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

Geographic Location: Ohio River basin, extending from the J.T. Myers Pool (RM 845.9) 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 Wabash, 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), Illinois Department of Natural Resources (ILDNR), Southern Illinois University (SIU)

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 invasive 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 invasive carp and fish communities in the ORB. Assembling information on distribution and habitat use of invasive carp provides an assessment tool that informs 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. Inform management actions using changes in the population structure, distribution, and relative abundance of invasive carp in the Ohio River.
2. Monitor long term trends in native fish communities as indicators of changes in invasive carp populations.
3. Survey invasive carp presence in upstream areas where carp are rarely detected to inform response and containment efforts.
4. Determine spatial distributions (hotspots) and densities of invasive carps in the lower Wabash and White rivers to inform and assess harvest.
5. Quantify changes in invasive carp density before and after select removal events in backwaters of the Wabash and White rivers to assess effectiveness at reducing abundance.
6. Utilize hydroacoustics surveys to determine biomass densities and verify patterns of relative abundance for Asian carp species within strategic management zones.

Project Highlights:
- With relatively few catches of both Bighead and Grass carps in the Ohio River and infrequent presences of Black Carp in commercial catches, Silver Carp have become the main focus of management efforts while Bighead remain a major focus ahead of the invasion front.
- Mean and median catch rates lack the precision necessary to track relatively small changes in catch per unit effort (CPUE) by year. Therefore, long-term trends and consistent reductions in catch will be necessary to determine if contract removal and agency efforts reduce invasive carp abundance along the intensive management zone.
- Since contract fishing was implemented in 2019, there has not been significant increases in the mean or median catch of Silver Carp, but there are lines of evidence (distribution of early life stages and evidence of spawning) indicating major shifts in population characteristics.
- With low precision tracking long-term trends in relative abundance through CPUE, other methods for monitoring and evaluation like hydroacoustics and occupancy modeling are being developed to inform decision making.

- No additional range expansion for Bighead, Silver, or Grass Carp was observed during the project period, however, Black Carp have now been observed as far up the Ohio River as Cannelton Pool.
- With reported sightings of potential young-of-year bigheaded carps, wide ranges in total length, and the presence of two age-1 carp from the Markland Pool, it is recommended that more effort be placed into monitoring the pool for successful year-class production along with a shift in contract fishing effort upstream.

Methods:

Clarification of Terminology Referenced in This Document

With the current rate of invasive 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 invasive carp populations that demonstrates reproduction and natural recruitment.
Invasion Front – the furthest upriver extent where reproduction has been observed (eggs, embryos, or larvae), but recruitment of 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)

Annual targeted sampling provides invasive carp relative abundance within each pool. Increased funding in 2021 allowed an increased number of sampling events. Targeted sampling was conducted 6 April – 6 May in 2021 across five pools (Cannelton – R.C. Byrd) of the Ohio River from the establishment front through the presence front (Figure 1). 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. 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 and 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). Invasive 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 misidentification of juvenile invasive carps. Relative abundance was inferred using CPUE data and compared to previous years to determine if there were changes in the mean and median fish caught per transect.

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 top water. Normally, KDFWR adds an additional 45-m 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. Relative abundance was inferred using CPUE data and compared to previous years to determine if there were changes in the mean and median fish caught per net. With catches per net being so low and a high level of 0-inflated sets, no comparison of catch rates for gill netting was made to previous sampling efforts.

Hydroacoustics Analysis
Mobile hydroacoustic sampling was conducted at twelve locations (four mile transects) in the Wabash River between Terre Haute, IN and the confluence with the Ohio River. Sampling was delayed until October in 2021 due to an extended low-water period in the Wabash River preventing site access. Hydroacoustic sampling equipment consisted of two 200-kHz split-beam BioSonics transducers that were horizontally oriented toward the center of the river while sampling. The fish community was also sampled in the same stretch of the Wabash River during October 2021 for determining species-specific proportional abundance that is needed for analyzing hydroacoustic data. Gill netting occurred using 7.6 cm (3" bar mesh), 8.9 cm (3.5" bar mesh), and 10.2 cm (4" bar mesh) mesh nets. Fish community data were also collected from 900 sec electrofishing transects throughout the Wabash River also in October 2021.

The Carterville FWCO completed hydroacoustic sampling during October 2021 in J.T. Myers and Newburgh pools of the Ohio River. Hydroacoustic data collection followed methods described in the Large River Hydroacoustics Mobile Survey Standard Operating Procedure, Region 3 U.S. Fish and Wildlife Service. Two multiplexed, 200 kHz, split-beam, BioSonics DTX echosounder transducers were mounted side-looking and offset in angle to maximize water column coverage (Figure 2). Both transducers were deployed from the vessel's port side at a depth of 0.5 m so the top edge of the shallow beam was parallel with the water surface. Hydroacoustic data collection was split among main channel, side channel, backwater, and tributary habitats. Within each pool, we collected hydroacoustic data in all side channels > 0.5 mi in length, navigable tributaries (up to five miles from confluence), and backwaters because invasive carps often inhabit these habitats. In the main channel, we selected ~35% of available one-mile sites for data collection using a stratified-random sampling approach. This resulted in 40 and 50 miles of main channel transects for Newburgh and J.T. Myers pools, respectively. Transducer direction (shore vs thalweg) was randomly assigned to each main channel site such that half of sites received each treatment. Both shore- and thalweg-facing transects were completed along each bank for all side channels with widths great enough to ensure sample area of thalweg-facing transects didn't overlap (i.e. thalweg facing hydroacoustic beams on opposite banks don't overlap in the middle of the side channel). In narrow side channels, two shore-facing transects were completed. Tributary data collection consisted of shore-facing transects with the boat centered within the channel and completed in both the upstream and downstream direction to ensure both banks were sampled. In backwaters, data were collected along the shoreline with the transducers facing towards shore. Calibration data were collected for both transducers prior to each survey to adjust hydroacoustic measurements.

Hydroacoustic data processing followed methods outlined in MacNamara et al. (2016) and the Large River Hydroacoustics Mobile Survey Standard Operating Procedure, Region 3 U.S. Fish and Wildlife Service using Echoview Version 11.0. Raw data and calibration files were imported into a mobile survey template for processing. Processing included a 1-m nearfield exclusion zone, bottom-line exclusions, and removal of bad data regions where wake disturbance or vegetation contributed to poor data quality. A single target detection algorithm (split beam method 2) facilitated the detection of individual fish targets using parameters suggested in Parker-Stetter et al. (2009). Using the equation developed by Love (1971), we estimated the target strength (TS) of 250 mm fish during each survey and used that value as a TS threshold to remove fish less than 250 mm from analyses. Groups of individual targets originating from the same fish were combined to make individual fish tracks to reduce the potential of overcounting. Fish targets and sample volume estimates were then exported from Echoview for further analysis.

To apportion hydroacoustic targets to fish species, the Carterville FWCO, INDNR, and KDFWR collected community data using a dozer trawl, boat electrofishing, and gill nets following the same hydroacoustics sampling design detailed above with two exceptions: 1) side channels sites were larger (1 mi) and sampling only occurred on one randomly selected bank to ensure that sites were long enough to complete electrofishing transects and 2) due to logistical limitations, we only attempted to collect community data at 30 main channel sites per pool (Figure 3). Deployments of all three community sampling gears (dozer trawl, boat electrofishing, and gill nets) were planned for all sites, but deployment of the gear was at the discretion of the boat operator based on river conditions (e.g., water velocity and debris). Deployment of each gear was standardized to allow for easy comparison among sites. The dozer trawl was deployed for 5-minutes at ~4.8 km/h, following the Long-Term River Monitoring power goal tables to maximize catch. Boat electrofishing transects were 15 minutes in a general downstream direction with one dip netter. 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). Gill nets 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 the surface. All fish greater than 250 mm were weighed (g) and measured (total length; TL).

To reduce bias in our hydroacoustic estimates, we used a Bayesian hierarchical model to account for uncertainty in TS measurements and paucity of community data at hydroacoustic sites. For this analysis, we modified the methods described in DuFour et al. (2021). Briefly, we used a fitted quadratic regression model to calculate the probability of a fish being a Silver Carp given its length (Figure 4). Our most complex model describing the fish community included pool, habitat, TL, and TL^2 as fixed effects and community site nested within habitat and both community site and habitat nested within pool as random effects using a Bernoulli distribution. We compared the most complex model and four models containing a subset of variables from the full model using k-fold cross validation (CV). The most parsimonious model describing the community data had TL and TL^2 as fixed effects and Community Site as a random effect; therefore, the results of this model were used in subsequent calculations. We also modeled TS as a function of individual fish track to obtain a mean TS and credible intervals (CrI's) for each fish track. Mean TS and CrI's were converted to total length (TL) using the multi-species, side-aspect equation developed by Love (1971) (Figure 5). Importantly, TL based on TS is uncertain, as are the model parameters describing the fish community. To account for this uncertainty, we integrate across TL and the model parameters to estimate the probability that an individual is a Silver Carp based on its TS (for details see DuFour et al. 2021). To solve this integration, we used Monte Carlo simulations (n = 1000) to estimate the number of Silver Carp at each site and converted this abundance to density by dividing by the volume of water sampled by hydroacoustics (i.e., Wedge_Volume_Sampled). To examine the potential effects of habitat and pool on the mean density of Silver Carp, we calculated the average mean and 90% CrI's by habitat and pool. Non-overlapping CrI's were used to indicate significant differences between habitats and among pools.
Our models differ from those described in DuFour et al. (2021) in three ways. First, because Silver Carp make up a large proportion of fish between 500 and 900 mm in our community sampling, but Silver Carp < 500 or > 900 mm are rarely captured, we use a quadratic regression to describe the probability of a fish of a given length being a Silver Carp rather than a logistic regression as in DuFour et al. (2021). Second, following discussions of our analyses with M. DuFour, we determined that converting TS to backscattering cross section was not necessary and modelled TS directly. Third, we used k-fold CV rather than leave-one-out (LOO) CV for model selection because model diagnostics suggested that LOO CV likely resulted in biased model selection criteria and k-fold CV is a reliable alternative to this method (Vehtari et al. 2017).

Assessing Invasive Carp Population Demographics
Population demographics information was collected on a subset of fish, post-spawn, between August and October 2021. Data was used to determine length distributions, age distributions, sex ratios, estimate growth, and report body condition of fish collected in the Cannelton, McAlpine, and Markland pools. Length distributions were formed using 25 mm length bins. Ages were estimated using lapilliar otoliths (Cannelton: n = 224; McAlpine: n = 270; and Markland: n = 36) encased in epoxy and thin-sectioned using agreed upon methods, developed from an invasive carp ORB workshop held in November of 2021. Age distributions were summarized by percent total in a histogram and growth was estimated with a von Bertalanffy growth equation in the form of:

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

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 t_0 was set to zero to discount the absence of data from younger fish not captured during the study period. Length-weight relationships were derived from $\log_{10}$ transformed lengths and weights of fish (Figure 6). A single regression line used to compare length-weight relationships to previous years. Regressions were achieved with the general linear model (lm()) in base R (R Core Team 2021) with lengths being measured in millimeters and weight measured in grams. The equations developed for the ORB as well as other waterbodies are reported below (Table 1 and 2) in the form of:

$$\log_{10}[Weight_g] = a + b * \log_{10}[Length_{mm}]$$

Lastly, body condition was reported using relative weight equations developed by James Lamer (Lamer 2015). Condition was only reported using data from fish, post spawn, between the months of August and September. Differences in body condition were compared between Cannelton, McAlpine, and Markland pools in 2021 and for Cannelton and McAlpine in previous years.

Development of a Tributary Monitoring Program

Considering the need for a more sensitive measure of change in fish number or abundance, a pilot study was conducted in the Kentucky River to determine the efficacy of occupancy modeling as a substitute for relative abundance measures. Ten sites were randomly selected over the first 79 river miles (four pools) of the Kentucky River. Fixed distance, half-mile boat electrofishing surveys were paired with entanglement gear and presence/absence of carp was recorded in addition to catch. Sites were visited three times to account for imperfect detection. Boat electrofishing was conducted 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). Invasive carp were specifically targeted using increased driving speeds and allowable pursuit of fish upon sightings. Occupancy and detection were estimated using a hierarchical model from the package 'unmarked' in R (Fisk and Chandler 2011).

Monitoring Ahead of the Invasion Front

Targeted sampling for Invasive Carp was conducted in November and December 2021 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 December. In the Montgomery Pool, sampling in November was conducted in the Montgomery Slough (RM 949.78 to 950.11) where positive eDNA hits for Bighead Carp were found 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 two sampling events for a total of six gill net sets.

Fish community monitoring was conducted in May and June, 2021 at the tailwaters of Lock 9 (Pool 8), Lock 4 (Pool 3), and Lock 3 (Pool 2) on the Allegheny River, the tailwaters of Point Marion (Grays Landing Pool), Maxwell (Charleroi Pool), and Elizabeth (Braddock Pool) locks and dams on the Monongahela River, and the Montgomery (New Cumberland Pool) lock and dam on the Ohio River. 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 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 2021. 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.

Additionally, fish community monitoring was also conducted via pulsed-DC boat electrofishing, gill netting and boat ramp seining in fall 2021 in the Greenup and R.C. Byrd pools of the Ohio River. Electrofishing surveys were completed during the day at fixed sites throughout each pool. Surveys consisted of 15-minute timed transects beginning at the marked coordinates and continued downstream in the mainstem river and large tributaries. Surveys of small tributaries and embayments began at the marked coordinates and continued upstream to the completion of the timed transect, or until navigation was blocked, upon which the remainder of the timed transect was completed in the main channel just downstream of the mouth. All species were collected during these surveys. Schools of small fish (minnows and shad) were sub-sampled by dipping a portion of each school encountered. Small shad-like fish were examined closely to identify potential juvenile invasive carp. All fish were identified to species; non-minnow species were measured for total length (mm) and total weight (g), up to 20 fish of a single species per transect. Invasive carps were examined for tags and any fish not implanted with a telemetry tag, were euthanized on site. Gill net sets consisted of two hour sets during the day at fixed sites throughout the two pools. Gill nets consisted of large mesh (5"; 127mm) that are 14ft in depth hobbled to 10ft (4.3m to 3m) or 24ft in depth hobbled to 20ft (7.3m to 6.1m) and in lengths of 150 ft (45.7m) and 300ft (91.4m); the size and depths of net used depended on the existing habitat, depth and suitability at each site. Each net set was actively monitored, and effort was expended to run fish into the nets with boat noise. All by-catch was identified to species and recorded and any non-target fish (excluding invasive carps) were released immediately after capture. Invasive carps were examined for tags and any fish not implanted with a telemetry tag, were euthanized on site. Boat ramp seine hauls were conducted at select boat ramps located directly on or adjacent to the mainstem Ohio River in the Greenup pool. One seine haul was conducted at each ramp with a 30ft seine with 3/16" mesh and a 6ft bag (1/8" mesh). Seine hauls were completed within the boundaries of the concrete structure boundary of each boat ramp. All fish contained within the seine were collected. Larger fish and species readily identifiable in the field were enumerated and released. All other fish were preserved in formalin and returned to the lab for identification.

Incidental sampling for invasive Carp was conducted using boat electrofishing through targeted gamefish surveys on each of the Three Rivers. Nighttime boat electrofishing using a ETS MBS electrofishing unit operated at 60 pps, 30% duty cycle, and 250-550 V was conducted in March on the Emsworth Pool, Pool 2, and Pool 6 of the Allegheny River, the Emsworth and Maxwell pools of the Monongahela River, and the Montgomery and Dashields Pools of the Ohio River. Sampling consisted of four non-overlapping 10-minute runs on each bank beginning immediately downstream of the lock and dam for 80 minutes of total effort in each pool. Adult Sander species were targeted during these surveys and presence/absence of invasive carp species was recorded. Sampling in October occurred at four fixed sites in Pool 4 of the Allegheny River, four fixed sites in the Emsworth Pool of the Monongahela River, and five fixed sites in the Charleroi pool of the Monongahela River. Effort was 1.80 hrs, 2.02 hrs, and 2.17 hrs of Pool 4, the Emsworth Pool, and Charleroi Pool, respectively, and gear type and settings were the same as in the March Sander surveys. Black Bass were the primary target of the October surveys and presence/absence of invasive carp species was recorded. In November, sampling and in the Emsworth and Charleroi pools of the Monongahela River. In November, nighttime boat electrofishing was conducted on the Monongahela River in the Braddock, Charleroi, and Grays Landing pools, the Allegheny River in Pool 3, Pool 6, and Pool 8, and the Ohio River in the Montgomery and Dashields pools. Sampling was conducted via pulsed DC night boat electrofishing (ETS MBS electrofishing unit operated at 250-550 V at 60 pps and 30% duty cycle or a Smith Root VVP-15B operated at similar settings). Sampling consisted of four non-overlapping 10-minute runs on each bank beginning immediately downstream of the lock and dam for 80 minutes of total effort in each pool. Adult Sander species were targeted during these surveys and presence/absence of invasive carp species was recorded.

Results:

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

Spring targeted boat electrofishing in 2021 yielded 237 Silver Carp and five Grass Carp through 33.25 hours of effort. The majority of Silver Carp captures were from the Cannelton Pool with 205 fish being captured compared to the 28 caught in McAlpine and only four in Markland (Table 3). Silver Carp mean catch rates remain low in Cannelton Pool and consistent with previous years. Large numbers of zero-catch transects and infrequently large catches remain an issue for mean CPUE data and 95% confidence intervals indicate no significant change in relative abundance since the start of targeted sampling in 2017 (Figure 7a). Median catch rates indicate a slight downward trend in catches since the implementation of contract fishing in 2019, but due to relatively low precision, it may take a number of years to determine if there is truly a downward trend in relative abundance at sampling locations (Figure 7b). Both mean and median catch rates above Cannelton Pool remain so low that no change in relative abundances have been apparent since monitoring began in 2017. Grass Carp catches remain relatively infrequent and only five total fish were captured through sampling efforts.

Spring gill netting in 2021 covered five pools of the middle Ohio River and consisted of 26,850 total feet of net over 179 sets. One hundred twenty-one fish were captured, with most of the catch consisting of non-target species. Twenty-eight total Silver Carp were captured with 25 being caught in Cannelton Pool, two additional in McAlpine Pool and one in R.C. Byrd Pool. (Table 4). Bighead carp were caught using gill nets in 2021 with one fish being captured in McAlpine and the other in Markland Pool. Nine total Grass Carp were also captured with gill net sets. Five fish were caught in Cannelton Pool, one fish was caught in McAlpine, two in Markland and one additional Grass Carp was caught in the Greenup Pool. The most commonly encountered bycatch was Smallmouth Buffalo and Blue catfish. Common carp were the next most frequent bycatch along with Paddlefish. The remaining 23% of bycatch consisted of Channel catfish, Longnose Gar, Hybrid Striped Bass, Flathead catfish, a redhorse, a Muskellunge, a Mirror carp, and a Spotted Bass (Table 5).

Hydroacoustic Analysis
Hydroacoustic data analysis for work conducted in the Wabash River has not yet been completed due to the need for additional staff training on post-processing and a late sampling season. Information will be presented and shared with the basin partnership as results are completed and updates to analysis will be included with the following report.

Community data collected for hydroacoustics in the Newburgh and J.T. Myers pools comprised samples from 91 electrofishing (J.T. Myers = 47, Newburgh = 44), 112 dozer trawl (J.T. Myers = 54, Newburgh = 58), and 88 gill net sites (J.T. Myers = 44, Newburgh = 44). Boat electrofishing collected the most fish > 250 mm (n = 900) followed by the dozer trawl (n = 430) and gill nets (n = 76). The dozer trawl, however, caught the greatest number of Silver Carp (n = 215) followed by boat electrofishing (n = 178) and gill nets (n = 12). Only four Bighead Carp were collected (gill net).

The greatest mean Silver Carp densities occurred at a site in the Little Hurricane Island side channel and at river mile 837 of the main channel in Newburgh and J.T. Myers pools, respectively (for site specific estimates contact the Carterville FWCO). Most Sites had relatively low Silver Carp densities; 76% of all sites had densities < 0.5 SVC/1000m^3 and 91% of all sites had densities < 1 SVC/1000m^3. Longitudinal trends exist within both pools with densities increasing in the downstream direction (Figure 8). On average, tributaries had the greatest densities among habitats and Newburgh Pool had greater densities than J.T. Myers Pool (i.e., mean CrI's did not overlap; Table 6) Main channel and side channel Silver Carp densities did not significantly differ. We did not include backwaters in these comparisons due to a paucity of data).

Assessing Invasive Carp Population Demographics
A total number of 10 Bighead Carp and 24 Grass Carp were captured through all project efforts in 2021. Bighead Carp ranged from 180 mm to 1140 mm in total length and 90 grams to 13.3 kg in weight with total catch comprised of 20% male, 70% female, and one immature fish, for which sex was undetermined. All Bighead Carp captures were in gill nets, except for the two smallest fish, which were captured during boat electrofishing surveys in the Smithland and Markland pools. Of the 10 Bighead Carp that were captured, lapilliar otoliths were collected from five of them and estimated ages ranged from 2 years to 18 years in age. Grass Carp ranged from 754 mm to 1125 mm in total length with catch approximately 55%

male and 45% female. With so few records of both Bighead and Grass Carp, no additional demographics information will be presented on these species within this report.

Length distributions for Silver Carp in both Cannelton and McAlpine pools were bimodal with no fish being captured between 200 mm and 500 mm in TL (Figure 9). However, a strong year-class was discovered in 2021 with many young-of-year fish reaching over 100 mm in the Cannelton Pool by fall 2021. Markland Pool displayed the widest range in length distributions with several fish being caught below 600 mm, including one Silver Carp at 136 mm TL (Figure 10). Male fish were encountered most frequently with Cannelton consisting of 53% male to 47% female fish, McAlpine having 58% male to 42% female fish, and Markland comprised of 58% male to 37% female with an additional 5% recorded as immature. Silver Carp ages ranged from three years to nine years in age in Cannelton (Figure 11) with the most frequently observed age being four years. McAlpine Pool Silver Carp ranged from three to thirteen years of age with the most frequently observed age being five years (Figure 12). Markland Pool contained the widest range of estimated ages with one Silver Carp estimated at 1 year and the oldest estimated to be 14 years old. The most commonly observed ages for Silver Carp in Markland were five and eight. Growth appears similar for both Cannelton and McAlpine pools and in both cases, there is a wide distribution in length at age (Figure 13 and Figure 14). Length-weight relationships for fish caught between the months of August and October match up well with previous data collected from the ORB. Typical body condition for Silver Carp in Cannelton has remained relatively consistent since 2016 while body condition for carp captured in McAlpine has declined slightly over the years (Figure 15). The median relative weight of fish in the McAlpine Pool is now more consistent with fish found in Cannelton Pool and far below that of fish found in Markland (Figure 16).

Development of a Tributary Monitoring Program

Ten sites were sampled on three separate occasions making 30 survey events the total effort for occupancy sampling in the Kentucky River. Of the ten sites, four sites contained invasive Silver Carp and Silver Carp were seen at the same sites on multiple occasions. The probability of detecting Silver Carp (p) in the first four pools of the Kentucky River, given that Silver Carp were present, was estimated to be around 51.8% (SE = 18.5%). The probability that Silver Carp occupied (Psi) any randomly selected transect in the first four pools of the Kentucky River was estimated to be around 45% (SE = 17.6%). A simulation model using the estimated values for p and Psi above and variations in the number of sites and site visits indicated that increasing site visits from three to four replicates greatly decreased standard errors associated with estimates of occupancy (Figure 17).

Monitoring Invasive Carps Ahead of the Invasion Front

Targeted gill net sampling for Invasive carp in the New Cumberland and Montgomery Pools of the Ohio River did not collect any invasive carp species. In the Montgomery Pool. Smallmouth Buffalo and River Carpsucker were the two most common species captured and comprised 42% and 38% of the total catch on the Ohio River, respectively. Sampling in December in the New Cumberland Pool was rendered ineffective by sustained high flows and debris. No fish were captured in the gill nets and additional sampling was canceled.

Fish community monitoring in the New Cumberland Pool of the Ohio River, Pools 8, 3, and 2 of the Allegheny River, and the Grays Landing, Charleroi, and Braddock Pools of the Monongahela River was conducted in May and June 2021 and consisted of 1.67 hrs of effort per pool using pulsed DC night electrofishing. Total number of species captured ranged from 33 to 39 species at each of the seven tailwaters sampled, with individual fish counts ranging from 895 to 2164 fish captured at each of the tailwaters. Emerald Shiner, Mimic Shiner, and Golden Redhorse comprised approximately 47% of the total catch between all pools (Table 7).

Beach seining on the Montgomery Island Pool in August 2021 collected no Invasive carp species. A total of 4,114 individuals of 21 different species were captured. Emerald Shiner comprised 84% of the total catch (Table 8).

The Pennsylvania Fish and Boat Commission tracks incidental captures of Invasive carp through other various projects. Efforts in 2021 included targeted gamefish surveys for *Sander spp* in March and

November at 14 tailwaters in the Allegheny, Monongahela, and Ohio Rivers and targeted surveys for black bass at 14 fixed sites in three pools of the Allegheny and Monongahela Rivers. No Invasive Carp species were captured or observed in any of the targeted gamefish surveys in March, October, or November 2021.

Twenty-six electrofishing surveys (6.5 hrs) were conducted by WVDNR staff in the R.C. Byrd Pool and 16 electrofishing surveys (4 hrs) were completed on the Greenup pool during Fall 2021. Fall electrofishing surveys yielded data from 45 fish species (Table 9). Gizzard Shad and Emerald Shiner constituted the bulk of collected fishes in both pools. Largemouth bass and Bluegill were the most caught sportfish species. Smallmouth buffalo and Freshwater drum were the most caught non-sport fishes. Relative weights (where applicable) were within the mean for all species. Boat electrofishing catch rates were quite variable between sites, habitat types, pools and years. Differences in catch rates between pools and years appears to be most attributed to changes in river conditions (i.e. flow and turbidity). It remains unclear if annual species abundance will be a useful metric to assess effects of invasive carp. Therefore, it is likely we will use mean abundance over a multi-year sampling period for each species as the metric we will use to assess effects in future years as the invasive carp population advances.

Twenty-one gill net surveys (3,150 ft deployed) were conducted in the R.C. Byrd pool and 13 gillnet surveys (1,800 ft) were conducted in the Greenup pool throughout Fall 2021. One Bighead carp was removed from the R.C. Byrd pool during fall gill netting. Gill net bycatch included only two additional species of fish (Table 10). Gill net catches remain quite variable and include many sites yielding no catches. More effort will be put into assessing sites for their appropriateness for catching carp. There were no discernable trends in species composition noted in the gill net data.

Four boat ramp seine hauls were conducted in the Greenup pool in Fall 2021. Seine hauls yielded fourteen species of fish (Table 11). Number of fish collected varied greatly by site (103-1920 individuals). Similar to the electrofishing surveys, Emerald Shiners were the most collected species, constituting 80% of the total catch. Channel Shiners were the second most common species at nearly 18% of the total catch; the seine's smaller mesh size allowed for more effective collection of smaller fishes compared to dipnets used in boat electrofishing surveys. Mean diversity abundance over the sampling period will be used as a metric for the diversity of the small, more littoral fishes of the mainstem Ohio River.

Compilation and Incorporation of Other ORB Data Sources

Previously, data was compiled from project efforts, ORSANCO records, and reports to the USGS NAS to determine changes to invasive carp distributions. With increased reporting and good participation, many records began to overlap between the datasets. Therefore, maps using only USGS record were created to show the full distribution for invasive carps in the ORB. The most notable change in distribution was that of the Black Carp, which now has records extending its known range to the Cannelton Pool. Silver Carp and Bighead Carp distributions remain relatively unchanged and Grass Carp records continue to be sporadic throughout the Ohio River and all internal waters of the surrounding basin states (Figure 18, Figure 19, Figure 20, Figure 21).

Discussion:

With relatively few catches of both Bighead and Grass carps in the Ohio River and infrequent presences of Black Carp in commercial catches, it becomes difficult to determine if the available level of effort will allow managers the ability to make any informed decisions concerning these species. However, with Silver Carp being the most prolific of the four species and capable of increasing their representation in riverine biomass so rapidly, most future evaluation efforts will likely focus primarily on their management and spread.

Catch or catch per unit effort (CUPE) has been used in the Ohio River for a number of years to determine if temporal changes in average catch rates could be used to track relative abundance in carp populations. In almost every year since 2017, average CPUE has been low and data is highly dispersed. Catches are more indicative of aggregated distributions of invasive carps and are further complicated by a high number of zero-catch runs paired with infrequently large catches. Median catches are less sensitive to infrequently large catches, but just as with mean estimates, lack the precision necessary to track relatively small changes in CUPE by pool. Therefore, long-term trends and consistent reductions in catch will be necessary to determine if contract removal and agency efforts begin to reduce invasive carp abundance along the intensive management zone. Since contract fishing was implemented in 2019, there has not been significant increases in the mean or median catch of Silver Carp, but there are lines of evidence indicating major shifts in population characteristics.

Silver Carp populations now have a strong bimodal length frequency distribution in Cannelton and McAlpine pools indicating the presence of a younger fish replacing older year-classes aging out or being removed through contract fishing efforts. Also, Silver Carp body condition has generally decreased in McAlpine Pool over time and may indicate crowding conditions much like those of Cannelton Pool below it. In addition, a far wider range of length-classes now exists in the Markland Pool than ever before. Historically Markland contained older fish that were more likely immigrants into that stretch of river. With strong presences seen in four- and five-year-old fish in McAlpine and a strong YOY year-class now confirmed in Cannelton, it appears there may be a general shift in Silver Carp establishment in the middle Ohio River.

Occupancy modeling appears to provide a convenient and time effective way to combine capture gears, structure better sampling designs, and account for imperfect detection of invasive carps (primarily Silver Carp) in a large river system. Based on results from the Kentucky River pilot project, a second year of sampling will incorporate more sites as well as four site replicates. We intend to track catches in addition to presence absence data and expect that with the incorporation of additional sampling events we will demonstrate a better ability to make recommendations for management actions while employing a less data intensive monitoring protocol.

We found that both habitat and pool significantly affected mean Silver Carp density. These results support previous research evaluating density gradients across invasion fronts (MacNamara et al. 2016; Erickson et al. 2021) and Silver Carp habitat use (DeGrandchamp et al. 2008; Gillespie et al. 2017; Pretchel et al. 2018). In contrast to previous literature (MacNamara et al. 2016; Lenaerts et al. 2021; Erickson et al. 2021), we found that the more upstream pool sampled for this analysis (Newburgh) had a greater mean density of Silver Carp than the more downstream pool (J.T. Myers). One possible explanation for this difference is the quantity and quality of habitat. Previous research suggests that Silver Carp preferentially select side channel habitat over main channel habitat (DeGrandchamp et al. 2008). We found, however, that for the Ohio River pools sampled here, Silver Carp densities did not differ between main channel and side channel habitats. The lack of differences in Silver Carp densities between main channel and side channel habitats may be explained by the physical similarities of these habitats. For instance, most Ohio River side channels are relatively short, have steep banks, and a deep thalweg, similar to the main channel. Further, our results suggest that Silver Carp densities are greater in tributaries than in either main channel or side channel habitats. This finding agrees with previous literature (Gillespie et al. 2017; Pretchel et al. 2018) that Silver Carp densities increase in tributary habitats. However, some literature suggest that tributary usage is less than mainstem usage in some Ohio River pools (Gillespie et al. 2017). These conflicting results may suggest that fine-scale environmental characteristics may have a greater impact on Silver Carp habitat use than large-scale habitat features as suggested by Glubzinski et al. (2021).

The longitudinal trends in our data support previous literature describing invasion ecology within impounded rivers (DeGrandchamp et al. 2008; MacNamara et al. 2016). Once populations become established upstream of a barrier, they expand their range upstream towards the next barrier. For Silver Carp, this expansion is often comprised of larger individuals (MacNamara et al. 2016; Lenaerts et al. 2021). The apparent longitudinal gradient in our density estimates may depict this upstream expansion but more information is needed to evaluate longitudinal changes in fish size within these pools.
Density estimates obtained from side-looking hydroacoustics have increased levels of uncertainty because bias is introduced from multiple sources. For example, target strength, which is converted to fish length, is a stochastic variable which depends on the physical (e.g., fish length and swim bladder presence) and behavioral (e.g., swimming direction and vertical movements) characteristics of the insonified fish (Foote 1980; Ona 1990; Boswell et al. 2009). For example, the orientation of insonified fish targets relative to

the transducer greatly affects measured TS (Boswell et al. 2009; Johnson et a. 2019a). We use a side-aspect TS-TL equation to convert TS measurements to TL (Love 1971). This equation assumes fish are oriented perpendicular to the transducer at the time of sampling. Deviation from this assumption affects the total number of fish targets included in analyses and fish size estimated from TS (Boswell et al. 2009; Johnson et a. 2019a). Because we orient our transects parallel to the current, fish facing against or with the current will be oriented near-perpendicular to the transducer, validating our use of a side-aspect equation. In areas with reduced current (backwaters), target orientation relative to the transducer may deviate from perpendicular causing the use of Love's 1971 equation to bias density and size estimates. Some additional sources of bias in side-looking hydroacoustic estimates include near-surface effects on sound propagation (Balk et al 2017), subjectivity during processing (i.e., interpretation of echograms, exclusion lines, and editing of fish tracks), and apportioning of hydroacoustic targets to species using community data.

Although hydroacoustics accurately samples pelagic fish populations (Johnson et al. 2019b), the use of community data to apportion hydroaoustic targets to species can bias estimates. The tools we used to collect community data (dozer trawl, boat electrofishing, and surface set gill nets) have size and species-related biases. For example, boat electrofishing is biased towards large individuals (Chick et al. 1999; Bayley and Austin 2002) and gill nets are more effective for highly mobile species (Argent and Kimmel 2005). Because community data are used to apportion hydroacoustic targets to species, these gear-specific biases are transferred to the hydroacoustic estimates. The combination of gears used here should reduce the effects of gear-specific biases, improving our assessment of the fish assemblage. Further, our Bayesian hierarchical models incorporate much of the uncertainty inherent to hydroacoustic estimates, reducing bias contributed by community sampling gears (DuFour et al. 2021).
Our use of Bayesian hierarchical modeling improves Silver Carp estimates by incorporating uncertainty from TS measurements, thresholding, and community sampling in the models. Previous methods ignored these sources of uncertainty, likely biasing density estimates. Additionally, this approach provides the capability of inferring the probability of a fish being a Silver Carp for lengths that have no community data. The ability to infer the probability of a fish target being a Silver Carp for lengths lacking Silver Carp catch data improves our estimates by reducing the effect of sparse or missing community data. Further, this approach is applicable in multiple situations because it has the flexibility to incorporate different patterns within species composition data as well as variable data distributions within the hydroacoustic data, which are affected by site characteristics and sampling design.

In congruence with objective 6.2 of the early detection and removal project plan, we took steps towards evaluating and improving the hydroacoustics survey design. First, we reallocated our effort into pools with established invasive carp populations. Because we use community sampling to apportion hydroacoustic targets, relatively high invasive carp catches are necessary to estimate invasive carp densities and biomass from hydroacoustic surveys. Pools with low catches of invasive carps inevitably have hydroacoustically derived invasive carp densities functionally equal to zero, reducing the usefulness of these surveys. The reallocation of effort to high-density pools allowed for the use of a stratified-random sampling design and improved spatial coverage of our survey within each pool. The Carterville FWCO also deployed a dozer trawl in addition to state partners' gill net and electrofishing efforts to increase and improve sampling of the pelagic fish community. The addition of the dozer trawl added 430 total fish and 215 Silver Carp to the community dataset, effectively doubling the Silver Carp catches. Furthermore, we implemented a Bayesian hierarchical design for data analyses that accounts for the uncertainty in hydroacoustic data, improving estimates of Silver Carp densities. Lastly, the Carterville FWCO and its Wilmington sub-station collected ~400 miles of hydroacoustic data in Cannelton Pool to help evaluate our sampling design. We will use a resampling analysis to determine the optimum transect length and number of transects needed to provide reliable hydroacoustically derived density estimates. The changes implemented in this report and the additional data collected will increase the usefulness of hydroacoustics surveys for informing invasive carp management in the Ohio River Basin.

Recommendations:
Targeted, standardized sampling should continue to add to our body of evidence indicating changes in relative abundances of invasive carps along the invasion front. However, occupancy modeling should be

further explored to determine its use and efficacy in monitoring distributions and evaluating change in carp populations in the Ohio River. Also, with the presence of age-1 fish in Markland and a comparatively large range in lengths and ages present in that pool, it is recommended that efforts to survey for young-of-year recruitment in the Ohio River be shifted into Markland. Along similar lines of logic, some contract efforts should be shifted into the McAlpine Pool to reflect the change in Silver Carp progression.

The new sampling design and analytical approach utilized during 2021 moved the hydroacoustic program closer to our goal of using this tool to evaluate Silver Carp densities within Ohio River pools. We recommend the continuation and further evaluation and development of the sampling design and analytical approaches to maximize the usefulness of the hydroacoustics program. Our results provide initial insights into Silver Carp densities throughout two Ohio River pools and the habitats within those pools. The approaches outlined within this report should be used in additional pools with established Silver Carp populations (e.g., Smithland, Cannelton, etc.), during future years to acquire a robust dataset that can be used to inform management decisions and evaluate the hydroacoustics program.

The use of the dozer trawl dramatically increased the number of total fish and effectively doubled Silver Carp catches. For this reason, we recommend the continuation of dozer trawl sampling as a part of the hydroacoustics program. Additionally, due to low catch rates and high effort, we recommend the elimination of gill nets from the community sampling portion of the hydroacoustics program. The addition of 76 total fish, including 12 Silver Carp and four Bighead Carp, do not justify the amount of effort needed to deploy gill nets for this program.

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Appendix A: Tables

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 transect) of three species of invasive carp captured in five pools of the Ohio River from spring targeted sampling in 2021. 95% confidence intervals are in brackets.

Spring Boat Electrofishing							
	Ohio River 2021						
	Cannelton	McAlpine	Markland	Meldahl	Greenup	RC Byrd	Total
Sampling Dates	06 April - 10 May						
Effort (Hours)	11.75	9.75	12.5	N/A	1.75	5.1	40.1
Sample Transects	47	39	50	N/A	7	22	162
All Fish (n)	205	28	8	N/A	0	0	241
Species	1	1	2		0	0	2
Bighead Carp	0	0	0		0	0	0
Silver Carp	205	28	4		0	0	237
Grass Carp	1	0	4		0	0	5
	CPUE (fish/transect)						
Bighead Carp	0	0	0		0	0	
Silver Carp	4.4 [2.9, 6.0]	0.7 [0.3, 1.2]	0.1 [0.0, 0.2]		0	0	
Grass Carp	0.02 [0.02, 0.2]	0	0.08 [0.08, 0.3]		0	0	

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 set) of three species of invasive carp captured in five pools of the Ohio River from spring targeted sampling in 2021. 95% confidence intervals are in brackets.

Spring Gill Netting							
Ohio River 2021							
	Cannelton	McAlpine	Markland	Meldahl	Greenup	RC Byrd	Total
Sampling Dates	05 April - 06 May						
Effort (ft)	9,600	7,050	5,250	N/A	1,650	3,300	26,850
Net Sets	64	47	35	N/A	11	22	179
All Fish (n)	38	22	33	N/A	2	26	121
Species	4	12	8		2	7	
Bighead Carp	0	1	1		0	0	2
Silver Carp	25	2	0		0	1	28
Grass Carp	5	1	2		1	0	9
CPUE (fish/set)							
Bighead Carp	0	0.02 [0.0,0.06]	0.03 [0.0,0.08]		0	0	
Silver Carp	0.39 [0.17,0.66]	0.04 [0.0,0.10]	0		0	0.05 [0.0,0.13]	
Grass Carp	0.08 [0.02,0.16]	0.02 [0.0,0.06]	0.06 [0.0,0.17]		0.1 [0.0,0.3]	0	

Table 5. A bycatch table showing the catch of non-target species through the use of gill netting during 2021 targeted monitoring. (Ohio River Pools: Cann = Cannelton; McAlp = McAlpine; Mark = Markland; Meld = Meldahl; Green = Greenup; RCBy = R.C. Byrd)

Spring Gill Netting							
	Ohio River 2021						
By-Catch	Cann	McAlp	Mark	Meld	Green	RCBy	Total
Blue Catfish			2			16	18
Channel Catfish		1	4				5
Common Carp		2	10		1	1	14
Flathead Catfish			2			2	4
Longnose Gar		2	1			2	5
Mirror Carp					1		1
Muskellunge		1					1
Paddlefish	3	3				1	7
Silver Redhorse		1					1
Smallmouth Buffalo	5	4	11		2	2	24
Spotted Bass		1					1
Hybrid Striped Bass		3					3

Table 6. Number of sites (N) and average mean and upper and lower 90% credible intervals (CrI) for Silver Carp density (SVC/1000m^3) within main channel (MC), side channel (SC), tributary (TRIB), and backwater (BW) habitats and by pool (J.T. Myers and Newburgh).

Level	N	Average Mean SVC Density	Average Lower 90% CrI	Average Upper 90% CrI
Habitat				
MC	86	0.383	0.299	0.476
SC	129	0.456	0.322	0.603
TRIB	16	0.876	0.612	1.161
Pool				
J.T. Myers	138	0.319	0.216	0.433
Newburgh	93	0.664	0.508	0.833

Table 7. Total number of fish captured per pool and percent of total captured at three pools combined in the Allegheny, Monongahela, and Ohio Rivers during spring night electrofishing surveys in 2021. (A=Allegheny, M=Monongahela, O=Ohio)

	Allegheny, Monongahela, and Ohio River Pools in 2021								
Species Captured	Pool 8 (A)	Pool 3 (A)	Pool 2 (A)	Grays Landing (M)	Charleroi (M)	Braddock (M)	New Cumberland (O)	Total	Percent
Banded Killifish							1	1	0.01%
Bigeye Chub						1		1	0.01%
Black Buffalo		1						1	0.01%
Black Crappie		1	1	2	2		2	8	0.09%
Black Redhorse	94	59	16	68	106	7	31	381	4.26%
Blacknose Dace			6					6	0.07%
Bluebreast Darter		1						1	0.01%
Bluegill	17	10	52	13	27	25	43	187	2.09%
Bluntnose Minnow	2	1	12	27	3	35	4	84	0.94%
Brook Silverside	4	1	11	5		4	1	26	0.29%
Channel Catfish	14	10	6	4	9	12	9	64	0.72%
Channel Darter	33	2	2	1	1	11	33	83	0.93%
Channel Shiner		102	89	61	51	27	92	422	4.72%
Common Carp				4	7			11	0.12%
Emerald Shiner	72	968	653	298	214	369	135	2709	30.28%
Flathead Catfish	3	6		1	1	6	1	18	0.20%
Freshwater Drum	6	15	7	6	15	18	5	72	0.80%
Ghost Shiner				2				2	0.02%
Gizzard Shad		4	1		1		19	25	0.28%
Golden Redhorse	132	59	25	131	155	26	113	641	7.16%
Golden Shiner	1							1	0.01%

Green Sunfish	1			3	20	1		25	0.28%
Greenside Darter	6	1	1	1	1	1		11	0.12%
Johnny Darter						1		1	0.01%
Largemouth Bass			1	6	12	1	6	26	0.29%
Lepomis hybrids				1		1		2	0.02%
Logperch	11	12	28	20	3	9	75	158	1.77%
Longhead Darter	8	4	6				2	20	0.22%
Longnose Gar	8	13	26	23	40	3	34	147	1.64%
Mimic Shiner	77	250	170	75	113	64	132	881	9.85%
Mooneye	4	2	1		3			10	0.11%
Muskellunge		1	2		3			6	0.07%
Northern Hog Sucker	42	5	5	13	5	16	6	92	1.03%
Northern Pike	1							1	0.01%
Ohio Lamprey		2						2	0.02%
Pumpkinseed			2	2	4	7		15	0.17%
Quillback	2	8	12	6	18	5	4	55	0.61%
Rainbow Darter	1							1	0.01%
Rainbow Trout - Hatchery		1						1	0.01%
Redear Sunfish				1				1	0.01%
River Carpsucker	1				1		2	4	0.04%
River Redhorse	50	63	29	1		2	18	163	1.82%
Rock Bass	37	18	20	4	23	64	14	180	2.01%
Sand Shiner		130	35	8	5		18	196	2.19%
Sauger	1	21	4	10	10	5	144	195	2.18%
Saugeye			1			1		2	0.02%
Silver Chub	1	1	12			1	2	17	0.19%
Silver Redhorse	62	66	77	68	34	45	57	409	4.57%
Smallmouth Bass	106	99	88	33	71	63	68	528	5.90%
Smallmouth Buffalo		25	10				34	69	0.77%
Smallmouth Redhorse	148	77	49	3	5	1	69	352	3.93%
Spotfin Shiner	15	14	7	3	8	39	13	99	1.11%

Spotted Bass			3	14	8	10		35	0.39%
Tiger Muskellunge							3	3	0.03%
Trout Perch		6	5					11	0.12%
Walleye	128	104	31	38	83	10	11	405	4.53%
White Bass					11	1	51	63	0.70%
White Crappie			1					1	0.01%
White Sucker	1			1		2		4	0.04%
Yellow Bullhead				1				1	0.01%
Yellow Perch		1		8	1	1		11	0.12%
Totals	1089	2164	1507	966	1074	895	1252	8947	
Total Species	33	39	39	38	36	37	35		

Table 8. Total number of fish captured and percent of total captured during annual beach seine surveys in the Montgomery Island Pool from 2021.

Species Captured	2021	Percent Abundance
Bluegill	4	0.10%
Bluntnose Minnow	74	1.80%
Brook Silverside	36	0.88%
Central Stoneroller	1	0.02%
Channel Shiner	160	3.89%
Emerald Shiner	3445	83.74%
Gizzard Shad	155	3.77%
Logperch	1	0.02%
Mimic Shiner	101	2.46%
Northern Hog Sucker	2	0.05%
Rainbow Darter	2	0.05%
River Redhorse	3	0.07%
Sand Shiner	32	0.78%
Sauger	1	0.02%
Silver Chub	1	0.02%
Smallmouth Bass	19	0.46%
Smallmouth Redhorse	1	0.02%
Spotfin Shiner	71	1.73%
Spotted Bass	1	0.02%
Streamline Chub	3	0.07%
White Sucker	1	0.02%
Totals	4114	

Table 9. Summary statistics for all fish captured during fall electrofishing surveys conducted in the Greenup and R.C. Byrd pools in 2021

Species	R.C. Byrd Pool					Greenup Pool				
	6.5 hrs					4 hrs				
	N	% catch	Wr	CPUE		N	% catch	Wr	CPUE	
				no./hr	95% CL				no./hr	95% CL
Black Crappie	-		-	-	-	2	0.16	91.9	0.50	0.98
Brook Silverside	2	0.07	-	0.37	0.73	-	-	-	-	-
Bluegill	42	1.52	99.7	6.85	6.72	14	1.11	93.8	3.50	3.42
Bigmouth Buffalo	1	0.04	-	0.15	0.29	-	-	-	-	-
Bluntnose Minnow	1	0.04	-	0.15	0.29	-	-	-	-	-
Bowfin	1	0.04	-	0.15	0.29	9	0.71	-	2.25	3.92
Common Carp	6	0.22	96.2	0.93	0.79	7	0.55	104.4	1.75	2.02
Channel Shiner	16	0.58	-	2.37	1.97	15	1.19	-	3.75	3.54
Channel Catfish	1	0.04	78.9	0.15	0.29	6	0.47	82.1	1.50	1.21
Emerald Shiner	342	12.39	-	50.95	30.93	178	14.08	-	44.50	30.59
Flathead Catfish	11	0.40	88.6	1.63	1.27	1	0.08	80.5	0.25	0.49
Freshwater Drum	32	1.16	92.5	4.81	2.22	142	11.23	99.1	35.50	27.77
Golden Redhorse	22	0.80	-	3.33	1.88	13	1.03	-	3.25	3.45
Green Sunfish	3	0.11	-	0.56	0.61	-	-	-	-	-
Greenside Darter	-	-	-	-	-	1	0.08	-	0.25	0.49
Gizzard Shad	1836	66.50	85.8	294.92	211.64	456	36.08	84.3	114.00	85.06
Highfin Carpsucker	3	0.11	-	0.44	0.48	1	0.08	-	0.25	0.49
Hybrid Sunfish	-	-	-	-	-	1	0.08	-	0.25	0.49
Hybrid Striped Bass	29	1.05	84.1	4.34	2.96	25	1.98	85.6	6.25	3.72
Longear Sunfish	7	0.25	-	1.04	1.54	5	0.40	-	1.25	1.55
Logperch	5	0.18	-	0.74	0.73	4	0.32	-	1.00	1.34
Largemouth Bass	44	1.59	99.4	6.81	6.13	7	0.55	94.9	1.75	1.23
Longnose Gar	6	0.22	77.8	0.89	0.76	19	1.50	77.5	4.75	3.59
Muskellunge	-	-	-	-	-	1	0.08	-	0.25	0.49

Northern Hogsucker	3	0.11	-	0.44	0.48	-	-	-	-	-
Quillback	3	0.11	-	0.44	0.64	3	0.24	-	0.75	1.47
Redear Sunfish	1	0.04	68.4	0.15	0.29	-	-	-	-	-
River Darter	1	0.04	-	0.15	0.29	-	-	-	-	-
River Carpsucker	18	0.65	96.04	2.93	2.63	17	1.34	92.1	4.25	4.44
River Redhorse	11	0.40	-	1.63	1.27	20	1.58	-	5.00	5.70
Spotfin Shiner	2	0.07	-	0.30	0.58	-	-	-	-	-
Sauger	28	1.01	76.2	4.38	2.33	48	3.80	77.5	12.00	8.74
Saugeye	1	0.04	70.03	0.19	0.36	-	-	-	-	-
Skipjack Herring	9	0.33	-	1.33	1.18	6	0.47	-	1.50	1.21
Smallmouth Buffalo	188	6.81	75.6	28.80	8.50	198	15.66	76.8	49.50	25.63
Smallmouth Bass	25	0.91	83.7	3.70	2.21	17	1.34	79.5	4.25	3.68
Smallmouth Redhorse	28	1.01	-	4.15	3.41	9	0.71	-	2.25	1.75
Spotted Sucker	1	0.04	-	0.19	0.36	2	0.16	-	0.50	0.98
Spotted Bass	29	1.05	102.9	4.44	2.89	29	2.29	102.7	7.25	4.25
Silver Chub	-	-	-	-	-	1	0.08	-	0.25	0.49
Silver Redhorse	-	-	-	-	-	6	0.47	-	1.50	2.01
Warmouth	1	0.04	-	0.19	0.36	-	-	-	-	-
White Bass	-	-	-	-	-	1	0.08	-	0.25	0.49
White Crappie	1	0.04	-	0.15	0.29	-	-	-	-	-
Yellow Perch	1	0.04	60.4	0.15	0.29	-	-	-	-	-

Table 10. Gill netting effort, catch and species counts from two pools of the Ohio River in Fall 2021.

Fall Gill Netting (4 October – 3 November 2021)			
Ohio River 2021			
	Greenup	R.C. Byrd	Total
Effort (ft)	1800	3150	4950
Net Sets	13	21	34
All Fish (n)	3	1	4
Bighead Carp	0	1	1
Silver Carp	0	0	0
Grass Carp	0	0	0
Common Carp	1	0	1
Smallmouth Buffalo	2	0	2

Table 11. The number of fish captured by species percent total catch from eight seine hauls in the Greenup Pool of the Ohio River in 2021

	Greenup Pool 2021	
Species	**N**	**% Catch**
Bluegill	2	0.13
Bullhead Minnow	5	0.33
Channel Chiner	268	17.78
Emerald Shiner	1211	80.36
Freshwater Drum	2	0.13
Ghost Shiner	5	0.33
Gizzard Shad	6	0.40
Hybrid Striped Bass	2	0.13
River Shiner	1	0.07
Silver Chub	2	0.13
Silver Redhorse	1	0.07
Smallmouth Redhorse	1	0.07
Spotted Bass	1	0.07
Total	1507	

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.

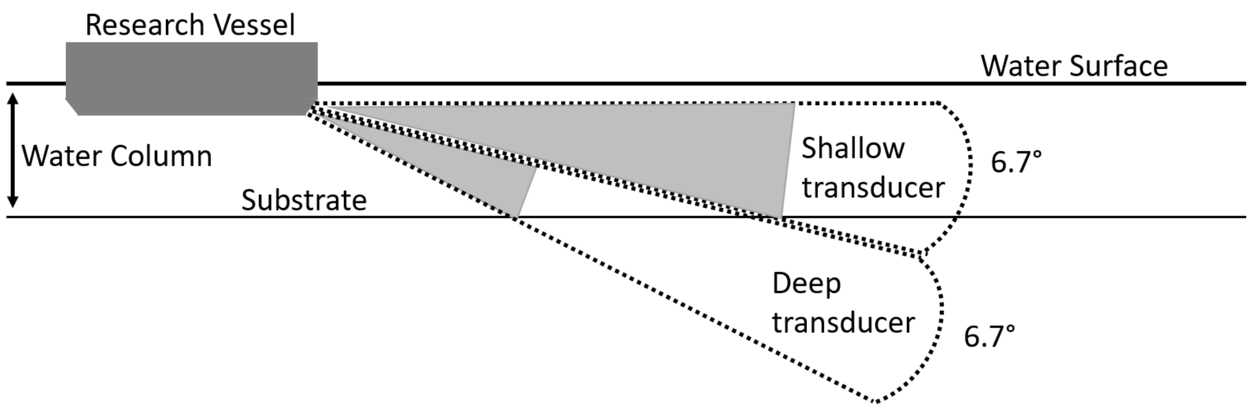


Figure 2. Depiction of hydroacoustic beams with transducers offset to maximize water column coverage for two split-beam echosounders.

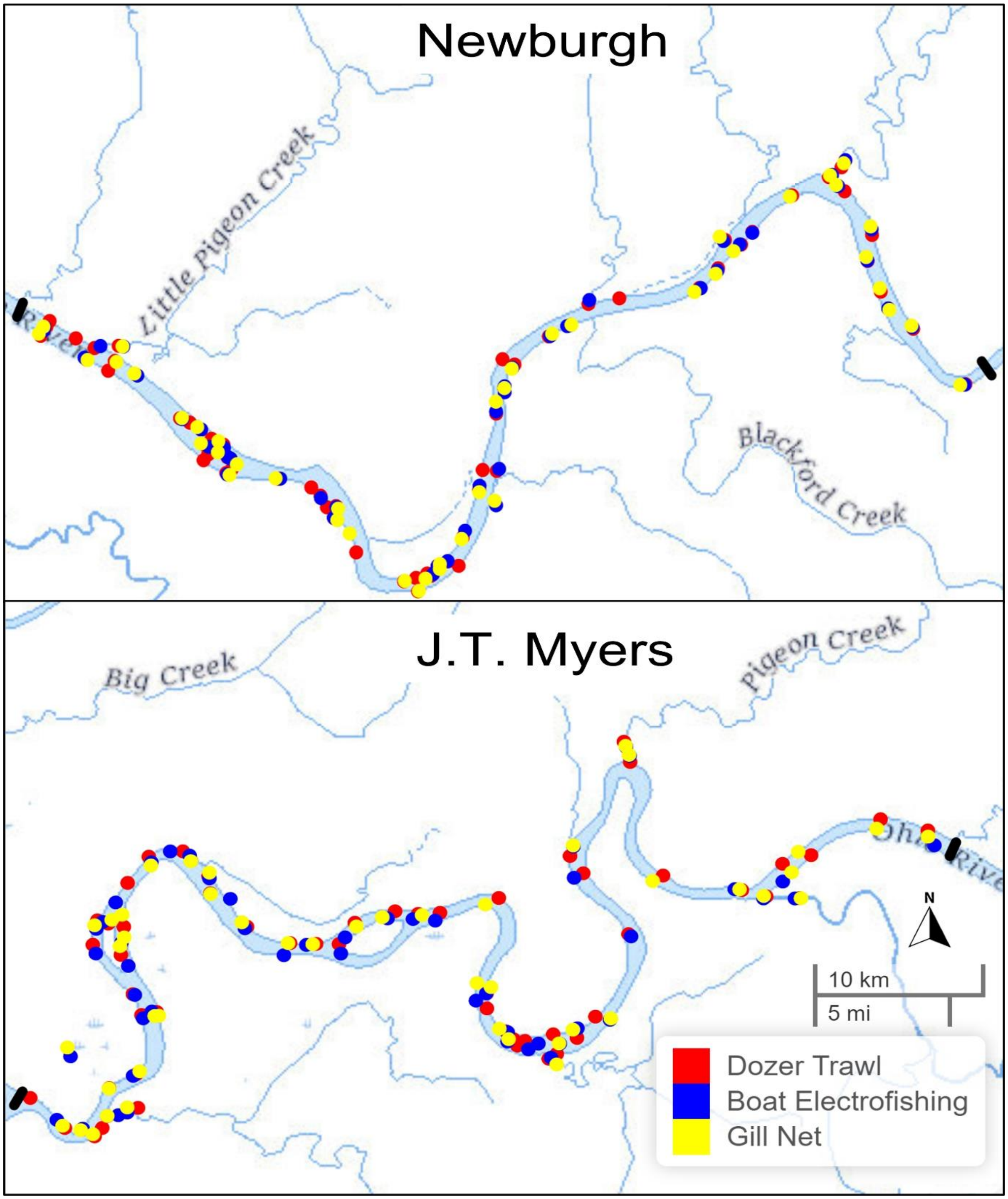


Figure 3. Map of dozer trawl (red), boat electrofishing (blue), and gill net (yellow) sites in Newburgh (top) and J.T. Myers (bottom) pools during October 2021. Community data were used to apportion hydroacoustic targets to species. Black lines across the river indicate dam locations.

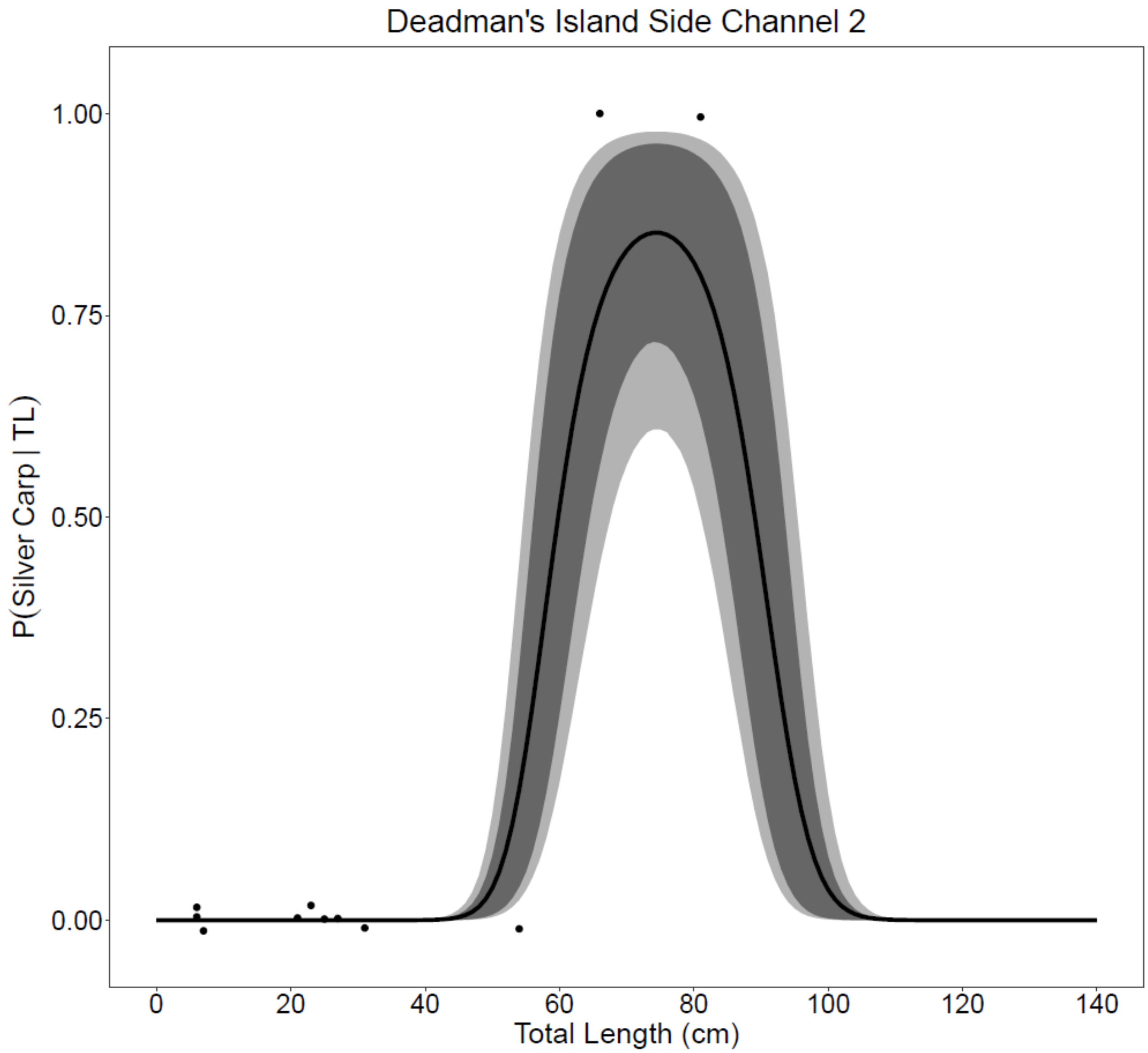


Figure 4. Estimated probability of a fish being a Silver Carp given its total length for Deadman's Island Side Channel 2. The dark line is the mean probability, and the gray-shaded areas represent the 90% (light) and 75% (dark) credible intervals, respectively. Black points represent individual fish captured at this site where 1 = Silver Carp and 0 = all other species.

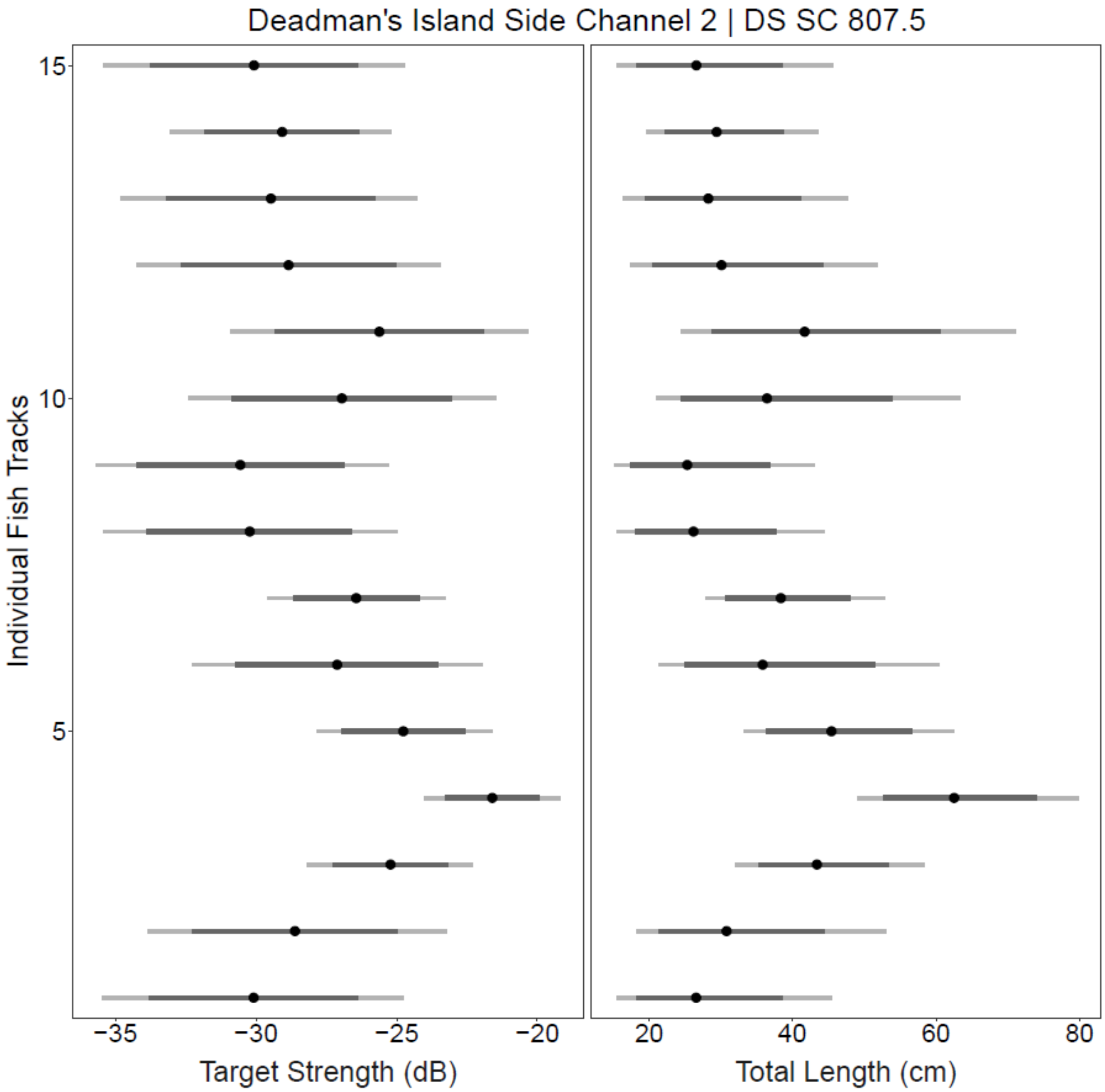


Figure 5. Estimated mean TS (dB) and TL (cm) for all fish tracks at Deadman's Island Side Channel 2 for the downstream, shore-facing transect. Black dots represent the estimated mean TS and TL. Dark and light gray lines represent 75 % and 90 % credible intervals, respectively.

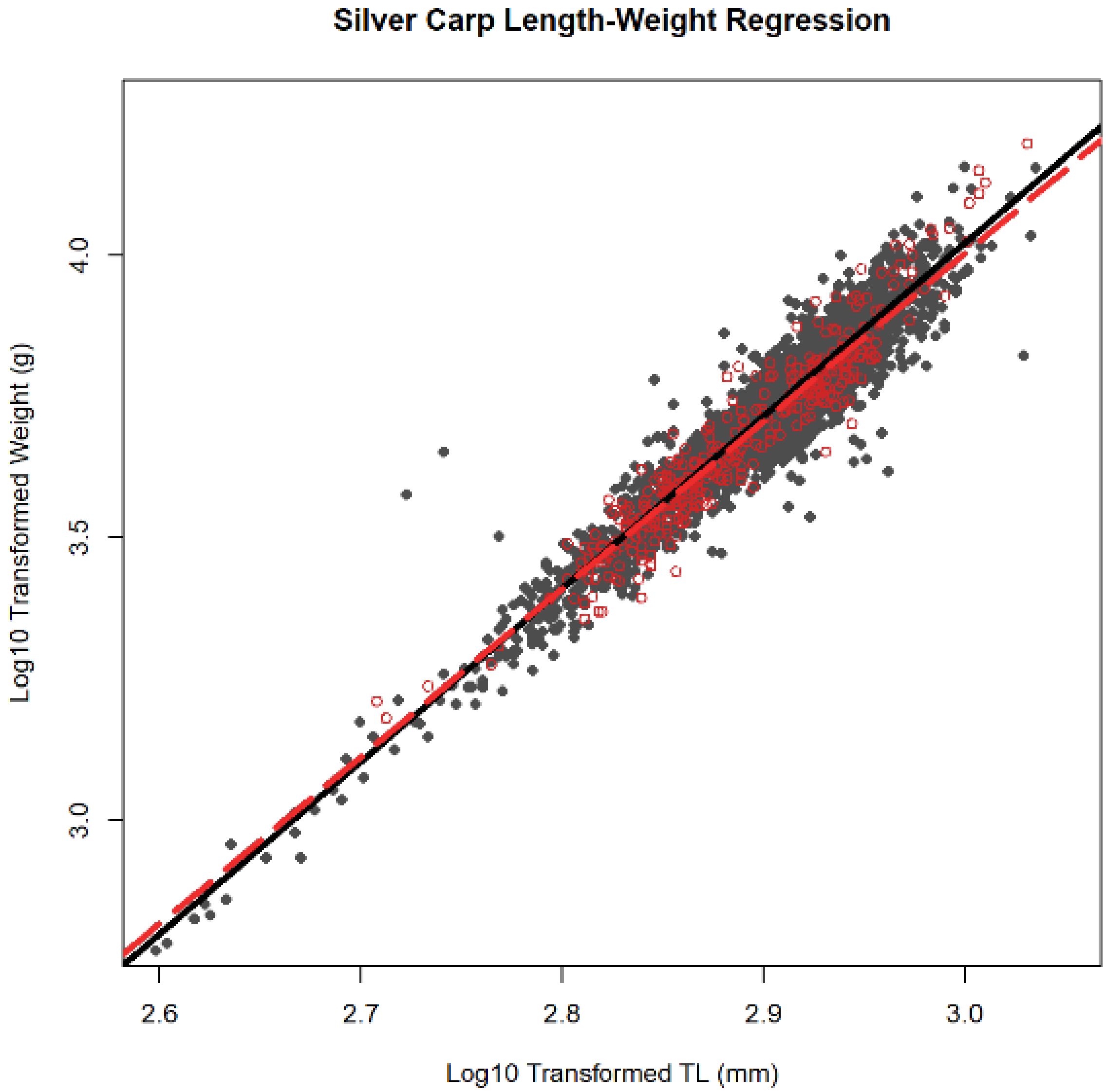


Figure 6. The log-transformed relationship between total length (mm) and weight (g) for Silver Carp in the middle Ohio River. The black line and dark data points represent the 'standard' regression for Silver Carp length-weight relationships in the ORB and the previous records used to compare changes in growth since 2016 (regression equation found in Table 1). The red line and red data points indicate the current year's regression line data collected in 2021.

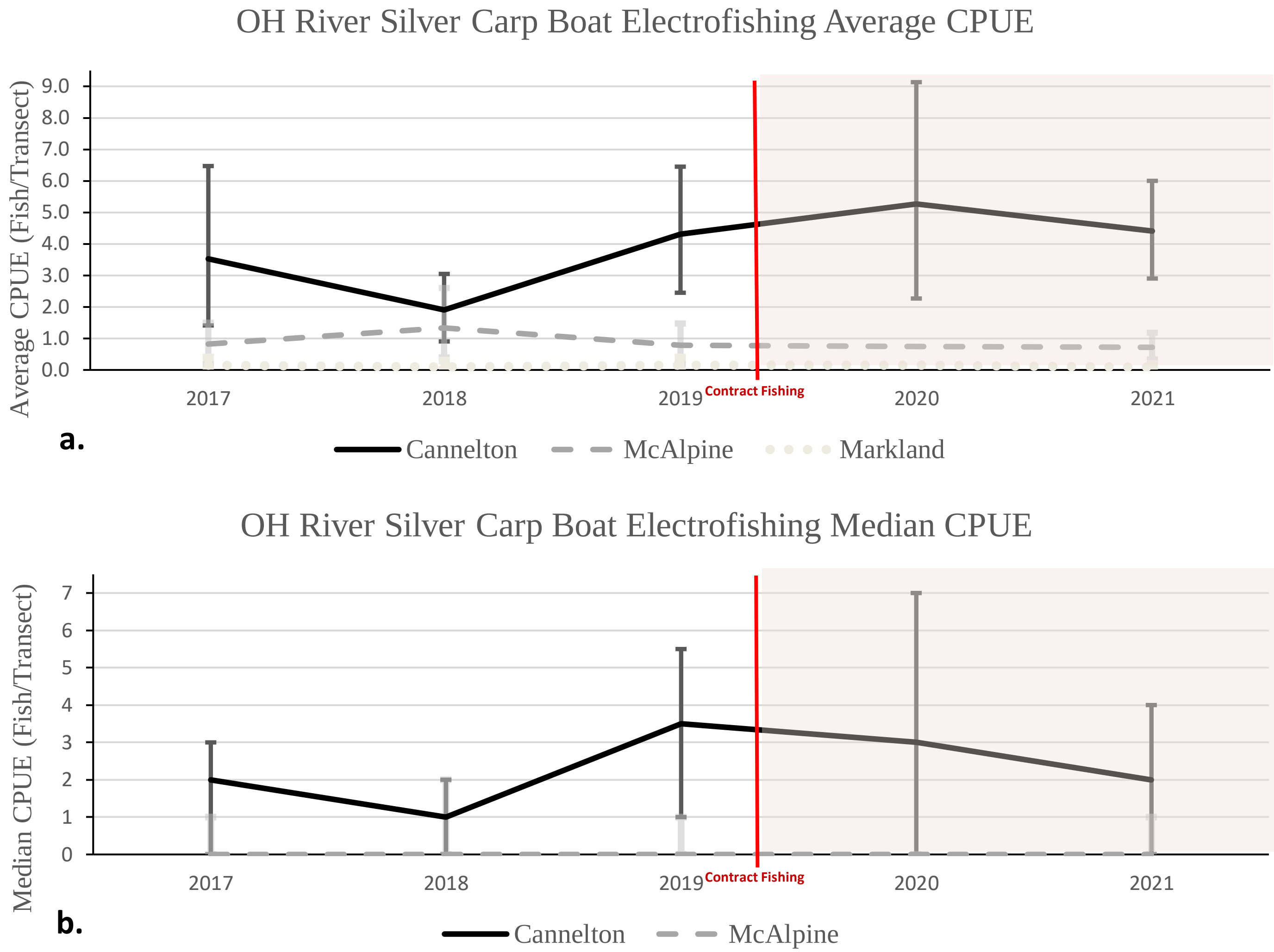


Figure 7. The change in catch per standard unit effort (CPUE) of Silver Carp in the middle Ohio River since 2017. Figure 7a. depicts the change in CPUE using the mean catch rate per transect. Figure 7b. depicts the change in CPUE using the median catch rate per boat electrofishing transect. Error bars represent the non-parametric 95% bootstrap confidence intervals. The red line represents the implementation of the contract fishing program within the Cannelton Pool.

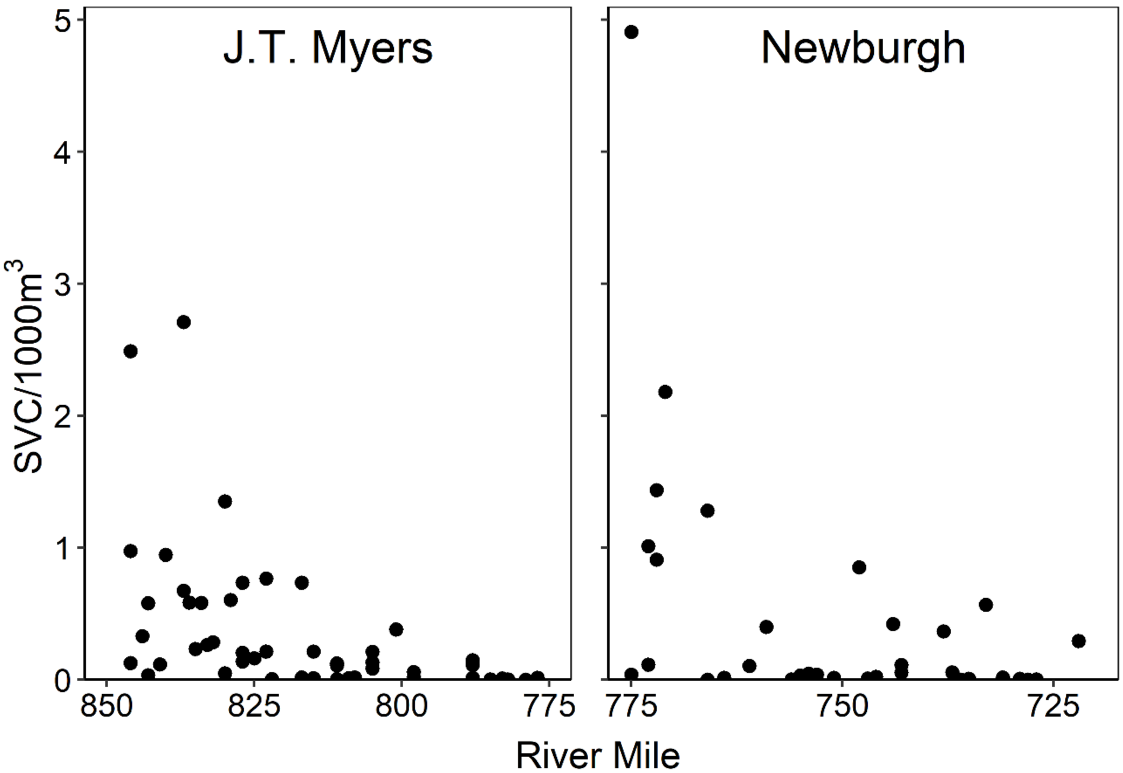
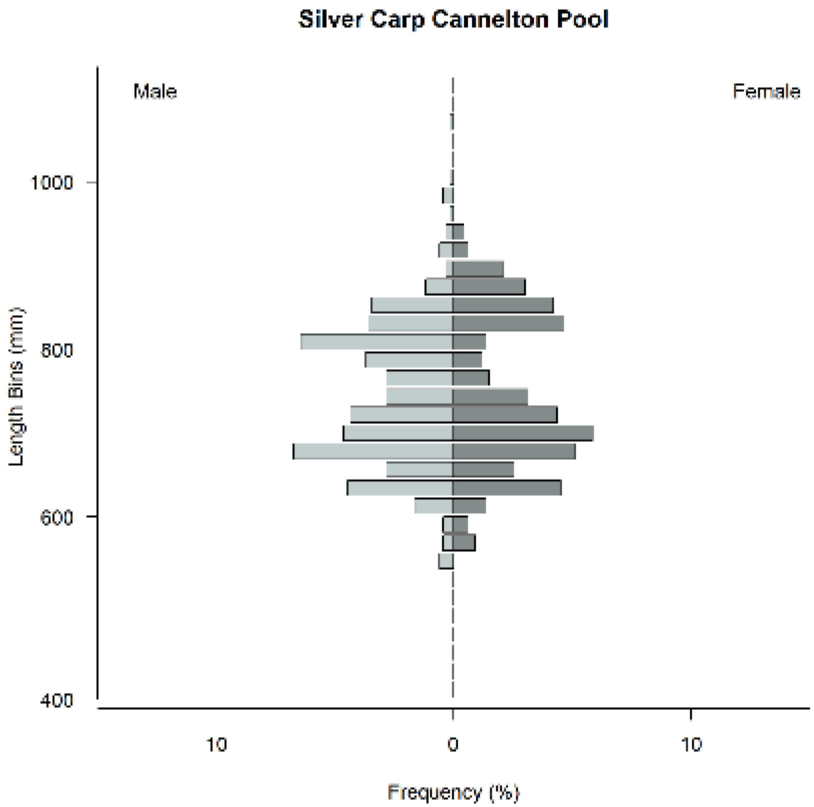


Figure 8. Change in Silver Carp (SVC) hydroacoustically derived density with river mile for main channel sites in J.T. Myers and Newburgh pools during October 2021. River miles decrease from downstream to upstream within the Ohio River (left to right on x-axis).



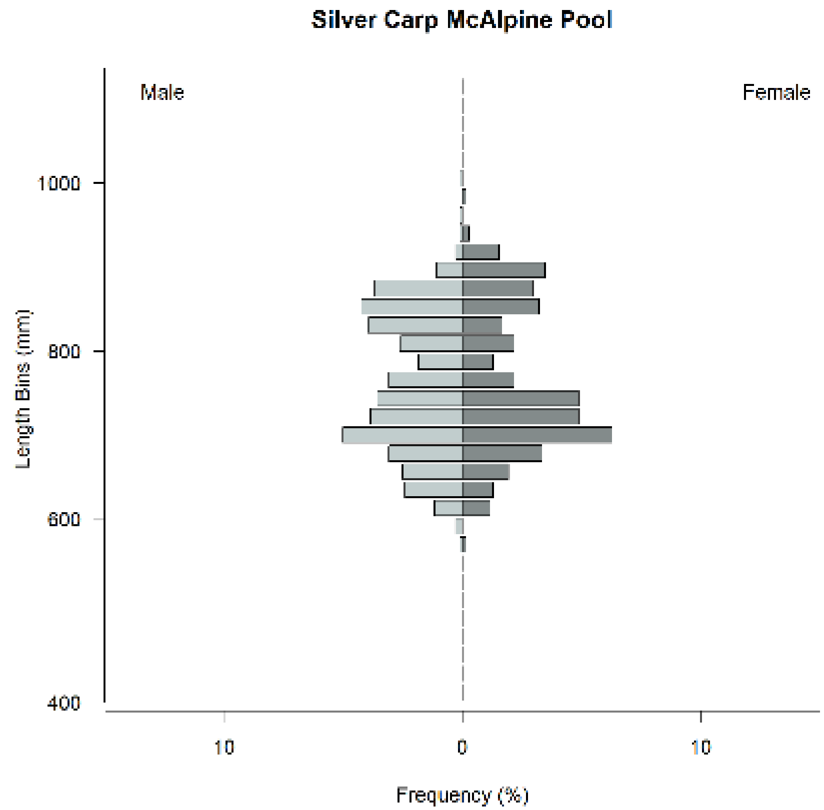


Figure 9. The percent frequency of both male and female Silver Carp, distributed by 20mm length-bins in the Cannelton and McAlpine pools in 2021.

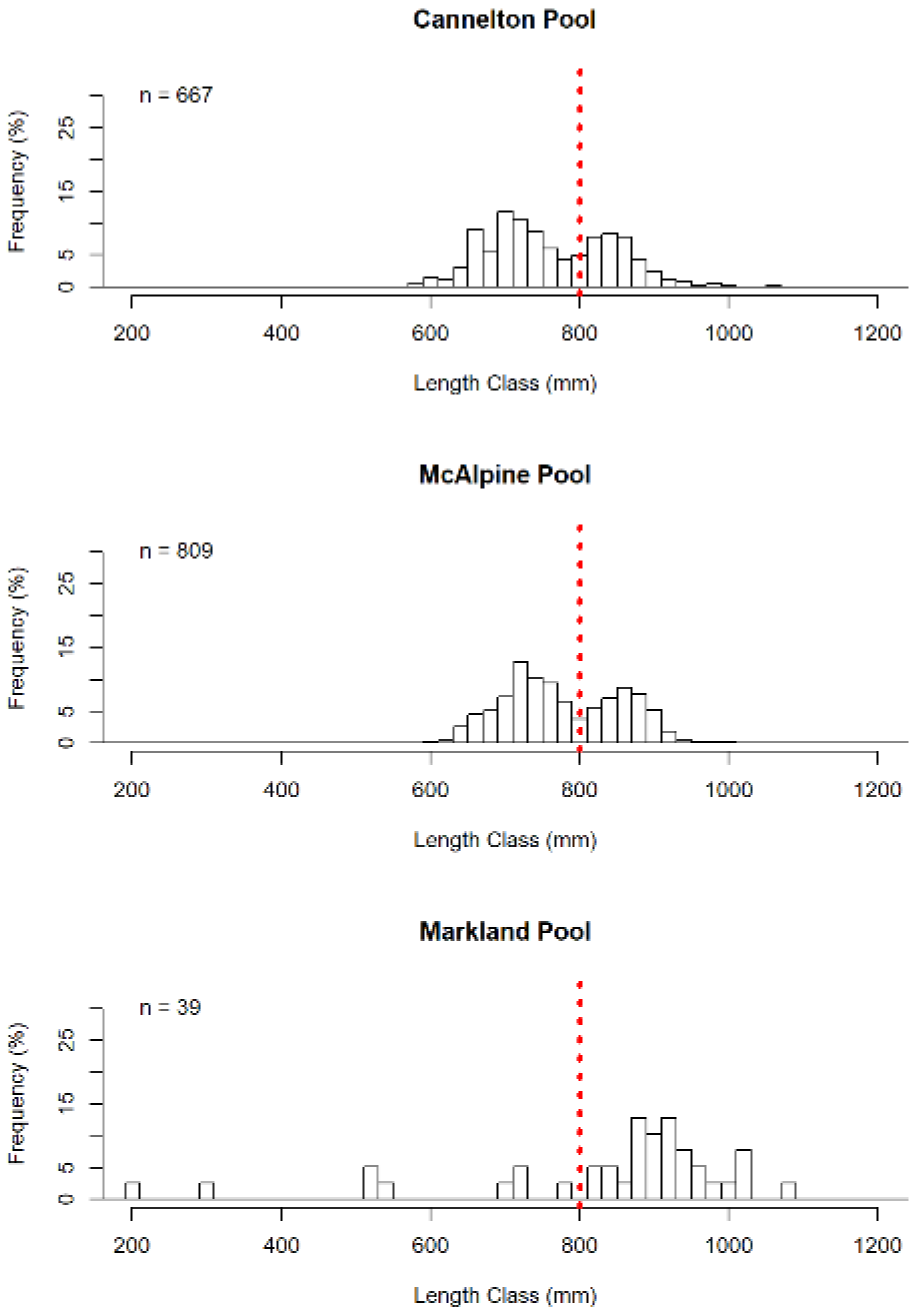


Figure 10. The distribution of 20mm total length bins for Silver Carp captured in Cannelton, McAlpine, and Markland pools in 2021.

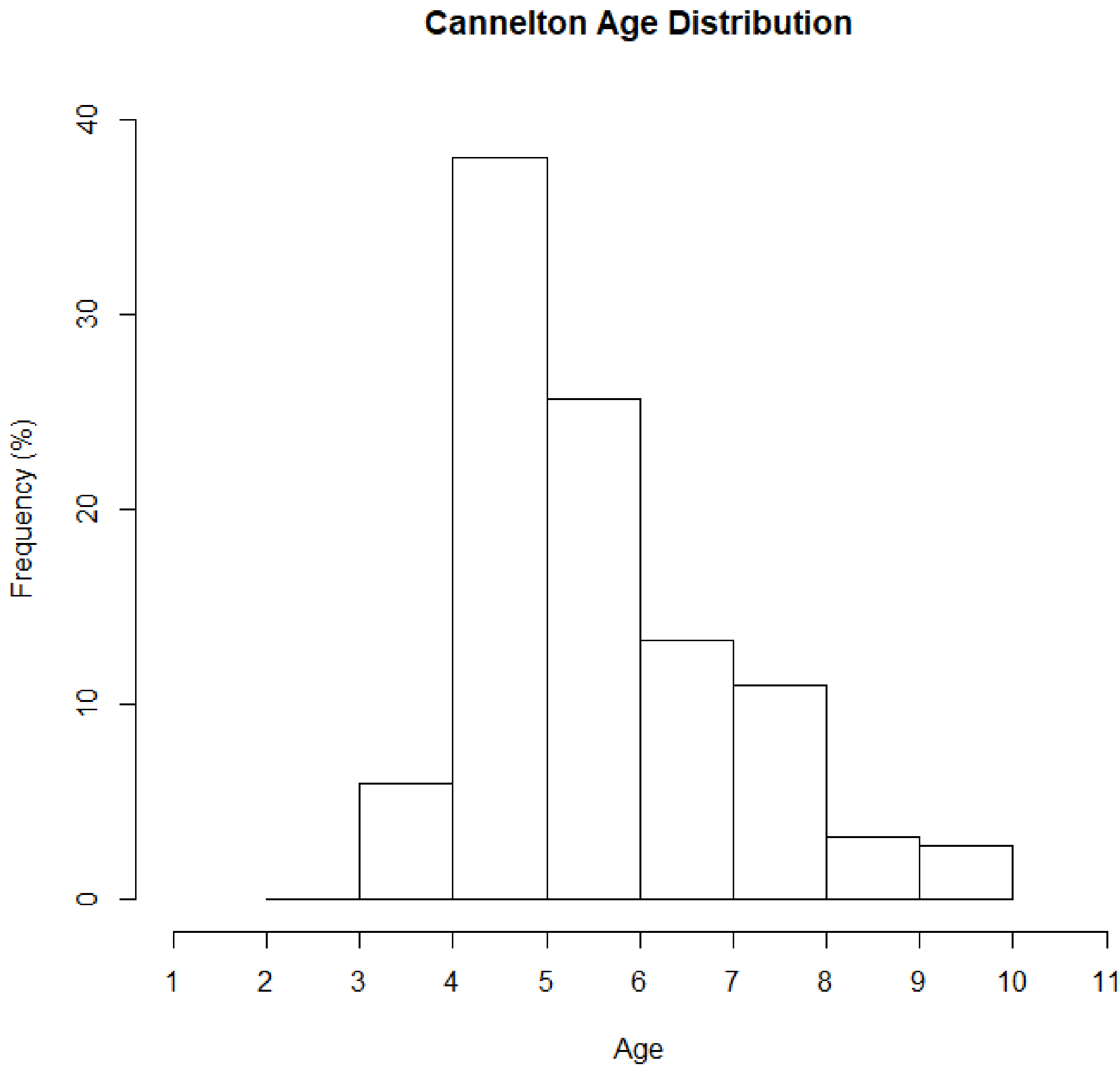


Figure 11. The distribution of ages for Silver Carp captured in Cannelton Pool in 2021. Age distributions were estimated from a sample of 218 Silver Carp otoliths.

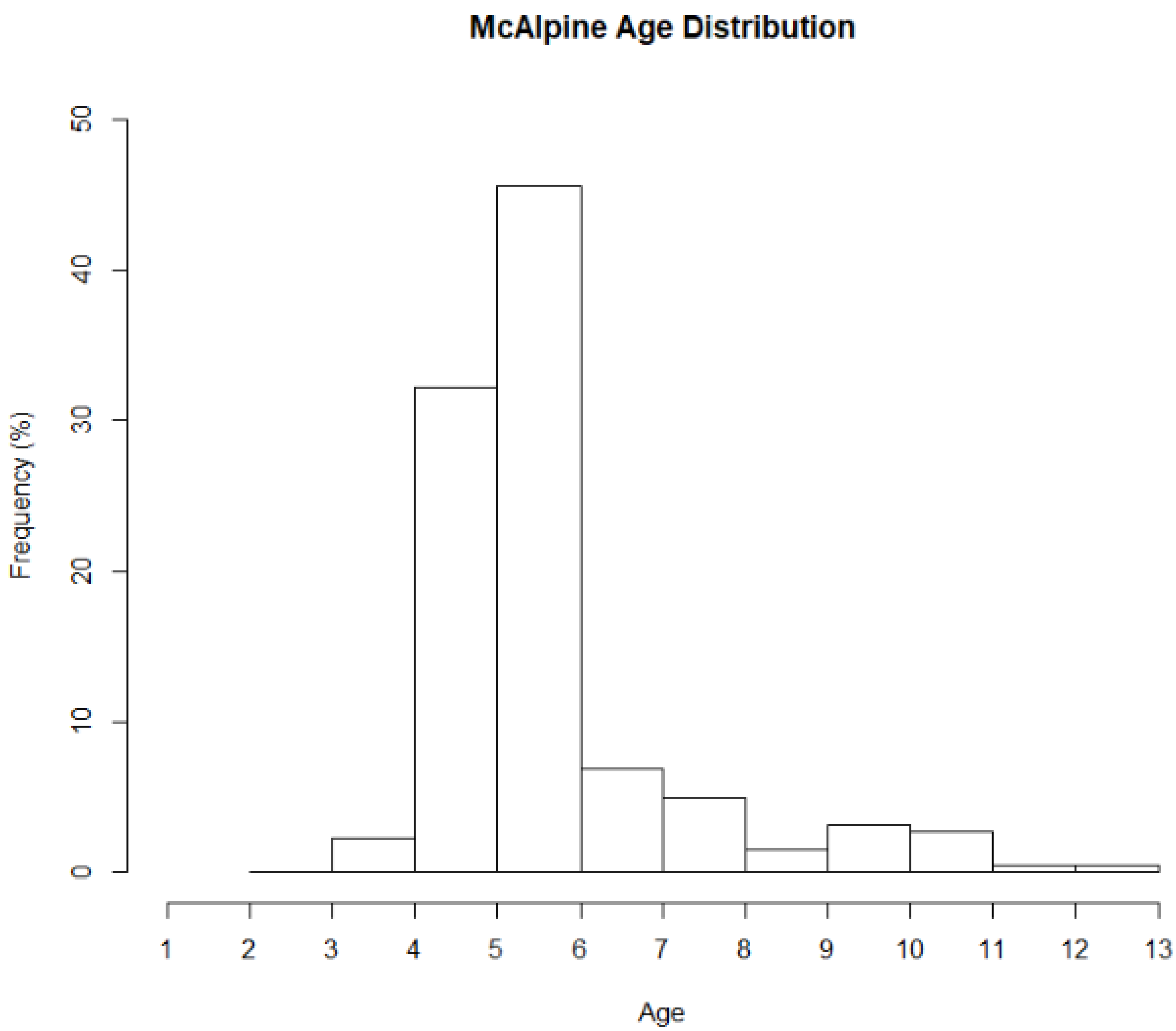


Figure 12. The distribution of ages for Silver Carp captured in McAlpine Pool in 2021. Age distributions were estimated from a sample of 261 Silver Carp otoliths.

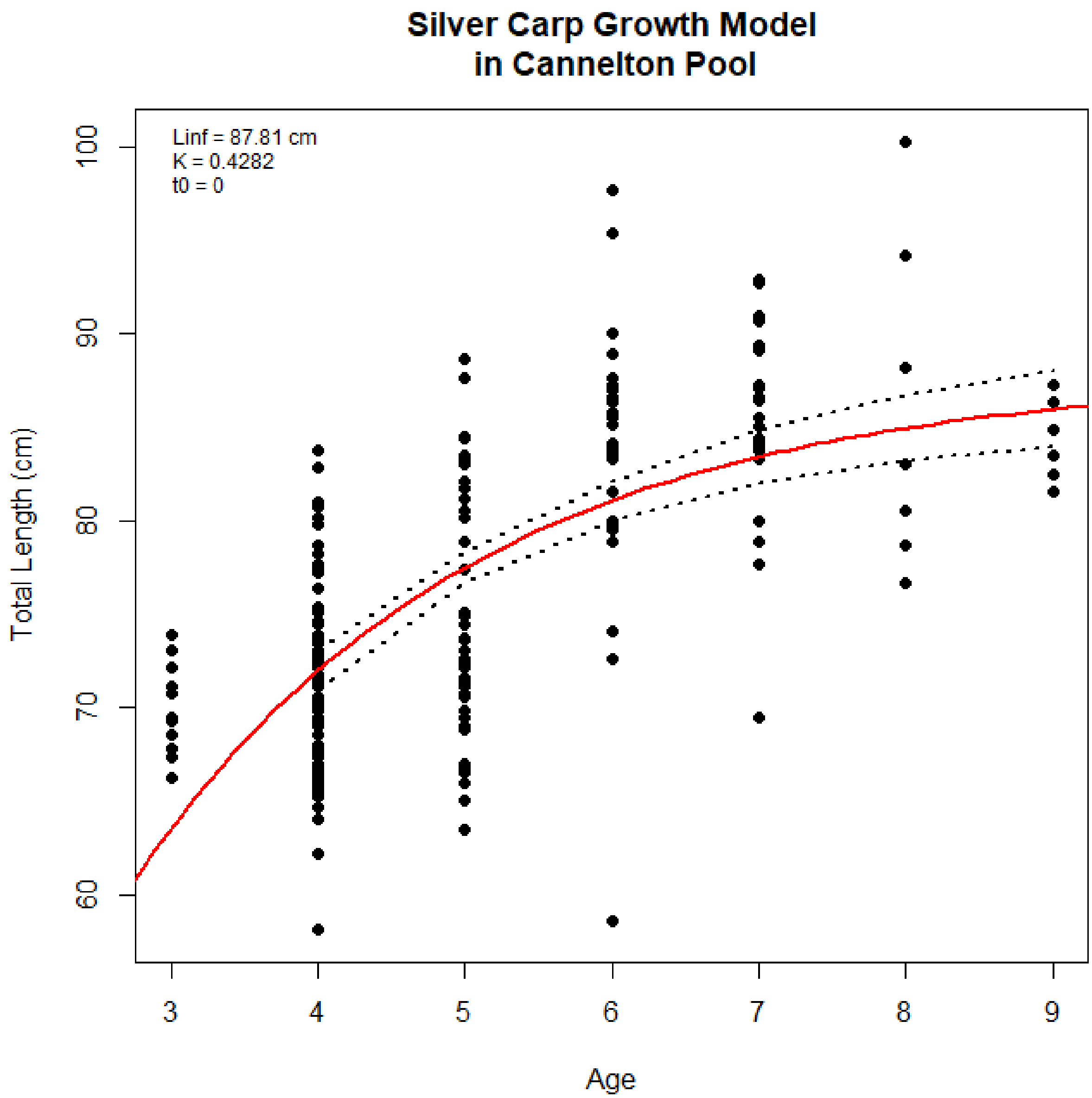


Figure 13. The Silver Carp growth model derived using length at age data from fish captured in the Cannelton Pool in 2021.

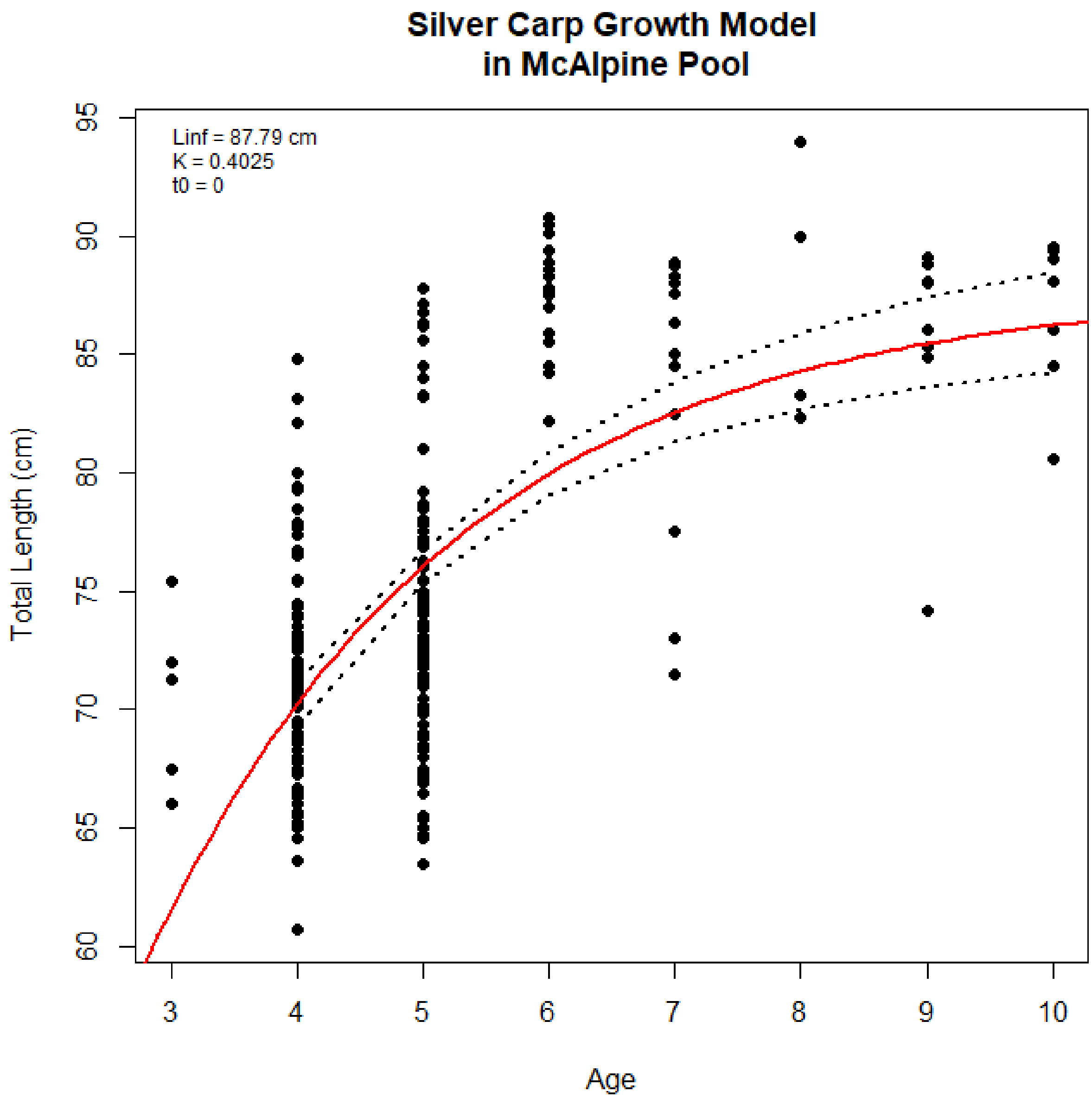


Figure 14. The Silver Carp growth model derived using length at age data from fish captured in the McAlpine Pool in 2021.

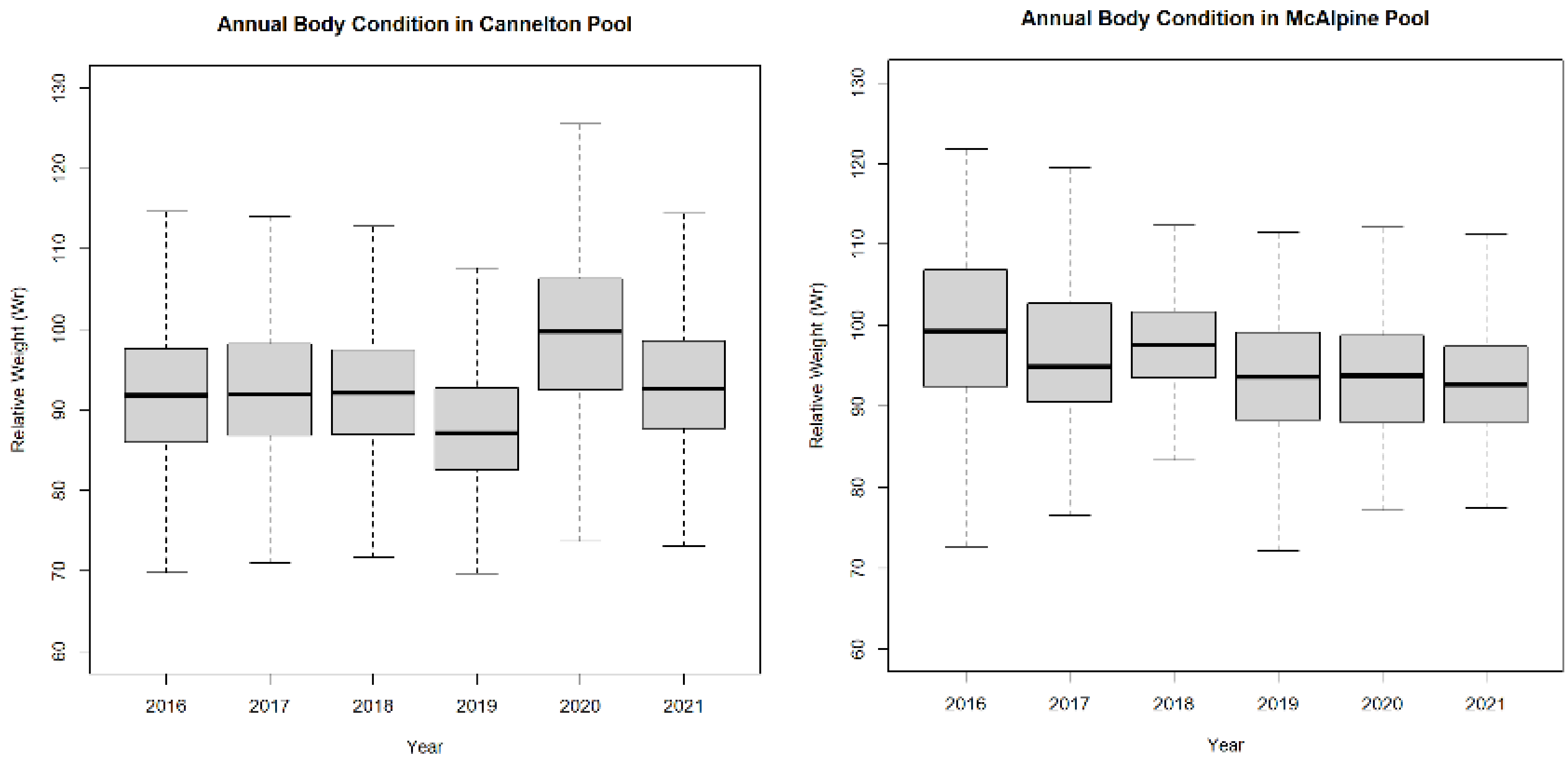


Figure 15. Boxplot comparisons of the distributions of relative weights (Wr) for Silver Carp captured post spawn, in the months of August through October, in the Cannelton and McAlpine pools from 2016 through 2021. Relative weights were calculated using the 50th percentile regression equation for Silver Carp established by Lamer *et al*, 2015.

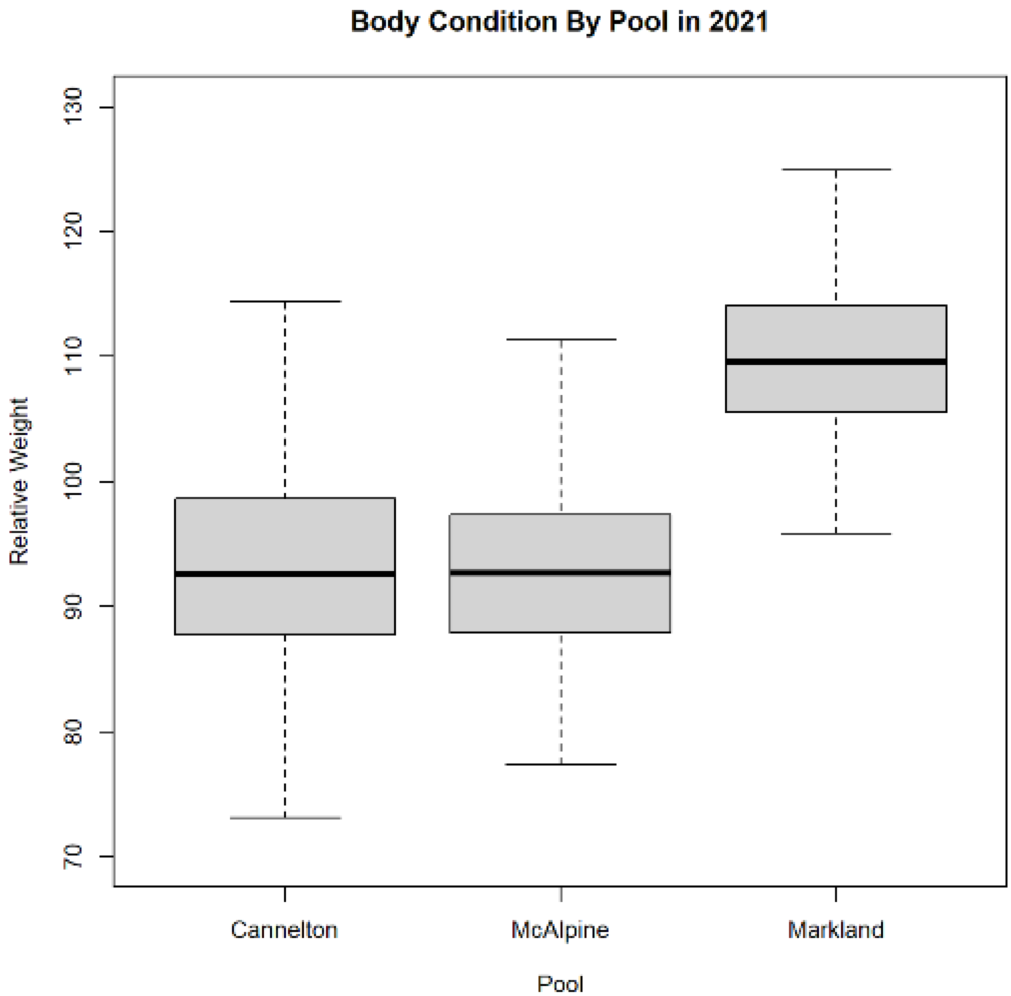


Figure 16. Boxplot comparisons of the distributions of relative weights (Wr) for Silver Carp captured post spawn, in the months of August through October, in the Cannelton, McAlpine, and Markland pools in 2021. Relative weights were calculated using the 50th percentile regression equation for Silver Carp established by Lamer *et al*, 2015.

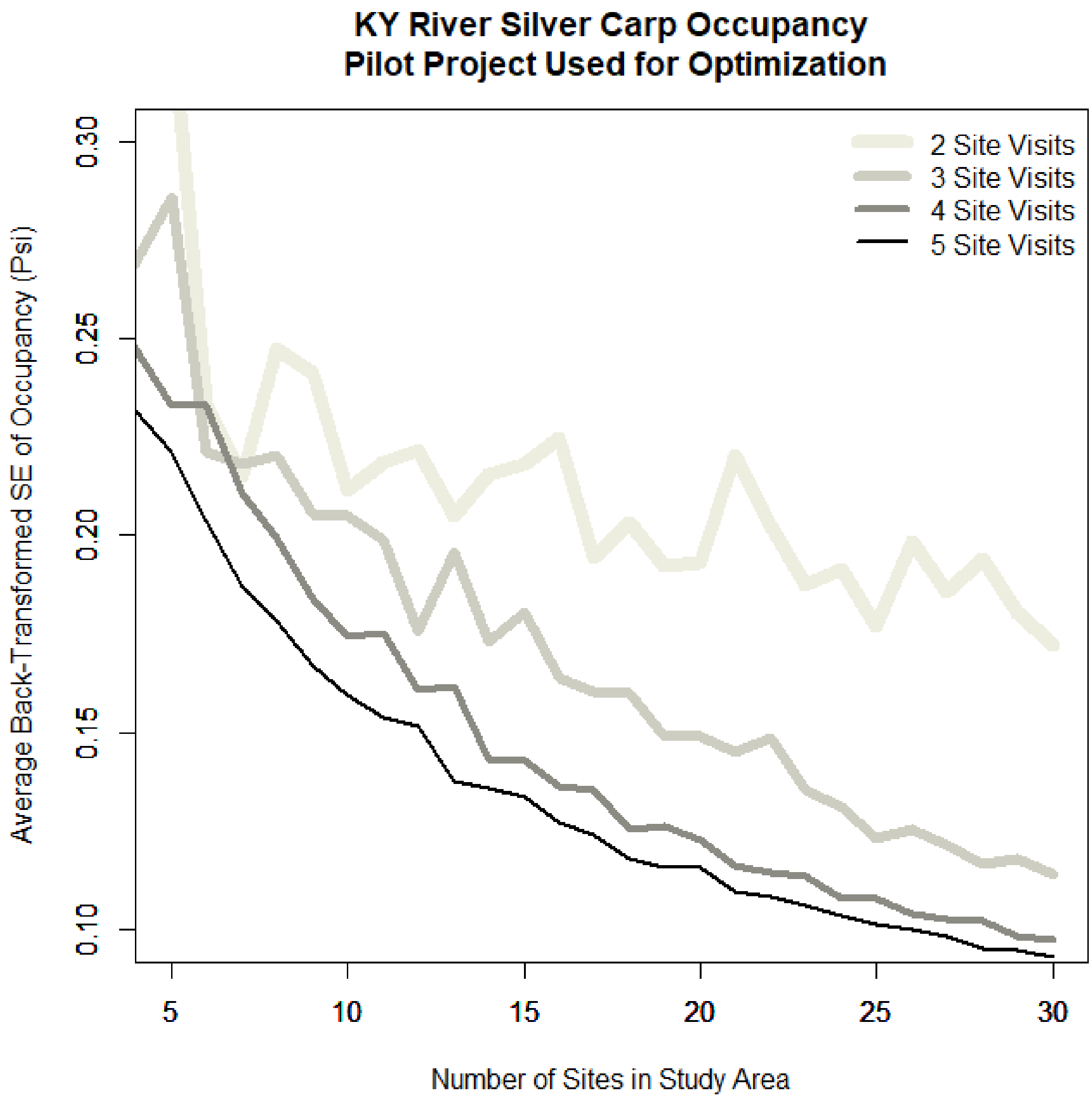


Figure 17. A graph of the average back-transformed standard error for occupancy estimates under different configurations for the number of selected sites and site visits. In general, increasing the number of visits from three to four shows a large improvement in the reduction of standard error estimates of site occupancy.

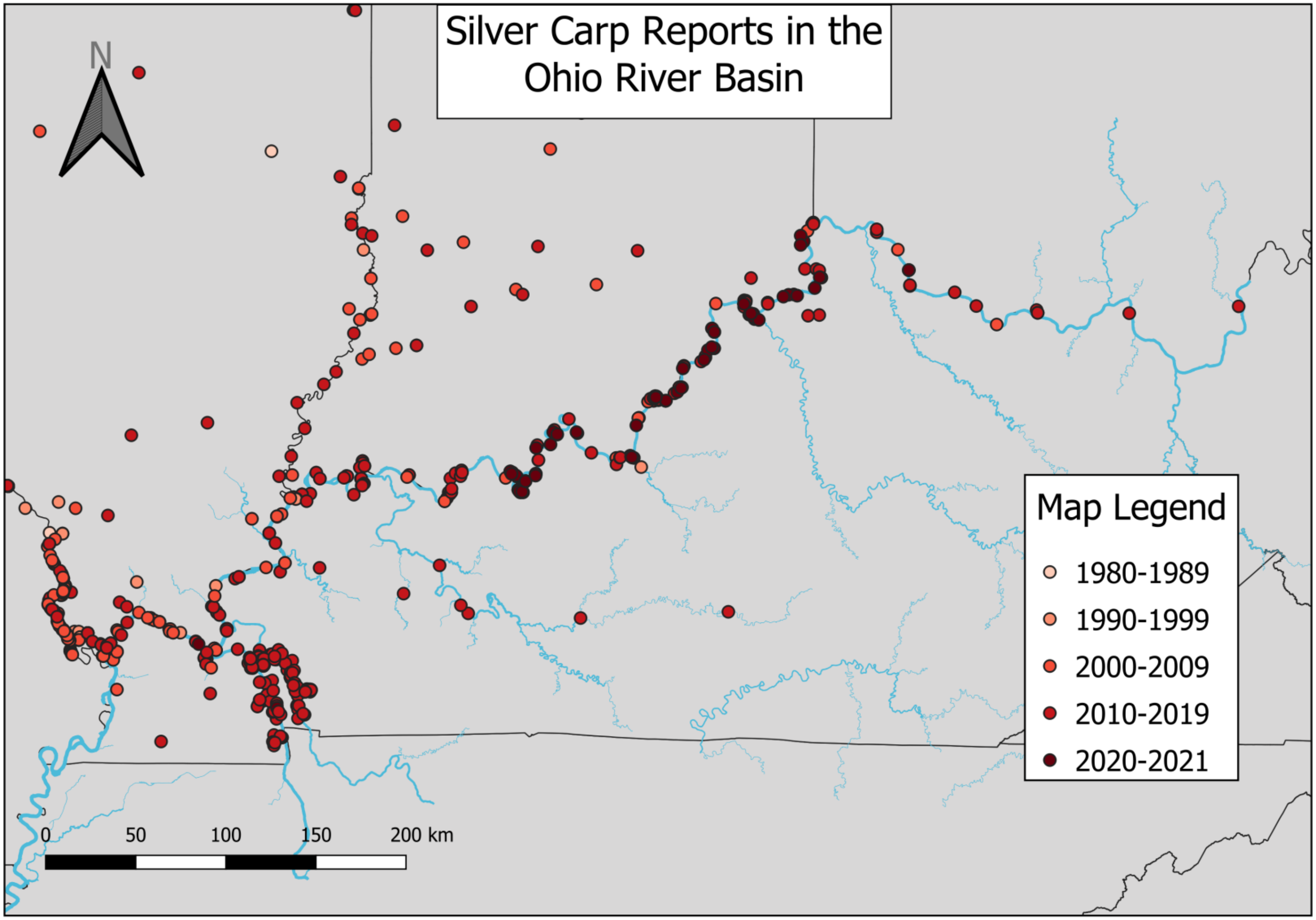


Figure 18. A map incorporating data on the geographic range and temporal proximity of Silver Carp records and reports in the ORB. Data compiled from the USGS NAS database and agency removal.

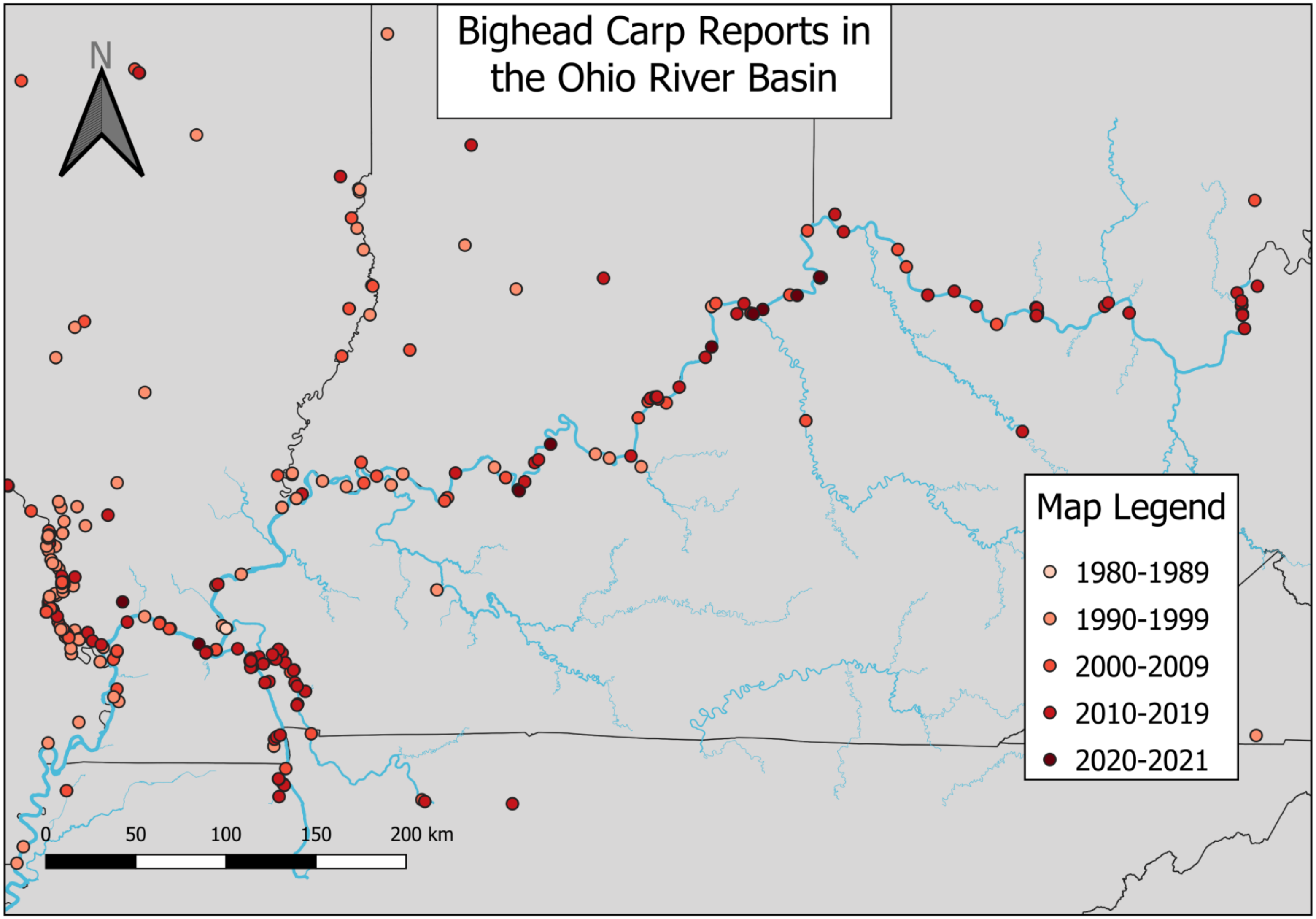


Figure 19. A map incorporating data on the geographic range and temporal proximity of Bighead Carp records and reports in the ORB. Data compiled from the USGS NAS database and agency removal.

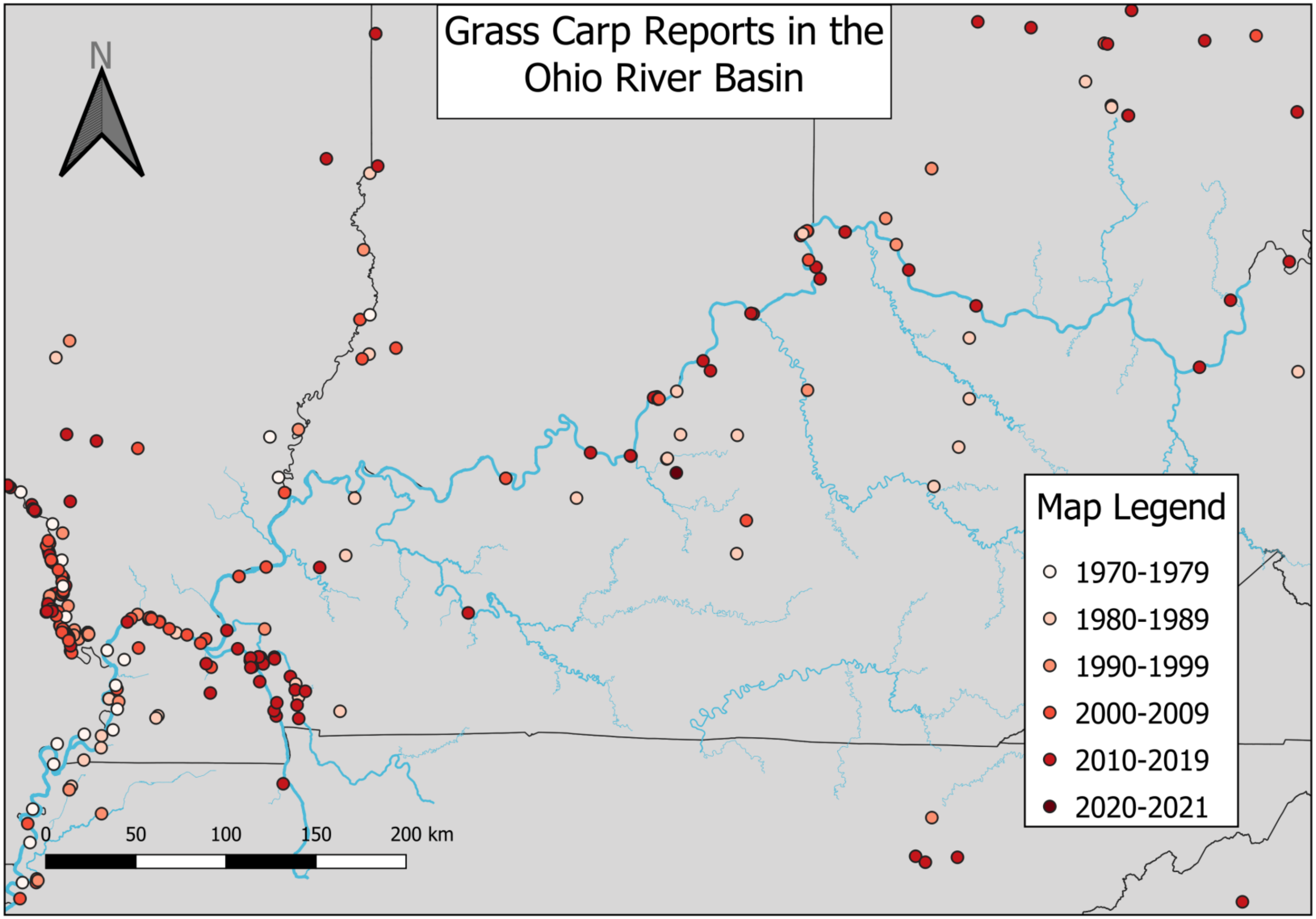


Figure 20. A map incorporating data on the geographic range and temporal proximity of Grass Carp records and reports in the ORB. Data compiled from the USGS NAS database and agency removal.

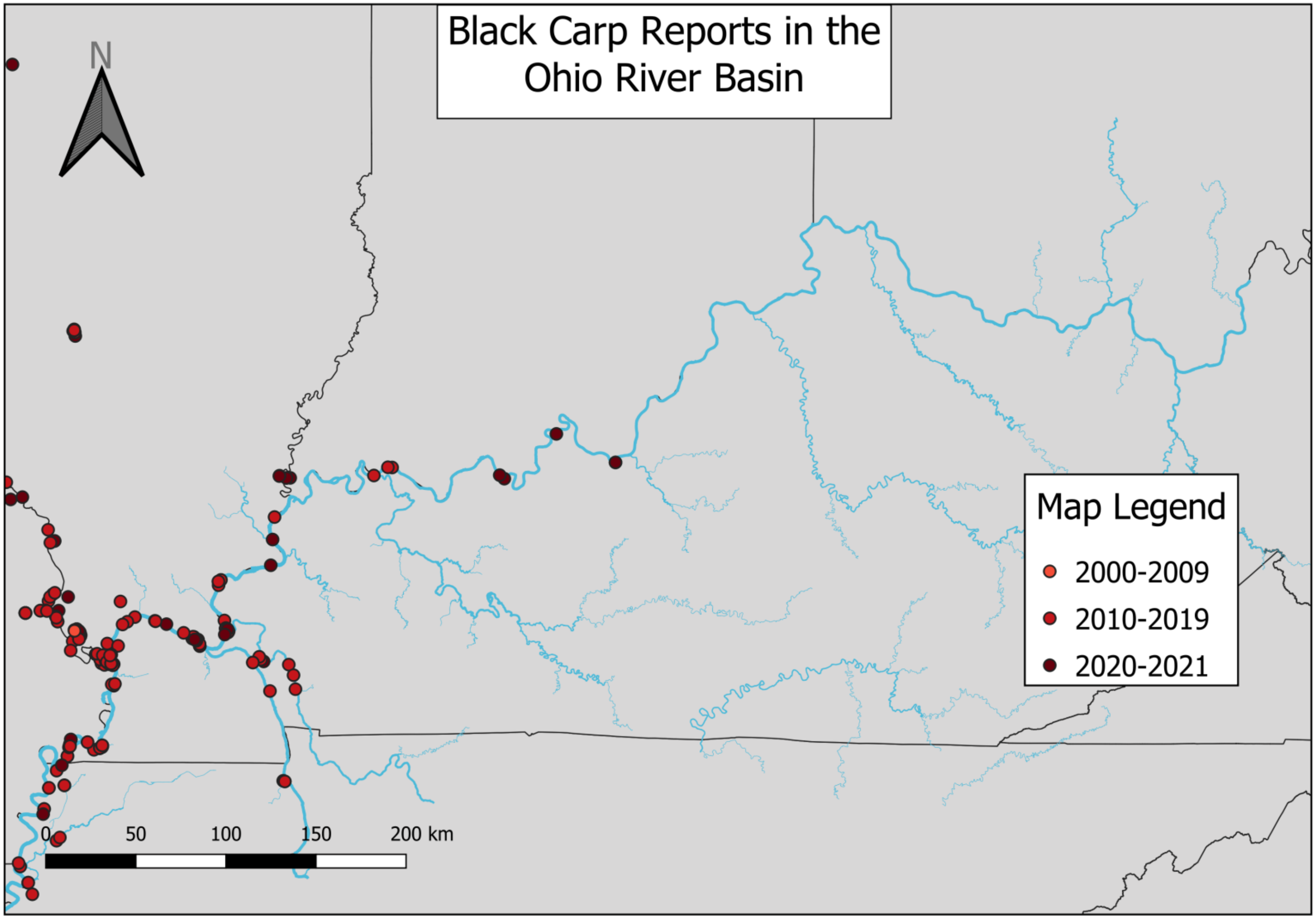


Figure 21. A map incorporating data on the geographic range and temporal proximity of Black Carp records and reports in the ORB. Data compiled from the USGS NAS database and agency removal