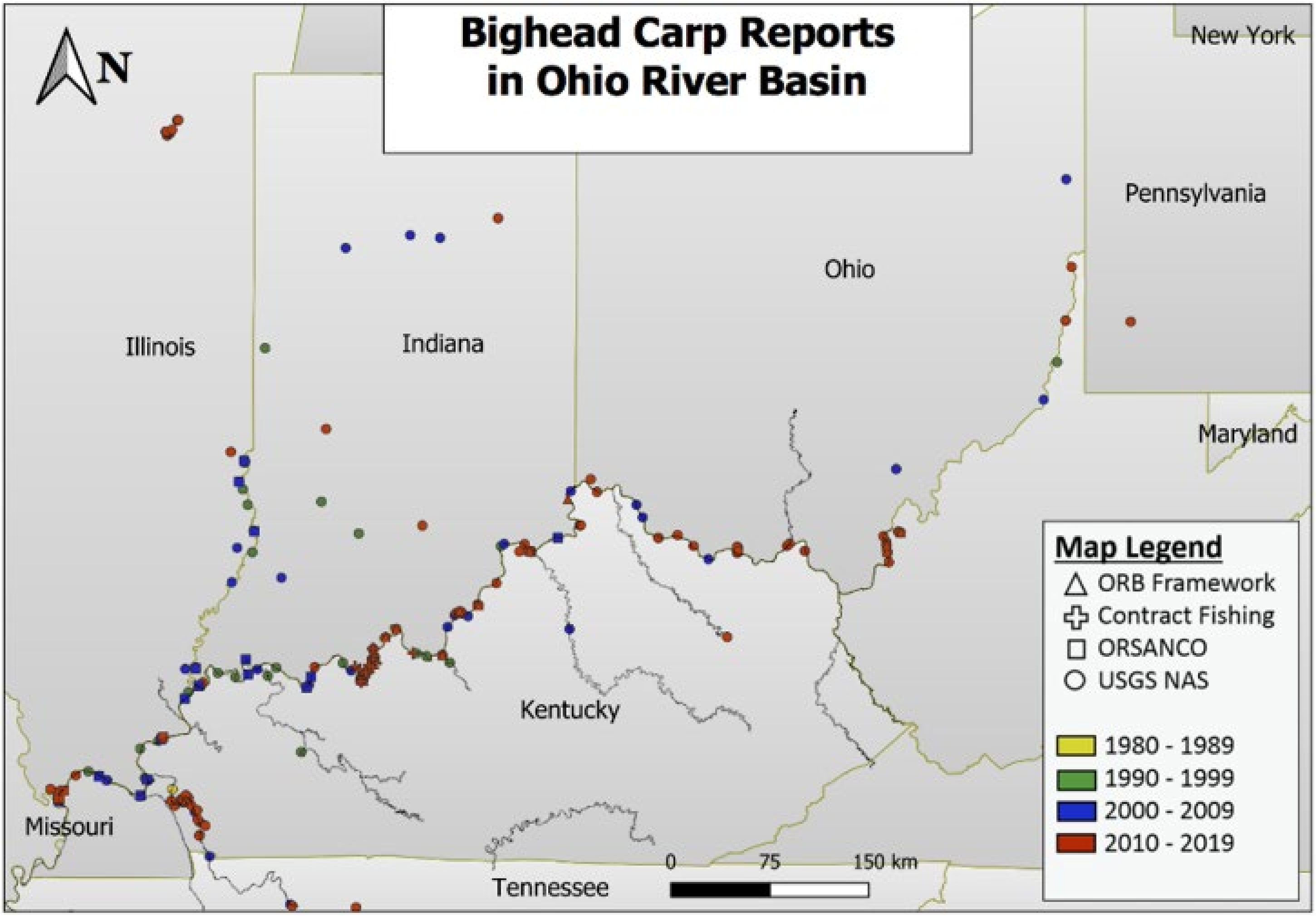


Figure 23. A map incorporating data on the geographic range and temporal proximity of Bighead Carp records and reports in the ORB. Data compiled from contract fishing (implemented in 2019), the Framework projects, ORSANCO, and the USGS NAS database.

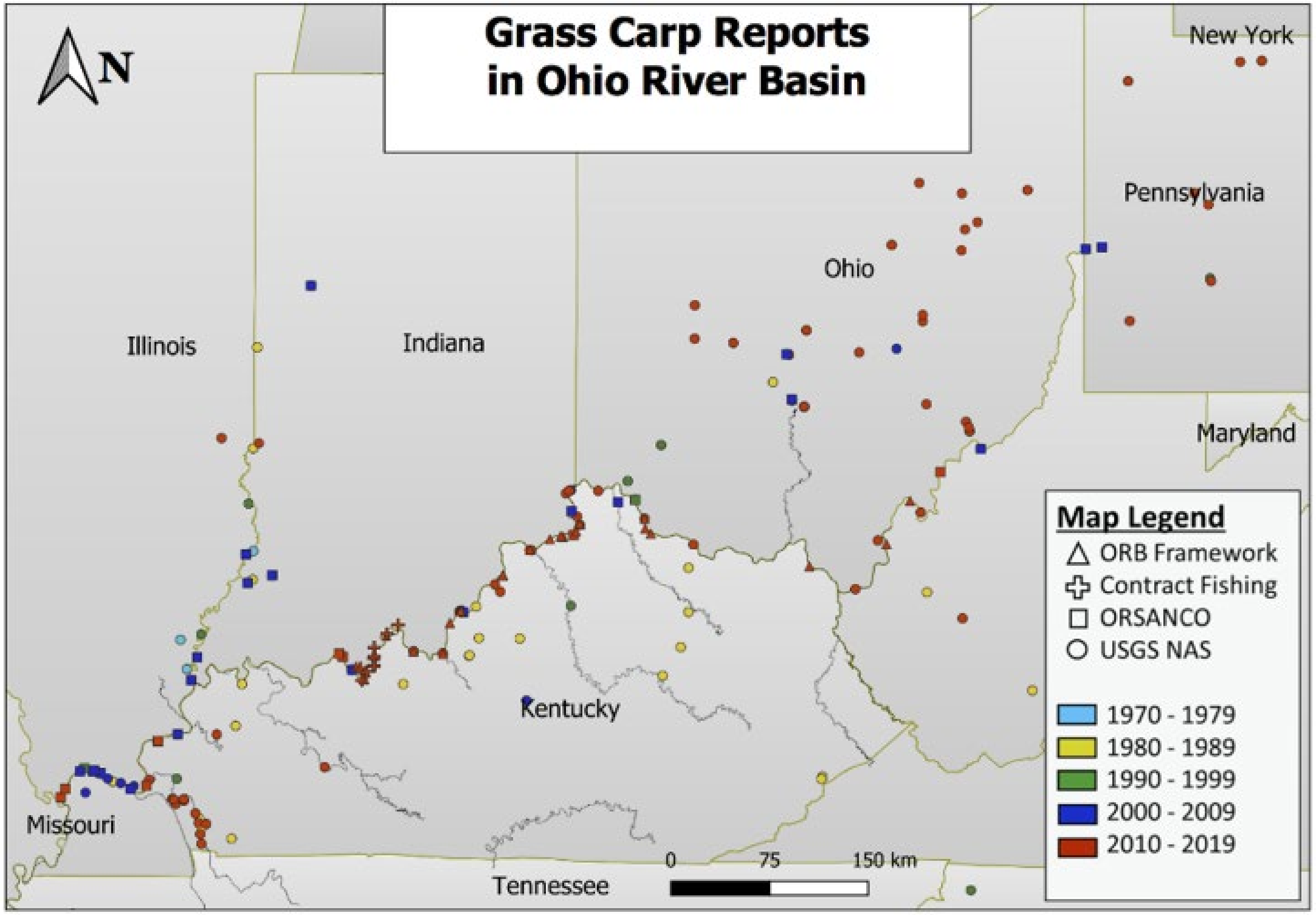


Figure 24. A map incorporating data on the geographic range and temporal proximity of Grass Carp records and reports in the ORB. Data compiled from contract fishing (implemented in 2019), the Framework projects, ORSANCO, and the USGS NAS database.

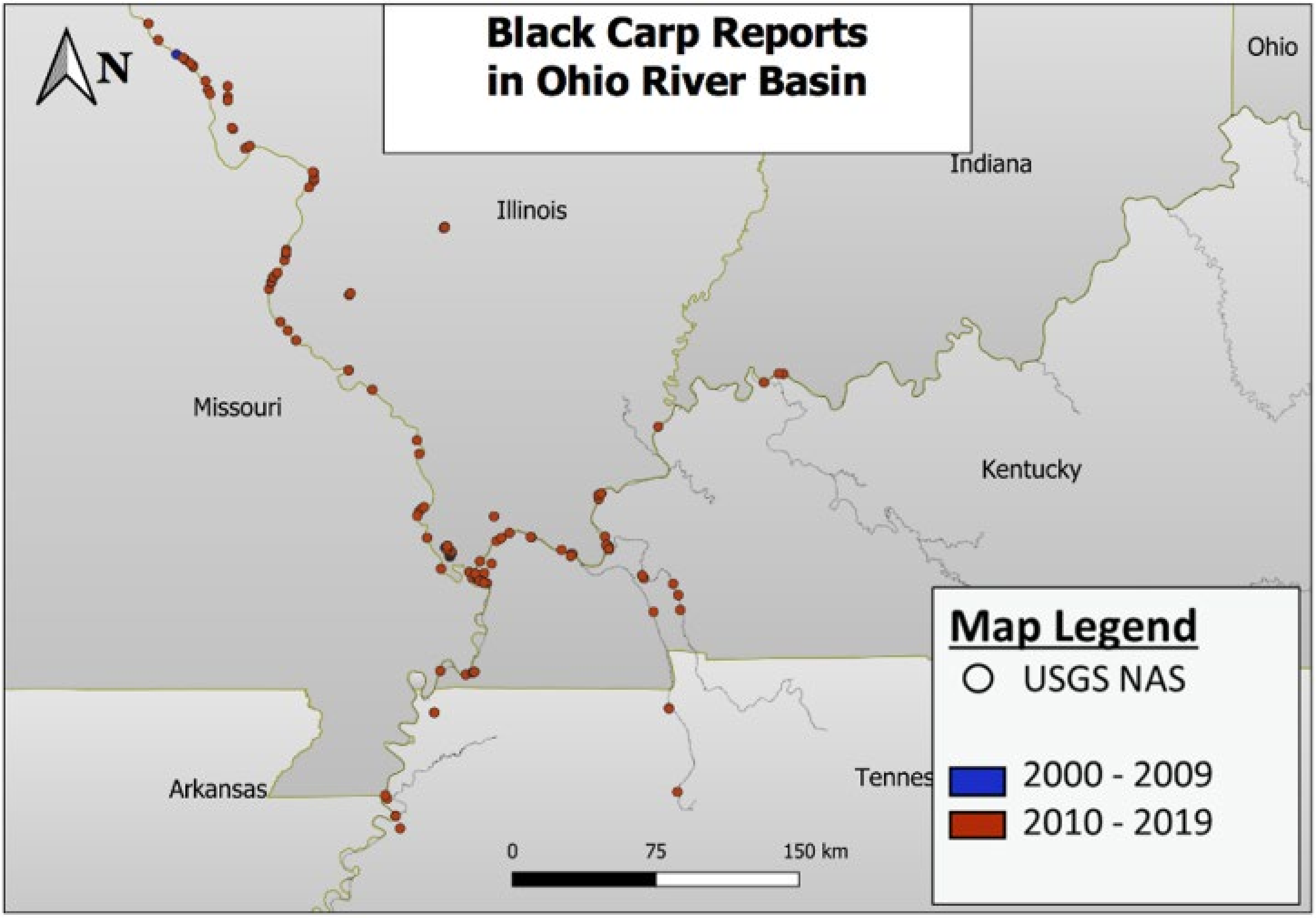


Figure 25. A map incorporating data on the geographic range and temporal proximity of Black Carp records and reports in the ORB. No Black carp have been captured through basin framework projects and all records listed were provided by the USGS NAS database.