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.

Project Highlights:

- In 2020, electrofishing catch rates for Silver Carp in Cannelton Pool 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 abundance 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 was not collected in 2020; however, a more robust sampling structure to collect community data is being developed by the USFWS in conjunction with state and university partners.

- Agency-based removal efforts have not slowed the growth of Silver Carp populations over the last four years, however, the newly established contract angling program was successful in increasing removal of 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 strategies 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.
- Mortality due to contract and commercial fishing pressure should be an additional focus for future efforts and the telemetry project currently being conducted within the ORB could be structured to estimate fishing related mortalities.

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. Targeted sampling was conducted 15 April – 27 April in 2020. Six concurrent pools (Cannelton – R.C. Byrd) are typically targeted (Figure 1), but due to COVID-19 precautions, only a fraction of this work was conducted. All fixed sampling sites were selected from a previous stratified-random design completed in 2015. Although the stratified-random design was considered ideal, it became clear that it was logistically prohibitive without additional funding, resources, and available personnel. Thus, sampling structure was adjusted to offset logistic limitations while maintaining adequate pool coverage. Pools are 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 is 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 sighting. 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 misidentification of juvenile Asian carps. Only 15 of the 24 planned electrofishing transects in the Cannelton pool were able to be completed in the spring of 2020.

Gill nets used in targeted sampling are typically 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 the surface of the water. Normally, KDFWR adds an additional 45m net with 7.6cm mesh (3” bar mesh) when sampling where flow and debris allow. Gill nets are set perpendicular from the shoreline and fished for two hours, during which noise and water disturbance is created every 30 minutes within 300 meters of the sets. Regular disturbance was intended to drive bigheaded carps into the entanglement gear. KDFWR did not conduct gill netting in the spring of 2020 due to COVID-19 precautions. In April 2020, WVDNR conducted targeted sampling for bigheaded carp using gill nets in R.C. Byrd pool. Gill net methods are consistent between agencies except WVDNR may fish deeper nets (24ft deep hobbled to 20) at deeper sampling locations. 5” bar mesh is used on all gill nets in WVDNR waters.

Fall Standardized Community Monitoring (Cannelton – R.C. Byrd)
During 05 October – 18 November, fish community surveys were repeated along standardized sites in the Cannelton, McAlpine, Greenup, and R.C. Byrd pools of the 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.
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 2020. Fish were collected at boat ramps on the R.C. Byrd (n=4) and Greenup (n=4) Pools of the Ohio River. One seine haul was conducted at each location (n=8) 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 not conducted in the fall of 2020 and there is no new information to report.

Assessing Asian Carp Population Demographics
Lengths and weights of bigheaded carps collected in 2020 (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 in the form of (Table 1 and 2):

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

During standardized, targeted monitoring in 2019 over 250 bigheaded carp lapilliar otoliths were removed from a subsample of fish for aging and were unable to be completed for the 2019 report. Those results are therefore provided in this document. Prior to aging, otoliths were prepared using thin cross-sections cut using a low-speed, Isomet saw, and the fish were aged with a microscope using transmitted or reflected light. Age data was used to calculate age distributions by pool, the mean length at age (range, 95% confidence interval) for Silver Carp, and compared to the predicted TL from 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 was fitted in R using non-linear modeling procedures (Ogle 2016) and used to estimate a pool-specific mortality rate for silver carp in Cannelton and McAlpine (Then et al. 2015).

Monitoring Ahead of the Invasion Front
Targeted sampling for Asian Carp was conducted in November and December 2020 in the New Cumberland Pool and the Montgomery Pool of the Ohio River. In the New Cumberland Pool, sampling was conducted near Phyllis Island in the vicinity of a warmwater discharge from the Beaver Valley Power Station, and near Georgetown Island in November. In the Montgomery Pool, sampling in November was conducted at the mouth of Raccoon Creek, the mouth of the Beaver River, and approximately 2 km upstream of the mouth of the Beaver River. December 2020 sampling in the Montgomery Pool was conducted in the Montgomery Slough (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. Three gill nets were fished for approximately 24 hours each during each of three sampling events for a total of nine gill net sets.

Fish community monitoring was conducted in June 2020 in the Allegheny River at the LD 7 tailwater (Pool 6) and in the Ohio River at the Emsworth tailwater (Dashields pool) and Dashields tailwater (Montgomery Pool) using night boat electrofishing. Five consecutive 10 minute 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 shock 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 2020. 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 single unbaited hoop nets, baited tandem hoop nets, and boat electrofishing. Single unbaited hoop nets (4' diameter, 1.5" mesh) were set in all pools of the Ohio River in June 2020 and were fished for three consecutive nights. Baited tandem hoop nets (4' diameter, 1.5" bar mesh, 3 nets in tandem) were set in Pools 6-8 of the Allegheny River in June and July 2020 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 from the Allegheny River only.

Nighttime boat electrofishing was conducted in October in Pool 4 of the Allegheny River and in November in the New Cumberland Pool, Montgomery Pool, and the Dashields pool of the Ohio River and Pool 2 and Pool 6 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. On the Allegheny River in October, four fixed length sites were sampled. Black bass and Sander species were collected, and presence/absence of other species was recorded. In the three pools of the Ohio River and two pools of the Allegheny River 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 was 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 2021 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 searched and are typically compiled to determine the additional occurrences of Asian carps in sampling data taken from 1957 – 2020. Since last reported, no additional data has been added to ORSANCO's online repository. All additional data have been 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 2020 was largely unable to be completed. However, INDNR was able to conduct ~3.75 hours of sampling effort which yielded no Bighead or Grass carp captures, but 79 Silver Carp were captured through these efforts (Table 3). These results suggest an additional year where catch rates for Silver Carp have increased from previous years standardized sampling efforts (Figure 2a).

Spring gill netting in 2020 was also restricted due to COVID 19 precautions. However, WVDNR was able to complete 16 total sets. Sampling produced no catches of Silver, Bighead, or Grass carp in R.C. Byrd (Table 4). Sixteen sets representing 732 meters (2,400ft) of net, yielded 8 fish and 5 taxa. Blue Catfish made up the majority of fish caught (3), followed by Smallmouth Buffalo (2), and one each of Flathead Catfish, Longnose Gar, and Paddlefish (Table 5).

The Cannelton Pool average catch rates peaked in 2017 for both Silver and Bighead carp (Figure 2b and Figure 3); 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 2020 produced zero Bighead Carp captures, eighty-nine Silver Carp captures, and one Grass Carp in the Cannelton Pool, and nineteen Silver Carp capture in McAlpine. A total of 90 transects (23.75 hours) yielded 14,938 fish comprising 63 taxa (Table 6). Gizzard Shad were the most commonly encountered species, ~67% of the total catch by number throughout the sampling period (Table 7). Emerald Shiner (~18% total catch), Bluegill Sunfish (~3% total catch), and Smallmouth Buffalo (~2% total catch) made the majority of the additional diversity seen during community monitoring. The remaining 10% of diversity varied widely by species and location. Accounts of all species captured during sampling can be found in Table 7 below.

In 2020, Bighead and Silver carp were both captured in McAlpine Pool, but only Silver Carp were captured in the Cannelton Pool. One hundred and three sets representing 4,686m (15,375ft), yielded a total catch of 79 fish and 21 taxa (Table 8). In 2020, Paddlefish was the most common species encountered (~32% of total catch) while Silver Carp captures made up an additional 23% of total catch (Table 9). Smallmouth Buffalo (~11%), Flathead Catfish (~8% of total catch), Longnose Gar (~6% of total catch), and Common Carp and Freshwater Drum (~4% of total catch) made up the majority of the remaining diversity encountered during sampling efforts. The additional diversity making up the remaining 12% of total fish captured in 2020 (Table 9).

Beach seine hauls in the R.C. Byrd Pool captured fourteen different fish species, including the Eastern Mosquitofish, which only last year has been represented in community data. Channel Shiners made up the majority of catch (~63% total catch) while Emerald Shiner was the second most frequent species (~ 29% of total catch). The next most frequent species encountered were Bluegill Sunfish, Gizzard Shad, and Ghost Shiner making up 6%, 1.4%, and 0.52% of total catch respectively. The remaining 0.05% of diversity is listed in Table 10.

Hydroacoustic Analysis

Hydroacoustic work was not able to be conducted in the fall of 2020 and there is no new information to report.

Assessing Asian Carp Population Demographics
In total, the number of Bighead Carp captured across all projects in 2020 was one female fish; a large decrease compared to previous years. This fish was an 840mm (33.1 inch) female fish weighing 6.2kg (13.7 lbs) captured in the McAlpine Pool. Due to a lack of information on bighead carp captures in 2020, no additional information on demographics can be added to previous data. Regressions from data collected in 2019 still support the previously reported length-weight regression for fish captured in the middle Ohio River (Table 2; Figure 5).

In 2020, 266 Silver Carp were captured across framework projects. In 2019, males were by far the most common sex encountered. Males and females captured in 2020 occurred with almost equal frequency with females making up approximately 53% of Silver Carp captured and males approximately 47% of total catch. More specifically, males in the Cannelton Pool made up approximately 56% of the population and averaged 714mm (n = 88, SD = 86mm) in total length, while females averaged slightly larger at 730mm (n = 68, SD = 102mm). Silver Carp captured in the McAlpine Pool were 53% male, averaging 728mm (n = 54, SD = 96mm) in total length while females were 742mm on average (n = 47, SD = 86mm). The ranges in total length were comparable between the two sexes in the Cannelton and McAlpine pools (Figure 4 and Figure 7). Silver Carp caught in the Markland Pool were 66% male with an average total length of 875mm (n = 6, SD = 111mm) and females around 976mm (n = 3, SD = 49mm). The weight-length regression for 2020 shows a similar slope when compared to the established ORB regression and a similar y-intercept (Figure 8). As in the past, fish found farther up the system tend not only to be larger (Figure 9), but also in better condition on average, as seen using the relative weight (Wr) equation developed by Lamer *et al*. 2015 for Silver Carp (Figure 10).

Evidence of recent spawning activity was seen over a much shorter duration in 2019 than in previous years (May 14 – June 12); however, reports from observers and contract fishers describing spawning behavior began in the first week of May, 2020. Additional data collected by agencies showed that recent spawning patches were displayed on 48% of female fish captured between June and August, 2020. 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 11). This is more consistent with previous years, which have shown spawning patches beginning in mid-May and continuing throughout the summer into August, indicating a protracted spawning season.

In total, otoliths from Silver Carp in 2019 were harvested to track age distribution, growth, and estimate mortality. Otoliths taken from fish above McAlpine Locks and Dam provided a snapshot of age distributions above Cannelton. Otoliths taken from Asian Carp in Cannelton Pool were aged and graphed with their associated total lengths to create a length-based growth model for predicting fish age (Figure 12). Otoliths taken from Asian Carp in McAlpine pool were also aged and graphed with their associated total lengths to create a length-based growth model for predicting fish age (Figure 13). Data to date suggests that the majority of Silver Carp captured in 2019 in the Cannelton Pool are likely between 4 and 7 years old, and Silver Carp Captured in the McAlpine Pool are between 5 and 8 years old. Of the 16 fish captured in Markland, the majority of fish were aged between 6 and 9 years old. The $\text{Pauly}_{\text{nls-T}}$ formula (Then et al. 2015) estimated instantaneous natural mortality (M) for fish in the Cannelton and McAlpine pools to be M = 0.644 and M = 0.607 respectively. Assuming no fishing mortality, interval mortality (A) would be estimated at A = 0.47 and A = 0.45 for Cannelton and McAlpine pools.

Monitoring Asian Carps Ahead of the Invasion Front
Targeted gill net sampling for Asian carp in the New Cumberland and Montgomery Pools of the Ohio River did not collect any Asian carp species. Common Carp, Smallmouth Buffalo, and River Carpsucker

were the three most common species captured and comprised 56%, 20%, and 9% of the total catch on the Ohio River, respectively.

Fish community monitoring in the Dashields Pool and Montgomery Pool of the Ohio River and Pool 6 of the Allegheny River Pool 7 of the Allegheny River was conducted in June 2020 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-eight species and 910 individuals, 35 species and 896 individuals, and 42 species and 1191 individuals were captured in the Dashields Pool (Ohio), Montgomery Pool (Ohio), and Pool 6 (Allegheny), respectively. Emerald Shiner, Smallmouth Bass, and Golden Redhorse comprised approximately 42% of the total catch between all pools (Table 11).

Beach seining on the Montgomery Island Pool in August 2020 collected no Asian carp species. A total of 1141 individuals of 23 different species were captured. Spotfin Shiner comprised 67% of the total catch (Table 12).

The Pennsylvania Fish and Boat Commission tracks incidental captures of Asian carp through other various projects. Efforts in 2020 included 12 baited tandem hoop nets that were fished for 36 net nights and 48 unbaited single hoop nets that were fished for 144 net nights and captured no Asian carp species. In the baited hoop nets, 12 species and 551 individuals were captured, with Channel Catfish and Smallmouth Buffalo comprising 62% and 27% of the total catch, respectively. In the unbaited hoop nets, 12 species and 206 individuals were captured, with Channel Catfish, Common Carp, and Flathead Catfish comprising 39%, 30%, and 19% of the total catch, respectively. Night boat electrofishing in Pool 4 of the Allegheny River for 1.92 hrs of effort captured no Asian Carp in October. No Asian carp were captured during night electrofishing surveys in November in the New Cumberland or Dashields Pools of the Ohio River, none were captured in Pool 3 or Pool 6 of the Allegheny River (1.33 hrs of effort per pool). However, one Grass Carp was captured during the November night electrofishing survey on the Montgomery Pool. The specimen was retained. However, due to logistics, it was not tested for ploidy and is currently awaiting processing for age/sex determination.

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. No additional data was posted by ORSANCO from 2019 or 2020 that could be used to update these range maps. 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 14). 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 15). Grass Carp records continue to be sporadic throughout the Ohio River and within all internal waters of the surrounding basin states (Figure 16). 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 17). With some recent captures as far up as the J.T. Meyers Pool, just below Newburgh, IN.

Discussion:

Work conducted in 2020 was impacted due to precautions taken to avoid the exposure and spread of the COVID-19 virus. Despite this, data 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 are difficult to capture along this range, but in the past, have been 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 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 along the project range and is likely the farthest upriver pool with an established Silver Carp population. Prior to work conducted in 2020, 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. The addition of data collected in 2020 through standard sampling protocols appears to support this steady increase in relative catch rates of Silver Carp in 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. Therefore, additional forms of evaluation that strengthen our understanding of changes in the population after the implementation of management actions are necessary. Measurements of baseline mortality rates and changes to mortality over time may provide additional information on populations resulting from management actions. The 2019 annual mortality estimated above utilized estimates of instantaneous mortality derived from age and growth data of fish harvested through removal efforts in 2019 and assumed that mortality from fishing pressure was negligible. With the implementation of a contract fishing program, there is now an opportunity to begin estimating fishing mortality through the use of passive tagging data collected through recaptures of telemetered fish. Adding this information will allow basin partners to track increases in interval mortality annually in carp populations as a result of increases in contract and commercial fishing effort.

Silver Carp relative abundance has varied over the past four years, but average electrofishing catch rates in 2020 were the highest in the Cannelton Pool to date. While standard sampling of carp in the McAlpine Pool was not completed in 2020, densities of Silver Carp have continually appeared to drop as much as 75% – 82% when moving just this one pool upriver according to data collected in 2019. In pools above McAlpine, electrofishing efforts have not provided sufficient information about changed in invasive carp abundances or demographics, and more effort would be necessary to prescribe 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 sporadic using this 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 irregular.

Catch rates of invasive carps during the spring season may be highly associated with spawning activity. Due to this behavior, 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 over short periods of time. 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 continually 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 herding techniques used in removal efforts can 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. More sensitive measures of change are under consideration (e.g. annual probabilities of detection, changes in proportion of zero-catches, and occupancy modeling).

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 the invasive carp population 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. Many contract fishers sell harvests using the Kentucky Fish Center (KFC) or other basin processors, thus expanding local economies while contributing to invasive carp population reduction. In addition, 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 carp population control.

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Table 1. 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 2. 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 3. 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 2020. Standard errors are in parentheses.

Spring Boat Electrofishing							
Ohio River 2020							
	Cannelton	McAlpine	Markland	Meldahl	Greenup	RC Byrd	Total
Sampling Dates	15 April - 27 April						
Effort (Hours)	3.75	N/A	N/A	N/A	N/A	N/A	3.75
Sample Transects	15	N/A	N/A	N/A	N/A	N/A	15
All Fish (N)	79						79
Species (N)	1						1
Bighead Carp (N)	0						0
Silver Carp (N)	79						79
Grass Carp (N)	0						0
CPUE (fish/hr)							
Bighead Carp	0.00 (0.00)						
Silver Carp	21.00 (7.14)						
Grass Carp	0.00 (0.00)						

Table 4. 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 2020. Standard errors are in parentheses.

Spring Gill Netting							
Ohio River 2020							
	Cannelton	McAlpine	Markland	Meldahl	Greenup	RC Byrd	Total
Sampling Dates	08 April - 22 April						
Effort (ft)	N/A	N/A	N/A	N/A	N/A	2400	2400
Net Sets	N/A	N/A	N/A	N/A	N/A	16	16
All Fish (N)						8	8
Species (N)						5	5
Bighead Carp (N)						0	0
Silver Carp (N)						0	0
Grass Carp (N)						0	0
CPUE (fish/yd)							
Bighead Carp						0.00 (0.00)	
Silver Carp						0.00 (0.00)	
Grass Carp						0.00 (0.00)	

Table 5. A bycatch table showing the catch of non-target species through the use of gill netting during 2020 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 2020						
By-Catch	Cann	McAlp	Mark	Meld	Green	RCBy	Total
Bigmouth Buffalo						0	0
Blue Catfish						3	3
Common Carp						0	0
Flathead Catfish						1	1
Freshwater Drum						0	0
Longnose Gar						1	1
Paddlefish						1	1
Smallmouth Buffalo						2	2
Striped Bass						0	0

Table 6. 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 2020. Standard errors are in parentheses.

Fall Boat Electrofishing							
Ohio River 2020							
	Cannelton	McAlpine	Markland	Meldahl	Greenup	RC Byrd	Total
Sampling Dates	05 October - 18 November						
Effort (Hours)	7.75	6.00	N/A	N/A	3.80	6.20	23.75
Sample Transects	24	24	N/A	N/A	16	26	90
All Fish (N)	2194	769			4187	7788	14938
Species (N)	51	32			40	45	63
Bighead Carp (N)	0	0			0	0	0
Silver Carp (N)	89	19			0	0	108
Grass Carp (N)	1	0			0	0	1
CPUE (fish/hr)							
Bighead Carp	0.00 (0.00)	0.00 (0.00)			0.00 (0.00)	0.00 (0.00)	
Silver Carp	1.67 (0.63)	3.17 (1.38)			0.00 (0.00)	0.00 (0.00)	
Grass Carp	0.17 (0.17)	0.00 (0.00)			0.00 (0.00)	0.00 (0.00)	

Table 7. 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 2020. (Ohio River Pools: Cann = Cannelton; McAlp = McAlpine; Mark = Markland; Meld = Meldahl; Green = Greenup)

	Ohio River Pools in 2020							
Species Captured	Cann	McAlp	Mark	Meld	Green	RC Byrd	Total	Percent
Banded Killifish	0	0			1	1	2	0.013%
Bigmouth Buffalo	1	1			0	0	2	0.013%
Bigeye Chub	0	0			0	1	1	0.007%
Black Buffalo	0	0			0	2	2	0.013%
Black Crappie	8	8			1	6	23	0.155%
Black Redhorse	0	1			0	0	1	0.007%
Blue Catfish	1	0			0	0	1	0.007%
Bluegill Sunfish	93	20			84	241	438	2.956%
Blue Sucker	1	0			0	0	1	0.007%
Bowfin	2	0			1	1	4	0.027%
Brook Silverside	7	0			3	0	10	0.067%
Central Stoneroller	4	0			2	1	7	0.047%
Channel Catfish	28	17			3	5	53	0.358%
Channel Shiner	0	0			16	41	57	0.385%
Chesnut Lamprey	1	0			0	0	1	0.007%
Common Carp	6	3			3	16	28	0.189%
Emerald Shiner	442	17			912	1237	2608	17.599%
Flathead Catfish	1	2			0	5	8	0.054%
Freshwater Drum	25	6			22	83	136	0.918%
Gizzard Shad	889	490			2918	5634	9931	67.015%
Golden Redhorse	20	5			12	12	49	0.331%
Grass Carp	1	0			0	0	1	0.007%
Green Sunfish	4	5			4	17	30	0.202%

Greenside Darter	0	0	1	0	1	0.007%
Highfin Carpsucker	0	0	3	1	4	0.027%
Johnny Darter	0	0	1	0	1	0.007%
Largemouth Bass	34	33	19	45	131	0.884%
Logperch	2	0	0	2	4	0.027%
Longear Sunfish	31	5	1	4	41	0.277%
Longnose Gar	11	14	2	7	34	0.229%
Mimic Shiner	22	0	0	0	22	0.148%
Mooneye	13	0	0	2	15	0.101%
Northern Hogsucker	0	2	0	4	6	0.040%
Orangespotted Sunfish	13	1	5	15	34	0.229%

Table 7 (cont). The number of fish captured by species and percent of total catch in six pools of the Ohio River with boat electrofishing surveys at fixed monitoring sites in 2020. (Ohio River Pools: Cann = Cannelton; McAlp = McAlpine; Mark = Markland; Meld = Meldahl; Green = Greenup)

Pimephales spp.	6	0	4	0	10	0.067%
Pugnose Minnow	1	0	0	0	1	0.007%
Quillback	3	2	0	3	8	0.054%
Redear Sunfish	10	1	4	5	20	0.135%
River Carpsucker	24	15	5	22	66	0.445%
River Redhorse	1	11	1	3	16	0.108%
River Shiner	13	0	0	0	13	0.088%
Sauger	4	4	10	21	39	0.263%
Saugeye	0	0	0	1	1	0.007%
Shorthead Redhorse	2	10	14	14	40	0.270%
Silver Carp	10	19	0	0	29	0.196%
Silver Redhorse	0	1	0	5	6	0.040%
Skipjack Herring	81	8	7	28	124	0.837%
Smallmouth Bass	30	5	11	38	84	0.567%
Smallmouth Buffalo	71	47	43	163	324	2.186%

Spotfin Shiner	9	0	2	5	16	0.108%
Spotted Bass	47	40	2	11	100	0.675%
Spotted Gar	8	0	0	0	8	0.054%
Spotted Sucker	11	4	12	5	32	0.216%
Striped Bass	2	0	1	2	5	0.034%
Threadfin Shad	1	0	0	0	1	0.007%
Warmouth	5	3	0	3	11	0.074%
Hybrid Striped Bass	8	0	38	55	101	0.682%
Walleye	0	0	6	0	6	0.040%
White Bass	11	7	11	1	30	0.202%
White Crappie	16	4	1	18	39	0.263%
White Sucker	1	0	0	0	1	0.007%
Yellow Bass	1	0	0	0	1	0.007%
Totals	2036	811	4186	7786	14819	

Table 8. 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 2020. Standard errors are in parentheses.

Fall Gill Netting							
	Ohio River 2020						
	Cannelton	McAlpine	Markland	Meldahl	Greenup	RC Byrd	Total
Sampling Dates	05 October - 22 October						
Effort (ft)	4800	6000	N/A	N/A	2025	2550	15375
Net Sets	32	40	N/A	N/A	14	17	103
All Fish (N)	46	27			1	5	79
Species (N)	8	10			1	2	21
Bighead Carp (N)	0	1			0	0	1
Silver Carp (N)	12	6			0	0	18
Grass Carp (N)	1	0			0	0	1
	CPUE (fish/yd)						
Bighead Carp	0.00 (0.00)	5.0E-4 (5.0E-4)			0.00 (0.00)	0.00 (0.00)	
Silver Carp	7.5E-3 (4.1E-3)	3.0E-3 (1.3E-3)			0.00 (0.00)	0.00 (0.00)	
Grass Carp	6.3E-4 (6.3E-4)	0.00 (0.00)			0.00 (0.00)	0.00 (0.00)	

Table 9. 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 2020. (Ohio River Pools: Cann = Cannelton; McAlp = McAlpine; Mark = Markland; Meld = Meldahl; Green = Greenup)

	2020 Fall Monitoring Gill Netting							
	River Pool							
Species Captured	Cann	McAlp	Mark	Meld	Green	RC Byrd	Total	Percent
Bighead Carp	0	1			0	0	1	1.266%
Bigmouth Buffalo	0	2			0	0	2	2.532%
Blue Catfish	2	0			0	0	2	2.532%
Channel Catfish	0	1			0	0	1	1.266%
Common Carp	1	3			0	0	4	5.063%
FlatheadCatfish	1	1			0	4	6	7.595%
FreshwaterDrum	2	2			0	0	4	5.063%
Grass Carp	1	0			0	0	1	1.266%
Longnose Gar	0	4			0	1	5	6.329%
Paddlefish	25	0			0	0	25	31.646%
Sauger	0	1			0	0	1	1.266%
Silver Carp	12	6			0	0	18	22.785%
Silver Redhorse	0	0			0	0	0	0.000%
Smallmouth Buffalo	2	6			1	0	9	11.392%
Totals	46	27	0	0	1	5	79	

Table 10. The number of fish captured by species and percent total catch from eight seine hauls in the Greenup and RC Byrd pools of the Ohio River.

Species Captured	N	% Catch
Bluegill	111	5.72
Bluntnose Minnow	4	0.21
Bullhead Minnow	1	0.05
Channel Shiner	1213	62.53
Cyprinella spp.	3	0.15
Eastern Mosquitofish	1	0.05
Eastern Banded Killifish	2	0.10
Emerald Shiner	559	28.81
Freshwater Drum	1	0.05
Ghost Shiner	10	0.52
Gizzard Shad	27	1.39
Orange Spotted Sunfish	6	0.31
River Shiner	1	0.05
Warmouth	1	0.05
Total	1940	

Table 11. Total number of fish captured per pool and percent of total captured at three pools combined in the Allegheny and Ohio Rivers during spring night electrofishing surveys in 2020. (A=Allegheny, O=Ohio)

	Allegheny and Ohio River Pools in 2020				
Species Captured	Pool 6 (A)	Dashields (O)	Montgomery (O)	Total	Percent
Black Crappie	3			3	0.10%
Black Redhorse	86	11	13	110	3.67%
Blackside Darter	38			38	1.27%
Bluebreast Darter	1			1	0.03%
Bluegill	6	3	1	10	0.33%
Bluntnose Minnow	9	4	15	28	0.93%
Brook Silverside	2			2	0.07%
Channel Catfish	17	12	8	37	1.23%
Channel Darter			1	1	0.03%
Channel Shiner	4	38	80	122	4.07%
Common Carp	2		2	4	0.13%
Emerald Shiner	44	403	269	716	23.89%
Flathead Catfish	3		3	6	0.20%
Freshwater Drum	9	30	19	58	1.94%
Gizzard Shad	1	11	17	29	0.97%
Golden Redhorse	127	10	27	164	5.47%
Golden Shiner			2	2	0.07%
Green Sunfish	2			2	0.07%
Greenside Darter	2		1	3	0.10%
Largemouth Bass			1	1	0.03%
Logperch	43	7	13	63	2.10%
Longhead Darter	14	4		18	0.60%
Longnose Gar	16	7	51	74	2.47%
Mimic Shiner	33	49	13	95	3.17%
Mooneye	1			1	0.03%

Muskellunge			1	1	0.03%
Northern Hog Sucker	26	1	4	31	1.03%
Northern Pike	2			2	0.07%
Ohio Lamprey	1			1	0.03%
Pumpkinseed			2	2	0.07%
Quillback		9	17	26	0.87%
River Carpsucker	3	14	5	22	0.73%
River Chub	2			2	0.07%
River Redhorse	15	2	3	20	0.67%
Rock Bass	56	6	19	81	2.70%
Rosyface Shiner	19	2		21	0.70%
Sand Shiner	87	15	4	106	3.54%

Table 11 (Cont.). Total number of fish captured per pool and percent of total captured at three pools combined in the Allegheny and Ohio Rivers during spring night electrofishing surveys in 2020. (A=Allegheny, O=Ohio)

Sauger	2	31	68	101	3.37%
Silver Redhorse	37	36	27	100	3.34%
Silver Shiner	4		7	11	0.37%
Smallmouth Bass	218	42	102	362	12.08%
Smallmouth Buffalo	11	96	33	140	4.67%
Smallmouth Redhorse	138	5	16	159	5.31%
Spotfin Shiner	19	45	32	96	3.20%
Spotted Bass		1	2	3	0.10%
Streamline Chub	1			1	0.03%
Walleye	82	16	18	116	3.87%
White Crappie	2			2	0.07%
Yellow Perch	3			3	0.10%
Totals	1191	910	896	2997	

Table 12. Total number of fish captured and percent of total captured during annual beach seine surveys in the Montgomery Island Pool from 2019.

Species Captured	2020	Percent Abundance
Bluegill	5	0.44%
Bluntnose Minnow	56	4.91%
Brook Silverside	6	0.53%
Central Stoneroller	3	0.26%
Channel Shiner	15	1.31%
Eastern Sand Darter	2	0.18%
Emerald Shiner	211	18.49%
Gizzard Shad	25	2.19%
Golden Redhorse	2	0.18%
Golden Shiner	1	0.09%
Logperch	4	0.35%
Mimic Shiner	12	1.05%
Northern Hog Sucker	1	0.09%
Quillback	6	0.53%
River Carpsucker	3	0.26%
Rock Bass	1	0.09%
Sand Shiner	17	1.49%
Silverjaw Minnow	2	0.18%
Smallmouth Bass	5	0.44%
Smallmouth Redhorse	1	0.09%
Spotfin Shiner	760	66.61%
Spotted Bass	2	0.18%
White Sucker	1	0.09%
Totals	1141	

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.

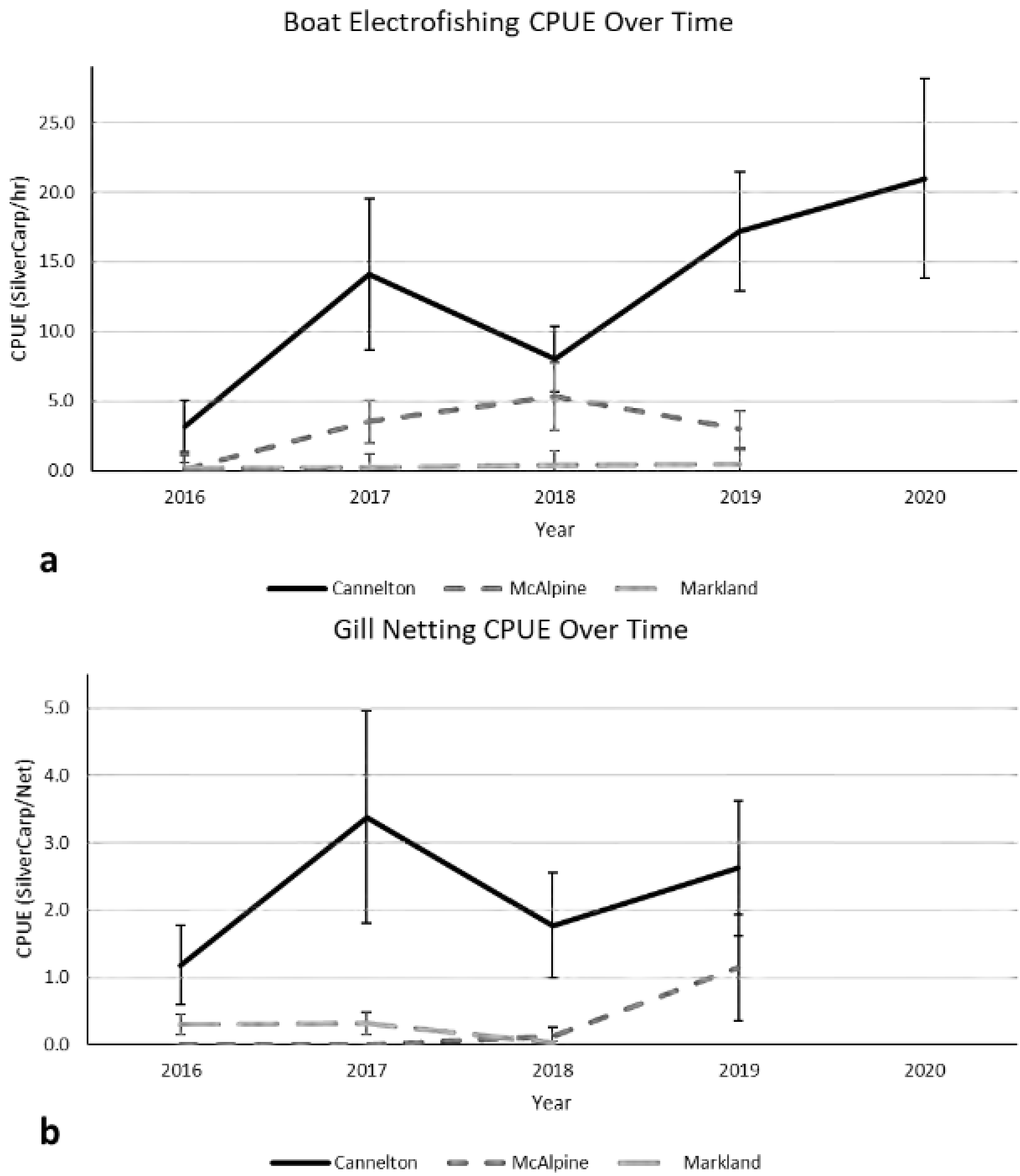

Figure 2. The change in catch per standard unit effort (CPUE) of Silver Carp in the middle Ohio River since 2016. Figure 2a depicts the change in CPUE, measured in fish/hour, for Silver Carp captures using targeted boat electrofishing. Figure 2b depicts the change in CPUE, measured in fish/net-set, for Silver Carp captured using gill netting. Error bars represent standard errors.

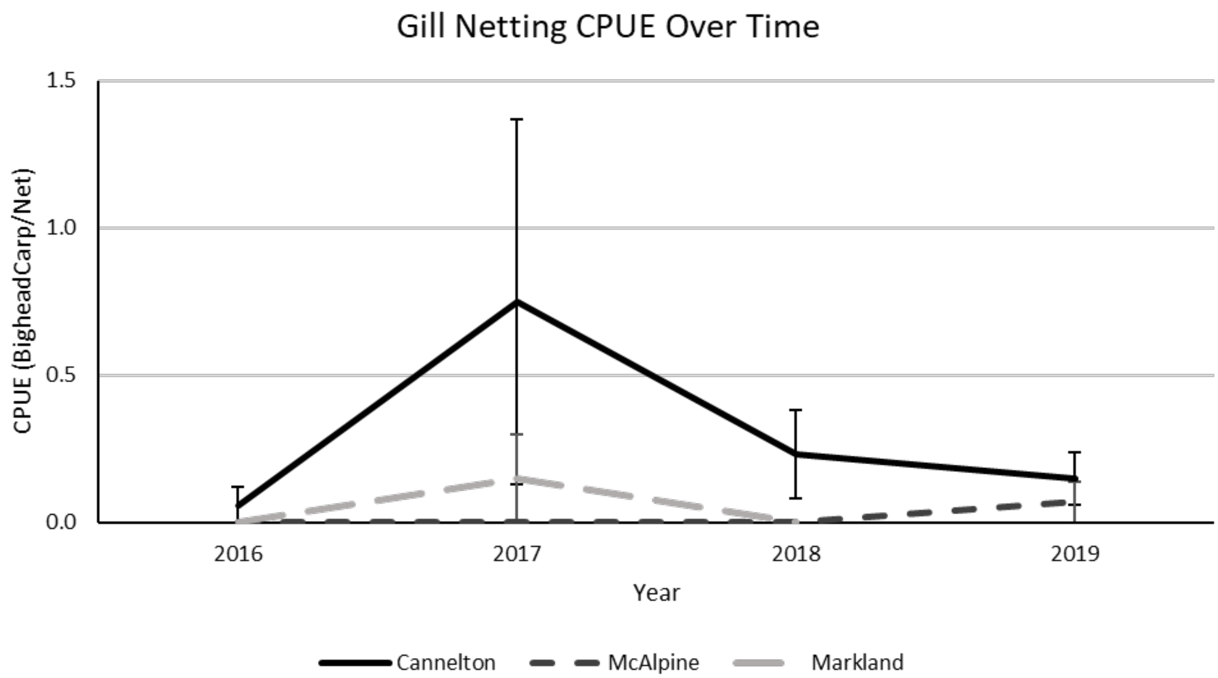

Figure 3. The change in catch per standard unit effort (CPUE) of Bighead Carp in the middle Ohio River since 2016. The CPUE is measured in fish/net-set for Bighead Carp captures using standardized gill netting protocol. Error bars represent standard errors.

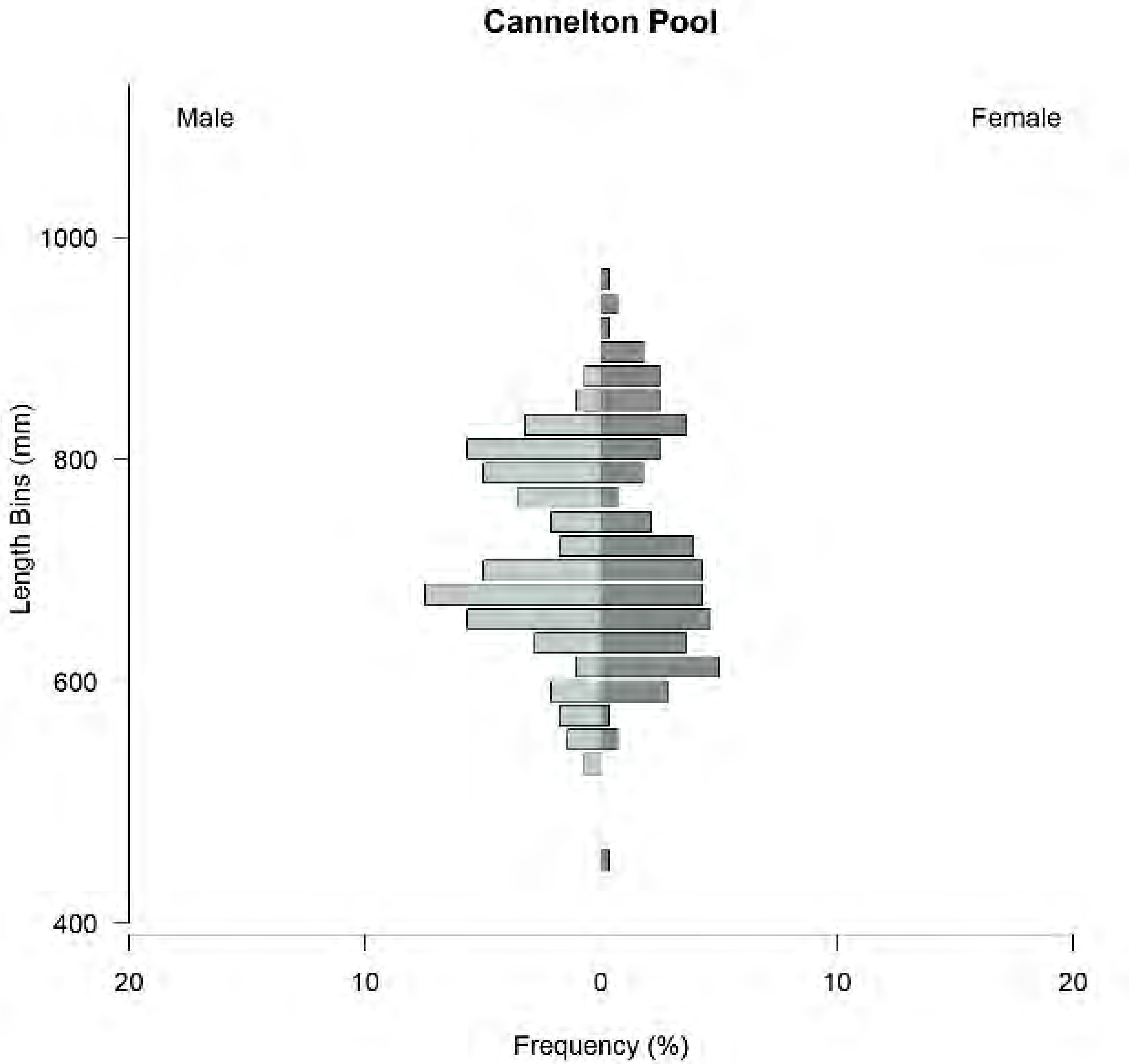

Figure 4. The percent frequency of both male and female Silver Carp, distributed by 20mm length-bins in the Cannelton Pool in 2020.

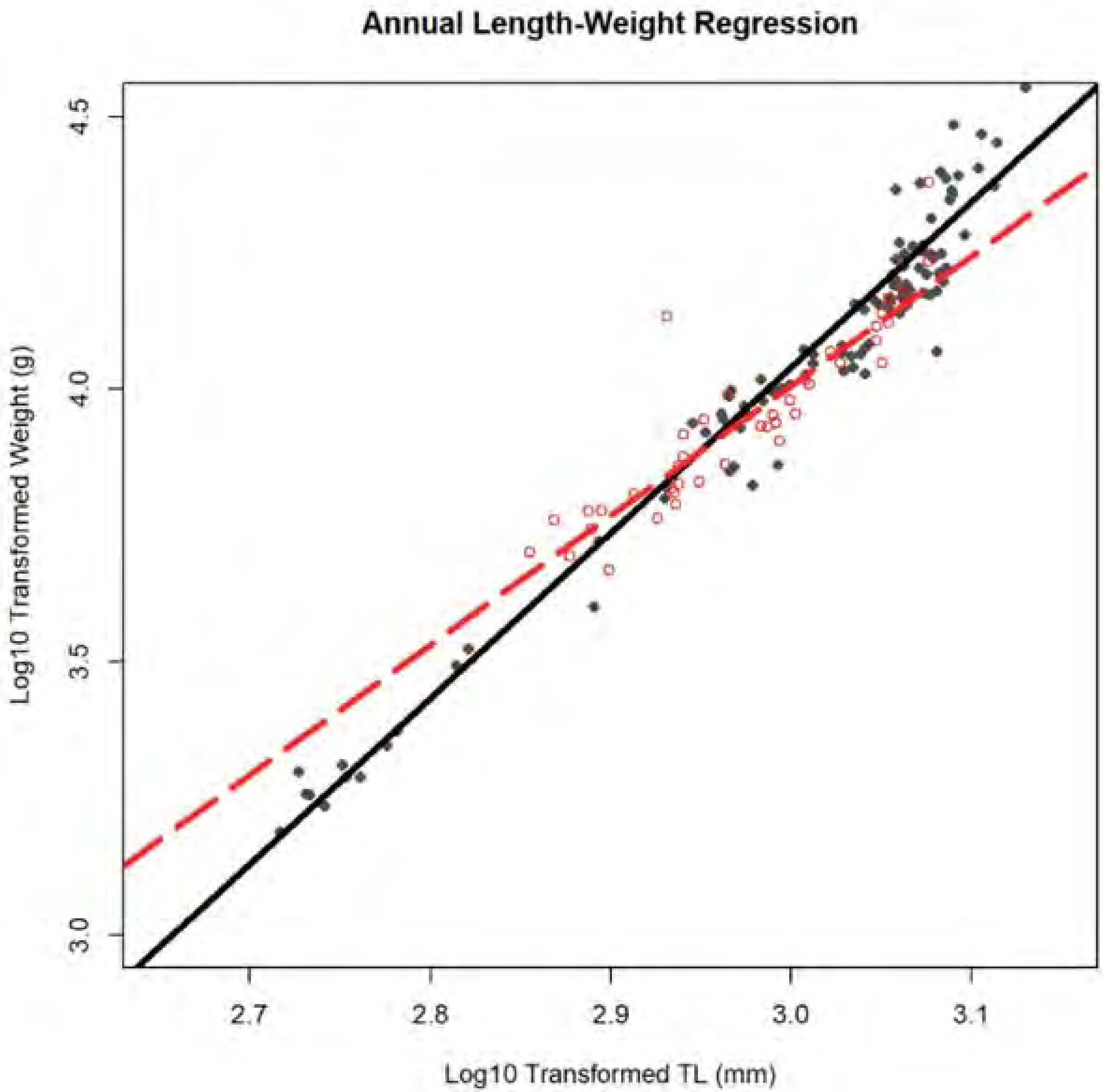

Figure 5. The log-transformed relationship between total length (mm) and weight (g) for Bighead Carp in the ORB. The black line and scatterplot indicate previously observed length-weight relationships for Bighead Carp in the ORB using data collected 2015 – 2017 (regression equation found in Table 2). The red line and data points indicate the regression line and length-weight relationships for new data, collected in 2020.

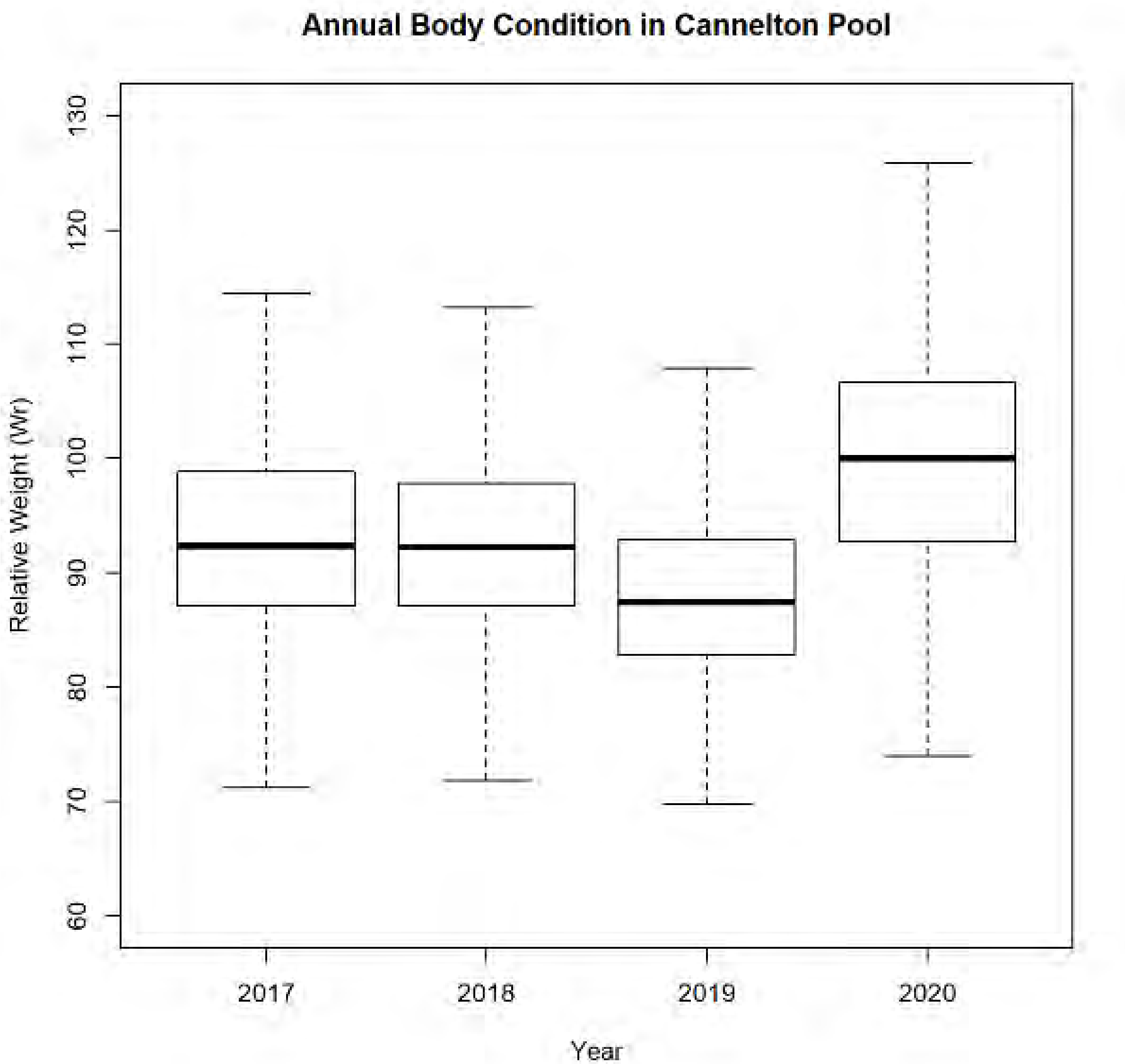

Figure 6. A boxplot comparison of the relative weights (Wr) of Silver Carp captured in the Cannelton pool from 2017 through 2020. Relative weights were calculated using the 50th regression percentile equation for Silver Carp established by Lamer *et al*, 2015.

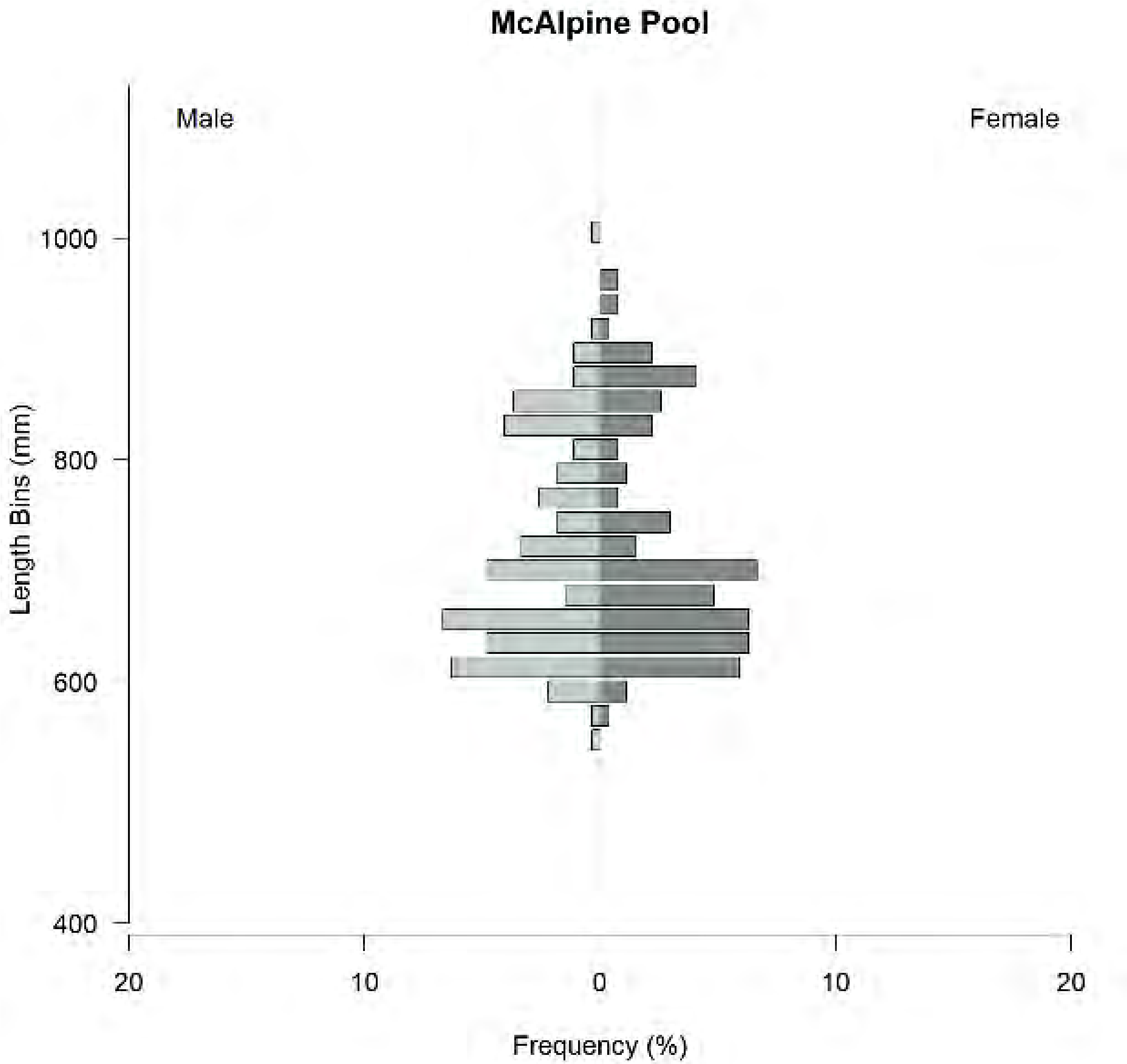

Figure 7. The percent frequency of both male and female Silver Carp, distributed by 20mm length-bins in the McAlpine Pool in 2020.

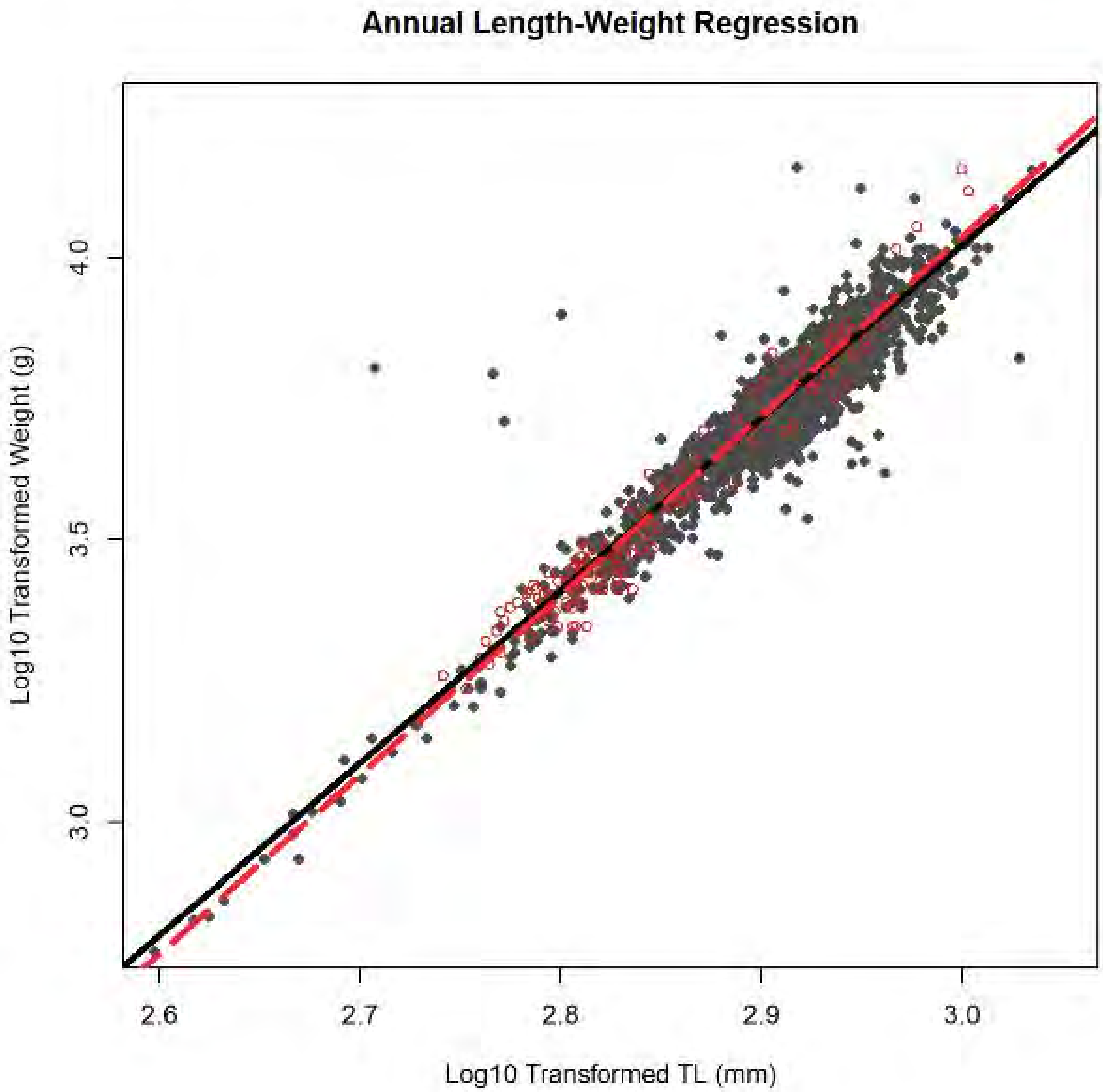

Figure 8. The log-transformed relationship between total length (mm) and weight (g) for Silver Carp in the middle Ohio River. The black line and scatterplot indicate the cumulative length-weight relationship for Silver Carp in the ORB using previous data since 2016 (regression equation found in Table 1). The red line and data points indicate the regression line and length-weight relationships for new data, collected in 2020.

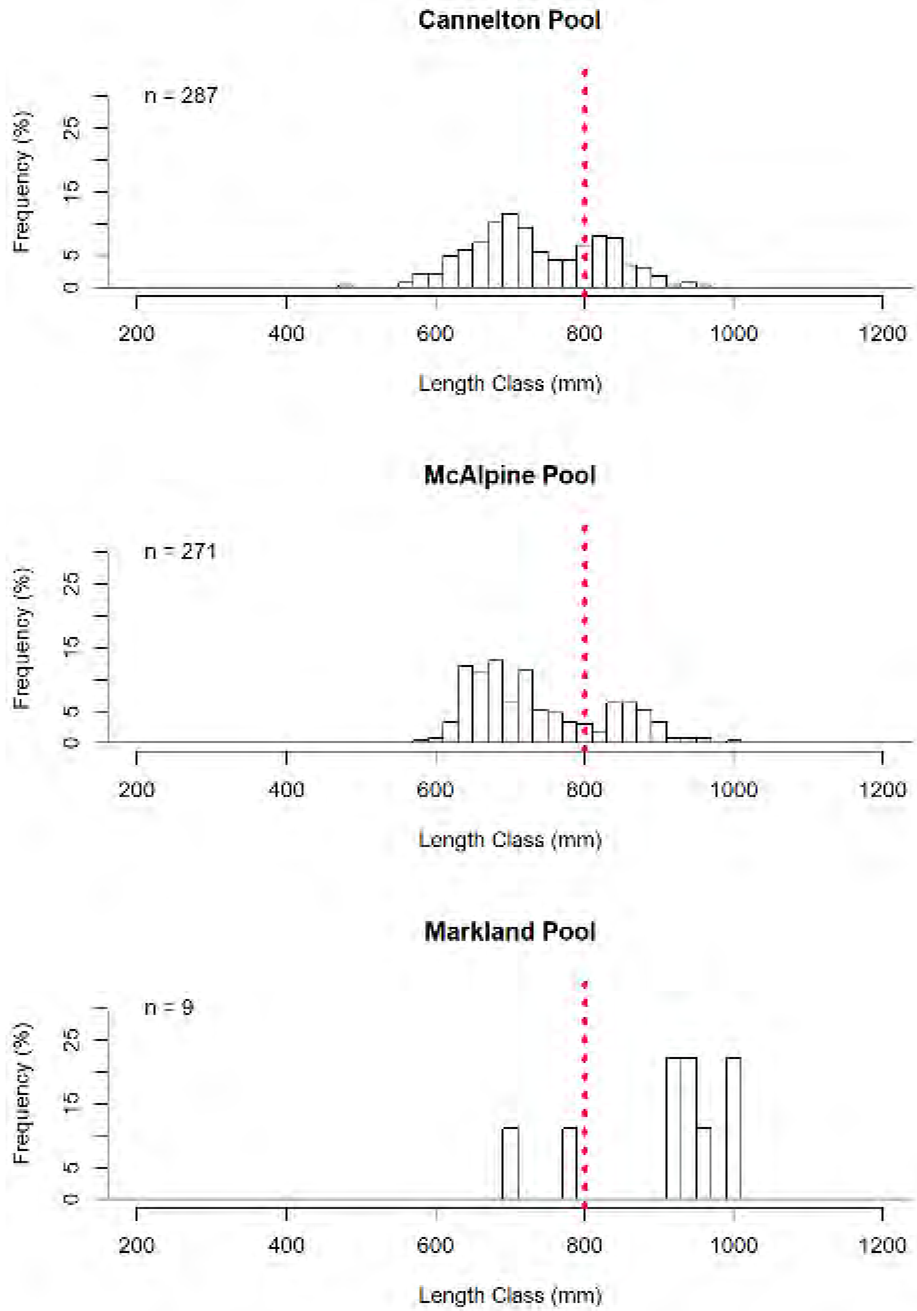

Figure 9. The frequency of total lengths for Silver Carp captured in the Cannelton, McAlpine, and Markland pools in 2020. The line at the 800mm serves as a reference point when considering changes in length-class distributions between pools.

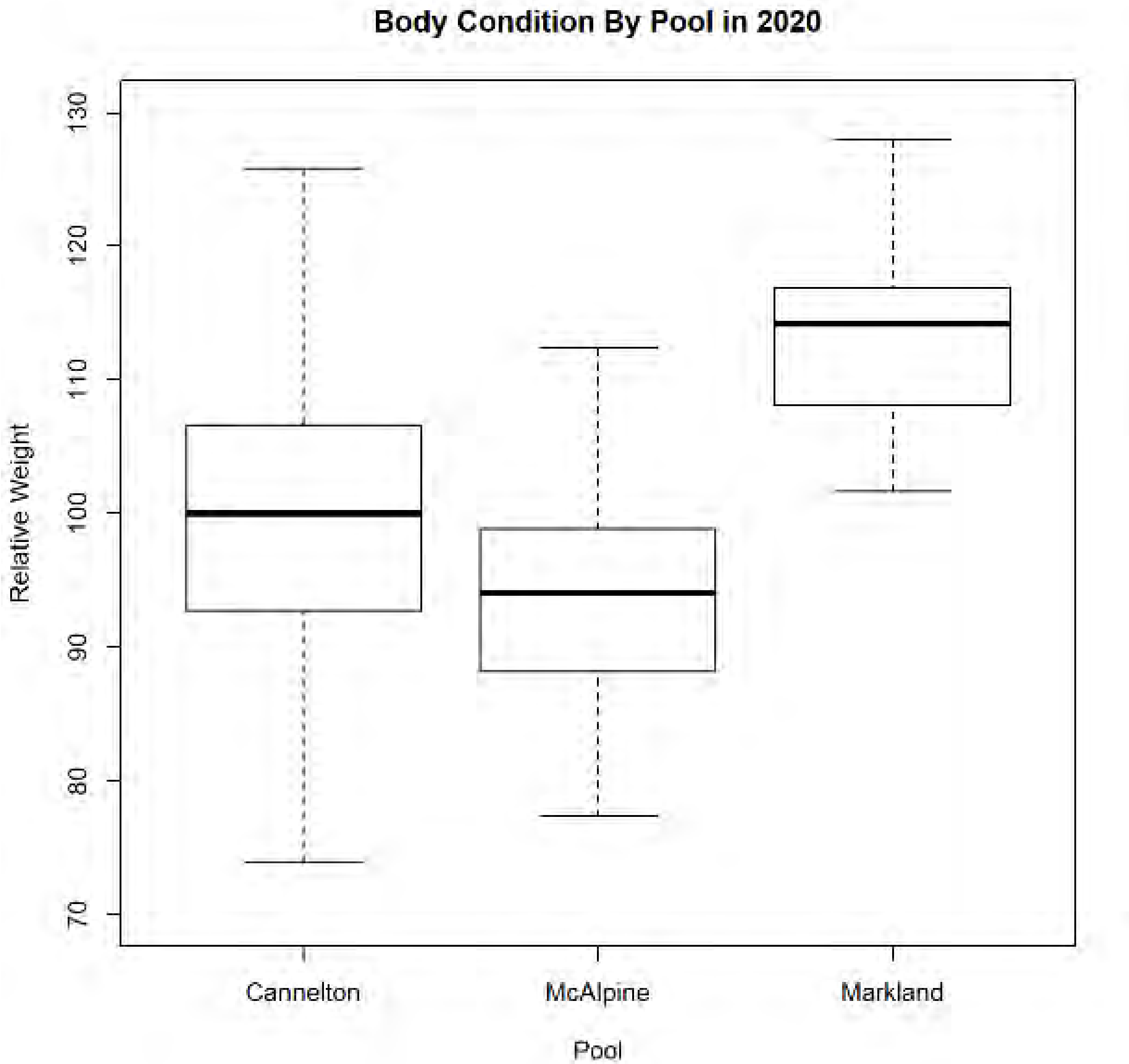

Figure 10. A boxplot comparison of the relative weights (Wr) of Silver Carp captured in the Cannelton, McAlpine, and Markland pools in 2020 Relative weights were calculated using the 50th regression percentile equation developed for Silver Carp by Lamer *et al.*, 2015.

Figure 11.   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.

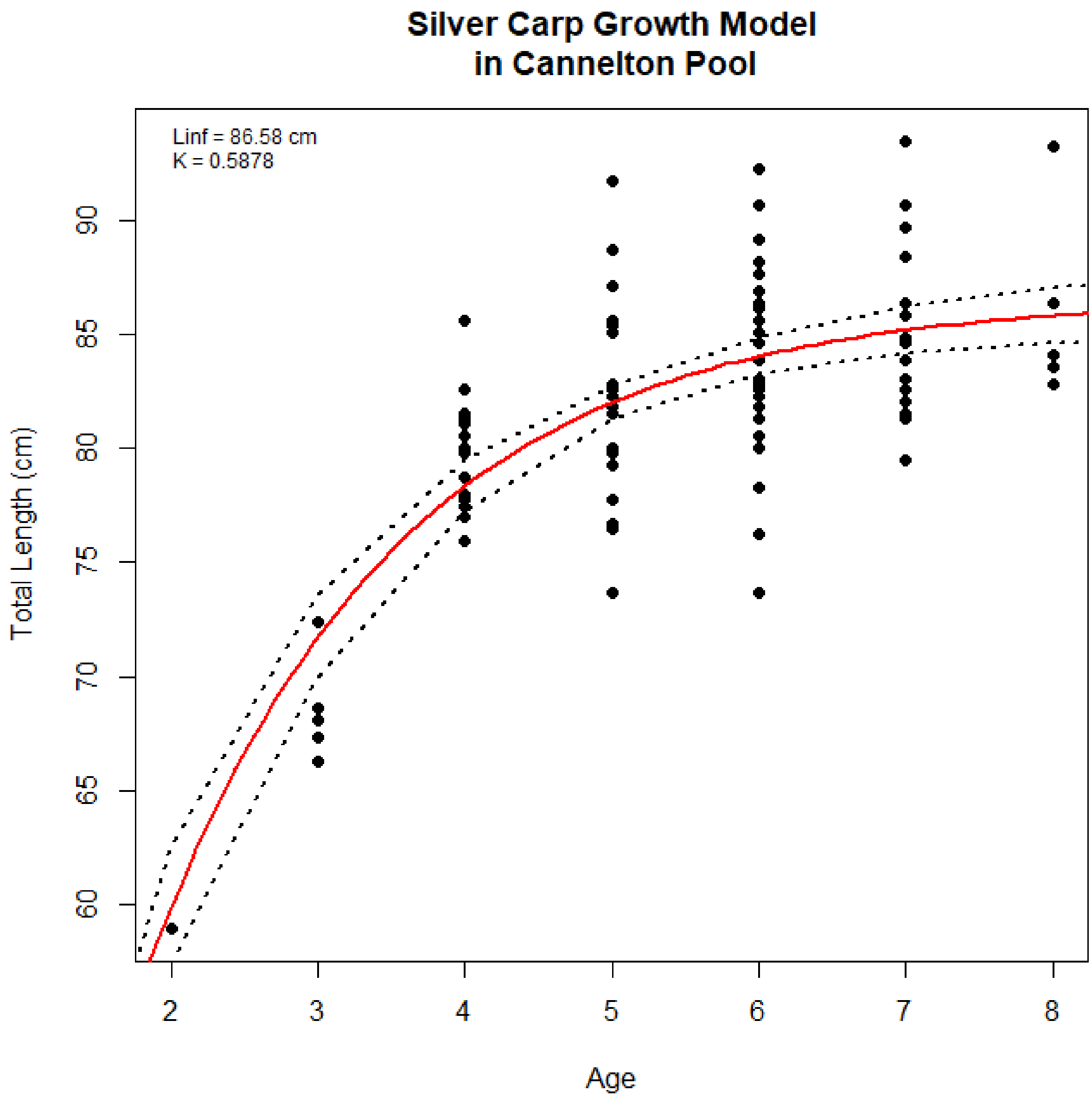

Figure 12. The Silver Carp growth model derived using length at age data from fish captured in the Cannelton Pool in 2019.

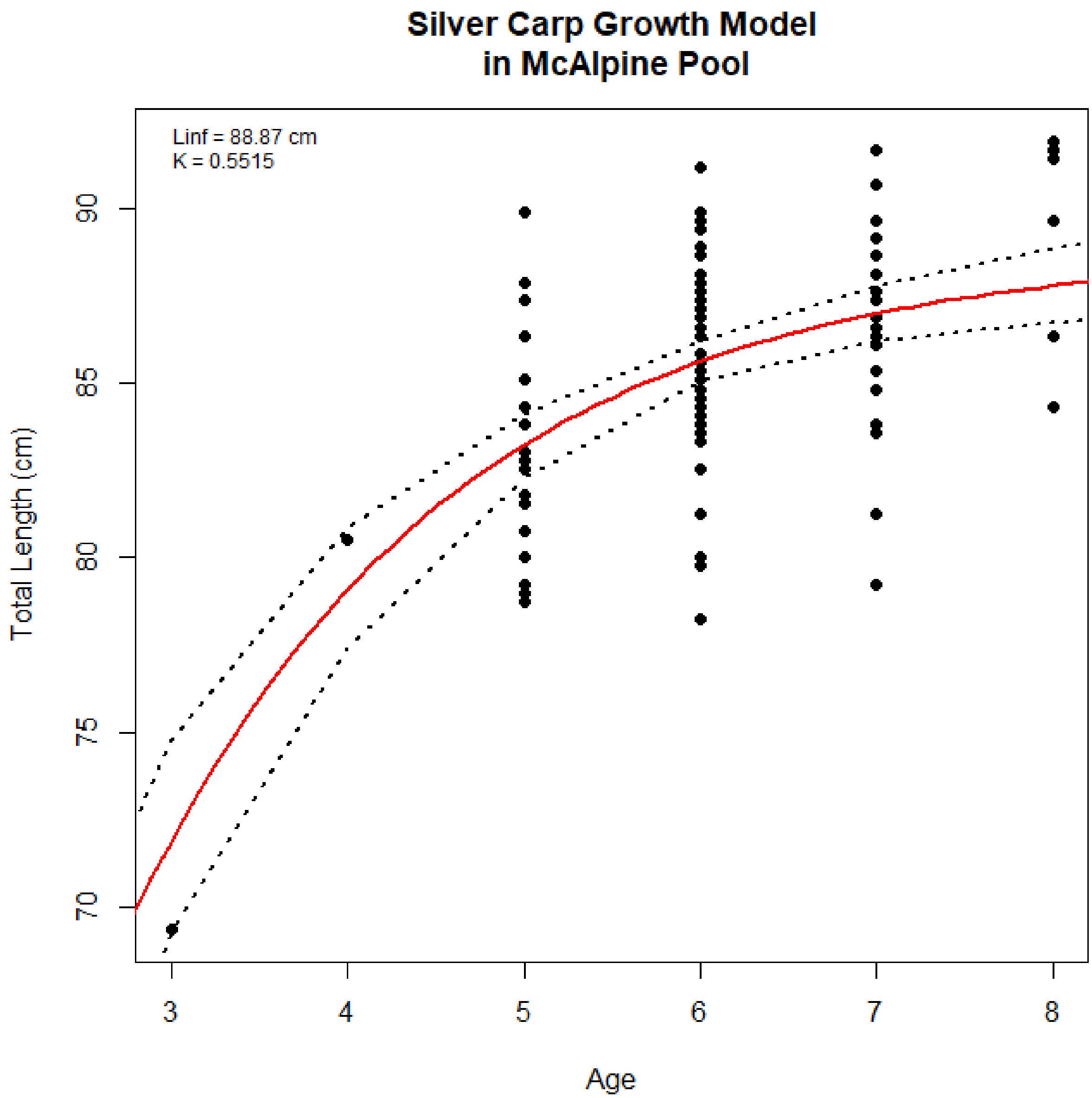

Figure 13. The Silver Carp growth model derived using length at age data from fish captured in the McAlpine Pool in 2019.

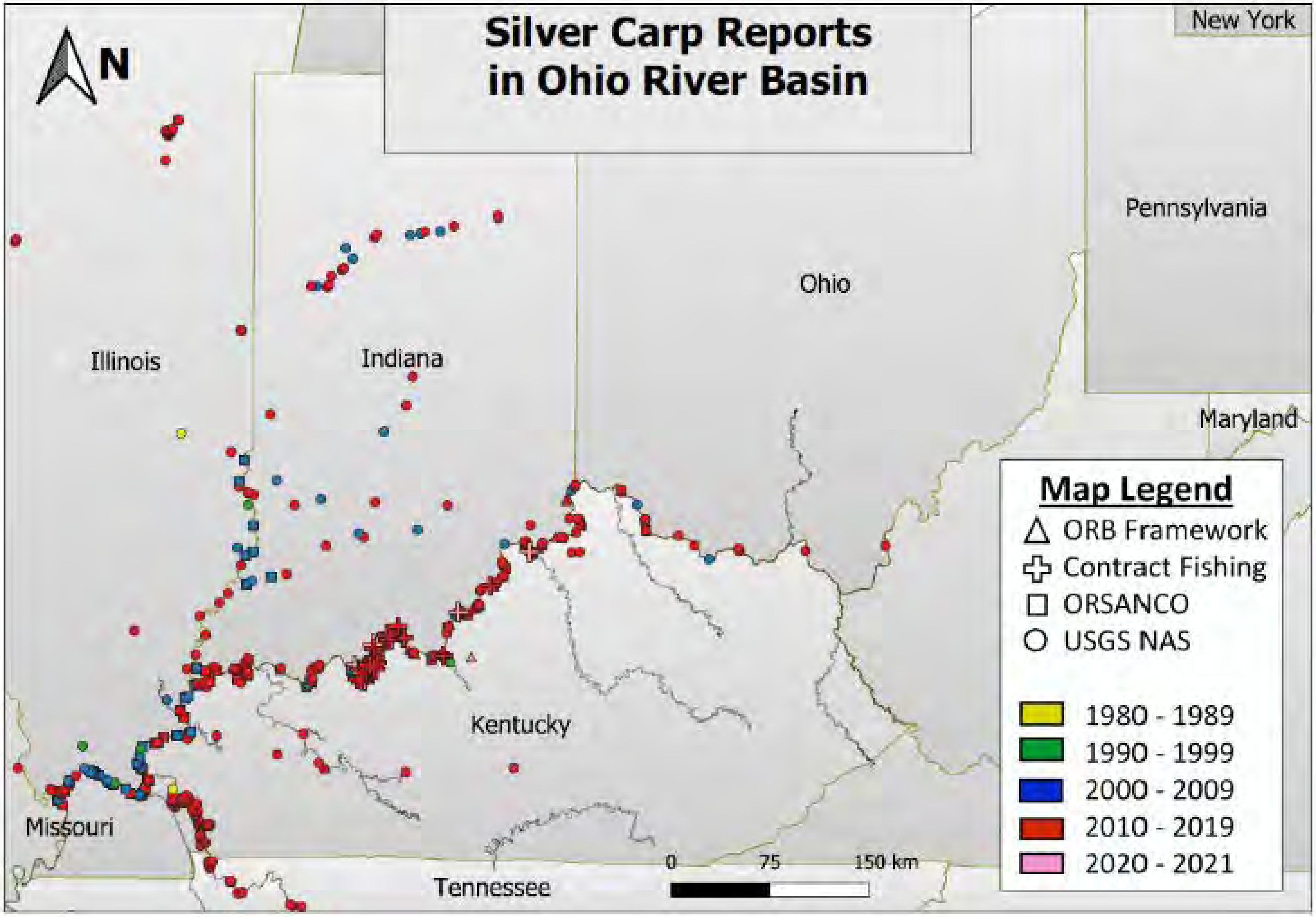

Figure 14. A map incorporating data on the geographic range and temporal proximity of Silver Carp records and reports in the ORB. Data compiled from contract fishing (implemented in 2019), the Framework projects, ORSANCO, and the USGS NAS database.

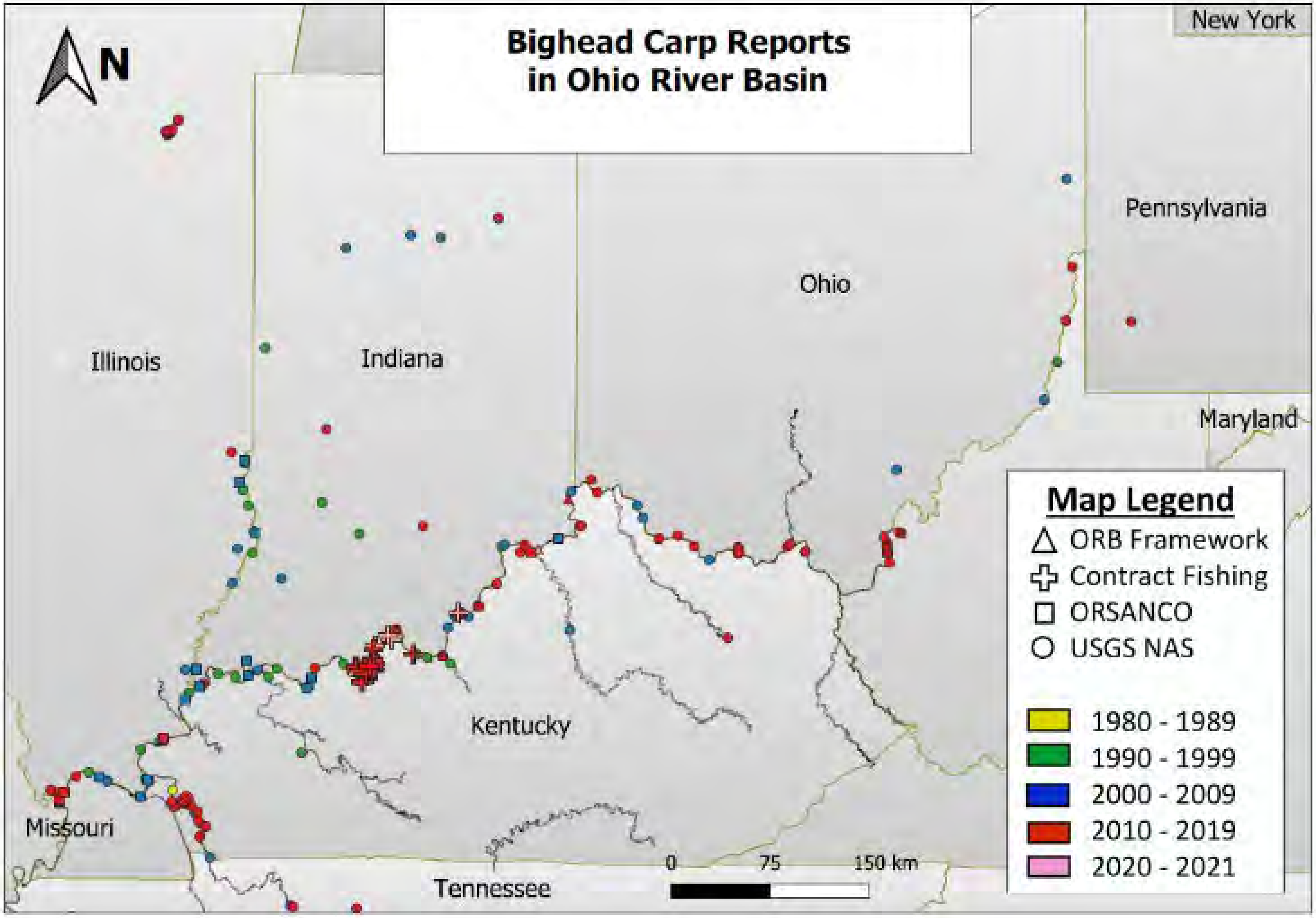

Figure 15. A map incorporating data on the geographic range and temporal proximity of Bighead Carp records and reports in the ORB. Data compiled from contract fishing (implemented in 2019), the Framework projects, ORSANCO, and the USGS NAS database.

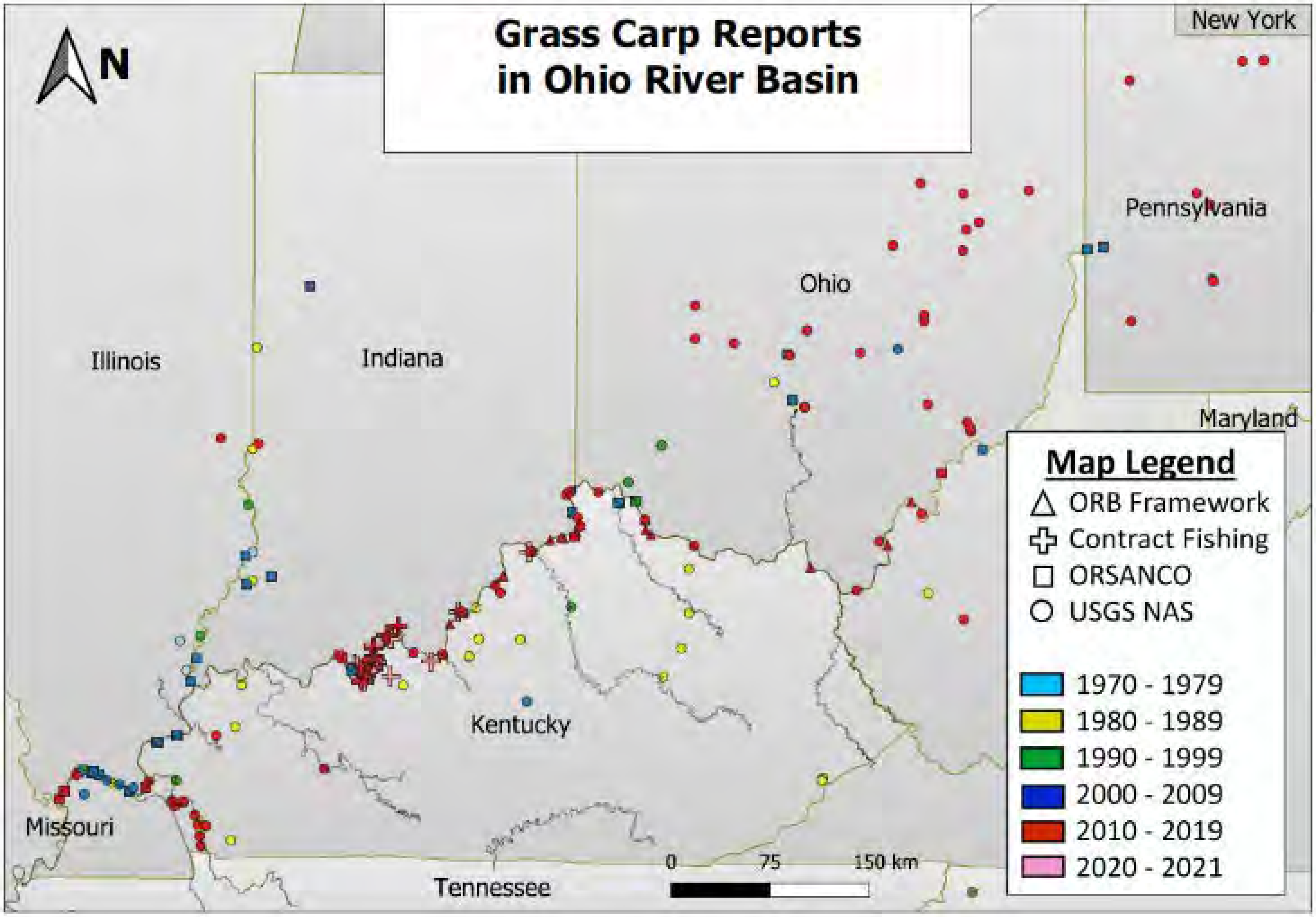

Figure 16. A map incorporating data on the geographic range and temporal proximity of Grass Carp records and reports in the ORB. Data compiled from contract fishing (implemented in 2019), the Framework projects, ORSANCO, and the USGS NAS database.

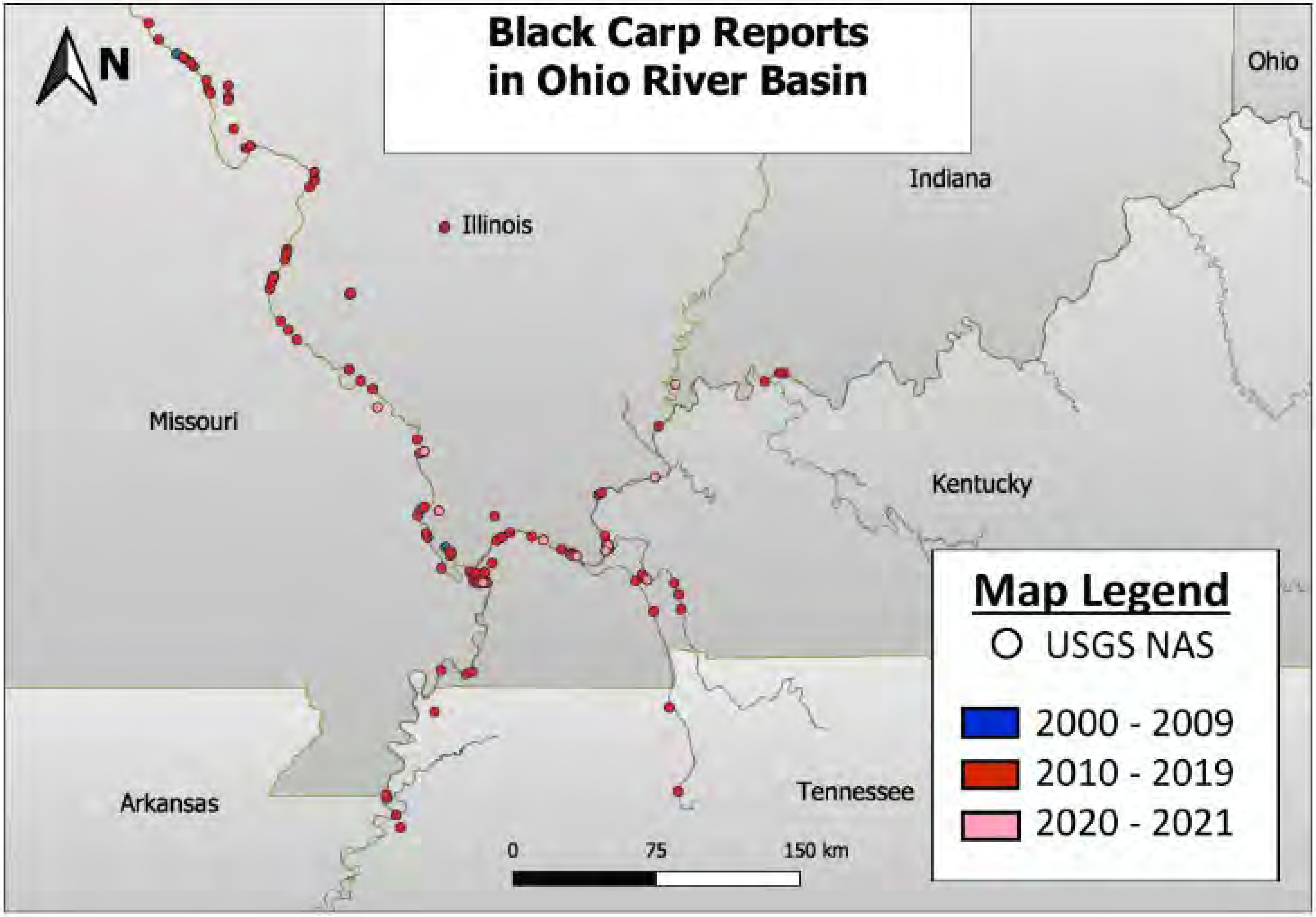

Figure 17. A map incorporating data on the geographic range and temporal proximity of Black Carp records and reports in the ORB. No Black carp have been captured through basin framework projects and all records listed were provided by the USGS NAS database.