Project Title: Quantifying lock and dam passage, habitat use, and survival rates of invasive carps in the Ohio River Basin

Geographic Location: The Ohio River basin from Olmsted Pool (RM 964.4) to Willow Island Locks and Dam (RM 161.7), including tributaries. The Wabash River from Terre Haute, IN downstream to the confluence with the Ohio River. White River from Indianapolis, IN downstream to the confluence with the Wabash River.

Lead Agency: U.S. Fish and Wildlife Service **(**USFWS)

Participating Agencies: Southern Illinois University (SIU), Eastern Illinois University (EIU), Indiana Department of Natural Resources (INDNR), Illinois Department of Natural Resources (ILDNR), Kentucky Department of Fish and Wildlife Resources (KDFWR), Ohio Division of Wildlife (ODOW), West Virginia Division of Natural Resources (WVDNR), Ecosystem Connections Institute (ECI)

Statement of Need: Silver and Bighead Carp (*Hypophthalmichthys molitrix* and *H. nobilis*, respectively), herein referred to as "invasive carps", are invasive fishes within the Mississippi River Basin. Since they were first detected within the Mississippi River Basin in the early 1980's (Freeze and Henderson 1982; Jennings 1988; Robison and Buchanan 1988; Burr et al. 1996), the range of invasive carps has expanded to include much of the mainstem of the Mississippi River as well as other large rivers within the Mississippi River Basin (e.g., the Ohio, Missouri, and Illinois rivers) (Burr et al. 1996; Garvey et al. 2006; Camacho et al. 2020; Schaick et al. 2020). This rapid expansion throughout the Mississippi River Basin is likely due, at least in part, to rapid population growth resulting from high individual growth rates, short generation times, high fecundity, a protracted spawning period, and long-distance dispersal capabilities (Garvey et al. 2006; Peters et al. 2006; DeGrandchamp et al. 2008; Lenaerts et al. 2021).

Invasive carp populations are established throughout the lower and middle reaches of the mainstem Ohio River as well as many of its tributaries and successful reproduction is suspected as far upstream as Louisville, Kentucky. The establishment of these populations and the potential for invasive carp populations to expand their range into the upper Ohio River has led to concern among natural resource managers that invasive carps might gain access to the Great Lakes Basin through tributaries of the Ohio River. If invasive carps were to gain entry to the Great Lakes, they could cause substantial ecological and economic damage by disrupting food webs (Sass et al. 2014; Collins and Wahl 2017) and commercial and recreational fisheries (Pimentel et al. 2000, 2005). Because of the ability of invasive carps to cause extensive economic and ecological damage, limiting the expansion of invasive carp populations into novel habitats is of the utmost concern.

To prevent the spread of invasive carps into the upper portions of the Ohio River basin and potentially into the Great Lakes, we must understand their propensity for upstream movement, habitat use, and the probability of among-pool transitions. These monitoring efforts will reveal the timing and conditions most likely associated with pool transitions and entry into novel habitats. Additionally, mass movements to "preferred" habitats may reveal the timing and locations of spawning aggregations. Knowledge of these movements will be used to create management strategies designed to limit population expansion and inform management actions such as mass removal efforts.

Project Objectives:

1) Understand tributary use by invasive carps and the role of tributaries as potential sources for recruitment and routes of invasion into adjacent basins.
2) Delineate the upstream population distribution of invasive carps.
3) Quantify passage of invasive carps through Ohio River locks and dams.
4) Quantify movement patterns of invasive carps within the Wabash River basin including assessing movement between the Wabash and Ohio rivers (i.e., the contribution of Wabash River populations to those of the Ohio River) and between the White and Wabash rivers.
5) Inform invasive carp removal efforts by quantifying fine-scale habitat use and how habitat use changes through time in the Wabash and White rivers.

Project Highlights:

- During 2022, 13 receivers were added to Cannelton Pool, filling a gap in the array.
- One-hundred thirty-seven Silver Carps were tagged during 2022 in Cannelton and Markland pools.
- During 2022, 99% of Silver Carp detections occurred in tributaries compared with 34% of Bighead Carp detections
- The estimated annual survival rate for Silver Carps during June 2013 – July 2022 when assuming a constant temperature was between 0.61 and 0.94
- Estimated mean pool-to-pool transition probabilities were generally low (< 0.2) for Silver Carps, suggesting that most of these fish remain within the pool in which they were tagged
- Estimated mean mainstem-tributary transition probabilities were generally low (< 0.2) for Silver Carps suggesting that fish tend to remain within one habitat or the other
- In the Wabash River, acoustically tagged fish were found to strongly associate with log jam habitats (67% use)

Methods:

Ohio River

Acoustic telemetry was used to determine the probabilities of survival, detection, lock and dam passage, and movement between tributary and mainstem habitats of invasive carps in the lower to middle Ohio River (Olmsted to R.C. Byrd pools but primarily focused from J.T. Myers to R.C. Byrd pools). To do this, the locations of individual invasive carps tagged with VEMCO, Model V16 acoustic tags were recorded using a stationary array of VR2 receivers. Receivers were placed either within the mainstem Ohio River, the lower reaches of select tributaries, or lock and dam (L&D) structures. Within some tributaries, a pair of receivers was deployed, one near the mouth of the tributary and the second further upstream. This arrangement of receivers allows for the interpretation of upstream and downstream movement of tagged carps and improves our ability to assess tributary use as well as the timing of entry into and exit from tributaries throughout the year. For L&Ds, at least four VR2 receivers were deployed at each L&D to record pool-to-pool transitions through the lock chambers with the exception of Cannelton and McAlpine L&Ds. During January – July 2022, three receivers were deployed at Cannelton L&D, one at the upstream approach and two in the lock chamber. Only one receiver was deployed at the upstream approach of McAlpine L&D. For all other L&Ds, two receivers were placed within the lock chamber and one receiver was placed on each of the downstream and upstream approach walls. These receivers provide consistent spatial coverage across L&Ds to ensure detection capabilities are similar at each location and increase confidence in interpretation of detection data.

Acoustic Receiver Array: During January – July 2022, the receiver array extended from river mile 937.0 in Olmsted Pool, ~20 miles downstream of the Smithland L&D, upstream to Willow Island L&D (river mile 161.7) (Figure 1). Most VR2 receivers deployed in the mainstem of the Ohio River were retrieved during November 2021 to avoid loss of equipment to ice flows, high water and barge collisions during winter. During April 2022, the mainstem VR2 receivers were redeployed, and downloads and maintenance performed for L&D and tributary receivers. Because receiver loss at tributary and L&D sites is low, most receivers deployed in these locations remained in the system throughout the year. During non-winter months, detection data were downloaded from receivers monthly or as often as possible.

Acoustic Transmitter Tagging: Adult invasive carps were collected via boat electrofishing and gill nets set to block or trap fish. Efforts were concentrated in areas where invasive carps are known to congregate such as side channels, backwaters, and tributaries. Fish were measured for total length (mm) and weight (g), and visually or manually sexed (if possible). Following these measurements, an acoustic transmitter (Vemco, Model V16-6H; 69 kHz) was implanted into the peritoneal cavity via a ~3 cm incision in the ventral musculature. The incision was closed with two or three sutures. The V16-6H transmitters provide individual identification and are nominally programmed to transmit a signal every 40 seconds yielding an expected battery life of ~1,825 days (5 years). Fish implanted with acoustic transmitters were also tagged externally using a lock-on tag inserted posterior to the dorsal fin (Floy Tag & Manufacturing, Inc. FT-4 Lock-on tag with clear over-tubing).

Active Tracking: To supplement detections from the acoustic receiver array, active tracking took place in select areas of the Ohio River. A VR100 omnidirectional hydrophone will be used to detect fish during these sampling trips.

Tributary Use: To assess tributary use by invasive carps, the proportion of detections by month and habitat type (tributary or mainstem) was determined for each species by dividing the number of detections for that species in each habitat within a month by the total number of detections for that species during June 2013 – July 2022. The proportion of transitions from mainstem to tributary and from tributary to mainstem habitats each month was also assessed for both Silver and Bighead Carps. To do this, the number of transitions in each direction were summed and divided by the total number of transitions made during June 2013 – July 2022 for each species. Lastly, the time spent between transitions from tributary to mainstem habitat and vice versa was determined for each species as the mean number of days between detections in these two habitat types.

Pool-to-Pool Transition Analysis: To determine the probabilities of transitions among pools, survival, and detection of Silver Carps in the Ohio River, a Multi-state with Live Recaptures analysis was conducted in Program Mark (Cooch and White 2008) using the RMark package (Laake 2013) in R version 4.1.2 (R Core Team 2021). In this analysis, each navigation pool of the Ohio River is considered a "state". Because environmental data (e.g., temperature and gage height) were included in this analysis and were collected from January 2014 to July 2022, detection data prior to January 2014 were omitted. Encounter histories were constructed for each individual by determining the pool of the last detection for each month (January 2014 – July 2022). Because tagging took place at various times throughout the duration of the study period and the expected battery life of the acoustic transmitters is ~5 years, not all individuals have a complete encounter history (maximum of 103 possible time periods). Encounter histories of tagged carps that were harvested during the study period were right-censored. This process removes these individuals from the estimation procedures for the times following harvest. Additionally, the probability of transitions among non-adjacent pools were only estimated if they occurred in the data. Transitions among non-adjacent pools that were not observed were fixed to 0. Due to the small number of fish tagged (n = 46) and tags currently active in the Ohio River (n = 8), Bighead Carps were not included in these analyses.

To examine the effects of environmental conditions on the survival, detection, and movement of Silver Carps in the Ohio River, daily water temperature, discharge, and gage height data were collected from U.S. Geological Survey gage stations from Olmsted to R.C. Byrd pools (Table 1). Data were collected for January 1, 2014 – July 31, 2022. Because the focus of this analysis was on pool-to-pool transitions, only data from mainstem gage stations were used. Although three variables were examined [i.e., temperature (°C), discharge (ft^3 sec^{-1}), and gage height (ft)], only five gage stations collected discharge data and collections were inconsistent temporally resulting in many gaps in these time series. Because discharge is also highly variable among gage stations, it was omitted from this analysis. Temperature data were only collected at four gage stations in the sampling area but were consistent among these gage stations. An overall mean monthly temperature was, therefore, calculated for the mainstem Ohio River using data from these fours gage stations. In contrast, all selected gage stations collected gage height data (ft) during the study period allowing pool-specific monthly mean gage height data to be calculated. To do this, gage heights were first converted to meters then the monthly mean gage height was calculated using all gages within a pool. Because monthly mean gage heights were highly variable among pools, these values were standardized within each pool by subtracting the mean and dividing by the standard deviation. Standardizing these data effectively places gage heights for all pools on the same scale, making comparisons more meaningful. After calculating standardized monthly mean gage heights, the time series for Olmsted, J.T. Myers, and R.C. Byrd pools were still incomplete. The methods used to complete the time series varied for each of the pool as a result of where in the time series gaps occurred and each pool's location in the river. For R.C. Byrd Pool (the farthest upstream pool for which data were collected), there were no gage height data collected during April 2017. To complete this time series, linear interpolation was conducted between March and May 2017. For J.T. Myers Pool, there were no gage height data from January – September 2014. Because this is the beginning of the time series, temporal interpolation within J.T. Myers Pool was not possible. Data from the pools directly upstream and downstream (Newburgh and Smithland pools, respectively) of J.T. Myers Pool were, therefore, used to spatially interpolate the missing data for each month using linear interpolation. Similar to J.T. Myers Pool, there were no gage height data from January – July 2014 in Olmsted Pool. In addition, Olmsted Pool is the furthest downstream pool in the Ohio River and, therefore, spatial interpolation cannot be performed. In this case, the remainder of the gage height time series for Olmsted Pool (August 2014 – July 2022) was compared with that of Smithland Pool and because the data (magnitude of gage height and patterns in the data) were consistent among these locations, data for Smithland Pool were used directly to complete the Olmsted Pool time series for gage height.

These time series of temperature and gage height as well as the encounter histories of individual Silver Carps were used to inform transition, survival, and detection estimates in multi-state models. Potential model structures included spatially and temporally invariant parameters, parameters that varied temporally (by month or season) and/or spatially (by pool), and parameters that varied with environmental conditions (e.g., mean temperature and standardized mean gage height). In addition, additive and interactive effects of covariates were considered. Due to the large number of potential model structures, a hierarchical model selection approach was used (Doherty et al. 2012). In this approach, detection and transition probabilities were held constant while the effects of month, season, mean temperature, and pool on survival probability were evaluated (Table 2). After determining, the best supported structure for survival probability, it was retained while evaluating the effects of month, season, standardized mean gage height, pool, the number of receivers per pool and the number of receivers per river mile in each pool on detection probabilities (Table 3). Lastly, the best supported structures for survival and detection probabilities were held constant while evaluating the effects of month, season, standardized mean gage height, and pool as well as a linear and quadratic effect of temperature on transition probabilities (Table 4). Models were compared using Akaike's information criterion corrected for small sample size (AIC_c; Burnham and Anderson 2002) to find the most parsimonious model. Akaike weights (W_i) were also calculated to examine uncertainty in model selection (Burnham and Anderson 2002).

Tributary vs. Mainstem Transition Analysis: To determine the probabilities of transitions between the mainstem Ohio River and its tributaries as well as the survival, and detection probabilities of Silver Carps, a Multi-state with Live Recaptures analysis was conducted in Program Mark (Cooch and White 2008) using the RMark package (Laake 2013) in R version 4.1.2 (R Core Team 2021). The tributaries chosen for this analysis were selected based on the presence of both VR2 receivers and USGS gage stations. Each tributary and the mainstem Ohio River were considered "states" in the model such that there were five states (i.e., Gunpowder Creek, Great Miami River, White Oak Creek, Ohio Brush Creek, and the Ohio River). To better understand movements among tributaries and the mainstem Ohio River, daily detections from January 1, 2021 to July 31, 2022 (577 days) for 46 Silver Carps whose tags were purportedly active throughout this time period were used. As with the pool-to-pool analysis, above, the probability of transitions among rivers were only estimated if they occurred in the data. Transitions among rivers that were not observed were fixed to 0.

To examine the effect that environmental conditions have on the survival, detection, and movement of Silver Carps between mainstem and tributary habitats in the Ohio River, daily water temperature, discharge, and gage height data were collected from U.S. Geological Survey gage stations from Markland and Meldahl pools (Figure 2) including three mainstem gages and gages in the Great Miami River, Gunpowder Creek, White Oak Creek, and Ohio Brush Creek (Table 5). Data were collected for January 1, 2021 – July 31, 2022. Although three variables were examined [i.e., temperature (°C), discharge (ft^3 sec^{-1}), and gage height (ft)], only three gage stations collected discharge data and collections were inconsistent temporally resulting in many gaps in these time series. Because discharge is also highly variable among gage stations, it was omitted from this analysis. Temperature data were not collected at any of the selected gage stations. To understand the potential effects of temperature on the survival and transition probabilities of Silver Carps, mainstem temperature data were estimated by calculating the mean daily temperature from mainstem gages that did record temperature (see above). In contrast, all selected gage stations collected gage height data (ft) during the study period allowing river-specific daily gage height data to be collected. Because gage heights are highly variable among tributary and mainstem habitats, these data were standardized by subtracting the mean and dividing by the standard deviation for each river which effectively results in all gage height data being on a similar scale. Additionally, only one gage station was present in each tributary, daily standardized gage height values were, therefore, converted to meters and then used directly in the models. For the mainstem Ohio River, the standardized daily mean gage height was calculated using the three mainstem gages in Markland and Meldahl pools. After calculating daily standardized gage heights, the time series for White Oak and Ohio Brush creeks were incomplete. In these cases, linear interpolation within each river was conducted as above for each instance where data were unavailable.

Time series of temperature and gage height as well as the encounter histories of individual Silver Carps were used to inform transition, survival, and detection estimates in multi-state models. Potential model structures included spatially and temporally invariant parameters, parameters that varied temporally (by month or season) and/or spatially (by pool), and parameters that varied with environmental conditions (e.g., mean mainstem temperature and standardized gage height). In addition, additive and interactive effects of covariates were considered. Due to the large number of potential model structures, a hierarchical model selection approach was used (Doherty et al. 2012). In this approach, detection and transition probabilities were held constant while the effects of month, season, mean mainstem temperature, and river on survival probability were evaluated (Table 6). After determining, the best supported structure for survival probability, it was retained while evaluating the effects of month, season, standardized gage height, river, and the number of receivers per river on detection probabilities (Table 7). Lastly, the best supported structures for survival and detection probabilities were held constant while evaluating the effects of month, season, standardized gage height, and river as well as a linear and quadratic effect of mean mainstem temperature on transition probabilities (Table 8). Models were compared using Akaike's information criterion corrected for small sample size (AIC_c; Burnham and Anderson 2002) to find the most parsimonious model. Akaike weights (W_i) were also calculated to examine uncertainty in model selection (Burnham and Anderson 2002).

Wabash River

Acoustic Receiver Array: Thirty-five VR2 receivers were deployed during 2022 throughout the Wabash River from the confluence with the Ohio River to 214 river miles upstream (near Terre Haute, Indiana) and within the White River, from its confluence with the Wabash River to 50 miles upstream (Figure 3). Receiver deployments followed the methods described above and receivers were retrieved and downloaded monthly. Extended periods of low water during 2022 prevented portions of the receiver array from being retrieved, especially during autumn.

Acoustic Transmitter Tagging: Tagging of invasive carps in the Wabash River occurred during May and October 2021 following the methods for the Ohio River, above. A total of 330 Silver Carps were tagged during 2021 at four locations in the Wabash River (river miles 52, 96, 129, and 172).

Fine-Scale Habitat Use: Fine-scale habitat use by tagged adult Silver Carps was assessed throughout the Wabash River. Monthly active tracking events occurred throughout 214 river miles from Terre Haute, IN to the confluence of the Ohio River to determine locations of tagged Silver Carps and the associated habitat conditions. Active tracking occurred primarily during daytime, but nighttime active tracking also occurred on select occasions to understand whether Silver Carps displayed diurnal patterns in fine-scale habitat use. During active tracking, the boat drifted downstream while towing an omnidirectional hydrophone. Once a transmitter was detected, the fish's position was identified by using a submersible directional hydrophone. Habitat characteristics including macrohabitat type (river channel border, inside river bend, outside river bend) and microhabitat type (log jam, rip-rap, river run, thalweg) were recorded at each fish's location. Additional microhabitat measurements, including substrate type, dissolved oxygen concentration, water velocity, water temperature, and water clarity were also measured at each fish's location for future analyses.

Invasive carp movement and distribution following dam removal

During November 2021, two dams were removed from the Eel River at river mile (RM) 1. The larger of these dams was 435-feet long and 9-feet tall. Although this dam served as a barrier to invasive carp migration in the Eel River, it was not large enough to prevent upstream movement of invasive carps into the Eel River. Removal of these dams, however, created a novel opportunity to better understand movement and ecological risk vs. ecological lift of invasive carp occupancy of the Eel River Basin including the Upper Wabash River as well as the Eel, Tippecanoe, Mississinewa, and Salamonie rivers.

Twenty-two sample sites were established throughout these areas to verify the presence or absence of invasive carps and to score each site using the Index of Biotic Integrity (IBI) and Qualitative Habitat Evaluation Index (QHEI). An Environmental DNA (eDNA) sample was collected at each of these 22 sites to validate presence or absence of invasive carps. Fish sampling also occurred at RM 35 using a trap net at an existing fish passageway around the Stockdale Mill Dam. Fish movement in the Mainstem Eel River was tracked using a network of six antenna arrays installed from RM 35 to RM 75 that can detect Passive Integrated Transponder (PIT) tags and eight VR2TW and VR2Tx receivers installed from RM 1 to RM 75 that can detect acoustic tags. Active tracking of fish implanted with acoustic tags was conducted throughout the entire length of the Eel River (RM 75 to RM 0).

Fish movement in the Upper Wabash, Tippecanoe, Mississinewa, and Salamonie rivers was tracked using a network of 12 VR2Tx receivers for detection of acoustic tags. Receivers in the Wabash River were installed upstream and downstream of the confluence of the four tributaries. The remaining four receivers were installed in the mainstem channel of each tributary upstream of the confluence with the Wabash River. Additional methodological details can be found in Appendix A.

Agency-Specific Accomplishments

Kentucky Department of Fish & Wildlife Resources (KDFWR)

During 2022, KDFWR maintained and offloaded receivers at sites located in the Cannelton (from the Salt River to McAlpine L&D), McAlpine, and Markland (from Markland L&D to Cincinnati) pools (n = 24). KDFWR also assisted other project partners with offloading and maintaining receivers at sites in the most downstream pools (Olmsted & Smithland) of the array (n = 8). KDFWR staff continued active tracking efforts in an area of the mainstem Ohio River located just upstream of Markland L&D. These efforts were conducted to determine if tagged invasive carps are moving from McAlpine Pool into Markland Pool without being detected by stationary receivers in the lock chambers, which would bias estimates of pool-to-pool transitions. KDFWR also continued to work on expanding the receiver array into the upper reaches of two Ohio River tributaries (Kentucky & Salt rivers), which included obtaining additional equipment, identifying sites for year-round receiver deployments, and conducting some initial tagging efforts in these areas. Lastly, KDFWR compiled all receiver data that was offloaded by project partners and continued to maintain updated records of tagged carps, receiver locations, and reports of harvested tags.

Indiana Department of Natural Resources (INDNR)

During 2022, INDNR deployed 13 additional VR2 receivers in tributaries of Cannelton Pool, and one receiver on the lake side of the Hovey Lake drain. INDNR conducted a tagging event on the upper Wabash River with the assistance of Ecosystems Connections Institute (ECI), tagging an additional 53 Silver Carps and one Grass Carp. Data from receivers in J.T. Myers, Newburgh, and Cannelton pools were downloaded regularly by INDNR and sent to KDFWR for processing. INDNR subcontracted with ECI to complete work in the upper Wabash River to evaluate movements of invasive carps in response to a dam removal.

Ohio Division of Wildlife (ODOW)

ODOW maintained and offloaded data from mainstem and tributary receivers in the Markland (from Cincinnati to Meldahl L&D), Meldahl, and Greenup pools as well as those located at the Meldahl and Greenup L&Ds during 2022. All data were made available to KDFWR for processing.

West Virginia Division of Natural Resources (WVDNR)

WVDNR maintained and offloaded data from mainstem and tributary receivers in the R.C. Byrd, Racine, and Belleville pools as well as those located at the Willow Island, Belleville, Racine, and R.C. Byrd locks and dams during 2022. Additionally, the WVDNR AIS acquired additional VR2s located in the R.C. Byrd pool from a completed project, vastly improving the coverage within this pool. All data were sent to KDFWR for processing and reporting.

US Fish and Wildlife (USFWS)

During 2022, USFWS, Carterville FWCO, tagged a total of 137 Silver Carps in Cannelton (n = 108) and Markland (n = 29) pools following the methods above. The Carterville FWCO also used the data collected by state agencies and processed by KDFWR to parameterize multistate models to better understand pool-to-pool and mainstem-tributary transition probabilities for Silver Carps. These data were also used to understand tributary use of Silver and Bighead Carps (see methods above for details). Additionally, the USFWS Ohio River

Substation (Lower Great Lakes FWCO) took over the maintenance of the VR2 array on the Ohio River L&Ds during late fall 2022.

Illinois Department of Natural Resources, Southern Illinois University (ILDNR, SIU)

Southern Illinois University deployed thirty-five VR2 acoustic telemetry receivers throughout the Wabash River from the confluence with the Ohio River to 214 river miles upstream (near Terre Haute, Indiana) and within the White River, from its confluence with the Wabash River to 50 miles upstream. Receivers were retrieved and detections downloaded monthly when river conditions allowed. Tagging of invasive carps in the Wabash River occurred during May and October 2021.

Illinois Department of Natural Resources, Eastern Illinois University (ILDNR, EIU)

Eastern Illinois University conducted active tracking of acoustically tagged Silver Carps throughout the Wabash River during 2022 to identify patterns in fine-scale habitat use. Active tracking occurred monthly during daytime, with some additional nighttime active tracking taking place on select occasions to understand diurnal trends in fine-scale habitat use. Habitat characteristics were recorded at each fish's location, including macrohabitat type (river channel border, inside river bend, outside river bend) and microhabitat type (log jam, rip-rap, river run, thalweg). Additional microhabitat measurements, including substrate type, dissolved oxygen concentration, water velocity, water temperature, and water clarity were also measured at each fish's location for future analyses.

Results and Discussion:

Ohio River

Acoustic Receiver Array: During 2022, 162 receivers were deployed from Olmsted Pool to Willow Island L&D. Of these, 45 were deployed at L&Ds, 36 at mainstem sites, and 81 at tributary sites (Figure 1, Table 9).

Fish Tagging Efforts: As of July 2022, 1501 invasive carps (1455 Silver and 46 Bighead) from J.T. Myers, Newburgh, Cannelton, McAlpine, Markland, Meldahl, and R. C. Byrd pools have been surgically implanted with acoustic transmitters (Table 10). Of the 1501 tagged carps, 23 Silver Carps have been harvested during the study (June 2013 – July 2022). During 2022, 107 invasive carps (105 Silver and 2 Bighead) had tags that were expected to expire (Table 10). To replace these tags and meet the needs of partner agencies, 137 Silver Carps were tagged in Cannelton (n = 108) and Markland (n = 29) pools. No Bighead Carps were tagged during January – July 2022 due to a lack of availability.

Fish Detections: There were 1145 active tags deployed in invasive carps (1137 Silver and 8 Bighead) in the Ohio River during January – July 2022, 612 (53%) of which were detected (605 Silver and 7 Bighead). Active tags included those expected to be active during 2022 (n = 1104) as well as those expected to expire prior to 2022 that were detected during 2022 (n = 45). Included in these 612 detected fish were 279 Silver Carps tagged in J.T. Myers, Newburgh, and Cannelton pools during 2022 indicating that the expansion of the receiver array and additional transmitter deployments in these high-density areas is yielding a substantial amount of additional information about invasive carp movements and habitat use that will benefit managers by improving our knowledge of where and when these fish congregate and their propensity for moving among pools.

Fish Movement: Throughout the study area, the net movement (i.e., the difference between the most upstream and most downstream detections for an individual) ranged from 0.0 km to 418.8 km for Silver Carps and from 0.0 km to 333.0 km for Bighead Carps during January – July 2022. The longest net movement by a Silver Carp was completed by a female fish travelling from McAlpine Pool to J.T. Myers Pool during January – March. In contrast, the longest net movement by a Bighead Carp during January – July 2022 was completed by a male fish that moved from McAlpine Pool to Meldahl Pool during March – May. Long-distance movements are relatively rare for Silver Carp; ~82% of Silver Carp had a maximum distance travelled of < 30 km during 2022. In contrast, only ~29% of Bighead Carp had a maximum distance travelled of < 30 km. Additionally, although detections of invasive carps above Greenup L&D were rare (~0.5% of total detections), the most upstream detection of a Silver Carp during 2022 occurred at river mile 276.0 in R.C. Byrd Pool. For Bighead Carps, the most upstream detection occurred at river mile 343.6 in Meldahl Pool.

Because there were relatively few detections of invasive carps in the pools upstream of Greenup L&D and below J.T. Myers L&D, further analysis of fish movement during January – July 2022 focused only on J.T. Myers, Newburgh, Cannelton, McAlpine, Markland, and Meldahl pools. In these pools, net movements are typically shortest during January – March and peak during late spring and summer (May – July) regardless of species or pool (Figures 4 and 5). For Silver Carp, mean net movements in Markland and Meldahl pools are typically longer than those in lower pools.

Dam Passage: Throughout the duration of this study (June 2013 – July 2022), there have been 237 dam passage events (78 upstream and 159 downstream passages) (Figure 6). Dam passages were completed by 136 Silver Carps and eight Bighead Carps. Of the upstream passages, six (7.7%) were completed by three Bighead Carps, with one fish accounting for three of those passages as it moved from Meldahl Pool to Racine Pool during May 2014 – August 2015. Seventy-two upstream passages (92.3%) were completed by 72 Silver Carps. Nine downstream passages (5.7%) were completed by seven Bighead Carps, whereas 150 (94.3%) were completed by 117 Silver Carps. Additionally, in only 29 of the 237 dam passages (12.2%) was the fish detected within the lock chamber, suggesting a high prevalence of passages through the dam gates. Passages where fish were detected within the lock chamber occurred at Meldahl, Markland, Cannelton, Newburgh, and J.T. Myers L&Ds during 2016 (n = 1; Silver Carp), 2017 (n = 1; Bighead Carp), 2019 (n = 1; Silver Carp), 2021 (n = 13; Silver Carp), and 2022 (n = 13; Silver Carp). All confirmed lock chamber passages were in the downstream direction.

The current arrangement of VR2 receivers around most L&D structures in the study area and their year-round deployment suggests a high probability of detecting invasive carps transitioning among pools through lock chambers. However, if fish pass through the dam gates they likely will not be detected.

Tributary Use: During January – July 2022, 99.0% of Silver Carp detections occurred in tributaries of the Ohio River, whereas 34.2% of detections of Bighead Carp detections occurred in these areas. Throughout the duration of this study (June 2013 – July 2022), 84.7% of Silver Carp detections and 69.5% of Bighead Carp detections occurred in tributaries.

During June 2013 – July 2022, mainstem and tributary habitat use appeared to differ by species. For Silver Carps, the proportion of detections in tributaries far exceeded those in mainstem habitats, regardless of month. In contrast, a higher proportion of Bighead Carps detections occurred in mainstem habitat during August and September, but the proportion of tributary detections exceeded those in the mainstem Ohio River during all other months. The proportion of detections that occurred in mainstem habitat peaked during September – November for Silver Carps and during August – October for Bighead Carps (Figure 7). This is consistent with a greater proportion of transitions between tributary and mainstem habitat occurring during summer and autumn for both species. The proportion of transitions from mainstem to tributary habitats and vice versa are similar within months (Figure 8). Interestingly, the data also suggest that when Silver Carps enter tributaries, they reside there for a mean of 26.9 days (SE = 0.9 days) before returning to mainstem habitat. In contrast, Silver Carps reside in the mainstem Ohio River for a mean of 15.4 days (SE = 0.8 days) before returning to tributary habitat. Bighead Carps spend a similar amount of time between transitions in tributary (mean ± SE = 22.1 ± 4.1 days) and mainstem (19.0 ± 3.7 days) habitats (Figure 9). These data suggest that tributaries provide important habitat for invasive carps, especially Silver Carps.

Pool-to-Pool Transition Results: For Silver Carps, AIC_c indicated that for each model parameter (*S*, *p*, and ψ) only one model structure was supported (Tables 2-4). Based on this hierarchical model selection process (ΔAIC_c and W_i), the final model included a survival probability (*S*) that varied with temperature, a detection probability (*p*) that varied with the additive effects of pool and the number of receivers per river mile (rprm), and transition probabilities (ψ) that varied with the additive effects of pool and month. The AIC weights of 1 for each part of the hierarchical model selection process indicate little to no uncertainty in model selection.

The mean probability of survival (*S*) of Silver Carps varied with temperature such that survival was highest at low temperatures and lowest at high temperatures (Figure 10). Estimated mean survival probability was, however, high (0.96 – 0.99) for temperatures ranging from 1 - 29°C. Based on these mean survival probability estimates and assuming constant temperature, annual survival of Silver Carps likely ranges from 0.61 (95% Confidence Interval (CI) = 0.25 – 0.84) to 0.94 (95% Confidence Interval (CI) = 0.91 – 0.96).

Estimated mean detection probabilities (*p*) for Silver Carp were affected by the additive effect of pool and the number of receivers per river mile and ranged from 0.00 to 1.00. The probability of detection increases following a sigmoidal curve such that there is a rapid increase in detection probability from 0 to ~0.2 receivers per river mile after which the rate of increase in detection probability slows (Figure 11). Interestingly, detection probabilities in Greenup Pool remain low, despite this pool having a higher density of receivers than some more downstream pools and likely reflects the relative lack of tagged fish in this pool.

Model estimates of mean transition probabilities (ψ) varied with the additive effect of pool and month and indicate that Silver Carps are most likely to move from one pool to another in April and October and are least likely to move among pools in August (Table 11, Figure 12). Furthermore, transition probabilities among pools were typically low (< 0.2) with some exceptions (e.g., Greenup to Meldahl and J.T. Myers to Smithland during April and October) indicating that the probability of Silver Carps remaining within a pool was typically high (>0.8). Lastly, transition probabilities from upstream to downstream pools tend to higher than those from downstream to upstream pools.

Tributary vs. Mainstem Transition Results: AIC_c indicated that three model structures for survival probability (*S*) were equally supported by the data (Table 6). Based on this hierarchical model selection process (ΔAIC_c and W_i), it is equally likely that *S* varies with temperature, the additive effect of temperature and river, or is invariant. Because these various model structures were equally supported, each one was then examined with various model structures for the detection probability (*p*) to determine the best supported model. Model selection (ΔAIC_c and W_i) indicated a single model structure that include *S* varying with temperature and *p* varying with the additive effect of river and the number of receivers was best supported by the data (Table 7). This model structure for S and p was then used to examine the best supported structure for ψ which was determined to include the additive effect of river and month (Table 8).

The mean daily probability of survival (*S*) of Silver Carps varied with temperature such that survival was highest at low temperatures and lowest at high temperatures (Figure 13). Estimated daily mean survival probability was, however, high (> 0.997) for temperatures ranging from 1 - 29°C. It is important to note that the estimates of daily survival probabilities were highly uncertain with confidence intervals ranging from 0 to 1 regardless of temperature. Thus, these values should be interpreted cautiously.

Estimated mean detection probabilities (*p*) for Silver Carps were affected by the additive effect of river and the number of receivers and ranged from 0.00 to 1.00. Even when few receivers were present, detection probabilities were generally high (≥ 0.45) with the exception of White Oak Creek, which had a very low detection probability (Table 12). This low detection probability is likely a function of both the number of receivers and the number of tagged fish entering that tributary.

Model estimates of mean transition probabilities (ψ) varied with the additive effect of river and month and indicate that Silver Carps are most likely to move among the mainstem Ohio River and its tributaries during July and are least likely to move among the mainstem Ohio River and its tributaries during November (Table 13, Figure 14). Furthermore, transition probabilities from the Ohio River to tributaries and vice-versa were typically low (< 0.2) regardless of month. The probability of Silver Carps remaining within tributaries is typically high (>0.8) throughout the year. The probability of a fish remaining in the mainstem Ohio River, by contrast, varies substantially from a low of ~ 0.65 in July to a high of ~0.95 in November (Table 13). Model estimates of parameters in this model should be interpreted cautiously as they are informed by few fish and using a receiver array that was not designed to examine movement between the mainstem Ohio River and its tributaries.

Wabash River

Fish Movement: Detections from the 330 Silver Carps tagged in the Wabash and White rivers during 2021 had a mean (standard deviation; SD) length of 661 (57) mm (Figure 15). During 2022, Silver Carps tagged in the Wabash River were detected an average (SD) of 2,039 (519) times per fish. Most fish throughout 2022 displayed relatively low annual net movements (difference between most upstream and downstream receiver detection), with 41% of detected fish moving ≤ 10 km (Figure 16). Of the remaining detected individuals, nearly equal numbers of fish displayed intermediate (27% moving 10-19 km) or large (32% moving ≥ 20 km) annual net movements. Silver Carps displayed seasonal patterns in movement and spatial distributions. Relatively few individuals were detected during winter (January - February) and summer (June –

August), with both fish detected on two receivers located near the confluence of the White and Wabash rivers (Figure 17). In contrast, many tagged individuals were detected during spring of 2022 (March – May) distributed from river mile 86 (near Mount Carmel, IL) to river mile 214 (near Terre Haute, IN) in the Wabash River. Low water levels from October – December prevented a sufficient number of telemetry receivers to be retrieved for analyses of 2022 fall movements.

Fine-Scale Habitat Use: Habitat use by Silver Carps detected in the Wabash and White Rivers varied between 2021 and 2022. Inside and outside bends were the most used macro-habitats in 2021 with only 23% of detections occurring in association with open channel borders (Figure 18). Additionally, detected fish were strongly associated with log jam habitats (67% use). During 2022, Silver Carps used inside bends in a much smaller proportion and both open channel border and outside bend areas had an increase in use. All types of available microhabitats were used in similar proportions in 2022. Seasonality influenced where detected Silver Carps were found across the period of active tracking (June 2021 to October 2022). In the spring, nearly all detected fish inhabited outside bends (88%) using log jam habitats (69%) (Figure 19). This can likely be attributed to high spring flows which forced fish into velocity refuges provided by log jams. During summer and fall, fish were more spread out across both macro and micro habitats. A majority of fish detections in the winter occurred at inside bend habitats (52%) near log jams (63%) (Figure 19). So far, there are no apparent diurnal trends in macro-habitat use of Silver Carp in the Wabash and White Rivers (Figure 20). However, individuals appear to move from log jam habitats (41% use during the day) into more open water areas at night (35% run and 27% thalweg). The number of detections per mile of active tracking increased from Spring to Fall in 2022. High flows in the spring and early summer of 2022 likely reduced the ability of the hydrophones to detect tags. As water levels decreased throughout the summer, detection efficiency increased, leading to a much higher detection rate specifically in September and October (Figure 21).

Invasive carp movement and distribution following dam removal

Results from the Eel River Basin showed IBI scores that ranged from “Fair” to “Exceptional” in Eel River tributaries and “Fair” to “Very Good” in the mainstem Eel River. QHEI scores at the Eel River tributary sites were geographically clustered with the lowest scores occurring at headwater sample sites. The mainstem Eel River had more consistent QHEI scores than tributary sites. Thirteen native species were identified during 2022 that had not previously been captured in past sampling efforts in the Eel River Basin. The presence of these species is an exciting development for the ecology of the Eel River and is a direct result of the removal of the dams at Logansport. There have been 61 fish species identified in the Eel River Basin upstream of the two dams removed. There are 48 new and potential fish species listed in the Eel and the Wabash River near the confluence of the Eel River not on the current fish species list.

Three adult Grass Carps were identified near RM 1 of the Eel River. Environmental DNA (eDNA) sampling detected Grass Carp DNA in 100% of replicates at Logansport (RM 1) and 33% of replicates at Adamsboro (RM 7.5). Silver Carp DNA was detected in 33% of replicates at Mexico (RM 18.5) and 33% of replicates at Columbia City (RM 75). Caution should be taken when reviewing eDNA results with low detection rates (e.g 33%) because false positives are common at this detection rate. No invasive carps were detected in the Eel River through the PIT tag antennas, passive acoustic receivers, or active acoustic tracking.

A total of 24 Silver Carps were located and identified through the acoustic receivers installed in the Wabash, Tippecanoe, and Mississinewa rivers. Twenty of the detected fish were tagged by ECI and DNR biologists on 2 August and 3 August 2022 in the Wabash River near Omer Cole Boat Ramp in Miami County (RM 380). Two fish were tagged in July 2011 in the Wabash River near Lafayette (RM 315) and two were tagged in the Cumberland River near Cheatham Dam (36.3202, -87.2235). The fish from the Cumberland River traveled 533 stream miles from their tagging location to the point they were detected in the Wabash River near the Tippecanoe River confluence.

Silver Carps mostly stayed within the Wabash River. One fish was detected in the Mississinewa River and two fish were detected in the Tippecanoe River. No Silver Carps were detected in the Eel or Salamonie rivers. Movement of Silver Carps tended to occur in small groups. For example, ten fish were detected in the Wabash River near the Mississinewa River (RM 376) near their release location. Nine fish tagged near Omer Cole Boat Ramp (RM 380) were detected in the Wabash River just upstream of the confluence with the Eel River (RM 358), five of which stayed in that section of the Wabash River. It was found that longer distance migrations of Silver Carps coincided with peaks in discharge in the Wabash River. For additional information, see Appendix A.

Year one of this study has documented trends in invasive carp colonization of the Eel River Basin and invasive carp movement in the Upper Wabash River Basin. Electrofishing, and eDNA have indicated invasive carps may have started to migrate into the Eel River. It is unknown how far upstream invasive carps have migrated since many of the positive results from eDNA sampling were inconclusive. The network of acoustic receivers in the Upper Wabash River Basin has provided the capability to identify and track carp movement. Data from receivers has shown Silver Carps will travel long distances and it appears they migrate during periods of high flow. However, the telemetry data collected during this project period only encompasses a six-month period. To allow for temporal and spatial variability of invasive carp biology and environmental conditions, it is very important to continue this study for multiple years.

Recommendations:

Expansion of the receiver array in Cannelton pool during 2022 will improve our understanding of fish movements and transition probabilities among the lower to middle Ohio River pools where invasive carp densities begin to decrease. Despite these improvements, there are still gaps in the receiver array that, if filled, could further improve our understanding of invasive carp movement and habitat use. For instance, receiver coverage in Smithland and Olmsted pools is poor with only two mainstem receivers near in the upper portion of Olmsted Pool and eight receivers at the locks and dams at the lower and upper ends of Smithland pool. Increasing receiver coverage in these pools would not only improve our understanding of movement and habitat use of invasive carps in the Ohio River, but would also inform movement between the Ohio River and three other large rivers with established invasive carp populations, the Wabash River (Smithland Pool) and the Tennessee and Cumberland Rivers (Olmsted Pool). Furthermore, deploying recievers at the downstream end of Olmsted Pool and in the open river between Olmsted Lock and Dam and the confluence of the Mississippi River would improve our understanding of movements between the Mississippi and Ohio rivers. Because all of these areas host large populations of invasive carps, understanding the movements of fish among these systems is critical to understanding source-sink dynamics and to effective management of these fishes. Specifically, understanding the movement of invasive carps between the Tennessee-Cumberland system and the Ohio River may elucidate movement patterns of invasive carps as they relate to deterrent technologies at Barkley Lock (e.g., do fish move away from the barrier at Barkley Lock and instead move upstream within the mainstem Ohio River?).

Although, current receiver deployments provide consistent year-round coverage of the lock chambers of all L&Ds between Smithland and Willow Island L&Ds, coverage near the gates of dams is lacking. Improving receiver coverage near dam gates could enhance our knowledge of pool-to-pool transitions (including the timing of these transitions as it relates to open-water conditions) as well as improve our ability to determine if L&D passages are primarily occurring through the lock chambers or through the dam gates. However, site selection near dam gates requires careful consideration because deploying stationary receivers in these areas is logistically challenging and raises concerns for the safety of agency personnel that would be tasked with downloading and maintaining the receivers.

In addition to adding receivers in specific areas to improve coverage, understanding the true coverage provided by those receivers currently deployed is critical to our understanding of fish movements and habitat use. The current combination of VR2W receivers and V16 transmitters used for invasive carp telemetry in the Ohio River ostensibly provides a detection range of 800 – 1200 m. Ambient conditions (e.g., turbidity, flow, receiver orientation) can, however, drastically affect detection ranges. It is, therefore, recommended that receivers be range-tested during a variety of conditions to determine reasonable expectations for the detection range of receivers in the Ohio River system.

Recently, there has also been an increased interest in trying to understand movements among the mainstem Ohio River and its tributaries and how environmental conditions and commercial harvest may affect the movements and habitat use of Silver Carps. Although a preliminary analysis using a multistate model was conducted here, the receiver array, in its current configuration, is not designed to examine questions related to movement between tributaries and the mainstem Ohio River. To determine the effect of environmental conditions and fishing effort on movements and tributary use of Silver Carps, a receiver array must be specifically designed and deployed (with additional tagged Silver Carps) for this study. For instance, this array must:

1) Be deployed in an area with ongoing commercial harvest (e.g., Cannelton Pool),
2) Cover several tributaries (preferably associated with USGS gage stations) in a relatively small area to potentially capture the movement of Silver Carps among these areas,
3) Include enough receivers in each tributary to determine the directionality of fish movements and if fish disperse upstream in response to fishing efforts or environmental cues, and
4) Include receivers in the mainstem Ohio River to capture movements into and out of tributaries.

With a well-planned and executed study design, a multistate model could be used to understand environmental or anthropogenic drivers of fish movements between habitats (e.g., tributary and mainstem) as well as the timing of these movements. This information could be used to improve the efficiency of targeted removals of invasive carps by improving our ability to predict the timing and location of invasive carp aggregations.

Lastly, data management will continue to be vital as the telemetry program adds to the existing data set. Increases in the number of invasive carp detections are anticipated, especially within the lower pools of the Ohio River where the array and tagging efforts were expanded during 2021. Due to the expected increase in detections, front-end data management and data processing capability will become increasingly important to ensure that data are available for analysis in a timely manner. Furthermore, to accommodate the likely increase in time necessary to process and analyze these larger quantities of data, it is recommended that, as in 2022, each agency perform a download of all receivers in their areas of management and transfer the downloaded data to KDFWR by July 31 of each year. This will allow ample time for data processing, analysis, and reporting, and increase time for discussion of the results and potential improvements to analyses prior to reporting in March of the following year.

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Figures and Tables

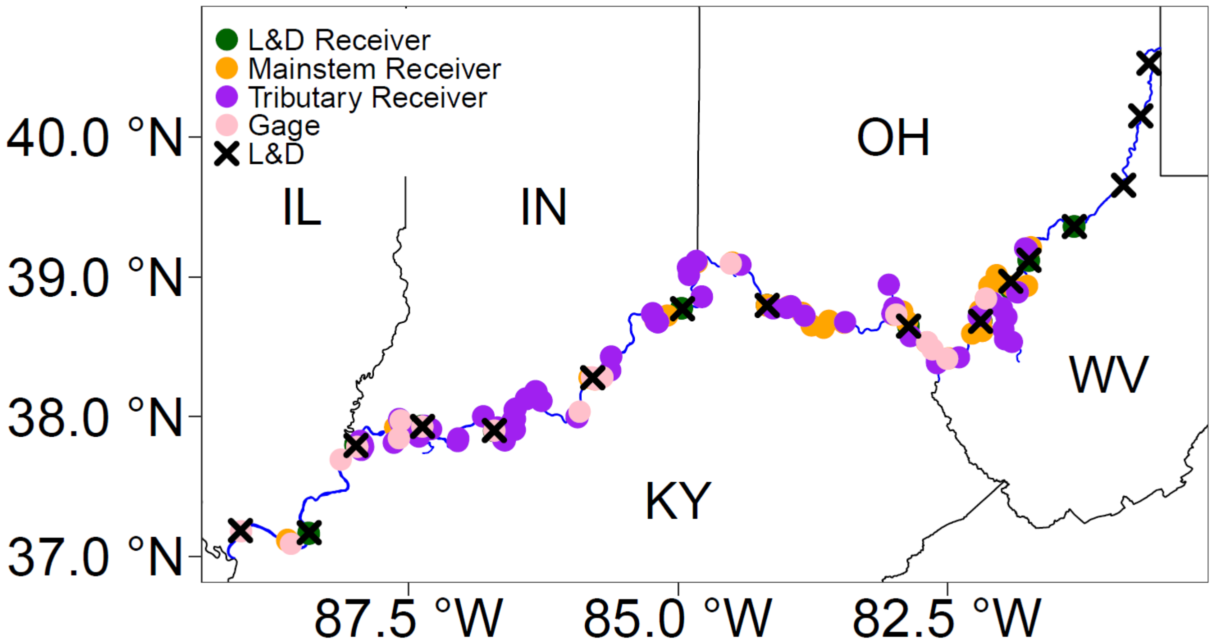

Figure 1. Locations of Lock and Dam structures (L&D; black crosses), USGS gage stations (pink circles), and acoustic receivers deployed at L&D structures (green circles), in the mainstem (orange circles), and tributaries (purple circles) of the Ohio River during 2022. Map shows the Ohio River (blue) from its confluence with the Mississippi River in the west to the Pennsylvania border in the east. Receivers were deployed from Olmsted Pool, downstream of the Smithland L&D, to the Willow Island L&D. From west to east, the L&Ds are Olmsted, Smithland, J.T. Myers, Newburgh, Cannelton, McAlpine, Markland, Meldahl, Greenup, R.C. Byrd, Racine, Belleville, Willow Island, Hannibal, Pike Island, and New Cumberland. Ohio River pools are named for the downstream L&D (e.g., Olmsted Pool begins at Olmsted L&D and ends at Smithland L&D).

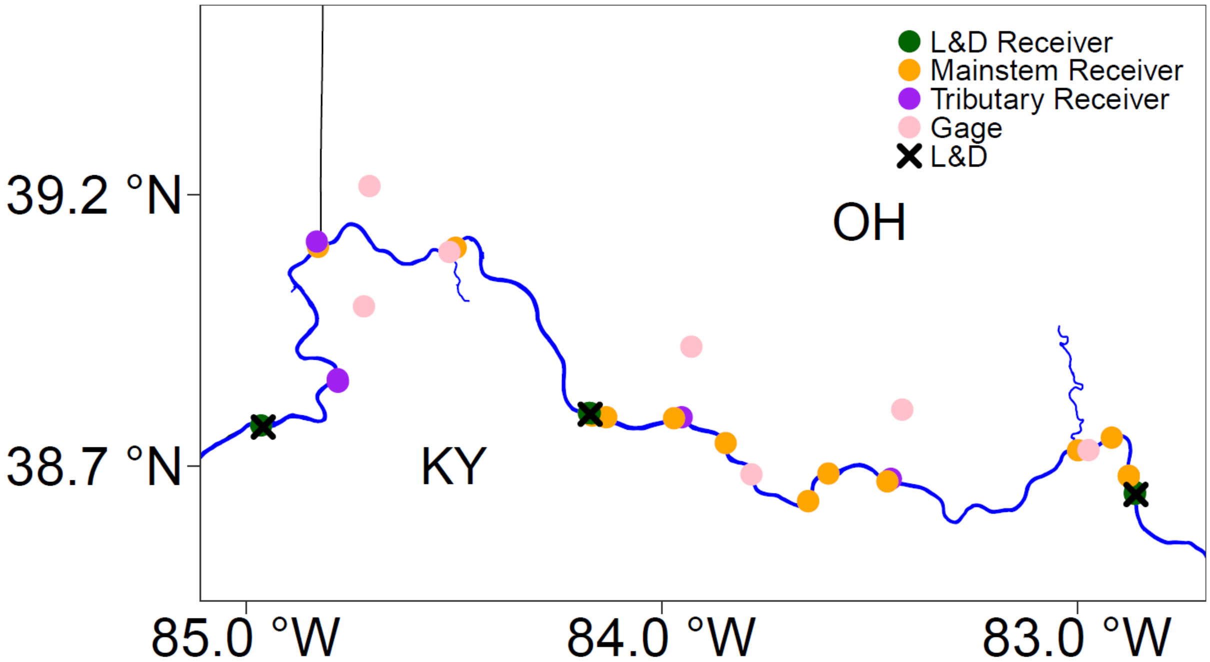

Figure 2. Locations of Lock and Dam structures (L&D; black crosses), USGS gage stations (pink circles), and acoustic receivers deployed at L&D structures (green circles), in the mainstem (orange circles), and tributaries (purple circles) of Markland and Meldahl pools during 2021 and 2022. Map shows the Ohio River (blue) from below Markland L&D in the west to the area above Greenup L&D in the east.

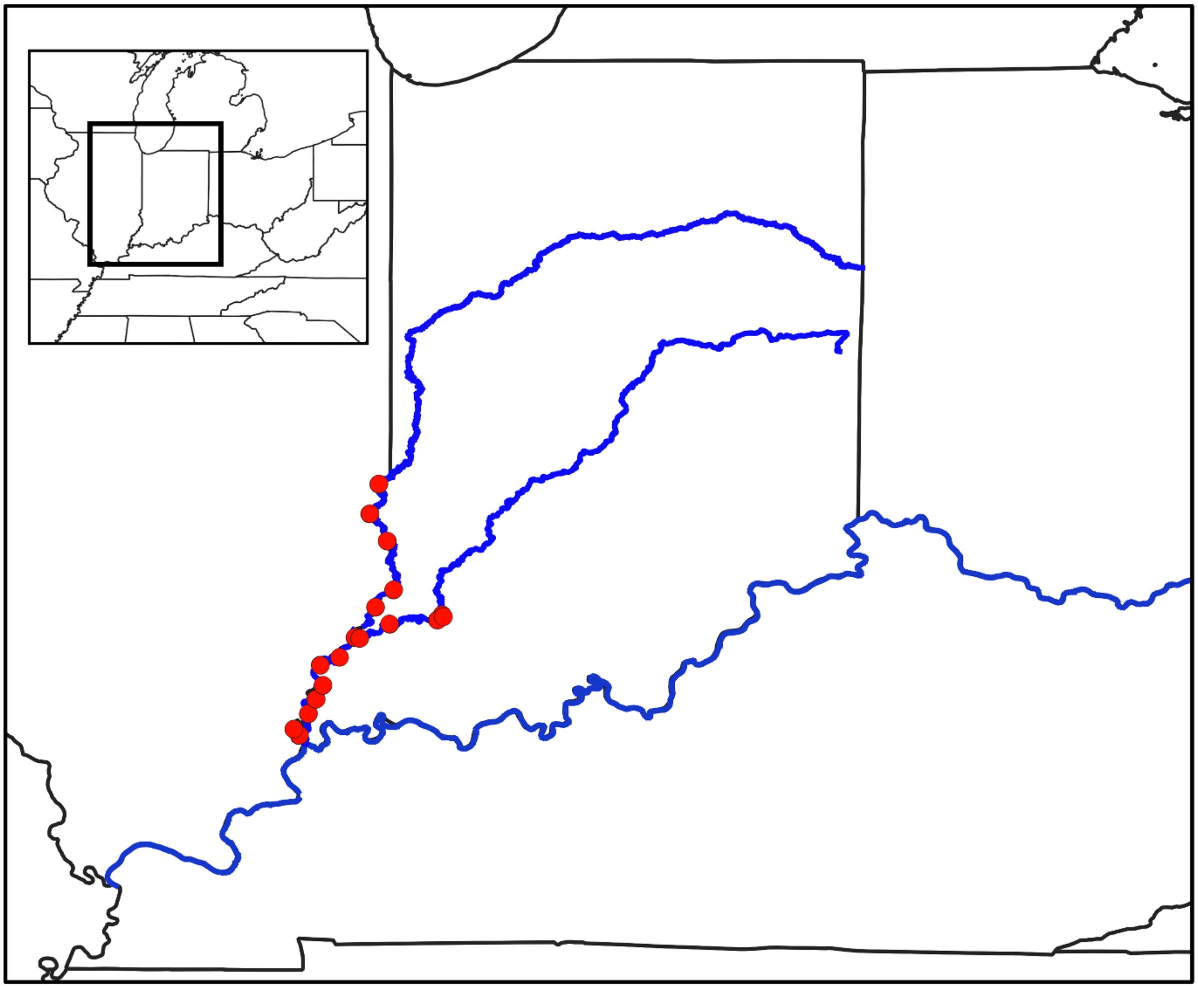

Figure 3. Location of 35 stationary acoustic telemetry receivers located throughout the Wabash and White rivers.

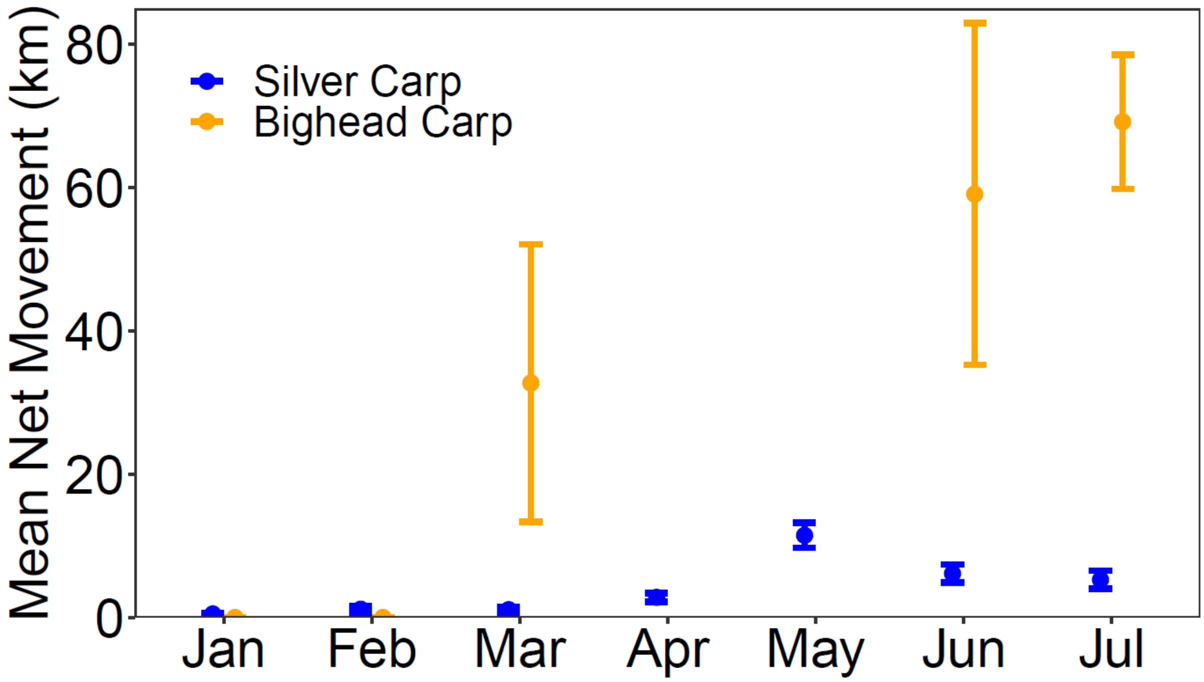

Figure 4. The mean monthly net movements (river kilometers) between the most upstream and downstream detections for tagged Silver Carp (blue) and Bighead Carp (orange) in J.T. Myers, Newburgh, Cannelton, McAlpine, Markland, and Meldahl pools during January – July 2022. Error bars represent standard error. Only tagged carp detected ≥ 2 times during a month were included in the distance calculations.

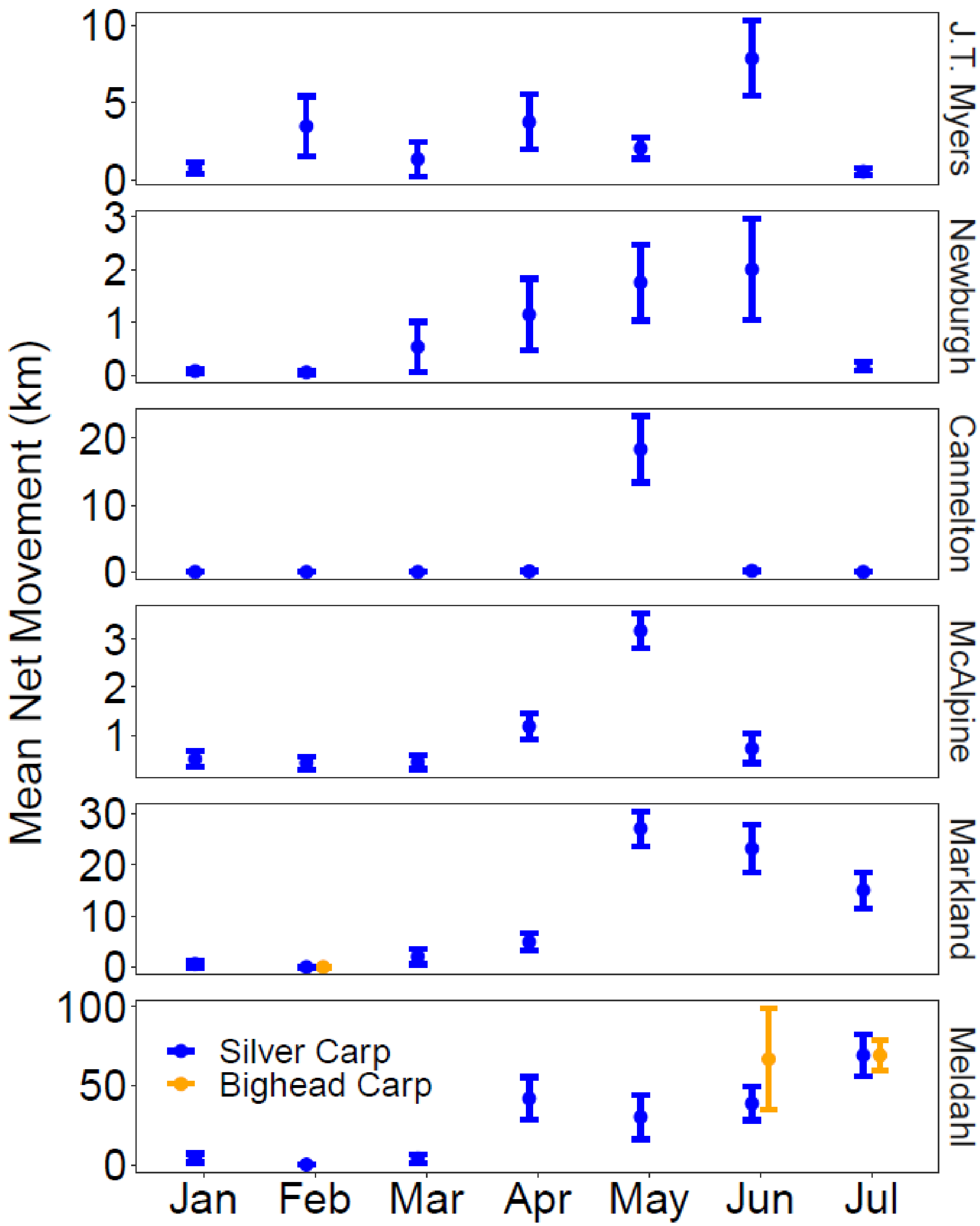

Figure 5. The mean monthly net movements (river kilometers) between the most upstream and downstream detections for tagged Silver Carp (blue) and Bighead Carp (orange) by pool in the six most active pools of the telemetry project (J.T. Myers, Newburgh, Cannelton, McAlpine, Markland, and Meldahl pools) during January – July 2022. Error bars represent standard error. Only tagged carp detected ≥ 2 times within a single pool each month were included in the distance calculations.

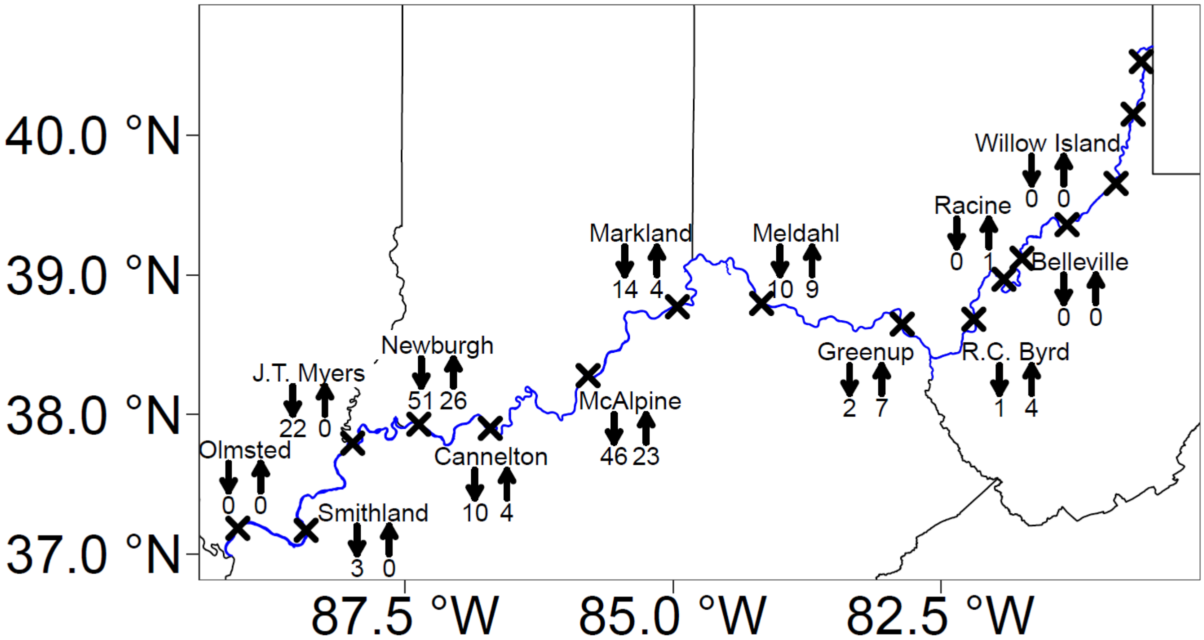

Figure 6. Total number of downstream (↓) and upstream (↑) lock and dam (L&D) passages by invasive carps during June 2013 – July 2022. Map shows passages from Olmsted L&D (river mile 964.4) near the confluence of the Ohio and Mississippi rivers to Willow Island L&D (river mile 161.7) which is the most upstream location at which acoustic receivers were deployed.

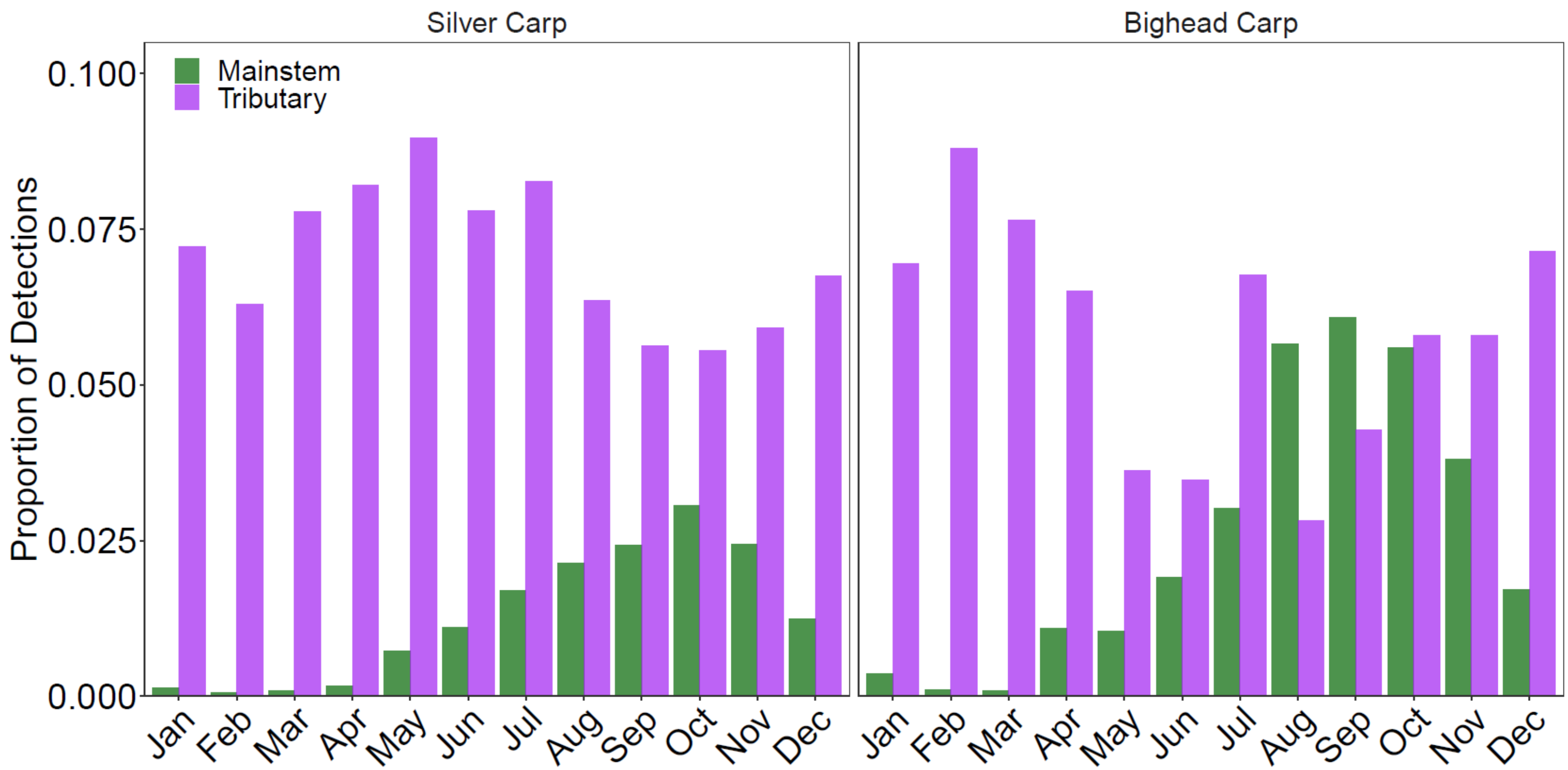

Figure 7. The proportion of detections by month for Silver (left) and Bighead (right) carps in mainstem (green) and tributary (purple) habitats of the Ohio River during June 2013 – July 2022.

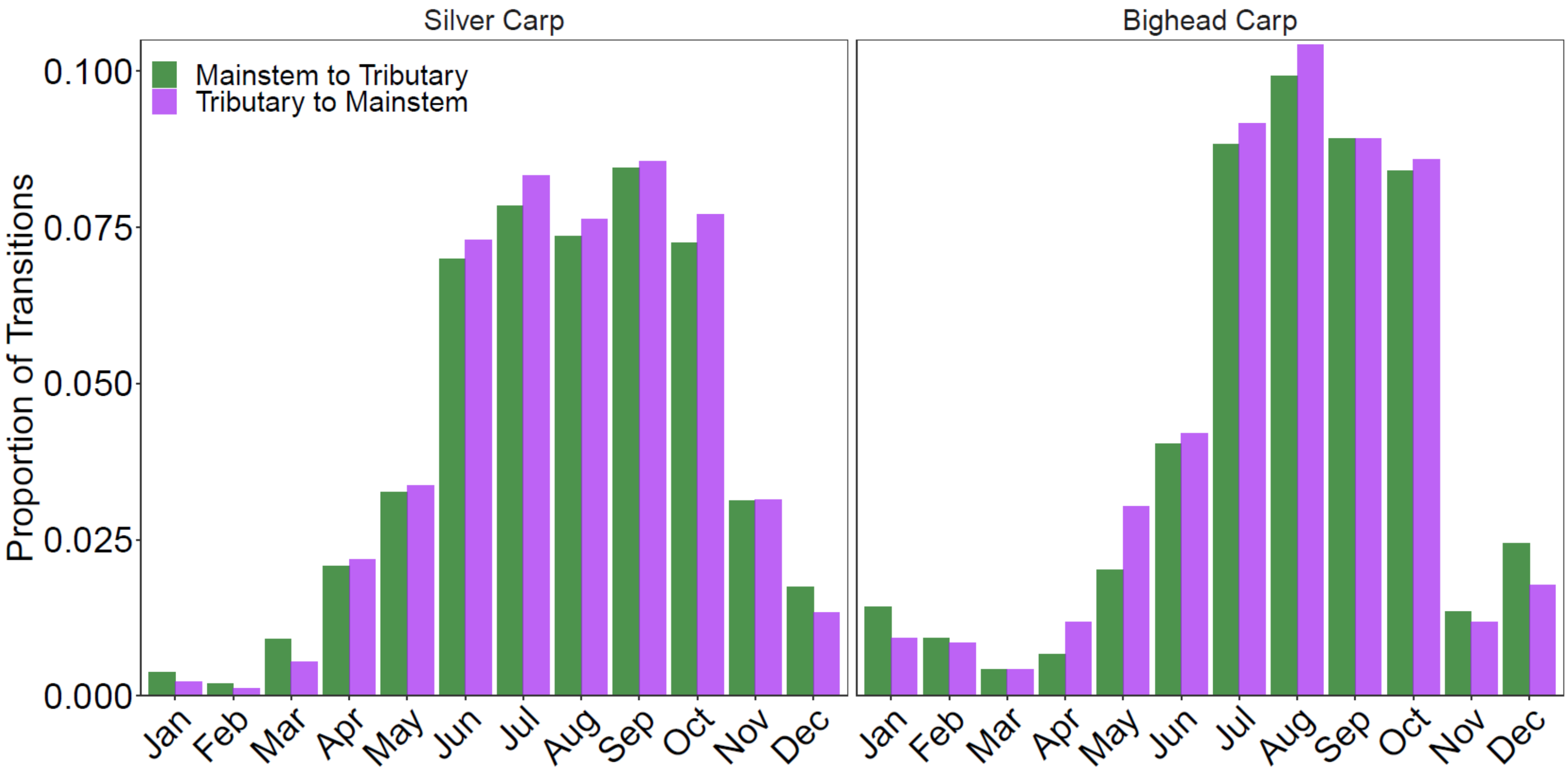

Figure 8. The proportion of transitions from mainstem to tributary (green) or from tributary to mainstem (purple) habitats by month for Silver (left) and Bighead (right) carps in the Ohio River during June 2013 – July 2022.

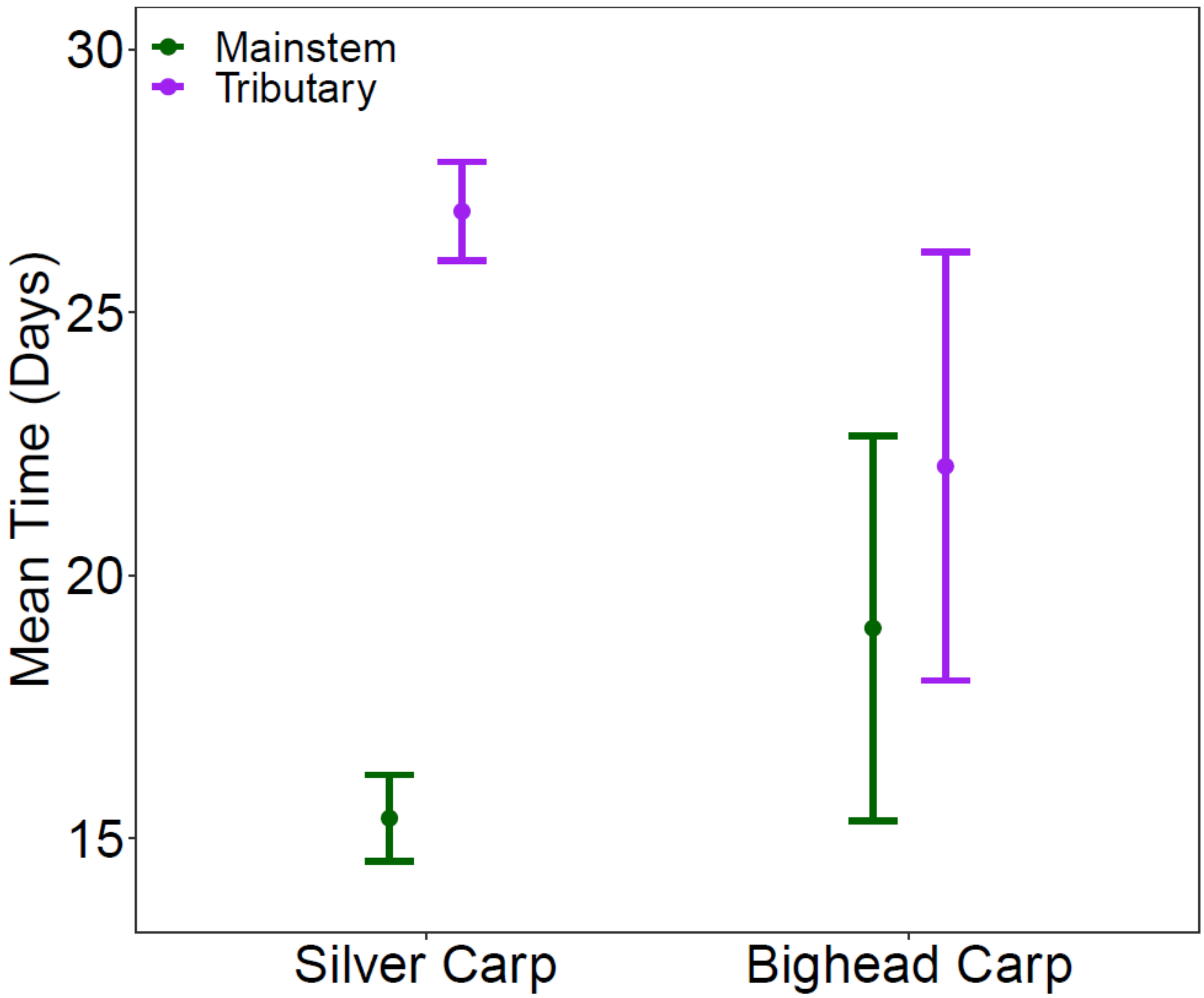

Figure 9. The mean time (days) spent in mainstem (green) or tributary (purple) habitat for Silver and Bighead Carps during June 2013 – July 2022. The number of days represents the time from the first detection of an individual in either the mainstem of the Ohio River or one of its tributaries to the first detection outside of that habitat.

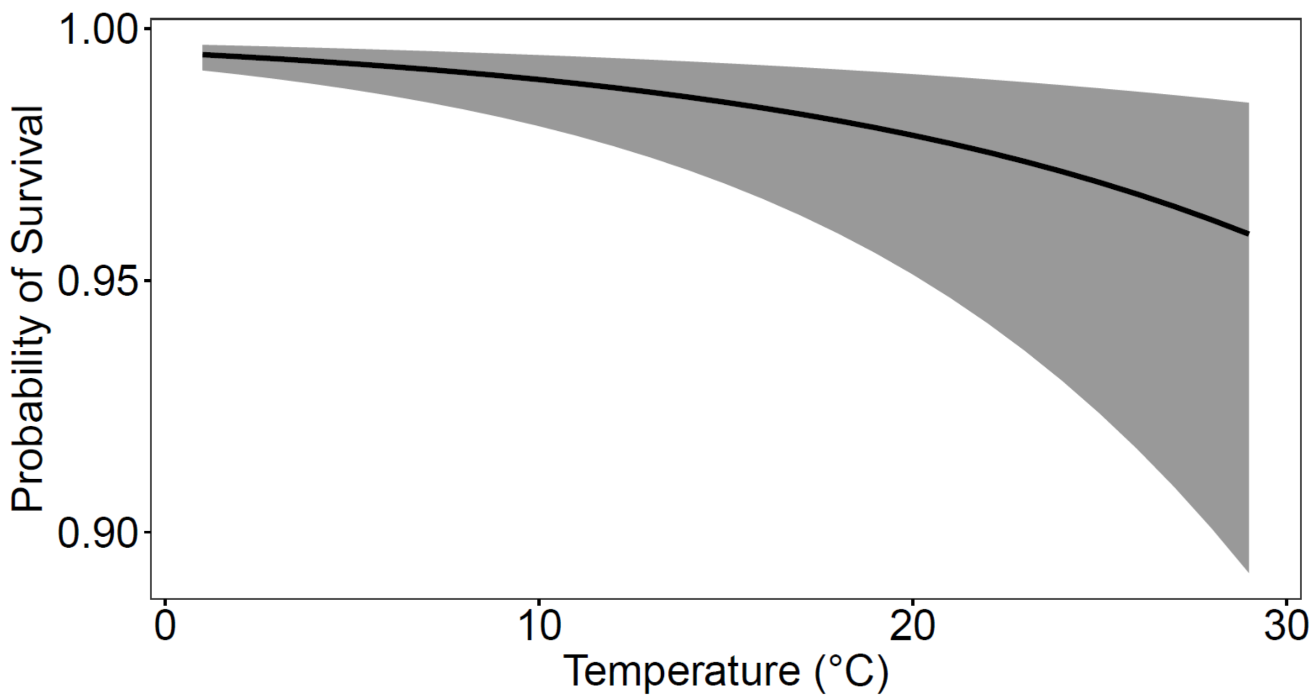

Figure 10. The effect of temperature (℃) on the monthly probability of survival (S) of Silver Carps. The range of temperatures for which S was estimated (1 – 29℃) was reflective of temperatures typically encountered by these fish in the Ohio River and its tributaries during January 2014 – July 2022. The solid line represents the mean probability of survival, whereas the gray-shaded area represents the 95% confidence interval surrounding the mean survival probability.

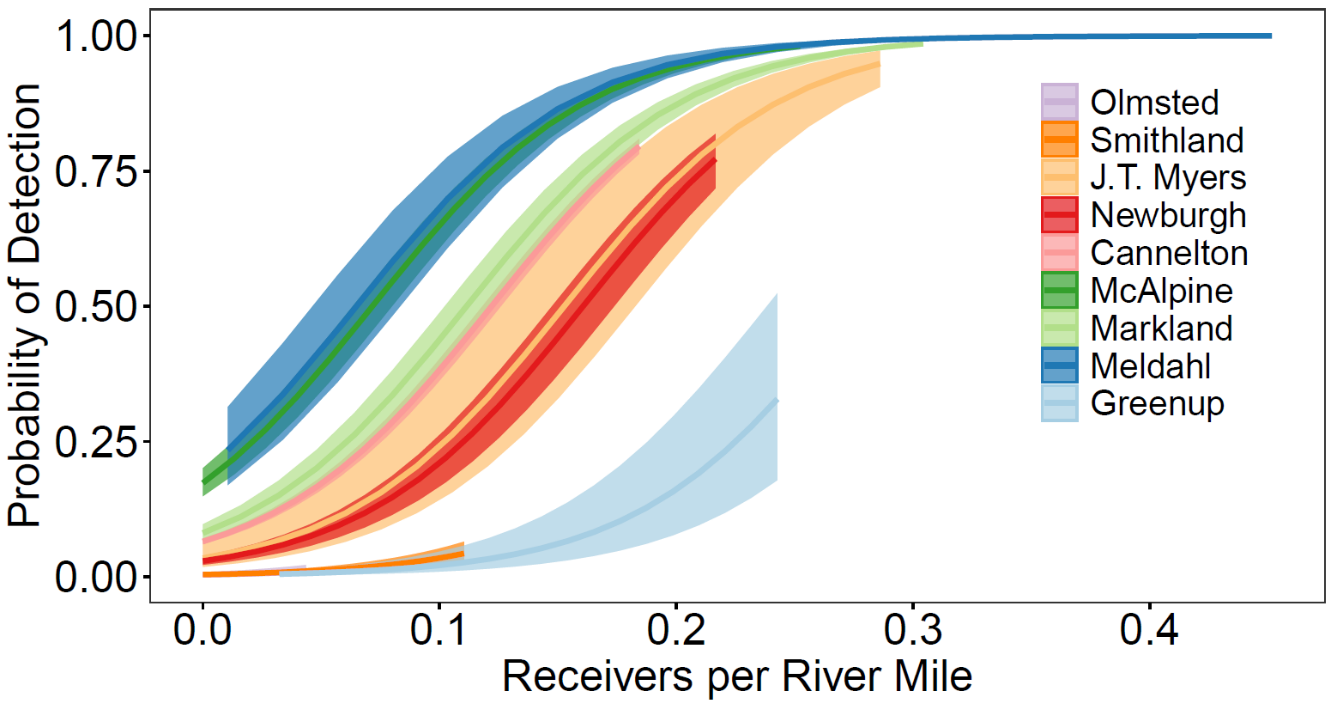

Figure 11. The effect of the number of receivers per river mile on the probability of detection (p) of Silver Carps in nine Ohio River pools. The number of receivers per river mile ranged from 0 to 0.45 and was representative of receiver densities during January 2014 – July 2022. The solid lines represent the mean probabilities of detection for each pool, whereas shaded areas represent the 95% confidence intervals surrounding those mean detection probabilities.

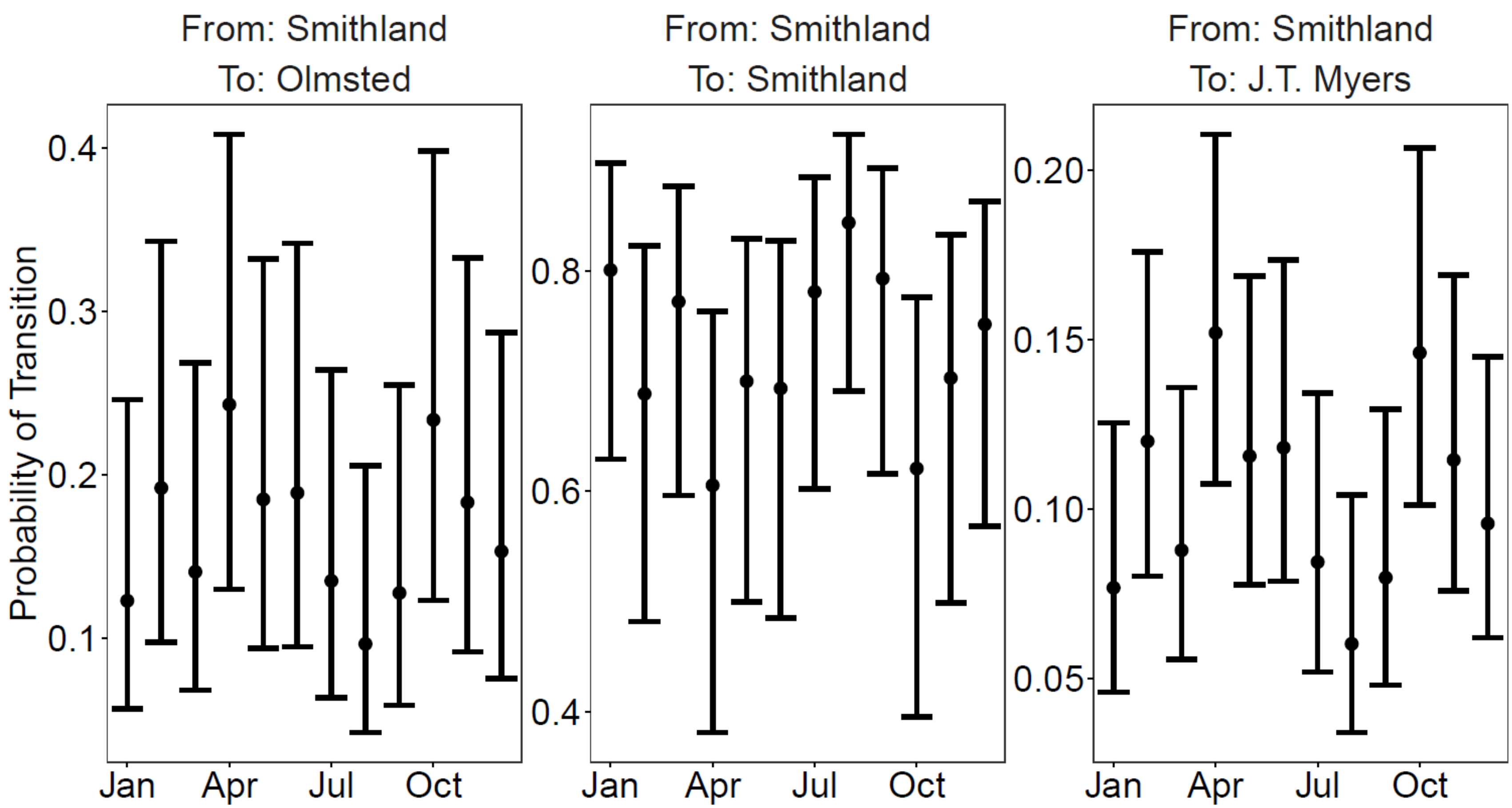

Figure 12. Monthly estimated transition probabilities (ψ) from Smithland Pool downstream to Olmsted Pool (left) and from Smithland Pool upstream to J.T. Myers Pool (right). The center panel shows the estimated probabilities of fish remaining within Smithland Pool in a given month. Plots for other pools are available from USFWS, CAR FWCO.

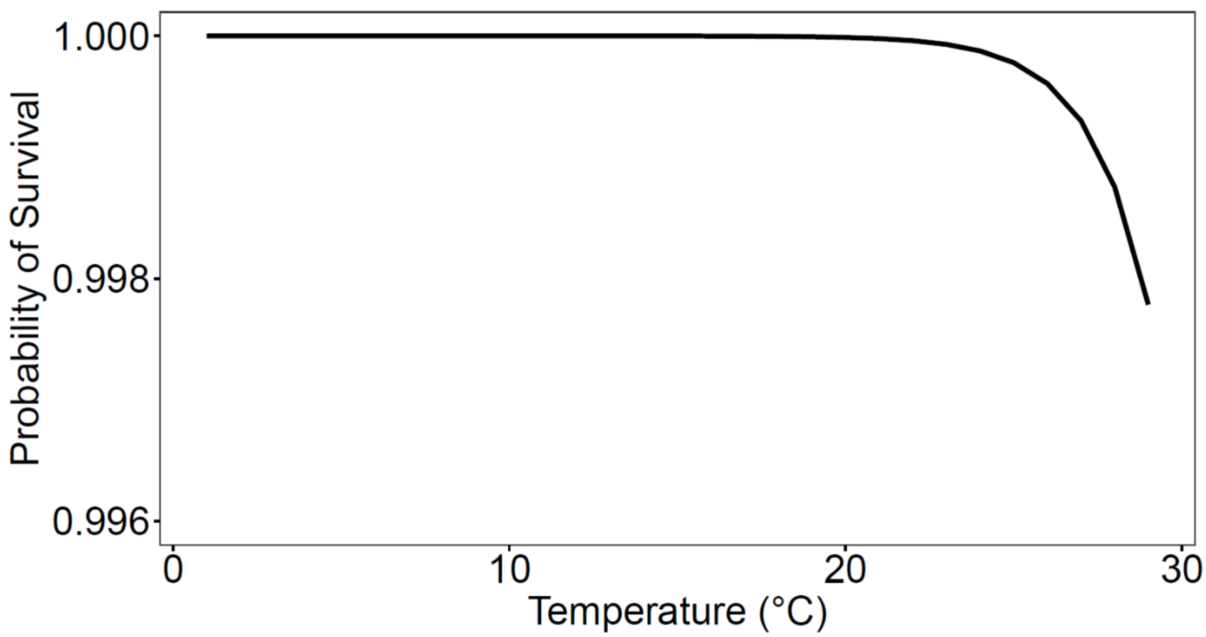

Figure 13. The effect of temperature (°C) on the daily probability of survival (S) of Silver Carps in Markland and Meldahl pools. The range of temperatures for which S was estimated (1 – 29°C) was reflective of temperatures typically encountered by these fish in the Ohio River and its tributaries during January 2021 – July 2022. The solid line represents the mean probability of survival. The 95% confidence interval surrounding the mean survival probability are not shown because they extend from 0 to 1 for all temperatures and are reflective of the lack of precision in the estimated daily survival probability.

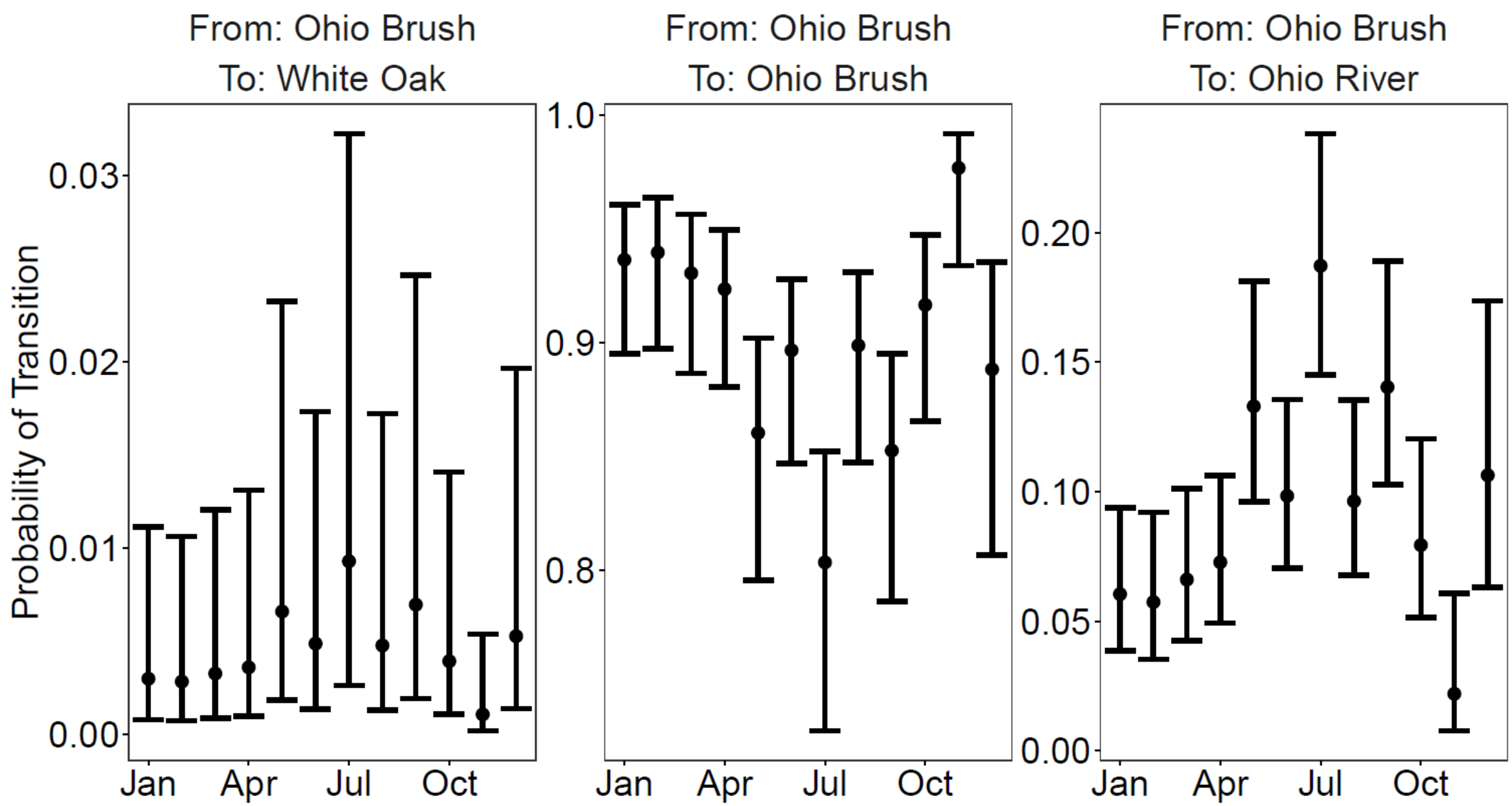

Figure 14. Monthly estimated transition probabilities (ψ) from Ohio Brush Creek to White Oak Creek (left) and from Ohio Brush Creek to the mainstem Ohio River (right). The center panel shows the estimated probabilities of fish remaining within Ohio Brush Creek in a given month. Plots for other rivers are available from USFWS, CAR FWCO.

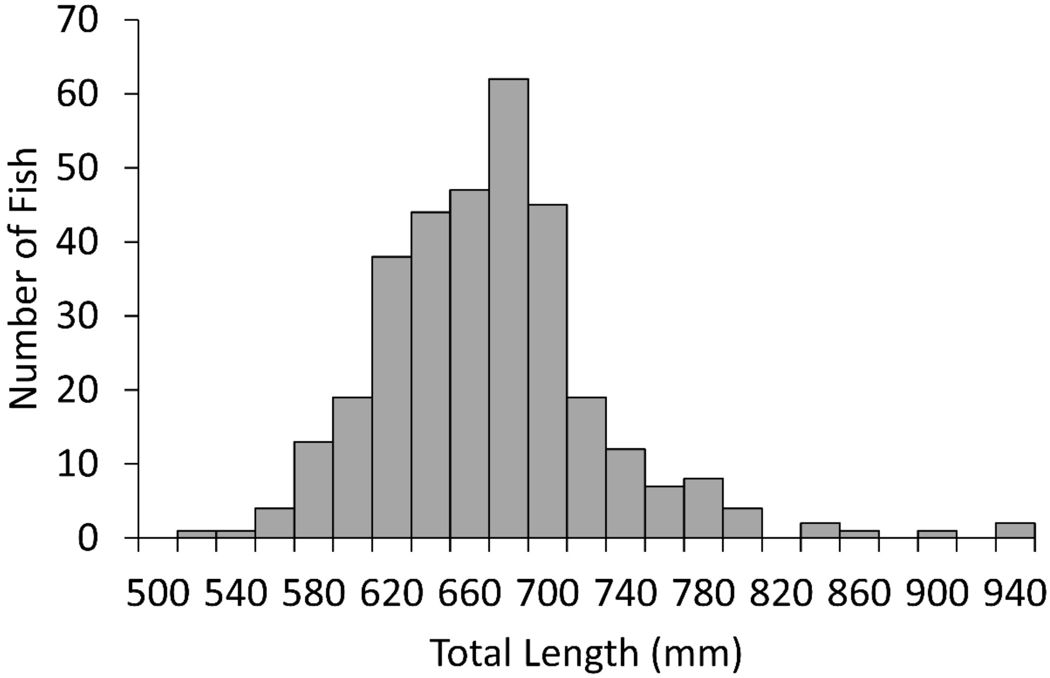

Figure 15. Size distribution of Silver Carp implanted with acoustic telemetry transmitters in the Wabash River during 2021 (n = 330).

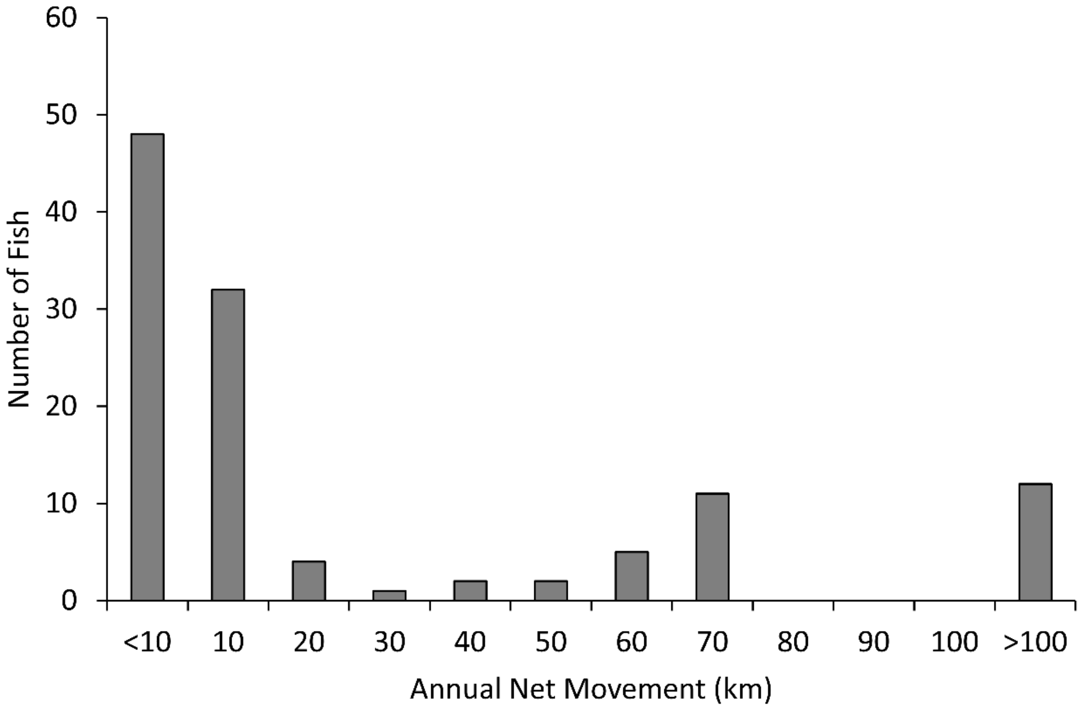

Figure 16. Annual net movement (difference between most upstream and downstream receiver detection) of Silver Carp in the Wabash River during 2022.

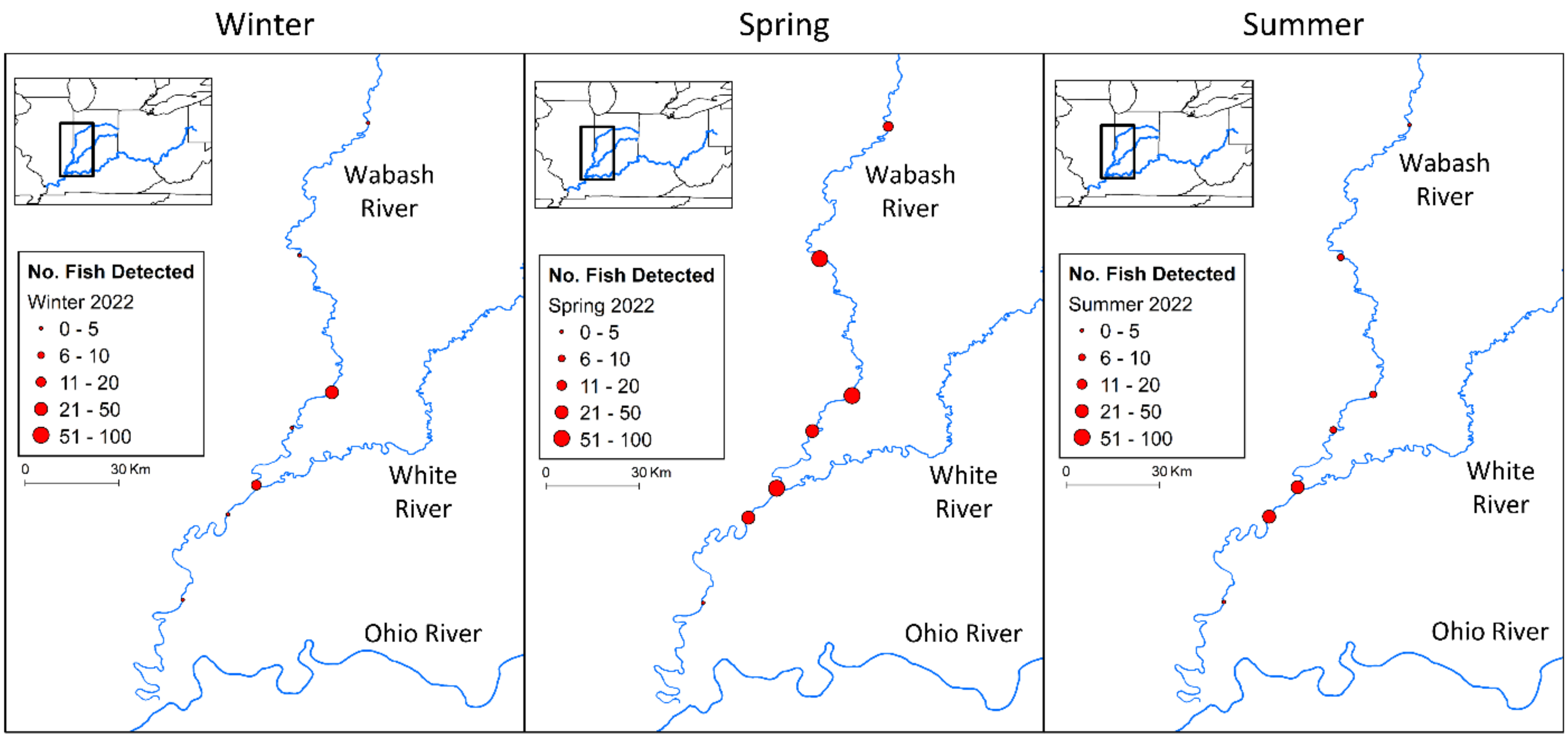

Figure 17. Seasonal patterns in Silver Carp detections and distribution in the Wabash River during 2022.

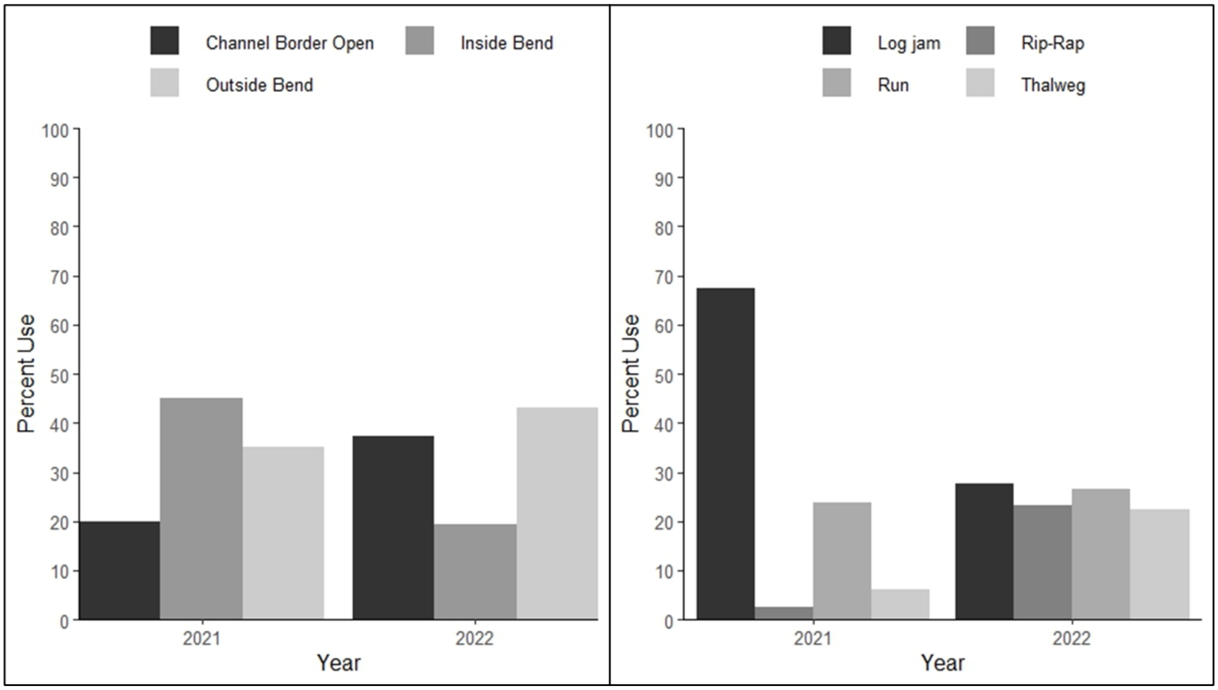

Figure 18. Large-scale habitat (left) and micro-habitat (right) use of Silver Carp detected in the Wabash and White Rivers in 2021 (n = 80) and 2022 (n = 227).

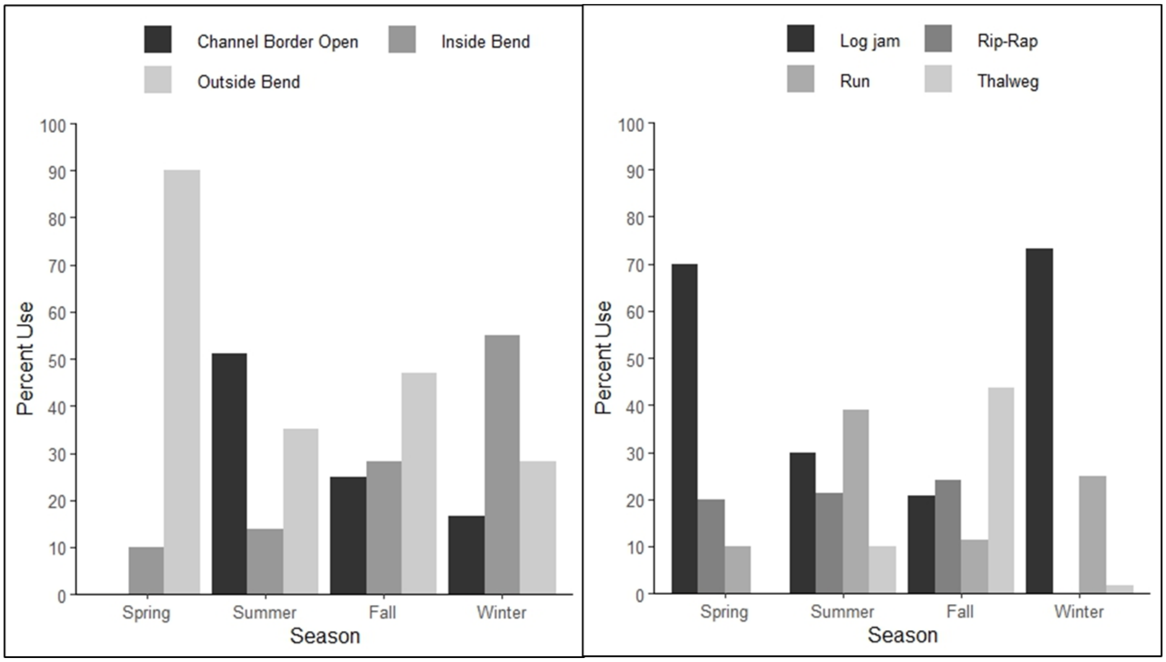

Figure 19. Large-scale habitat (left) and micro-habitat (right) use by season of Silver Carp detected in the Wabash and White Rivers from June 2021 to October 2022. The number of detections varied by season with the most in Summer (n = 98) followed by the Fall (n = 78), Winter (n = 27) and Spring (n = 16).

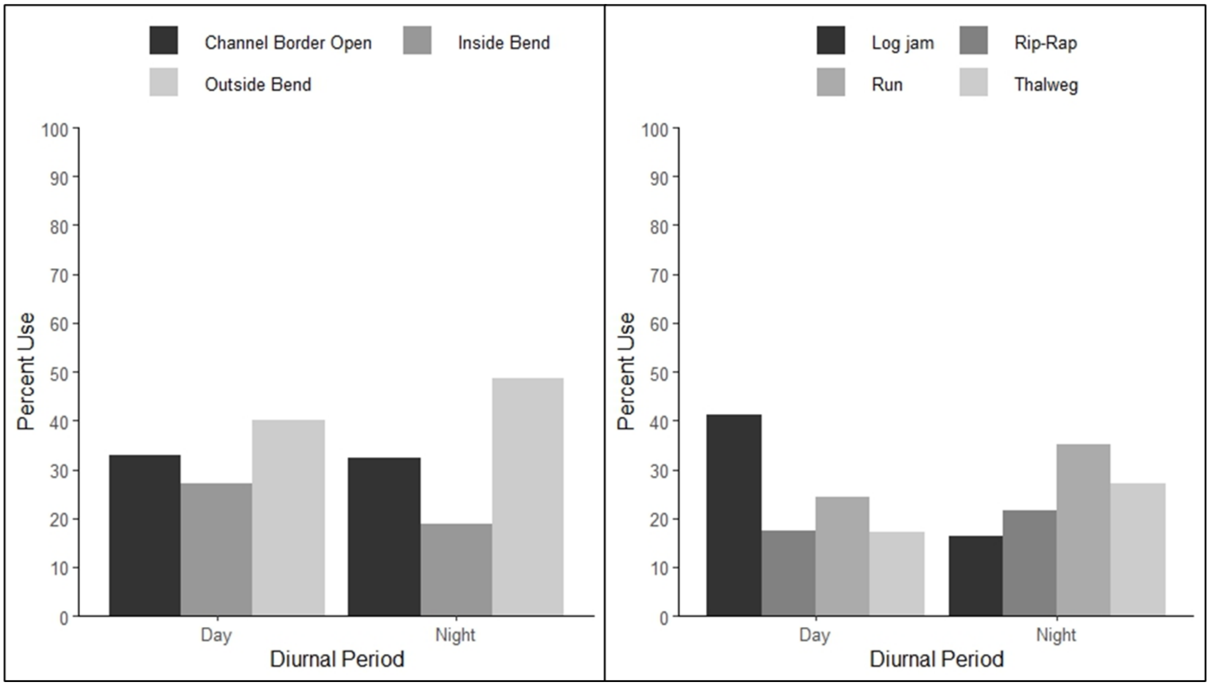

Figure 20. Large-scale habitat (left) and micro-habitat (right) use by time of day of Silver carp in the Wabash and White Rivers from June 2021 to October 2022. Most detections were made during the day (n = 270) compared to the night (n = 37).

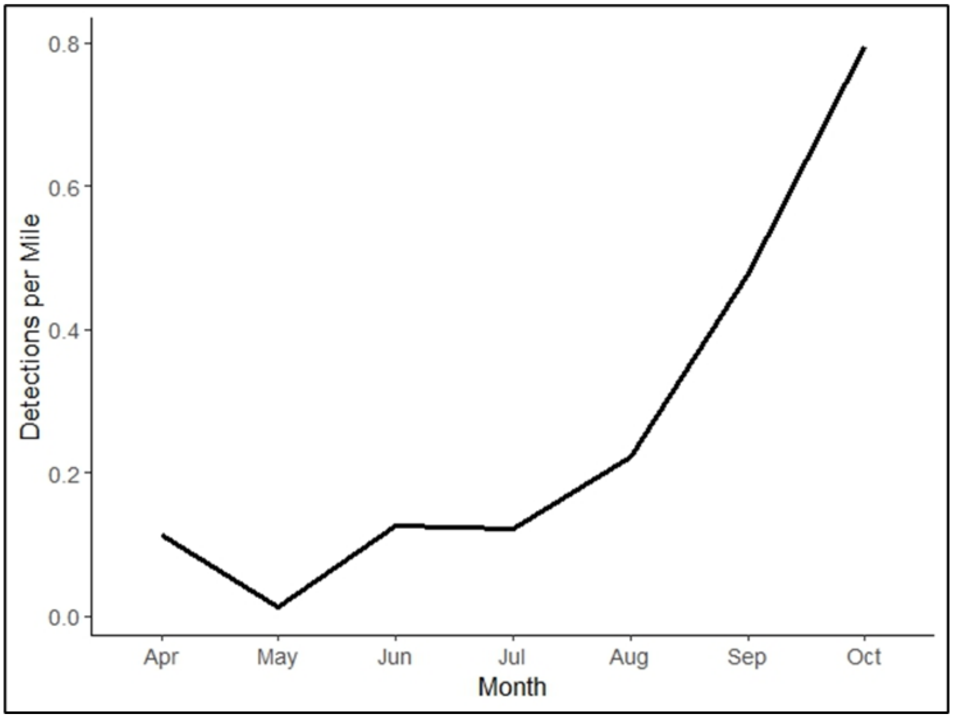

Figure 21. Silver Carp active tracking detections per mile from April to October of 2022 in the Wabash and White Rivers.

Table 1. The ID number, pool, and available data for US Geological Survey gage stations used in the pool-to-pool multistate model.

Gage ID	Pool	Gage Height	Temperature	Discharge
3611000	Olmsted	X		
3612600	Olmsted	X	X	X
3381700	Smithland	X		X
3304300	J.T. Myers	X		
3322000	J.T. Myers	X		
3322190	J.T. Myers	X		
3322420	J.T. Myers	X		
3303280	Newburgh	X	X	X
3294500	Cannelton	X		
3294600	Cannelton	X		
3292494	McAlpine	X	X	X
3293551	McAlpine	X		
3255000	Markland	X		
3217200	Meldahl	X		
3206000	Greenup	X		
3216000	Greenup	X		
3216070	Greenup	X	X	X
3201500	R.C. Byrd	X		

Table 2. Model selection results for survival probability (*S*) of the multi-state with live recaptures model for Silver Carp pool-to-pool movements. The table shows the model structure, number of parameters in the model (npar), AIC_c, ΔAIC_c, and the AIC weight (W_i) for all model structures for survival probability. The covariates affecting estimates of the survival probability are shown in parentheses and include temperature (temp), month, season, and pool. The "." notation indicates an invariant survival probability. The model structures for detection (*p*) and transition (*ψ*) probabilities were held constant and included only a pool effect for both parameters.

Model	npar	AIC_c	ΔAIC_c	W_i
S(temp)p(pool)ψ(pool)	39	28165.21	0	1
S(.)p(pool)ψ(pool)	38	28220.63	55.42	0
S(month)p(pool)ψ(pool)	49	28266.28	101.07	0
S(pool + season)p(pool)ψ(pool)	50	28291.94	126.73	0
S(season)p(pool)ψ(pool)	41	28313.82	148.61	0
S(pool + temp)p(pool)ψ(pool)	48	28321.72	156.51	0
S(pool)p(pool)ψ(pool)	47	28386.64	221.43	0

Table 3. Model selection results for detection probability (*p*) of the multi-state with live recaptures model for Silver Carp pool-to-pool movements. The table shows the model structure, number of parameters in the model (npar), AIC_c, ΔAIC_c, and the AIC weight (W_i) for all model structures for detection probability. The covariates affecting estimates of the detection probability are shown in parentheses and include the number of receivers (num_rec), the number of receivers per river mile (rprm), standardized gage height (std.height), month, season, and pool. The "." notation indicates an invariant detection probability. The model structures for survival (*S*) and transition (ψ) probabilities were held constant and included only a temperature effect for *S* (the best supported model structure) and a pool effect for ψ.

Model	npar	AIC_c	ΔAIC_c	W_i
S(temp)p(pool + rprm)ψ(pool)	40	27181.02	0	1
*S(temp)p(pool*month)ψ(pool)*	149	27211.93	30.91	0
S(temp)p(pool + num_rec)ψ(pool)	40	27232.43	51.41	0
S(temp)p(pool + month)ψ(pool)	50	27690.67	509.64	0
*S(temp)p(pool*season)ψ(pool)*	69	27792.21	611.19	0
S(temp)p(num_rec)ψ(pool)	31	27894.99	713.97	0
S(temp)p(pool + season)ψ(pool)	42	27920.23	739.21	0
S(temp)p(pool + std.height)ψ(pool)	40	28107.62	926.60	0
S(temp)p(pool)ψ(pool)	39	28165.21	984.19	0
S(temp)p(rprm)ψ(pool)	31	28803.48	1622.46	0
S(temp)p(month)ψ(pool)	41	32505.57	5324.55	0
S(temp)p(season)ψ(pool)	33	32838.91	5657.88	0
S(temp)p(std.height)ψ(pool)	31	33181.35	6000.33	0
S(temp)p(.)ψ(pool)	30	33329.44	6148.42	0

Table 4. Model selection results for transition probabilities (ψ) of the multi-state with live recaptures model for Silver Carp pool-to-pool movements. The table shows the model structure, number of parameters in the model (npar), AIC_c, ΔAIC_c, and the AIC weight (W_i) for all model structures for transition probabilities. The covariates affecting estimates of the transition probabilities are shown in parentheses and include standardized gage height (std.height), linear and quadratic effects of temperature (temp), month, season, and pool. The "." notation indicates an invariant transition probability. The model structures for survival (*S*) and detection (*p*) probabilities were held constant and included only a temperature effect for *S* and the additive effect of pool and receivers per river mile for *p*.

Model	npar	AIC_c	ΔAIC_c	W_i
S(temp)p(pool + rprm)ψ(pool + month)	52	27074.54	0	1
S(temp)p(pool + rprm)ψ(pool + std.height)	41	27126.51	51.97	0
S(temp)p(pool + rprm)ψ(pool + season)	44	27163.32	88.77	0
S(temp)p(pool + rprm)ψ(pool)	40	27181.02	106.48	0
S(temp)p(pool + rprm)ψ(pool + temp)	41	27183.71	109.16	0
S(temp)p(pool + rprm)ψ(pool + temp + temp^2)	41	27183.71	109.16	0
S(temp)p(pool + rprm)ψ(pool + std.height + temp + temp^2)	42	27184.38	109.84	0
S(temp)p(pool + rprm)ψ(pool + std.height + temp)	42	27184.38	109.84	0
S(temp)p(pool + rprm)ψ(month)	25	28543.92	1469.38	0
S(temp)p(pool + rprm)ψ(season)	17	28591.12	1516.58	0
S(temp)p(pool + rprm)ψ(std.height)	15	28612.17	1537.63	0
S(temp)p(pool + rprm)ψ(.)	14	28615.41	1540.87	0
S(temp)p(pool + rprm)ψ(temp)	15	28616.62	1542.08	0
S(temp)p(pool + rprm)ψ(temp + temp^2)	15	28616.62	1542.08	0

Table 5. The ID number, river, and available data for US Geological Survey gage stations used in the mainstem-tributary multistate model.

Gage ID	River	Gage Height	Temperature	Discharge
3217200	Ohio River	X		
3237500	Ohio Brush Creek	X		X
3238000	Ohio River	X		
3238495	White Oak Creek	X		X
3255000	Ohio River	X		
3274615	Great Miami River	X		
3277075	Gunpowder Creek	X		X

Table 6. Model selection results for survival probability (*S*) of the multi-state with live recaptures model for Silver Carp mainstem-tributary movements. The table shows the model structure, number of parameters in the model (npar), AIC_c, ΔAIC_c, and the AIC weight (W_i) for all model structures for survival probability. The covariates affecting estimates of the survival probability are shown in parentheses and include temperature (temp), month, season, and river. The "." notation indicates an invariant survival probability. The model structures for detection (*p*) and transition (*ψ*) probabilities were held constant and included only a river effect for both parameters.

Model	**npar**	**AIC_c**	**ΔAIC_c**	**W_i**
S(temp)p(river)ψ(river)	17	11672.04	0	0.39
S(.)p(river)ψ(river)	16	11672.14	0.10	0.37
S(river + temp)p(river)ψ(river)	21	11673.54	1.50	0.18
S(season)p(river)ψ(river)	19	11675.61	3.57	0.06
S(river)p(river)ψ(river)	20	11762.66	90.62	0
S(river + season)p(river)ψ(river)	23	11765.57	93.53	0
S(river + month)p(river)ψ(river)	31	11769.69	97.65	0
S(month)p(river)ψ(river)	27	12234.49	562.45	0

Table 7. Model selection results for detection probability (*p*) of the multi-state with live recaptures model for Silver Carp mainstem-ttibutary movements. The table shows the model structure, number of parameters in the model (npar), AIC_c, ΔAIC_c, and the AIC weight (W_i) for all model structures for detection probability. The covariates affecting estimates of the detection probability are shown in parentheses and include the number of receivers (num_rec), standardized gage height (std.height), month, season, and river. The "." notation indicates an invariant detection probability. The model structure for survival probability (*S*) included either temperature only, the additive effect of temperature and river, or was invariant. The model structure for transition probabilities (ψ) was held constant and included only a river effect.

Model	npar	AIC_c	ΔAIC_c	W_i
S(temp)p(river + num_rec)ψ(river)	18	11208.14	0	0.80
S(.)p(river + num_rec)ψ(river)	17	11211.83	3.69	0.13
S(river + temp)p(river + num_rec)ψ(river)	22	11212.88	4.73	0.07
*S(.)p(river * season)ψ(river)*	31	11269.32	61.18	0
*S(river + temp)p(river * season)ψ(river)*	36	11318.15	110.01	0
*S(.)p(river * month)ψ(river)*	71	11543.12	334.98	0
S(.)p(river + month)ψ(river)	27	11567.24	359.10	0
S(temp)p(river + month)ψ(river)	28	11567.45	359.30	0
S(river + temp)p(river + month)ψ(river)	32	11641.87	433.72	0
S(.)p(river + season)ψ(river)	19	11660.25	452.11	0
S(temp)p(river)ψ(river)	17	11672.04	463.89	0
S(.)p(river)ψ(river)	16	11672.14	464.00	0
S(river + temp)p(river)ψ(river)	21	11673.54	465.40	0
S(temp)p(river + std.height)ψ(river)	18	11674.02	465.87	0
S(.)p(river + std.height)ψ(river)	17	11674.13	465.99	0
*S(temp)p(river * month)ψ(river)*	72	11701.44	493.30	0
*S(river + temp)p(river * month)ψ(river)*	76	11750.9	542.77	0
S(river + temp)p(river + std.height)ψ(river)	22	11786.55	578.40	0
*S(temp)p(river * season)ψ(river)*	32	11812.77	604.63	0
S(river + temp)p(river + season)ψ(river)	24	12081.59	873.44	0
S(temp)p(river + season)ψ(river)	20	12284.88	1076.73	0
S(.)p(num_rec)ψ(river)	13	15052.22	3844.07	0
S(river + temp)p(num_rec)ψ(river)	18	15342.01	4133.86	0
S(temp)p(num_rec)ψ(river)	14	15374.17	4166.03	0
S(river + temp)p(month)ψ(river)	28	15926.44	4718.30	0
S(temp)p(month)ψ(river)	24	15930.29	4722.15	0
S(.)p(month)ψ(river)	23	15937.74	4729.60	0
S(river + temp)p(season)ψ(river)	20	16374.37	5166.23	0
S(temp)p(season)ψ(river)	16	16378.48	5170.33	0
S(.)p(season)ψ(river)	15	16385.5	5177.35	0
S(river + temp)p(std.height)ψ(river)	18	16483.34	5275.19	0

S(temp)p(std.height)ψ(river)	14	16490.63	5282.49	0
S(.)p(std.height)ψ(river)	13	16496.52	5288.37	0
S(river + temp)p(.)ψ(river)	17	16501.54	5293.40	0
S(temp)p(.)ψ(river)	13	16508.35	5300.20	0
S(.)p(.)ψ(river)	12	16513.8	5305.66	0

Table 8. Model selection results for transition probabilities (ψ) of the multi-state with live recaptures model for Silver Carp mainstem-tributary movements. The table shows the model structure, number of parameters in the model (npar), AIC_c, ΔAIC_c, and the AIC weight (W_i) for all model structures for transition probabilities. The covariates affecting estimates of the transition probabilities are shown in parentheses and include standardized gage height (std.height), linear and quadratic effects of temperature (temp), month, season, and pool. The "." notation indicates an invariant transition probability. The model structures for survival (*S*) and detection (*p*) probabilities were held constant and included only a temperature effect for *S* and the additive effect of river and the number of receivers for *p*.

Model	npar	AIC_c	ΔAIC_c	W_i
S(temp)p(river + num_rec)Psi(river + month)	30	11144.60	0	0.89
S(temp)p(river + num_rec)Psi(river + std.height + temp)	20	11150.23	5.63	0.05
S(temp)p(river + num_rec)Psi(river + std.height + temp + temp^2)	20	11150.23	5.63	0.05
S(temp)p(river + num_rec)Psi(river + temp)	19	11174.52	29.93	0
S(temp)p(river + num_rec)Psi(river + temp + temp^2)	19	11174.52	29.93	0
S(temp)p(river + num_rec)Psi(river + season)	22	11198.95	54.35	0
S(temp)p(river + num_rec)Psi(river + std.height)	19	11199.65	55.05	0
S(temp)p(river + num_rec)Psi(river)	18	11208.14	63.55	0
S(temp)p(river + num_rec)Psi(month)	20	11653.00	508.41	0
S(temp)p(river + num_rec)Psi(temp)	10	11697.42	552.83	0
S(temp)p(river + num_rec)Psi(temp + temp^2)	10	11697.42	552.83	0
S(temp)p(river + num_rec)Psi(season)	12	11736.52	591.92	0
S(temp)p(river + num_rec)Psi(.)	9	11781.59	636.99	0
S(temp)p(river + num_rec)Psi(std.height)	10	11783.02	638.42	0

Table 9. Number and distribution of VR2 receivers in the Ohio River during 2022. One-hundred sixty-two receivers were deployed from Olmsted pool, downstream of the Smithland lock and dam, to Willow Island lock and dam.

Ohio River Pool	Pool Length (km)	Lock and Dam Receivers (N)	Mainstem Receivers (N)	Tributary Receivers (N)	Total Receivers (N)
Olmsted	73.9	0	2	0	2
Smithland	116.7	8	0	0	8
J.T. Myers	112.5	5	1	15	21
Newburgh	89.1	4	0	8	12
Cannelton	183.3	1	1	19	21
McAlpine	121.2	3	3	9	15
Markland	153.3	4	4	6	14
Meldahl	153.2	4	12	8	24
Greenup	99.4	3	6	4	13
R.C. Byrd	67.1	4	5	8	17
Racine	54.1	4	1	2	7
Belleville	67.9	4	1	2	7
Willow Island	56.8	1	0	0	1
Total	1348.3	45	36	81	162

Table 10. The number of Silver and Bighead Carps tagged with acoustic transmitters by year and pool during June 2013 – December 2022. Numbers in parenthesis are fish with tags that have been reported as harvested before expected tag expiration and, therefore, are no longer active. Tags deployed for > 5 years are expected to be expired (inactive). Also included are species composition calculations for the tags expected to be active in each pool and the mean total length (mm) of all tagged fish by pool.

Year(s)	**Status after 2022**	**Species**	**Ohio River Pool**								**Total**
			J.T. Myers	**Newburgh**	**Cannelton**	**McAlpine**	**Markland**	**Meldahl**	**Greenup**	**R.C. Byrd**	
2013	Inactive	SVCP	-	-	-	-	-	6	-	-	6
		BHCP	-	-	-	-	-	13	-	-	13
2014	Inactive	SVCP	-	-	-	111	6	10	-	-	127
		BHCP	-	-	-	4	4	-	-	-	8
2015	Inactive	SVCP	-	-	-	23	3	5	-	-	30
		BHCP	-	-	-	1	1	5	-	-	7
2016	Inactive	SVCP	-	-	92	94	6	-	-	-	192
		BHCP	-	-	4	1	4	2	-	3	14
2017	Inactive	SVCP	-	-	90	-	12	3	-	-	105
		BHCP	-	-	-	-	2	-	-	-	2
2018	Active	SVCP	-	-	-	-	21	10	-	-	31
		BHCP	-	-	-	-	-	1	-	-	1
2019	Active	SVCP	-	-	-	30	-	-	-	-	30
		BHCP	-	-	-	1	-	-	-	-	1
2020	Active	SVCP	-	-	-	100 (1)	18	-	-	-	118
2021	Active	SVCP	226	230	92	97	3	-	-	-	648
2022	Active	SVCP	-	-	108	-	29	-	-	-	137
2018-2022	Active	SVCP	226	230	200	226	71	10	-	-	963
		BHCP	-	-	-	1	-	1	-	-	2
		Combined	226	230	200	227	71	11	-	-	956
2013-2017 (Including harvested)	Inactive	SVCP	-	-	182	229	27	24	-	-	461
		BHCP	-	-	4	6	11	20	-	3	44
		Combined	-	-	186	235	38	44	-	3	505
	Active	SVCP	23.4	23.8	20.7	23.4	7.4	1.0	0.0	0.0	99.8
		BHCP	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.2

% Species Composition (2018-2022)		Combined	23.4	23.8	20.7	23.5	7.4	1.1	0.0	0.0	100.0
Mean Total Length (mm) (2013-2022)	Combined	SVCP	699.7	708.5	787.7	818.7	923.2	965.2	-	-	803.4
		BHCP	-	-	1139.8	1169.0	1175.1	1154.5	-	1210	1160.1

Table 11. Model-estimated mean (95% confidence intervals) pool-to-pool transition probabilities (ψ) of Silver Carps in the Ohio River derived from acoustic telemetry during January 2014 – July 2022. The highest-ranked model for Silver Carp included the additive effect of pool and month on transition probabilities. Black-shaded cells represent transitions among non-adjacent pools for which there were no observations. These transition probabilities were fixed to 0 and are, therefore, not reported in the table below. The probability of fish remaining within a pool is given in the gray shaded cells; upstream transition probabilities are to the right of gray-shaded cells and downstream transition probabilities are to the left of gray-shaded cells. No Silver Carps were detected above Racine Lock and Dam. Therefore, transition probabilities were not estimated for pools upstream of R.C. Byrd Pool. Shown here are the estimated transition probabilities during April and August, the months of the highest and lowest estimated pool-to-pool transition probabilities, respectively. Tables for other months are available from USFWS, CAR FWCO.

Departure Pool	**Destination Pool**									
	Olmsted	Smithland	J.T. Myers	Newburgh	Cannelton	McAlpine	Markland	Meldahl	Greenup	R.C. Byrd
April										
Olmsted	0.888 (0.663-0.970)	0.112 (0.030-0.337)								
Smithland	0.243 (0.130-0.408)	0.605 (0.381-0.763)	0.152 (0.107-0.211)							
J.T. Myers	0.000 (0.000-1.00)	0.369 (0.305-0.437)	0.602 (0.000-0.677)	0.029 (0.018-0.049)						
Newburgh		0.069 (0.049-0.096)	0.030 (0.020-0.045)	0.900 (0.846-0.931)	0.003 (0.000-0.013)					
Cannelton	0.003 (0.000-0.010)	0.000 (0.000-0.000)	0.000 (0.000-0.000)	0.002 (0.000-0.006)	0.888 (0.857-0.909)	0.107 (0.090-0.127)				
McAlpine			0.000 (0.000-0.002)		0.123 (0.103-0.146)	0.874 (0.845-0.896)	0.002 (0.001-0.004)	0.000 (0.000-0.002)		
Markland					0.020 (0.011-0.034)	0.007 (0.003-0.018)	0.968 (0.935-0.984)	0.005 (0.002-0.013)		
Meldahl							0.007 (0.003-0.018)	0.941 (0.888-0.969)	0.052 (0.028-0.094)	0.000 (0.000-0.000)
Greenup								0.371 (0.229-0.539)	0.502 (0.220-0.708)	0.128 (0.063-0.241)
R.C. Byrd									0.264 (0.135-0.453)	0.736 (0.547-0.865)
August										
Olmsted	0.965 (0.870-0.992)	0.035 (0.008-0.131)								
Smithland	0.096 (0.042-0.205)	0.844 (0.691-0.924)	0.060 (0.034-0.104)							
J.T. Myers	0.000 (0.000-1.000)	0.147 (0.099-0.212)	0.842 (0.000-0.895)	0.012 (0.006-0.021)						
Newburgh		0.021 (0.013-0.034)	0.009 (0.005-0.016)	0.969 (0.946-0.982)	0.001 (0.000-0.004)					

Cannelton	0.000 (0.000-0.003)	0.000 (0.000-0.000)	0.000 (0.000-0.002)	0.000 (0.000)	0.965 (0.947-0.977)	0.033 (0.023-0.048)				
McAlpine			0.000 (0.000-0.001)		0.038 (0.027-0.055)	0.961 (0.942-0.973)	0.000 (0.000-0.001)	0.000 (0.000-0.000)		
Markland					0.006 (0.003-0.011)	0.002 (0.001-0.005)	0.991 (0.979-1.000)	0.001 (0.000-0.004)		
Meldahl							0.002 (0.001-0.006)	0.983 (0.963-0.992)	0.016 (0.008-0.031)	0.000 (0.000-0.000)
Greenup								0.164 (0.084-0.295)	0.780 (0.587-0.890)	0.056 (0.026-0.118)
R.C. Byrd									0.093 (0.040-0.199)	0.907 (0.801-0.960)

Table 12. The effect of the number of receivers per river on the probability of detection (*p*) of Silver Carps in the mainstem Ohio River (Markland and Meldahl pools) as well as four tributaries (River). The number of receivers per river ranges from one to 24. LCL represents the lower confidence limit for estimates of detection probabilities and UCL represents the upper confidence limit.

River	Number of Receivers	LCL	Mean	UCL
Great Miami	1	0.45	0.51	0.57
Ohio Brush	1	0.53	0.57	0.61
Gunpowder	2	0.47	0.52	0.56
White Oak	1	0.00	0.00	0.00
Ohio River	24	1.00	1.00	1.00

Table 13. Model-estimated mean (95% confidence intervals) mainstem-tributary transition probabilities (ψ) of Silver Carps in the Ohio River derived from acoustic telemetry during January 2021 – July 2022. The highest-ranked model for Silver Carps included the additive effect of river and month on transition probabilities. Black-shaded cells represent transitions among areas for which there were no observations. These transition probabilities were fixed to 0 and are, therefore, not reported in the table below. The probability of fish remaining within a river is given in the gray shaded cells. Shown here are the estimated transition probabilities during July and November, the months of the highest and lowest estimated mainstem-tributary transition probabilities, respectively. Tables for other months are available from USFWS, CAR FWCO.

July

Departure Area	**Arrival Area**				
	Great Miami River	Ohio Brush Creek	Gunpowder Creek	White Oak Creek	Ohio River
Great Miami River	0.846 (0.791-0.888)				0.154 (0.112-0.209)
Ohio Brush Creek		0.804 (0.730-0.852)		0.009 (0.003-0.032)	0.187 (0.145-0.238)
Gunpowder Creek	0.000 (0.000-0.000)		0.931 (0.895-0.955)		0.069 (0.105-0.031)
White Oak Creek				0.961 (0.952-0.969)	0.039 (0.031-0.048)
Ohio River	0.034 (0.025-0.048)	0.101 (0.080-0.126)	0.014 (0.008-0.022)	0.199 (0.166-0.238)	0.652 (0.566-0.722)
November					
Great Miami River	0.983 (0.951-0.994)				0.017 (0.006-0.049)
Ohio Brush Creek		0.977 (0.933-0.992)		0.001 (0.000-0.005)	0.022 (0.008-0.061)
Gunpowder Creek	0.000 (0.000-0.000)		0.993 (0.979-0.998)		0.007 (0.002-0.021)
White Oak Creek				0.996 (0.989-0.999)	0.004 (0.001-0.011)
Ohio River	0.005 (0.002-0.013)	0.014 (0.005-0.038)	0.002 (0.001-0.006)	0.028 (0.010-0.074)	0.951 (0.869-0.982)