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 Cincinnati, Ohio. 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) Quantify movement probabilities among navigation pools within the Ohio River, between the Wabash and Ohio rivers, and between the Wabash and White rivers.
2) Understand movements among tributary and mainstem habitats within the Ohio River basin in response to environmental conditions and commercial harvest.
3) 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:

- Two-Hundred Eighty-Two Silver Carps were tagged during 2025 in the mainstem Ohio River (J.T. Myers – McAlpine pools) and 170 Silver Carps were tagged in the White (n = 78) and Wabash (n = 92) rivers.
- During the course of this study, ~76% of Silver Carps have inhabited tributaries compared with ~56% of Silver Carps detected in mainstem habitats.
- Estimated mean monthly 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.
- Within each pool examined (J.T. Myers – Meldahl) at least one tributary was occupied by ≥ 25% of tagged Silver Carp present in that pool.

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 Innovasea, Model V16 acoustic tags were recorded using a stationary array of acoustic receivers (VR2W, VR2AR, VR2Tx, NexTrak, and HR3). Receivers were placed either within the mainstem Ohio River, the lower reaches of select tributaries, on the approach walls, or within the chambers of locks. Within some tributaries, multiple receivers were deployed from the mouth to several miles 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 locks and dams (L&Ds), at least four receivers were deployed at each L&D to record pool-to-pool transitions through the lock chambers with some exceptions. During 2025, three receivers were deployed at Newburgh, Markland, and R.C. Byrd L&Ds. At Newburgh L&D one receiver was deployed at each approach and one was deployed in the shorter lock chamber. At Markland L&D, one receiver was deployed at the downstream approach and one was deployed in each lock chamber.

At R.C. Byrd L&D one receiver was deployed at the upstream approach and one was deployed in each lock chamber. There were no receivers deployed at McAlpine and Meldahl L&Ds. All other L&Ds had one receiver deployed in each lock chamber and one receiver at each approach. These receivers provide relatively 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 August 2024 – July 2025, the receiver array extended from river mile 937.0 in Olmsted Pool, ~20 miles downstream of the Smithland L&D, upstream to Willow Island Pool (river mile 161.7) and included receivers in portions of the Wabash, Tennessee, and Cumberland rivers (Figure 1). Detection data were downloaded from receivers bi-monthly or as often as possible.

Acoustic Transmitter Tagging: Adult invasive carps were collected via boat electrofishing. 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 (Innovasea, 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 ~1,460 days (4 years). Fish implanted with acoustic transmitters were also tagged externally using a lock-on tag inserted through the dorsal musculature posterior to the dorsal fin (Floy Tag & Manufacturing, Inc. FT-4 Lock-on tag with clear over-tubing).

Tributary Use: To assess tributary use by Silver Carps (Bighead Carps were omitted due to a paucity of data), the proportion of detected Silver Carp in each habitat was determined by dividing the number of individual Silver Carps in each habitat by the total number of detected individuals June 2013 – July 2025. Additionally, to determine if specific tributaries may be of increased importance to Silver Carps, the number of individual Silver Carp detected in a tributary was divided by the total number of Silver Carps detected in that pool. 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 and Wabash rivers, 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 4.4.2 (R Core Team 2024). In this analysis, the Wabash River, TNCR, and each navigation pool of the Ohio River are considered "states". Due to a relative lack of detection data during 2013 (few Silver Carp tagged and few receivers deployed), detection data prior to January 2014 were omitted. Encounter histories were constructed for each individual by determining the pool within which an individual was most frequently detected during each month (January 2014 – July 2025). Because tagging took place at various times throughout the duration of the study period and the expected battery life of the acoustic transmitters is ~4 years, not all individuals have a complete encounter history (maximum of 139 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, transition probabilities were estimated only for adjacent pools because there were very few detected movements among non-adjacent pools. Transition probabilities among non-adjacent pools were, therefore, fixed to 0. Due to the small number of fish tagged (n = 49) and few active tags in the Ohio River (n = 3), Bighead Carps were not included in these analyses.

The encounter histories of individual Silver Carps were used to inform transition, survival, and detection probability 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), 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, and pool on survival probability were evaluated (Table 1). After determining the best supported structure for survival probability, it was retained while evaluating the effects of month, season, pool, the number of receivers per pool and the number of receivers per river mile within each pool on detection probabilities (Table 2). Lastly, the best supported structures for survival and detection probabilities were held constant while evaluating the effects of month, season, and pool on transition probabilities (Table 3). 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: Because the high sediment load and fluctuating current of the Wabash River can quickly bury bottom set receivers, alternative methods for receiver (Innovasea VR2Tx) deployment were tested during 2025. Specifically, SIU began hard mounting receivers to either trees or bridges. One receiver was placed on I-70 bridge pylons in Terre Haute and four new tree set receivers were deployed in the White and Wabash rivers. These receivers added to the existing network for a total of 19 and 4 active receivers in the Wabash and White Rivers, respectively (Figure 2). These alterations to receiver deployments were largely successful and yielded 19 downloads from 13 unique receivers. These results contrast with those from 2024 when only 7 receivers were recovered. Although low water levels during late summer and fall still present a challenge because boat ramps become unusable, SIU is investigating the use of a smaller vessel for downloading receivers during 2026. One tree-set receiver was lost when its cable was cut on shore and SIU has purchased high-quality steel signs with university contact information to deploy with tree and bridge set receivers to mitigate receiver loss due to this type of tampering.

Acoustic Transmitter Tagging: Tagging of invasive carps in the Wabash River follows the methods for the Ohio River, above. A total of 768 Silver Carp have been tagged since 2021 at multiple locations in the Wabash and White rivers. Tagging during 2024 was delayed by low water levels during spring and summer. EIU assisted in tagging efforts alongside SIU during fall 2025. Thirty-eight tags were deployed in Mt. Carmel, IL (05/05/25), 9 tags in Grayville, IL (05/06/25), 33 tags at the Wabash-Ohio river confluence (10/28/2025), 15 tags at St. Francisville (10/29/2025), 44 at Merom (11/4/2025), and 78 at Petersburg (11/5/2025; White River). SIU independently tagged an additional 47 fish at Dogtown Ferry, IN (05/23/25) and 45 fish in New Harmony, IN (05/26/25), for a total of 231 Silver Carp tagged in the Wabash River. An analysis of historical data from 2011-2018 for Silver Carp tagged in the Wabash River was conducted to determine the survival and detection probabilities. Detection and survival probabilities were determined using a longitudinal Cormack-Jolly-Seber model of acoustically tagged adult Silver Carp during 2011 through 2018 in both rivers, which is a unique approach only possible with long-term data from individual fishes.

Active Tracking for Habitat Use: Fine-scale habitat selection by tagged adult Silver Carps was assessed throughout the Wabash and White rivers during 2025. Monthly active tracking events occurred throughout the 305 river kilometers (rkm) from Terre Haute, IN to the confluence of the Ohio River and the lower 32 rkm of the White River from Hazelton to its confluence with the Wabash RIver in Mt. Carmel, IL. During active tracking, the boat was maneuvered downstream while towing an omnidirectional hydrophone (Vemco VH165). Once a transmitter was detected, the fish's position was triangulated by using a submersible directional hydrophone (Vemco VH110). Habitat characteristics including macro-habitat type (channel border open, inside river bend, outside river bend) and micro-habitat type (log jam, rip-rap, run, thalweg, sandbar, tributary) were recorded at each fish’s location.

Invasive carp movement and distribution following dam removal

During November 2021, two dams were removed from the Eel River at river kilometer (RKM) 2. The largest of these two dams was 435-feet long and 9-feet tall and served as a barrier to invasive carp movement further up the Eel River. Removal of these dams created a novel opportunity to better understand invasive carp establishment in newly accessible habitat and evaluate the ecological risk of invasive carp occupancy in comparison to the ecological lift of new native species establishing in the Eel River basin.

ECI tagged 50 Silver Carp with Innovasea model V16T-4x tags during 2025. All carp tagged with an acoustic transmitter were also tagged with an HPT 12 Biomark PIT tag. Tagging occurred on 2 July 2025 and 3 July 2025 in the Wabash River at the France Park Boat Ramp (RM 349). A total of 227 Silver Carp have been tagged in the Wabash River from 2022 to 2025.

Fish movement in the upper Wabash River, Eel River, Tippecanoe River, Mississinewa River, and Salamonie River 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 each of the four tributaries during May 2022. This project also used eight passive acoustic receivers and a network of six Biomark antenna arrays that were previously installed in the Eel River during summer 2020. Those receivers were relocated throughout the Eel River from RM 7 to RM 75 during 2025. Data were downloaded monthly from antennas and passive receivers. The last data download included in this report occurred on 29 December 2025. All receivers and PIT tag antennas remain operational to date. Active tracking on the Eel River (RM 75 to RM 0) was completed using a multi-directional hydrophone and VR 100 receiver deployed from a canoe between 16 June 2025 and 27 June 2025.

A linear mixed model (LMM) was used to examine the effects of season, water-temperature, movement direction and the interaction between season and movement direction on the distance traveled by Silver Carp in the Upper Wabash River Basin. To account for individual variation, fish ID was included as a random effect. Because distance traveled was right-skewed, a natural log transformation was used to normalize this response. In addition, a generalized linear mixed model with a binomial distribution was used to examine the effects of season and water temperature on movement direction (0 = downstream, 1 = upstream). As with the LMM above, fish ID was included as a random effect to account for individual level variation. Both models were developed using the lme4 package in R (Bates et al. 2015). Model selection was performed using likelihood ratio tests and Akaike's Information Criterion (AIC). Models were considered different if AIC differed by > 2 points.

Agency-Specific Accomplishments

Kentucky Department of Fish & Wildlife Resources (KDFWR)

During 2025, KDFWR maintained and offloaded ~20 tributary and mainstem receivers located in the upper Cannelton, McAlpine, and lower Markland pools. KDFWR also assisted other project partners with offloading an additional 20+ receivers located in the furthest downstream pools of the Ohio River (Olmsted, Smithland and J.T. Myers pools). Field staff assisted the USFWS with tagging additional Silver Carp in the McAlpine Pool to replace expired and/or harvested transmitters. KDFWR also continues to maintain and offload stationary receiver sites (n = 9) in the upstream sections of the Kentucky (McAlpine Pool) and Salt (Cannelton Pool) rivers. These receivers are located up to 60 miles above the confluences of these tributaries with the Ohio River. During Spring 2025, field crews also implanted new transmitters into Silver Carp (n = 5) that were captured within the upper Salt River. The objective of this effort was to identify if the carp in this area return to the mainstem Ohio River, or if they maintain permanent residence within the Salt River. KDFWR intends to use the combination of stationary receivers and newly tagged fish to help evaluate Invasive Carp movements in the upper reaches of tributaries that directly connect the Ohio River to other valuable aquatic resources within Kentucky.

KDFWR continued to manage all data that project partners collected over the course of this reporting period. These efforts included the intensive processing of receiver data from 190+ sites in the Ohio River basin that was ultimately imported into the project's primary database (PostgreSQL), which consisted of more than 130M detection records through the end of 2024. KDFWR also maintained and updated multiple tables containing information on the project's tagged fish, stationary receiver sites, harvested tag reports and daily receiver histories. Additionally, KDFWR managed a second pgSQL database of environmental data that was collected from throughout the Ohio River Basin. Sources of this data included 60+ USGS gage stations and over a dozen temperature loggers that were deployed in conjunction with stationary receiver sites in the lower Cannelton Pool. Lastly, KDFWR compiled multiple data summaries and tables that were shared with all project partners and ultimately used to conduct most of the modeling/analysis efforts in this report.

Indiana Department of Natural Resources (INDNR)

INDNR subcontracted with ECI to complete work in the upper Wabash River evaluating movements of invasive carps in response to a dam removal. INDNR also regularly downloaded data from receivers in J.T. Myers and Newburgh pools including J.T. Myers, Newburgh, and Cannelton lock and dams. Their data were sent to KDFWR for processing. During June 2025, INDNR assisted with a tagging event in Newburgh Pool and implanted 15 Silver Carp with acoustic transmitters.

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 2024. 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 Pool, including the portion of the Kanawha River within the pool. All data were sent to KDFWR for processing and reporting. To ensure that tagged fish were present in these areas and to determine the likelihood that translocated fish would move back upstream, WVDNR collaborated with USFWS-LGL FWCO to tag seven bigheaded carps in the old lock chambers of R.C. Byrd L&D and Raccoon Creek. Three of these fish were translocated downstream of R.C. Byrd L&D to examine dam passage by translocated fish.

U.S. Fish and Wildlife (USFWS)

During 2025, USFWS, Carterville FWCO (with assistance from state and federal partners, tagged a total of 282 Silver Carps in J.T. Myers (n = 73), Newburgh (n = 101), Cannelton (n = 5), and McAlpine (n = 103) 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 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) continued maintenance of 29 VR2Tx receivers (17 at locks and dams and 12 within either mainstem or tributary locations) in R.C. Byrd, Racine, Belleville, and Willow Island pools. The substation took over the maintenance of this portion of the Ohio River Basin VR2 array from WVDNR during late fall 2022.

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

Southern Illinois University maintained 19 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 (n = 3), from its confluence with the Wabash River to 50 miles upstream. Receivers were retrieved and detections downloaded monthly when river conditions allowed. Hard mounting of receivers to trees and bridges has improved our ability to recover receivers for downloads. Tagging of 231 silver carps occurred in the Wabash and White rivers during Fall 2025.

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

Data collected from 2021 to 2023 was prepared and submitted as a manuscript entitled "Habitat Use and Selection of Silver Carp in the Lower Wabash River System" by Coy Blair, et al. The manuscript focused on fine scale habitat use, habitat selection, and relationship of habitat use to environmental variables (temperature and discharge). Analysis of telemetry detections suggested that Silver Carp selected specific habitat types, generally preferring areas of greater depth and lower flow velocity while avoiding the main channel. However, selection varied throughout the study reach, with different patterns in upstream versus downstream areas. Both temperature and discharge were useful predictors of habitat use, with logjams serving as important refuge habitat in high flow conditions and throughout the winter months. Habitat selection patterns observed through these data provide useful insights into what areas may be important for Silver Carp to become established in unregulated free-flowing river systems.

Results and Discussion:

Ohio River

Acoustic Receiver Array: During 2025, 239 receivers were deployed from Olmsted Pool (including the lower Tennessee and Cumberland rivers and the Wabash River) to Willow Island L&D. Of these, 49 were deployed at L&Ds, 45 at mainstem sites, and 145 at tributary sites (Figure 1, Table 4).

Fish Tagging Efforts: As of July 2025, 2371 invasive carps (2322 Silver and 49 Bighead) from J.T. Myers, Newburgh, Cannelton, McAlpine, Markland, Meldahl, Greenup, and R. C. Byrd pools have been surgically implanted with acoustic transmitters (Table 5). Of the 2371 tagged carps, 67 Silver Carps have been harvested during the study (June 2013 – July 2025). One-hundred eighteen Silver Carps had tags that were expected to expire during 2024 (Table 5). To replace these tags and meet the needs of partner agencies, 282 Silver Carps in J.T. Myers (n = 73), Newburgh (n = 101), Cannelton (n = 5), and McAlpine (n = 103) pools. No Bighead Carps were tagged during 2025 due to a lack of availability.

Fish Detections: During 2025, there were 1804 tags deployed in Silver Carps expected to be active in the Ohio River. Of these, 995 Silver Carps (~55%) were detected. In addition, 173 Silver Carps whose tags were beyond their expected life were also detected on the Ohio River receiver array.

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 860.3 km for Silver Carps and 58 km to 82 km for Bighead Carps during August 2024 – July 2025. The longest net movement by a Silver Carp during this time frame was completed by a female fish travelling from Meldahl Pool to the tailwaters of Barkley Lock and Dam during September 2024 – March 2025. In contrast, the longest net movement by a Bighead Carp was completed within Meldahl Pool during October 2024 – May 2025. Long-distance movements of Silver Carps were more common than in previous years with 35% of tagged Silver Carp having a maximum distance travelled of > 30 km during August 2024 – July 2025. This contrasts with the previous year during which only ~15% of Silver Carps had a maximum distance travelled of > 30 km. For Bighead Carps 40% of fish had a maximum distance travelled of > 30 km, however, given the small sample size (n = 5), these data should be interpreted cautiously.

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 June 2013 – July 2025 focused only on J.T. Myers, Newburgh, Cannelton, McAlpine, Markland, and Meldahl pools. In these pools, net movements are typically shortest during December – March and peak during April – August regardless of species or pool (Figures 3 and 4). For Silver Carp, mean monthly net movements in Markland and Meldahl pools are typically longer than those in lower pools (Figure 4). In addition, a larger proportion of tagged Silver Carp had longer annual net movements in the upper pools examined (e.g., Markland and Meldahl pools) relative to the lower pools (e.g., J.T. Myers and Newburgh pools; Figure 5).

Dam Passage: Throughout the duration of this study (June 2013 – July 2025), there have been 2638 dam passage events (1897 upstream and 741 downstream passages) (Figure 6). Dam passages were completed by 586 Silver Carps and 14 Bighead Carps. Of the upstream passages, 50 (2.6%) were completed by 10 Bighead Carps and 1847 (97.4%) were completed by 390 Silver

Carps. Seventeen downstream passages (2.3%) were completed by nine Bighead Carps, whereas 724 (97.7%) were completed by 412 Silver Carps. Additionally, in only 575 of the 2638 dam passages (21.7%) was the fish detected within the lock chamber, suggesting a high prevalence of passages through the dam gates. Of these 575 dam passages, 469 were in the downstream direction, whereas 106 were in the upstream direction. Downstream passages through the lock chambers occurred at R.C. Byrd, Meldahl, Markland, Cannelton, Newburgh, J.T. Myers, Smithland, Kentucky, and Barkley (TNCR; Olmsted Pool) L&Ds. Upstream passages through lock chambers occurred at Racine, R.C. Byrd, Cannelton, Newburgh, J.T. Myers, and Smithland.

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 are unlikely to be detected in the vicinity of the dam, making it more challenging to understand pool-to-pool movements.

Tributary Use: Throughout the study period, ~76% of detected Silver Carps have been detected in tributaries of the Ohio River whereas ~56% of these fish have been detected in mainstem Ohio River habitats (Figure 7). In addition, when Silver Carps enter tributaries, they tend to spend more time (mean ± SE = 39.6 ± 1.0 days) there than in mainstem habitats (15.5 ± 0.6 days; Figure 8).

There is at least one tributary within each pool examined (J.T. Myers – Meldahl) that was visited by ≥25% of Silver Carps detected within that pool (Figure 9). In J.T. Myers and Newburgh pools, only one tributary met this criterion, Pigeon Creek (29%) and Little Pigeon Creek (50%), respectively. In Cannelton Pool there were six tributaries that were inhabited by ≥25% of tagged Silver Carps, Deer Creek (35%), Clover Creek (32%), Sinking Creek (37%), Oil Creek (37%), the Little Blue River (30%), and the Salt River (57%; Figure 9). McAlpine and Markland pools each contained three tributaries that were inhabited by ≥25% of tagged Silver Carps, Indian-Kentuck Creek (40%), the Little Kentucky River (38%) and the Kentucky River (76%) in McAlpine Pool and Big Bone Creek (27%), Laughery Creek (76%), and Hogan Creek (42%) in Markland Pool. Lastly, in Meldahl Pool, two tributaries, Ohio Brush Creek (80%) and the Scioto River (32%) exceeded this 25% threshold. These data suggest that not only do tributaries provide important habitat for Silver Carps, but some tributaries may provide more suitable habitat or otherwise be preferred over others and should, therefore, be more closely monitored to determine if these areas can be targeted for control efforts.

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 strongly supported (Tables 1-3). Based on this hierarchical model selection process (ΔAIC_c and W_i), the final model included an invariant survival probability (S), a detection probability (p) that varied with the additive effects of pool and the number of receivers per river mile, and transition probabilities (ψ) that varied with the additive effects of pool and month. The AIC weights near 1 for each part of the hierarchical model selection process indicate little to no uncertainty in model selection.

The estimated mean probability of survival (S) did not vary spatially or temporally and was high (mean = 0.989, 95% confidence interval = 0.988 – 0.990). The estimated mean detection probabilities (p) for Silver Carp were, however, affected by the additive effect of pool and the number of receivers per river mile and increases following a sigmoidal curve such that there is typically a rapid increase in detection probability from 0 to ~0.2 receivers per river mile. The rate of increase in detection probability decreases at higher receiver densities until reaching a pool-specific asymptote (Figure 11).

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 (Figure 12). Interestingly, transition probabilities from the TNCR to the Olmsted Pool were consistently higher than those from the mainstem Ohio River. Although these results support the idea that these tributaries may act as source populations to the Ohio River Silver Carp population, it is important to note that movements from the Ohio River to this tributary may be underestimated because there has been little tagging effort in Olmsted Pools.

Within the mainstem Ohio River, transition probabilities among pools were typically low (< 0.2) with some exceptions (e.g., TNCR to Olmsted throughout the year and Smithland to Olmsted and J.T. Myers to Smithland during April-June and November-December) indicating that the probability of Silver Carps remaining within a pool was typically high (>0.8). Lastly, transition probabilities tended to higher in the downstream direction than in the upstream direction (Figure 12).

Wabash River

Fish Movement: During 2025 receivers deployed in the Wabash and White rivers detected between 18 and 222 unique tagged carp (Figure 13) and had a range of 1,230 to 71,681 detections per receiver (Table 6). The most unique fish were detected in the Wabash River at Mount Carmel, IL, and the fewest unique fish were detected on the White River at Petersburg, IN. This contrasts with previous years where the most unique fish were detected in the upper river, although this may be because lower river sites were downloaded later in the Fall, whereas upper river sites were inaccessible at this time due to low water levels. The Wabash and White rivers have presented unique challenges to passive telemetry. Under normal conditions water levels fluctuate rapidly, and the river carries a high sediment load, as well as other hazards such as downed trees. During 2025 the Wabash and White rivers experienced a record drought, dropping water levels and making the river inaccessible for much of the summer. For these reasons, recovery of receivers has been limited to when ramps and river channels are deep enough for boat access. To address these challenges, SIU has moved to hard mounting all receivers on either bridges or bank structure, usually trees, and is investigating the feasibility of small boats which can operate in low water conditions. Tree set deployment began during 2024 and has thus far improved our ability to relocate and recover receivers. These improvements provide consistent coverage of multiple sections of the Wabash River between Terre Haute and the confluence with the Ohio River.

Fine-Scale Habitat Selection (Eastern Illinois University):

During May 2025, reach-scale tracking efforts were conducted on the Wabash River with 35 individuals detected over 115 rkm tracked in the upper and middle sections of the reach between Terre Haute, IN and St. Francisville, IL. Of these 35 individuals, 23 were unknown tags. Upon further investigation, it was determined that 15 of these individuals were silver carp tagged in other systems within the greater Ohio and Mississippi river basins (Figure 14). Seven individuals were tagged in Pickwick Lake, located in southern Tennessee, between 2021-2024 and were detected in the Wabash up to 774 rkm away from release location. Three individuals tagged upstream of Barkley Lock and Dam between 2022 and 2024 traveled up to 480 rkm. Another individual tagged in the Tennessee portion of Lake Barkley/Cumberland River during 2022 traveled 531 rkm. Two individuals tagged in the Lower Tennessee River in Kentucky during 2020 and 2023 traveled up to 444 rkm. One individual, captured in Reelfoot Lake in northwest Tennessee was tagged and translocated below the lake's spillway during 2024 travelled 673 rkm (32 rkm Running Reelfoot Bayou -> 44 rkm Obion river -> 215 rkm Mississippi River -> 210 rkm Ohio River -> 172 rkm Wabash River). None of these individuals were re-detected in the Wabash later in the 2025 sampling period. The remaining eight unknown fish could not be identified. During the same month, one Silver Carp tagged during 2021 was detected in the upper section of the reach near Darwin, IL. Prior to this detection, this fish had only been detected at its tagging location near New Harmony, IN with two distinct occurrences during 2022 and three occurrences during 2024. This individual was later found to have returned 218 rkm downstream to New Harmony in July 2025, suggesting some individuals in the Wabash River may exhibit seasonal homing behaviors following spawning migrations.

During June, three reach-scale tracks were conducted covering 115 rkm in the middle and lower sections of the reach between Crawleyville, IN and Harmony Hills, IN. Only two detections were made across these tracks, however, the river rose to action stage during this time, which may have negatively impacted tracking efficiency. During July, reach-scale tracks covered the remainder of the accessible sections within the active tracking reach from New Harmony, IN to the confluence with the Ohio River on the Wabash (63 rkm) and from Hazleton, IN to the confluence with the Wabash in Mt. Carmel, IL (32 rkm). Fifteen detections were made across these tracks. During August, upper sections of the reach were revisited covering 42 rkm between Hutsonville, IL and Vincennes, IN producing 15 detections. Interestingly, although none of the previous unknown individuals from May were re-detected, a new unknown individual, later identified as a Silver Carp tagged in Pickwick Lake during 2024, was detected just downstream of Merom, IN. It is unclear whether this individual traveled upstream with the other migrants in the spring and decided to join the resident Wabash population or if it was a newer arrival in the system.

Additional tracks were made during October and November. October consisted of two reach-scale tracks between Hutsonville, IL and Vincennes, IN spanning 34 rkm. Thirty-seven individuals were detected on these tracks, with a large aggregation of 17 tagged Silver Carp occurring near Vincennes just downstream of the boat ramp. The November track served as methods testing for potential future diel acoustic tracking studies. Three passes were made over the same approximately 2.4 rkm stretch throughout the day to observe fine-scale movement between habitats. Preliminary results found little daytime movement observed between habitat types.

Invasive carp movement and distribution following dam removal

A total of 116 Silver Carp were located and identified through the acoustic receivers installed in the Wabash River, Tippecanoe River, Eel River, and Mississinewa River from 2022 through 2025. A Silver Carp was detected near the confluence of Salamonie River and Wabash River for the first time during 2025. Fish detected were tagged over twelve separate tagging events. Multiple Silver Carp tagged in the Cumberland River, near Cheatham Dam were detected on multiple receivers in the Upper Wabash River Basin. There were also 21 Silver Carp detected in the Upper Wabash River that were tagged in the Lower Wabash River near the towns of Hutsonville, Illinois, Merom, Indiana, and New Harmony, Indiana. The fish tagged at these locations traveled 150 miles, 158 miles, and 267 miles, respectively to be detected at the most downstream receiver in the array which was installed in the Wabash River Downstream of the Tippecanoe River. No Bighead Carp or Grass Carp were detected.

There was a total of 12,536 detections of Silver Carp in 2022, 14,878 detections in 2023, and 12,496 detections in 2024, and 10,659 detections in 2025. The receiver installed in the Wabash River upstream of the Eel River accounted for 46% of the detections during 2022, 62% during 2023, 36% during 2024, and 31% during 2025. The majority of detections at this receiver occurred during the fall and winter of each year (Figure 15).

The receiver in the Wabash River upstream of the Mississinewa River accounted for 30% of total detections during 2025. This is the first time during the study period that this receiver had a high detection rate. Spring, summer, and fall had similar number of detections at this receiver, but winter had few detections when compared to the other three seasons.

The receivers at the Wabash River upstream and downstream of the Tippecanoe River and the Tippecanoe River mainstem had the highest number of Silver Carp detected of any other group of receivers during 2023, 2024, 2025. This was especially pronounced during the spring of 2023 and 2024 and, to a lesser extent, spring 2025 (Figure 16). Seasonal changes in the number of Silver Carp detected were not as pronounced further up the Upper Wabash River but the receiver in the Wabash River Downstream of the Mississinewa River did show a similar trend as the receivers in and around the Tippecanoe River where the number of Silver Carp detected was highest during the spring and decreased in each subsequent season during 2025.

The results of the LMM on distance traveled showed that season, movement direction, and to a lesser extent, water temperature were significant factors in determining travel distance in Silver Carp in the upper Wabash River (Table 7). These effects were particularly pronounced in the spring and summer where upstream movements were 120% longer and 39% longer, respectively, than downstream movements (Figure 17). Silver Carp migrated downstream during fall with upstream movements being 51% shorter than downstream movements. Silver Carp were found to move 2% further with every 1°C increase in water temperature. Carp were mostly sedentary (99.9% of detections were sedentary) during winter so no statistically meaningful conclusions could be made about movement distance during winter.

The model on movement direction had similar findings to the model on movement distance. Water temperature was a significant factor in determining if a Silver Carp were to move with each 1°C increase in water temperature increasing the odds of upstream movement by 6%. Fall was the only season to show downstream movement, with 95% lower odds of upstream movement when compared to winter (Figure 18). Odds of upstream movement in spring and summer were not significantly different from odds in winter when controlled for water temperature, suggesting that water temperature is the key indicator for upstream migration for Silver Carp.

Recommendations:

Despite the expansion of the receiver array in Cannelton Pool during 2023 which was implemented to better understand tributary vs mainstem habitat use, 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 nine mainstem receivers in the upper portion of Olmsted Pool and six receivers primarily near locks and dams in 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?). In addition, broader spatial coverage in areas of low invasive carp density (i.e., upstream of Meldahl Pool) would help agencies understand the distribution of invasive carps in these areas and allocate removal efforts more efficiently. Accomplishing this may require the reallocation of some receivers in the upper pools or from lower pools to upper pools to increase spatial coverage in areas of low Silver Carp density.

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.

Although there are currently 23 active receivers deployed in the White and Wabash rivers, low waters and siltation have resulted in low levels of success in retrieving these receivers, especially during summer and fall conditions. Despite these challenges, the data collected in the Wabash and White rivers have been used to improve our understanding of the movements and habitat use of bigheaded carps in this river system. Given the high costs associated with this work, however, it is recommended that the receivers in the Wabash River be reallocated such that there are a few receivers positioned to detect movement between the mainstem Ohio River and the Wabash River.

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.

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.

References:

Bates, D., M. Mächler, B. Bolker, and S. Walker. 2015. Fitting linear mixed-effects models using lme4. Journal of Statistical Software 67:1–48.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach2nd ed. Springer, New York.

Burr, B. M., D. J. Eisenhour, K. M. Cook, C. A. Taylor, G. L. Seegert, R. W. Sauer, and E. R. Atwood. 1996. Nonnative Fishes in Illinois Waters: What Do the Records Reveal? Transactions of the Illinois State Academy of Science 89(2):73–91.

Camacho, C. A., C. J. Sullivan, M. J. Weber, and C. L. Pierce. 2020. Invasive Carp Reproduction Phenology in Tributaries of the Upper Mississippi River. North American Journal of Fisheries Management:1–13.

Collins, S. F., and D. H. Wahl. 2017. Invasive planktivores as mediators of organic matter exchanges within and across ecosystems. Oecologia 184(2):521–530.

Cooch, E. G., and G. C. White, editors. 2008. Program MARK A Gentle Introduction.

DeGrandchamp, K. L., J. E. Garvey, and R. E. Colombo. 2008. Movement and Habitat Selection by Invasive Asian Carps in a Large River. Transactions of the American Fisheries Society 137(1):45–56.

Doherty, P. F., G. C. White, and K. P. Burnham. 2012. Comparison of model building and selection strategies. Journal of Ornithology 152(S2):317–323.

Freeze, M., and S. Henderson. 1982. Distribution and Status of the Bighead Carp and Silver Carp in Arkansas. North American Journal of Fisheries Management 2(2):197–200.

Garvey, J. E., K. L. DeGrandchamp, and C. J. Williamson. 2006. Life history attributes of Asian carps in the Upper Mississippi River System. ANSRP Technical Notes Collection (ERDC/EL ANSRP-07-1), U.S. Army Corps of Engineer Research and Development Center. Vicksburg, MS.

Jennings, D. P. 1988. Bighead Carp (*Hypophthalmichthys nobilis*): A Biological Synopsis. Page 35pp. U.S. Fish and Wildlife Service, Biological Report 88(29).

Laake, J. L. 2013. RMark: An R interface for analysis of capture-recapture data with MARK. Page AFSC Processed Rep. 2013-01, 25 p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 7600 Sand Point Way NE, Seattle WA 98115.

Lenaerts, A. W., A. A. Coulter, K. S. Irons, and J. T. Lamer. 2021. Plasticity in Reproductive Potential of Bigheaded Carp along an Invasion Front. North American Journal of Fisheries Management:10.1002/nafm.10583.

Peters, L. M., M. A. Pegg, and U. G. Reinhardt. 2006. Movements of Adult Radio-Tagged Bighead Carp in the Illinois River. Transactions of the American Fisheries Society 135(5):1205–1212.

Pimentel, D., L. Lach, R. Zuniga, and D. Morrison. 2000. Environmental and economic costs of nonindigenous species in the United States. BioScience 50(1):53–65.

Pimentel, D., R. Zuniga, and D. Morrison. 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecological Economics 52(3 SPEC. ISS.):273–288.

R Core Team. 2024. R: A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, Austria.

Robison, H. W., and T. M. Buchanan. 1988. Fishes of Arkansas. University of Arkansas Press, Fayetteville.

Sass, G. G., C. Hinz, A. C. Erickson, N. N. McClelland, M. A. McClelland, and J. M. Epifanio. 2014. Invasive bighead and silver carp effects on zooplankton communities in the Illinois River, Illinois, USA. Journal of Great Lakes Research 40(4):911–921.

Schaick, S. J., C. J. Moody-Carpenter, E. L. Effert-Fanta, K. N. Hanser, D. R. Roth, and R. E. Colombo. 2020. Bigheaded Carp Spatial Reproductive Dynamics in Illinois and Wabash River Tributaries. North American Journal of Fisheries Management:1–11.

Tables

Table 1. 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 that converged 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**	**AICc**	**ΔAICc**	**weight**
S(.) p(pool) Psi(pool)	32	246807.2	0	0.91
S(season) p(pool) Psi(pool)	35	246811.8	4.5	0.09
S(pool + season) p(pool) Psi(pool)	45	248825.4	2018.2	0
S(month) p(pool) Psi(pool)	43	248833.8	2026.6	0
S(pool + month) p(pool) Psi(pool)	53	248881.9	2074.7	0
S(pool) p(pool) Psi(pool)	42	248935.2	2127.9	0

Table 2. 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), median standardized gage height (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 month effect for *S* (the best supported model structure) and a pool effect for ψ.

Model	npar	AICc	ΔAICc	weight
S(.) p(pool + rprm) Psi(pool)	33	242526.4	0	1
S(.) p(pool + num_rec) Psi(pool)	33	243024.8	498.4	0
S(.) p(rprm) Psi(pool)	23	246119	3592.6	0
S(.) p(pool + month) Psi(pool)	43	246250.5	3724.1	0
S(.) p(pool + season) Psi(pool)	35	246428.3	3902.0	0
S(.) p(num_rec) Psi(pool)	23	246567.5	4041.1	0
*S(.) p(pool * month) Psi(pool)*	153	246796.1	4269.7	0
S(.) p(pool) Psi(pool)	32	246807.2	4280.9	0
*S(.) p(pool * season) Psi(pool)*	65	247363.2	4836.9	0
S(.) p(month) Psi(pool)	33	258034.4	15508.0	0
S(.) p(season) Psi(pool)	25	258322.7	15796.3	0
S(.) p(.) Psi(pool)	22	259014.4	16488.1	0

Table 3. 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 that converged for transition probabilities. The covariates affecting estimates of the transition probabilities are shown in parentheses and include median standardized gage height (height), month, the number of open river days per month (ord), and pool. The model structures for survival (*S*) and detection (*p*) probabilities were held constant and included only a month effect for *S* and the additive effect of pool and number of receivers (num_rec) for *p*.

Model	**npar**	**AICc**	**ΔAICc**	**weight**
S(.) p(pool + rprm) Psi(pool + month)	45	242508.9	0	1
S(.) p(pool + rprm) Psi(pool)	33	242526.4	17.5	0
S(.) p(pool + rprm) Psi(pool + season)	37	242659.5	150.6	0
S(.) p(pool + rprm) Psi(month)	25	244333.5	1824.6	0
S(.) p(pool + rprm) Psi(season)	17	244349.1	1840.2	0
S(.) p(pool + rprm) Psi(.)	14	244389.1	1880.2	0

Table 4. Number and distribution of VR2 receivers in the Ohio River and three major tributaries, the Wabash River and the Tennessee/Cumberland rivers (TNCR), during 2025. Two-hundred thirty-nine receivers were deployed from Olmsted pool, downstream of the Smithland lock and dam, to Willow Island lock and dam.

Ohio River Pool/River	Pool/River Length (km)	Lock and Dam Receivers (N)	Mainstem Receivers (N)	Tributary Receivers (N)	Total Receivers (N)
Olmsted	73.9	3	4	3	10
TNCR	222.2	12	5	28	45
Smithland	116.7	4	2	0	6
Wabash	344.5	0	0	24	24
J.T. Myers	112.5	3	2	10	15
Newburgh	89.2	4	0	8	12
Cannelton	183.4	1	11	38	50
McAlpine	121.2	3	4	6	13
Markland	153.4	0	2	6	8
Meldahl	153.3	3	4	4	11
Greenup	99.5	3	4	2	9
R.C. Byrd	67.1	4	5	12	21
Racine	54.1	4	1	3	8
Belleville	67.9	4	1	1	6
Willow Island	56.8	1	0	0	1
Total	NA	49	45	145	239

Table 5. The number of Silver and Bighead Carps tagged with acoustic transmitters by year and pool during June 2013 – December 2024. 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 > 4 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 2023	Species	Ohio River Pool								Total
			J.T. Myers	Newburgh	Cannelton	McAlpine	Markland	Meldahl	Greenup	R.C. Byrd	
2013-2019	Inactive	SVCP	-	-	182 (10)	256 (5)	49 (1)	34	-	-	521
		BHCP	-	-	4	7	11	21	-	3	46
2020	Active	SVCP	-	-	-	100	18	-	-	-	118
2021	Active	SVCP	226 (1)	230	92 (5)	97 (2)	3	-	-	-	648
2022	Active	SVCP	(2)	(1)	109 (5)	-	29	-	-	-	138
2023	Active	SVCP	-	-	(7)	-	54(1)	30	-	-	84
		BHCP					1				1
2024	Active	SVCP	124	92 (1)	200 (4)	110 (2)	-	(1)	-	-	526
2025	Active	SVCP	73	101	5 (6)	103	-	-	3	2	287
		BHCP	-	-	-	-	-	-	-	2	2
2020-2025	Active	SVCP	423	423	406	410	104	30	3	2	1,801
		BHCP	-	-	-	-	1	-	-	2	3
2013-2019 (Including harvested)	Inactive	SVCP	-	-	182	256	49	34	-	-	521
		BHCP			4	7	11	21	-	3	46
		Overall	-	-	186	263	60	55	-	3	564
% Species Composition	Active	SVCP BHCP	23.448	23.448	22.506	22.727	5.820	1.663	0.166	0.222	100
Mean TL (mm)	Combined	SVCP	712.3	727.9	787.5	827.0	893.8	949.0	988.3	946	612.2
		BHCP	-	-	1139.8	1146.3	1132.5	1153.6	-	1171.4	1148.7

Table 6. Summary of detections from the 13 successfully recovered receivers in 2025.

Receiver	Unique fish detected	Total number of unfiltered detections	Location
VR2W-138902	151	18,543	New Haven 1
VR2W-138891	68	7,409	New Haven 2
VR2W-138901	48	1,610	New Haven 3
VR2W-138913	90	1,230	New Harmony State Park
VR2W-138903	28	3,094	New Harmony Boat Ramp
VR2W-100200	204	32,772	Grayville
VR2W-125867	222	36,202	Mt. Carmel (Wabash River)
VR2W-138912	202	48,828	St. Francisville
VR2Tx-486769	124	20,247	Hutsonville
VR2Tx-491680	112	8,779	1-70 Bridge
VR2Tx-486794	165	71,681	Terre Haute
VR2W-138898	218	11,540	Mt. Carmel (White River)
VR2W-138911	18	4,460	Petersburg (White River)

Table 7. Coefficients, standard error, and resulting p-values for each term in the linear mixed model where natural log-transformed distance traveled is the response variable. Significance was determined using an α-level of 0.05.

Parameter	Estimate	Standard Error	P-Value
Intercept (Winter x Dowstream)	1.875	0.375	<0.001
Spring	-0.995	0.414	0.017
Summer	-0.907	0.458	0.048
Fall	-0.344	0.43	0.423
Winter x Upstream	-0.957	0.592	0.107
Spring x Upstream	0.785	0.608	0.004
Summer x Upstream	0.326	0.611	0.036
Fall x Upstream	-0.707	0.702	0.722
Temperature	0.021	0.011	0.068

Figures

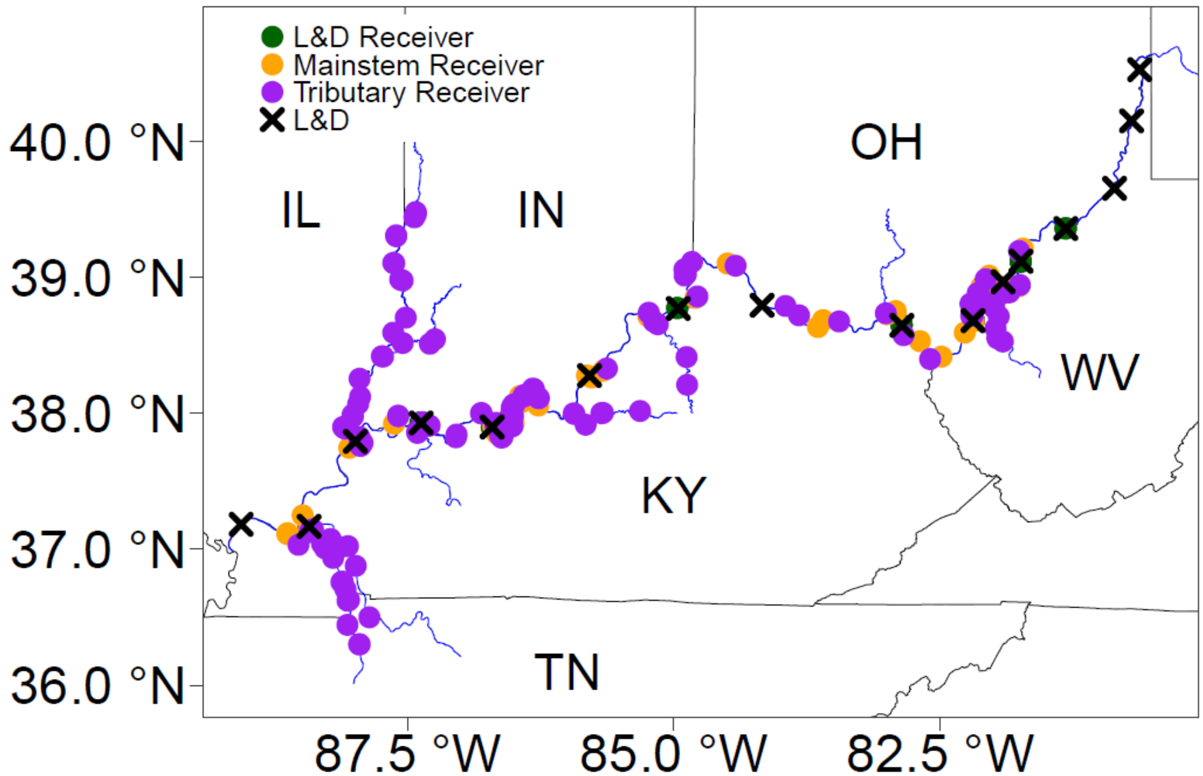

Figure 1. Locations of mainstem Ohio River Lock and Dam structures (L&D; black crosses) and acoustic receivers deployed at L&D structures (green circles), in the mainstem (orange circles), and tributaries (purple circles) of the Ohio River during 2025. Map shows the Ohio River and some of its major tributaries (blue) from the confluence of the Ohio and Mississippi rivers 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).

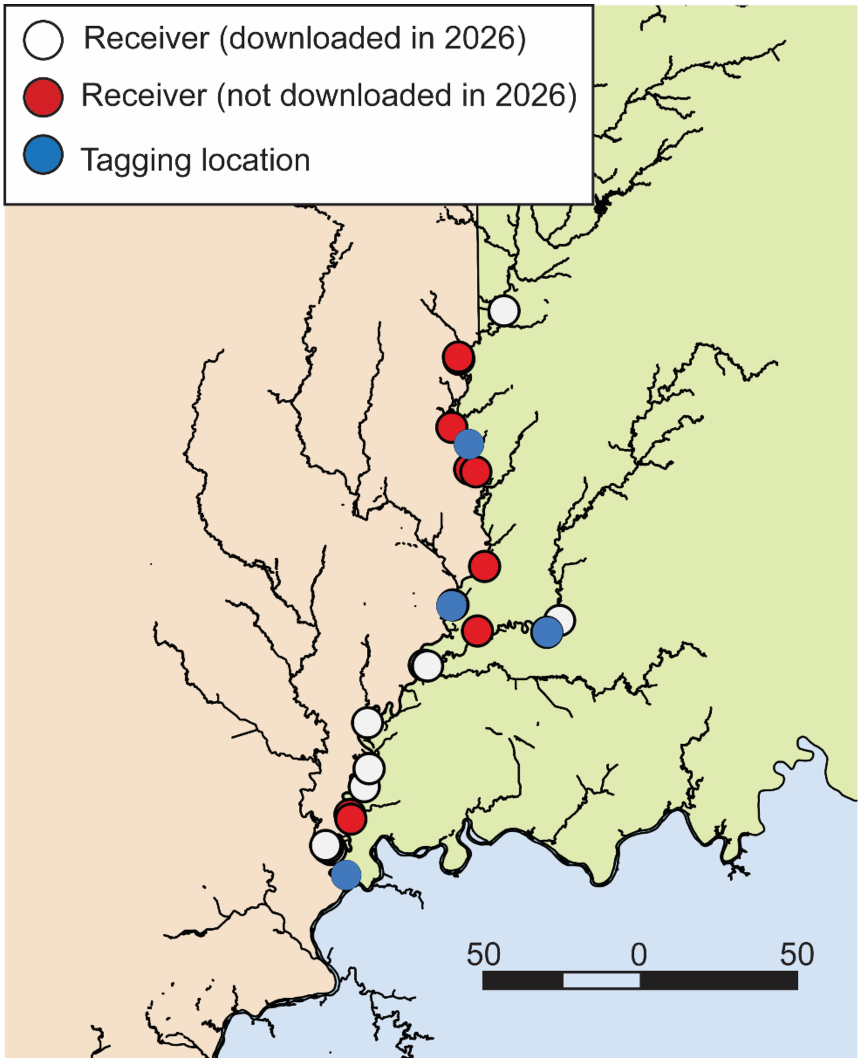

Figure 2 Map of tagging locations (blue), receivers that were successfully downloaded during 2025 (white) and existing receivers that were not downloaded during 2025 due to river conditions (red).

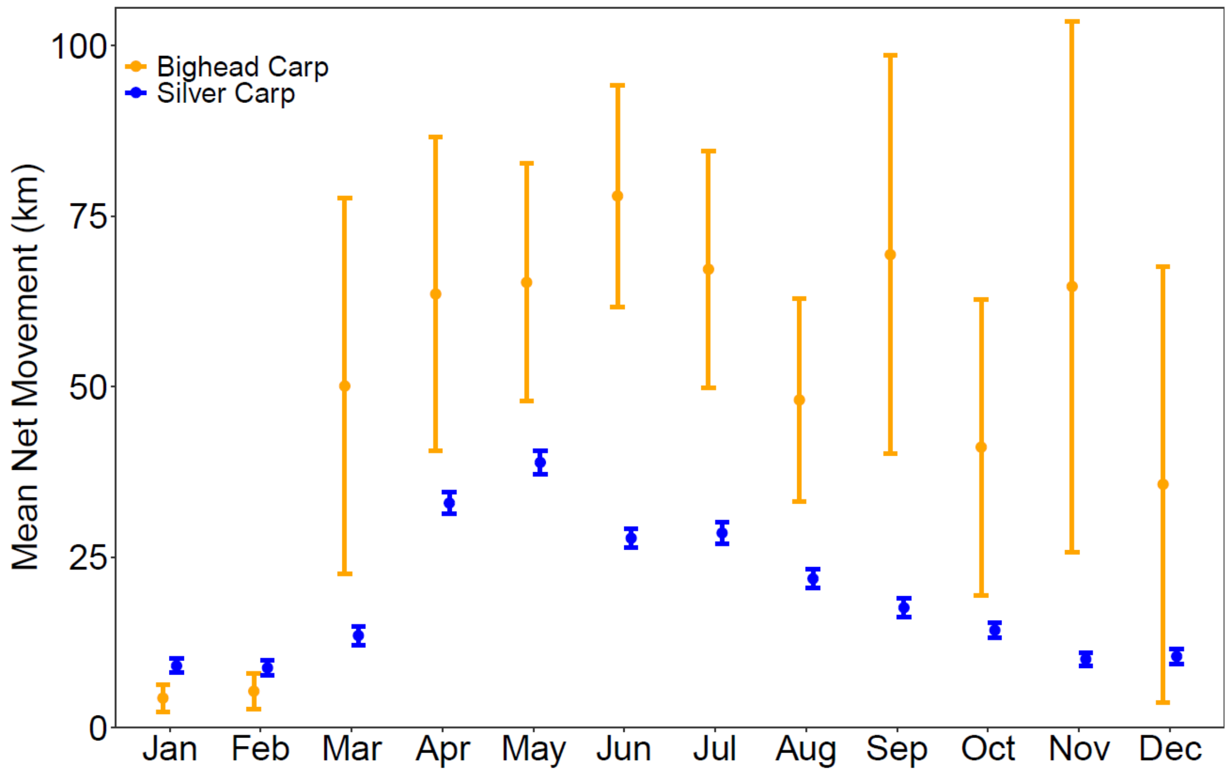

Figure 3. The mean monthly net movements (kilometers) between the most upstream and downstream detections for tagged Silver Carp (blue) and Bighead Carp (orange) in J.T. Myers, Newburgh, Cannelton, McAlpine, Markland, and Meldahl pools during June 2013 – July 2025. Error bars represent standard error. Only tagged carp detected ≥ 2 times during a month were included in distance calculations.

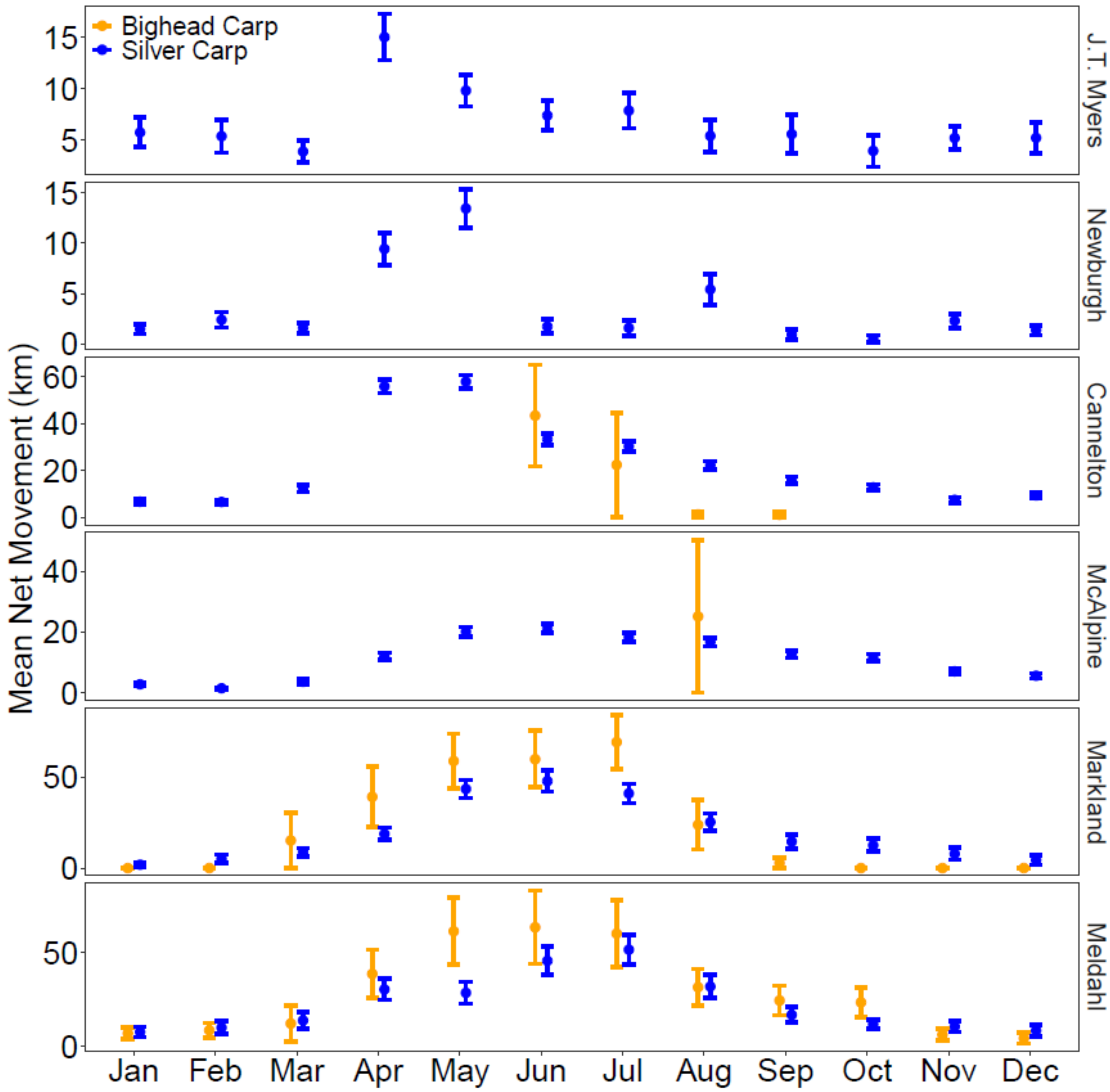

Figure 4. The mean monthly net movements (kilometers) between the most upstream and downstream detections for tagged Silver Carp (blue) and Bighead Carp (orange) by pool in the six most active pools of the telemetry project (J.T. Myers, Newburgh, Cannelton, McAlpine, Markland, and Meldahl pools) during June 2013 – July 2025. Error bars represent standard error. Only tagged carp detected ≥ 2 times within a single pool each month were included in distance calculations.

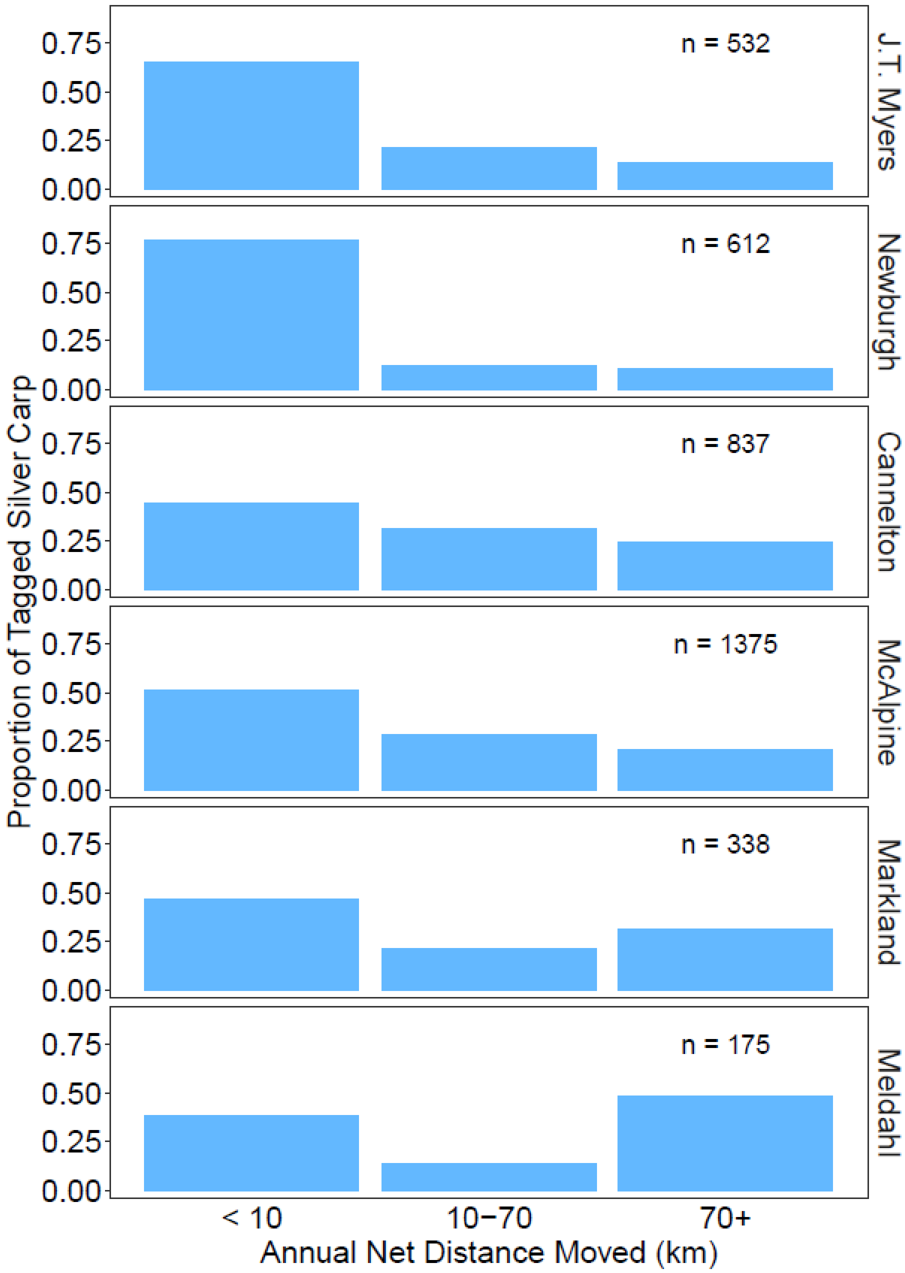

Figure 5. The proportion of tagged Silver Carp with annual net movements of < 10, 10-70, or 70+ km for each pool from J.T. Myers to Meldahl pools (top to bottom) during 2014-2024 (complete sampling years). The number of individuals included in the summarization for each pool is included in the top-right corner of each panel.

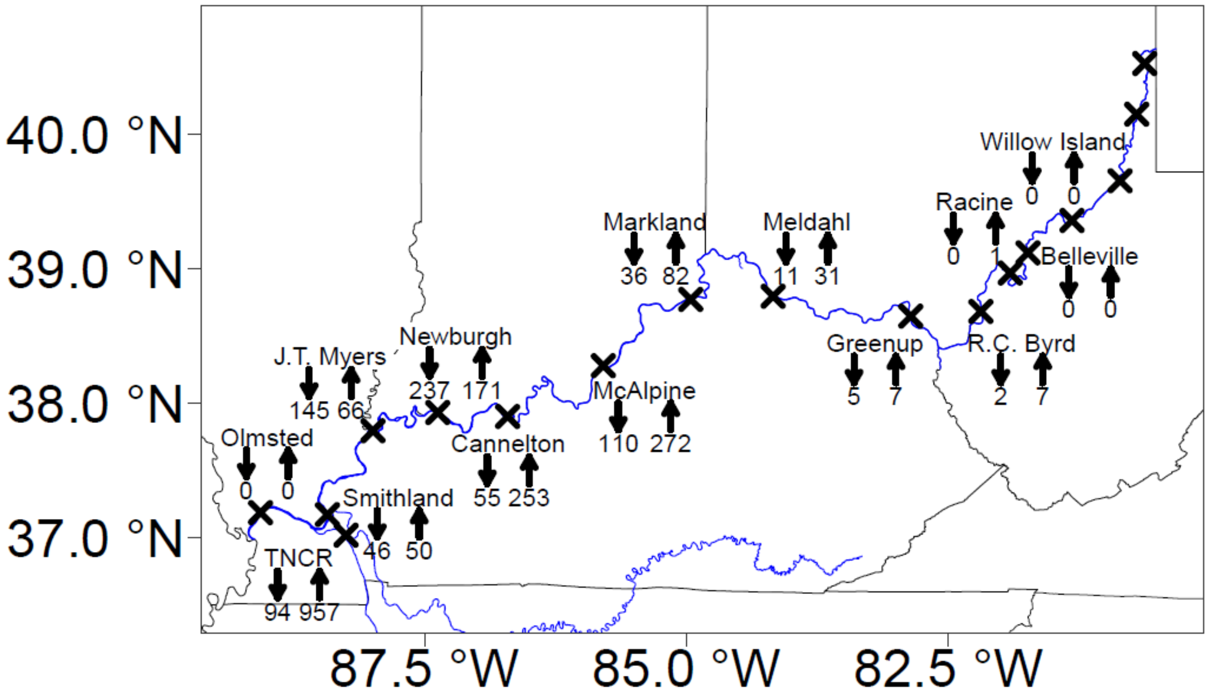

Figure 6. Total number of downstream (↓) and upstream (↑) lock and dam (L&D) passages by invasive carps during June 2013 – July 2025. Map shows passages from Olmsted L&D (river mile 964.4) near the confluence of the Ohio and Mississippi rivers to Willow Island L&D (river mile 161.7) which is the most upstream location at which acoustic receivers were deployed.

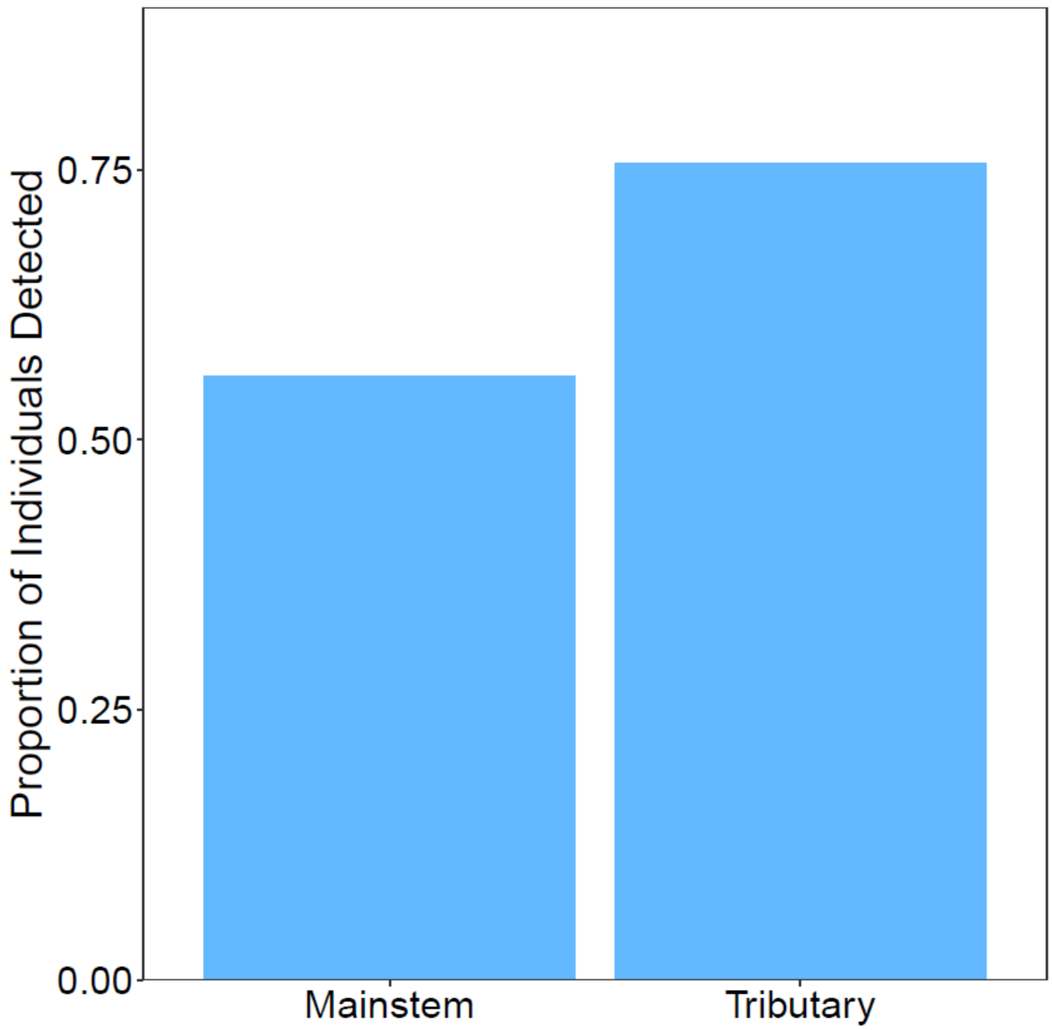

Figure 7. The proportion of individual Silver Carp detected in mainstem and tributary habitats during June 2013 – July 2025.

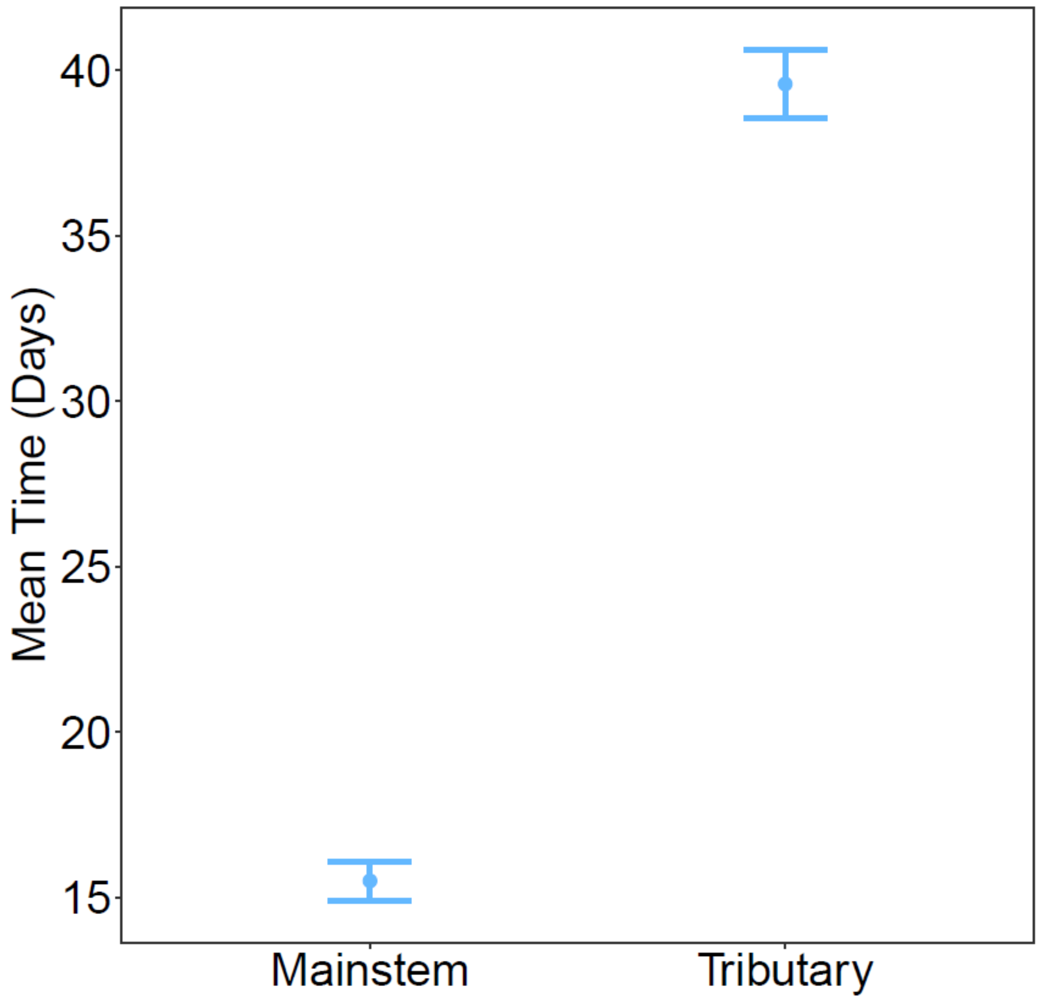

Figure 8. The mean time (days) spent in mainstem or tributary habitat for Silver Carps during June 2013 – July 2025. The number of days represents the time from the first detection of an individual in either the mainstem of the Ohio River or one of its tributaries to the first detection outside of that habitat.

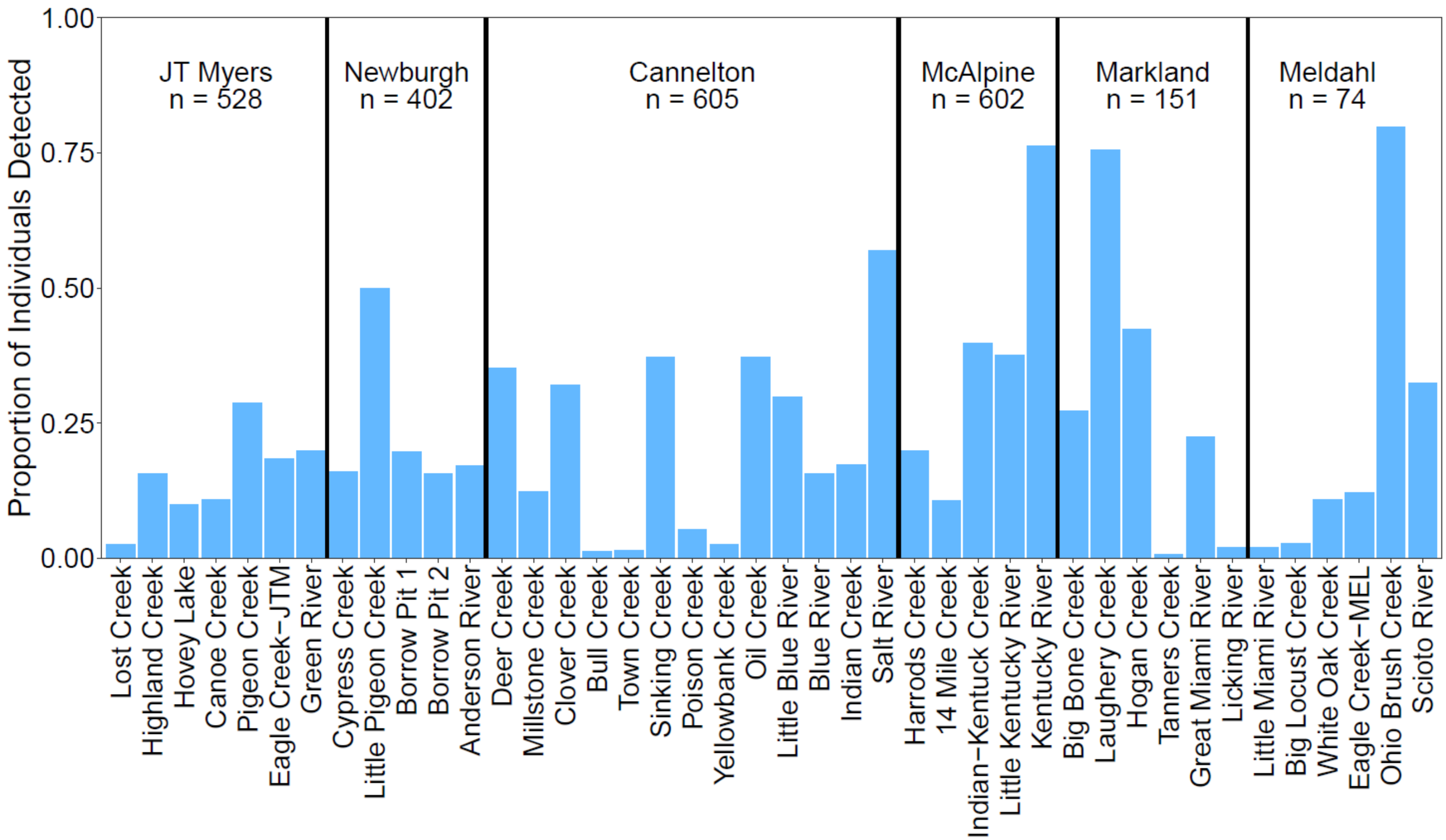

Figure 10. The proportion of individual Silver Carp in each pool that were detected in tributaries of those pools during June 2013 – July 2025. Numbers represent individual fish detected within that pool and the vertical lines are used to separate pools from most downstream to most upstream.

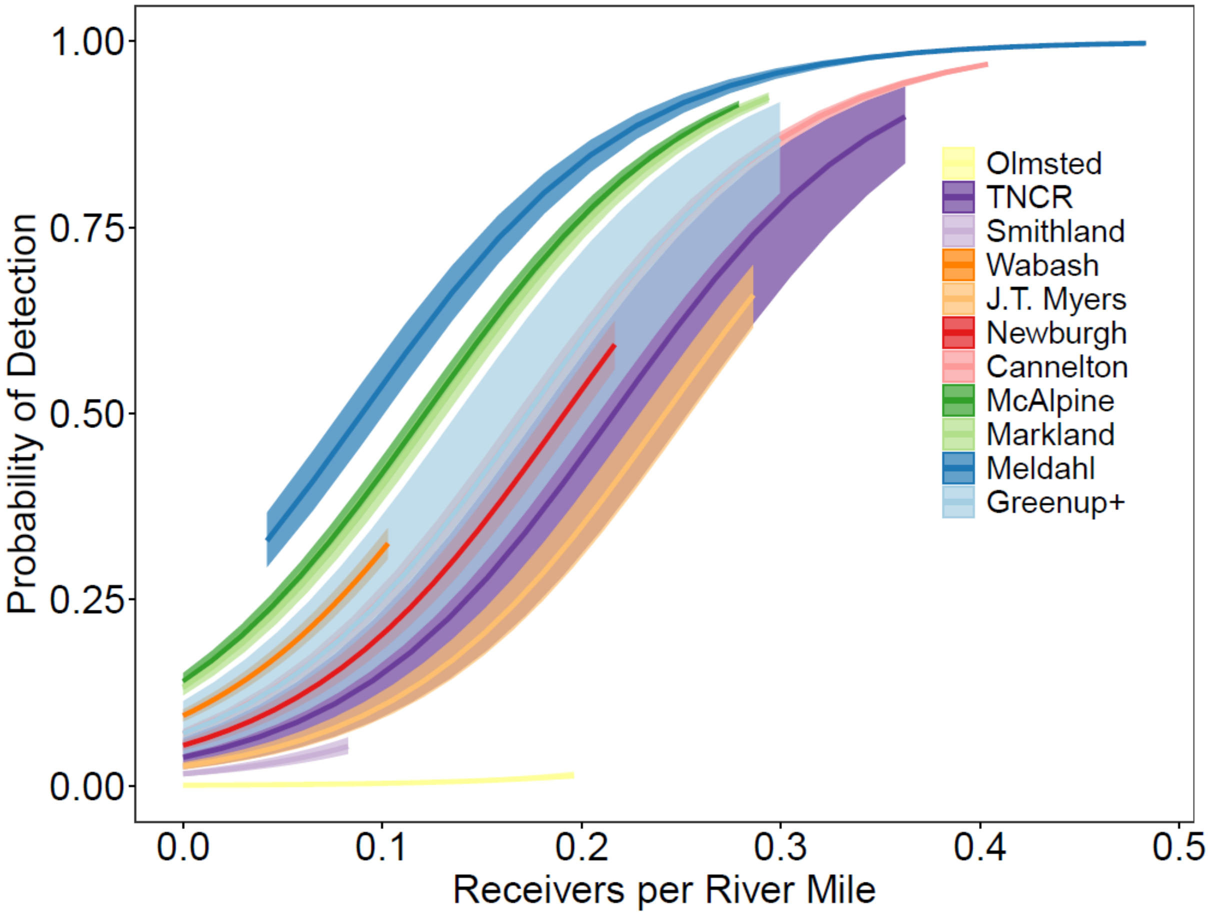

Figure 11. The effect of the number of receivers per river mile on the probability of detection (p) of Silver Carps in nine Ohio River pools, the Wabash River, and the Tennessee/Cumberland rivers (TNCR) during 2014-2025. The solid lines represent the mean probabilities of detection for each pool, whereas shaded areas represent the 95% confidence intervals surrounding those mean detection probabilities.

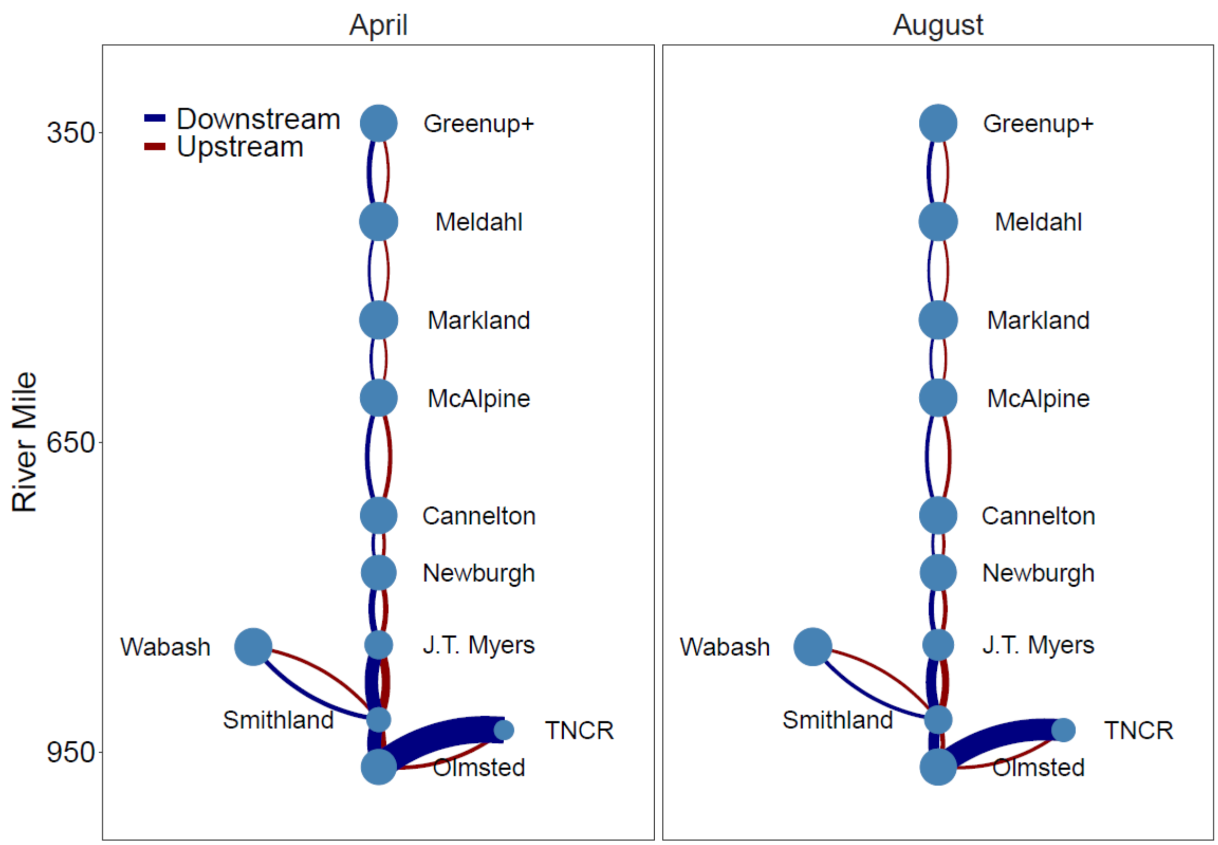

Figure 12. Mean estimated transition probabilities (ψ) among pools and river systems within the Ohio River Basin for April and August. Red lines indicate upstream transition probabilities, whereas blue lines denote downstream transition probabilities. Line thickness is proportional to the transition probability from one area to another. Blue points represent each pool or river and their size is proportional to the probability that Silver Carp remain within that pool during a month. Plots for other months are available from USFWS, CAR FWCO.

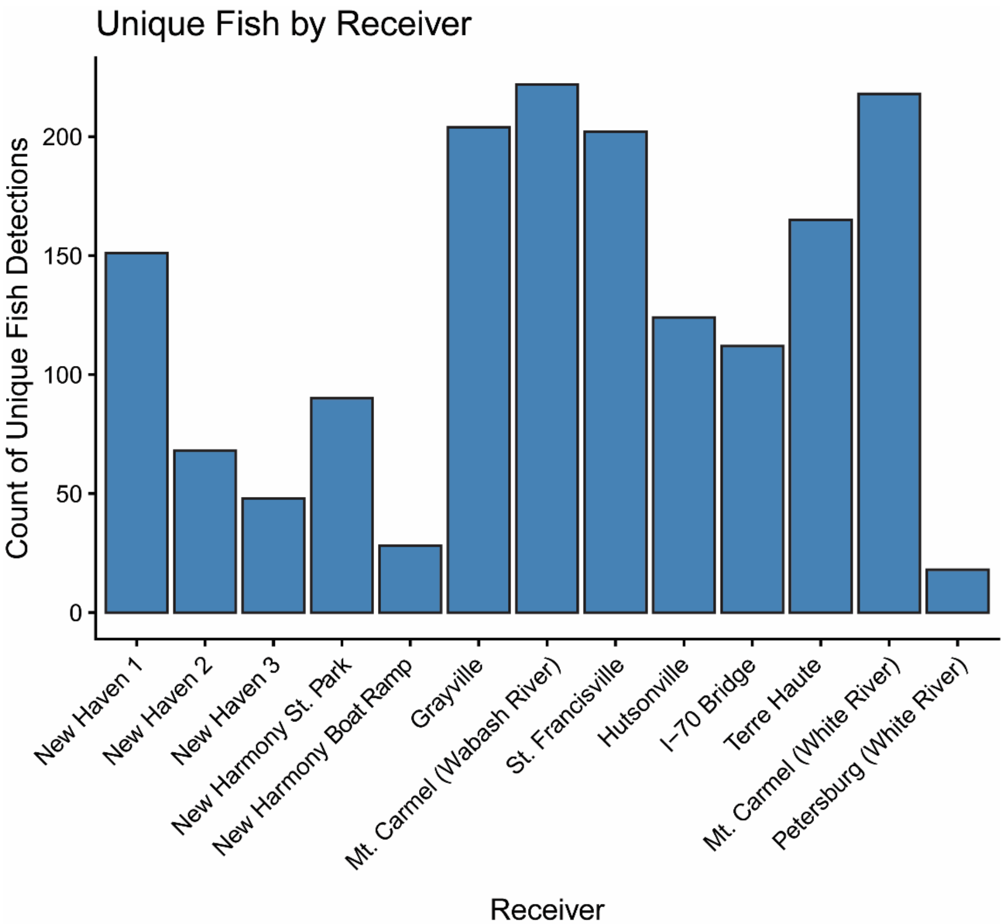

Figure 13. Number of unique fish detections by receiver during 2025.

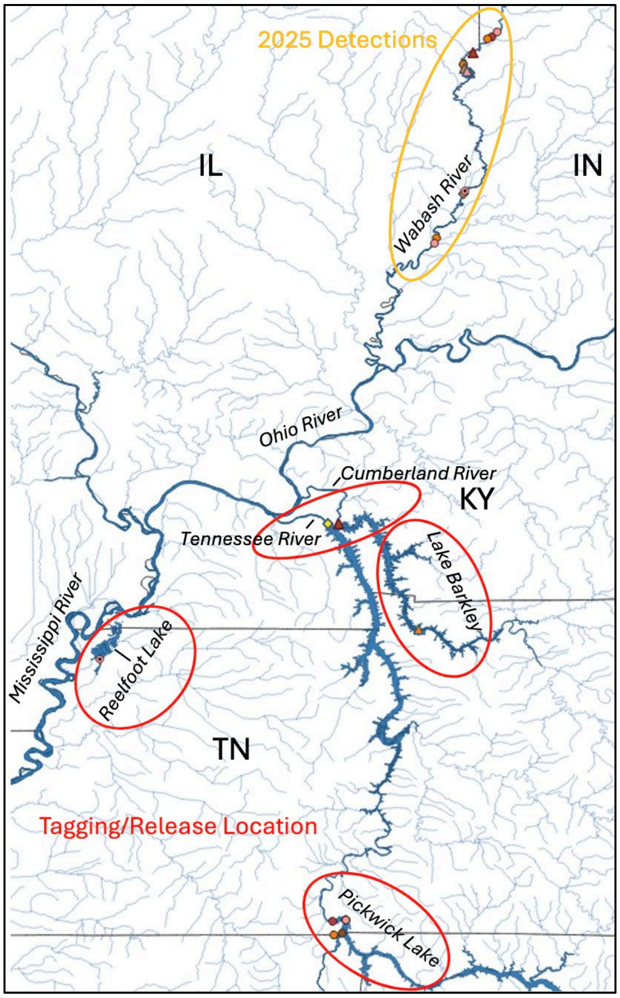

Figure 14. Map of unknown individual detections made during May 2025 (yellow oval) and their origins (red ovals).

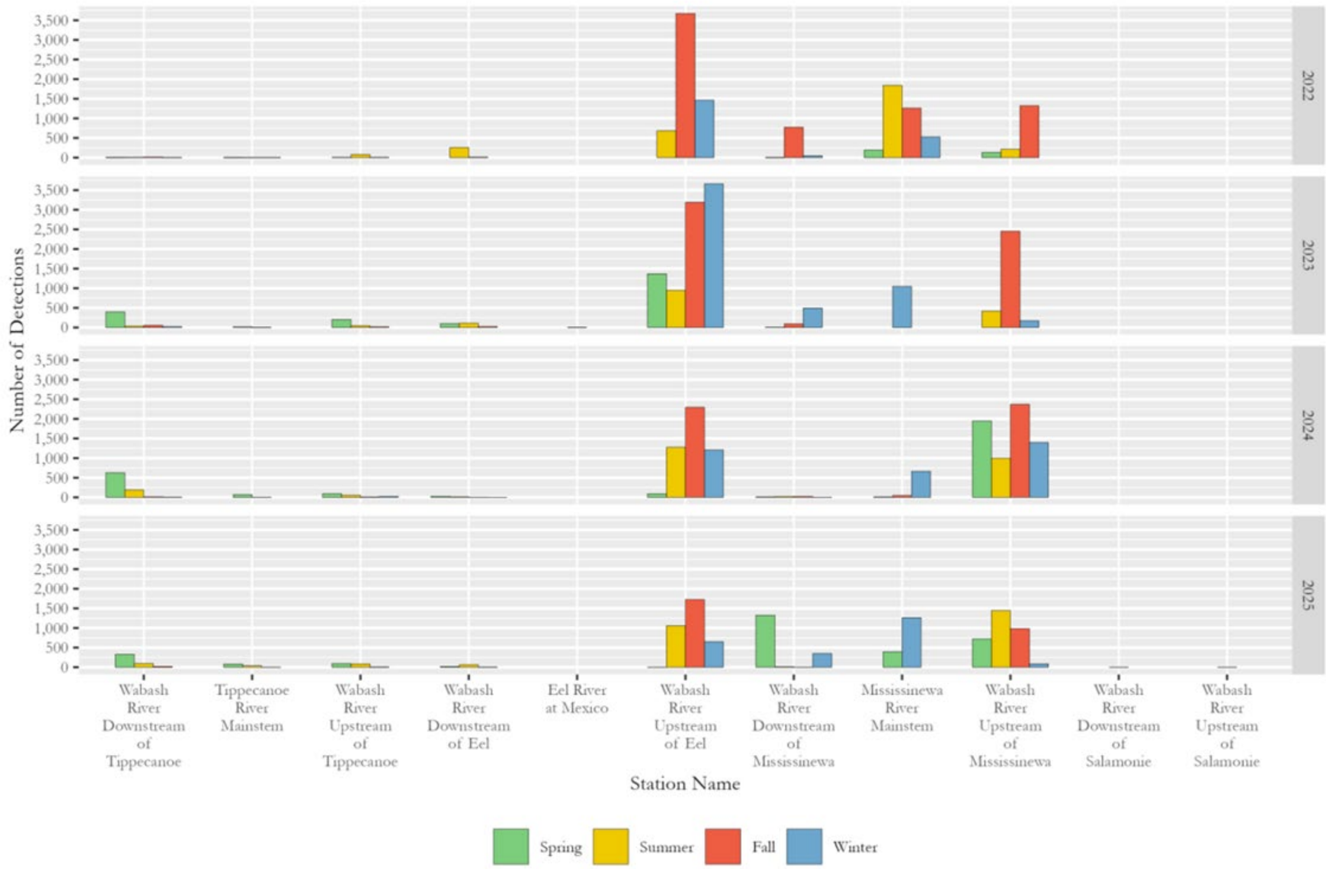

Figure 15. Number of detections of tagged Silver Carp at each receiver location during spring (March-May; green), summer (June-August; yellow), fall (September-November; red), and winter (December-February; blue) during 2022 to 2025. No Silver Carp have been detected in the Salamonie River. Data collected during May 2022 (initial receiver deployment) through December 2025 were used for this analysis.

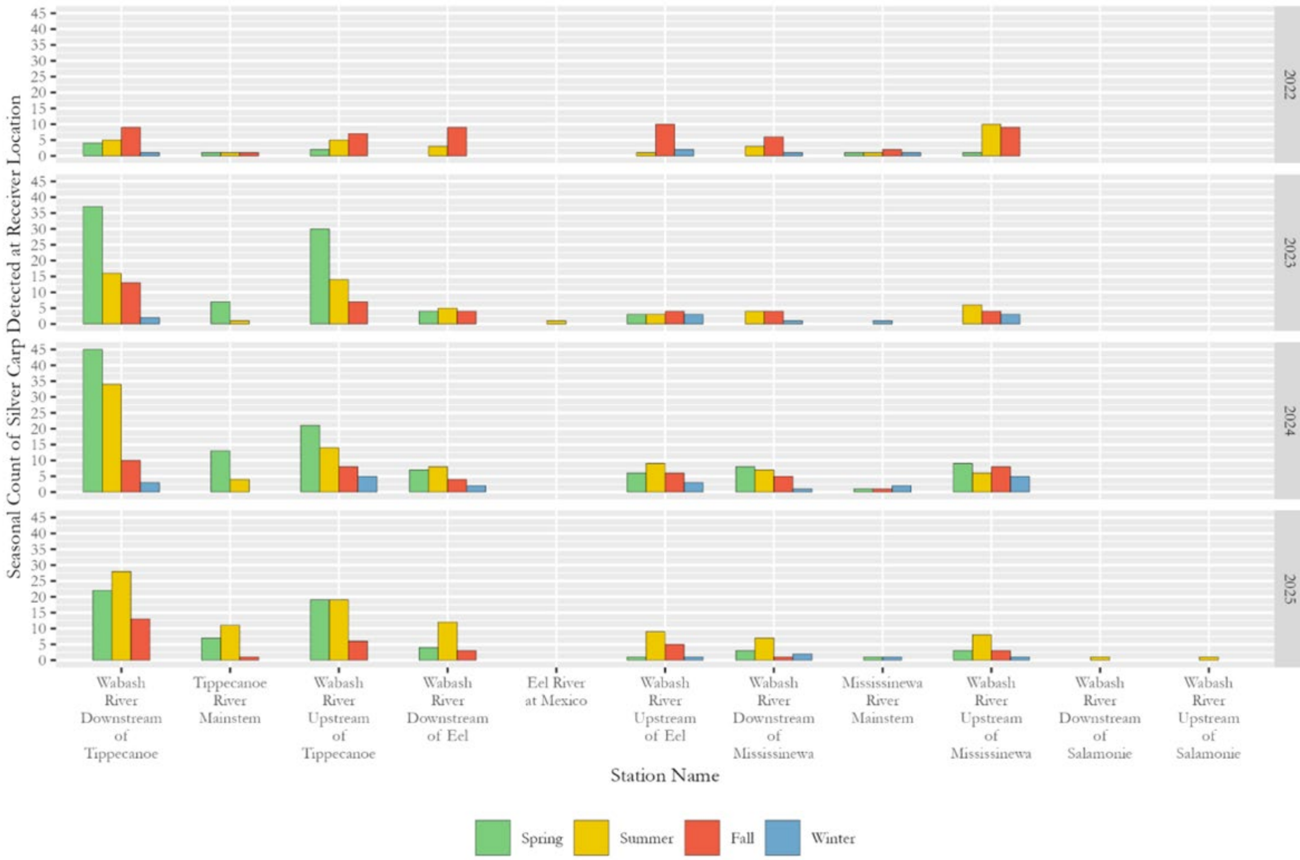

Figure 16. Number of Silver Carp detected at each receiver location during spring (March-May; green), summer (June-August; yellow), fall (September-November; red), and winter (December-February; blue) during 2022 to 2025. No Silver Carp have been detected in the Salamonie River. Data collected during May 2022 (initial receiver deployment) through December 2025 were used for this analysis.

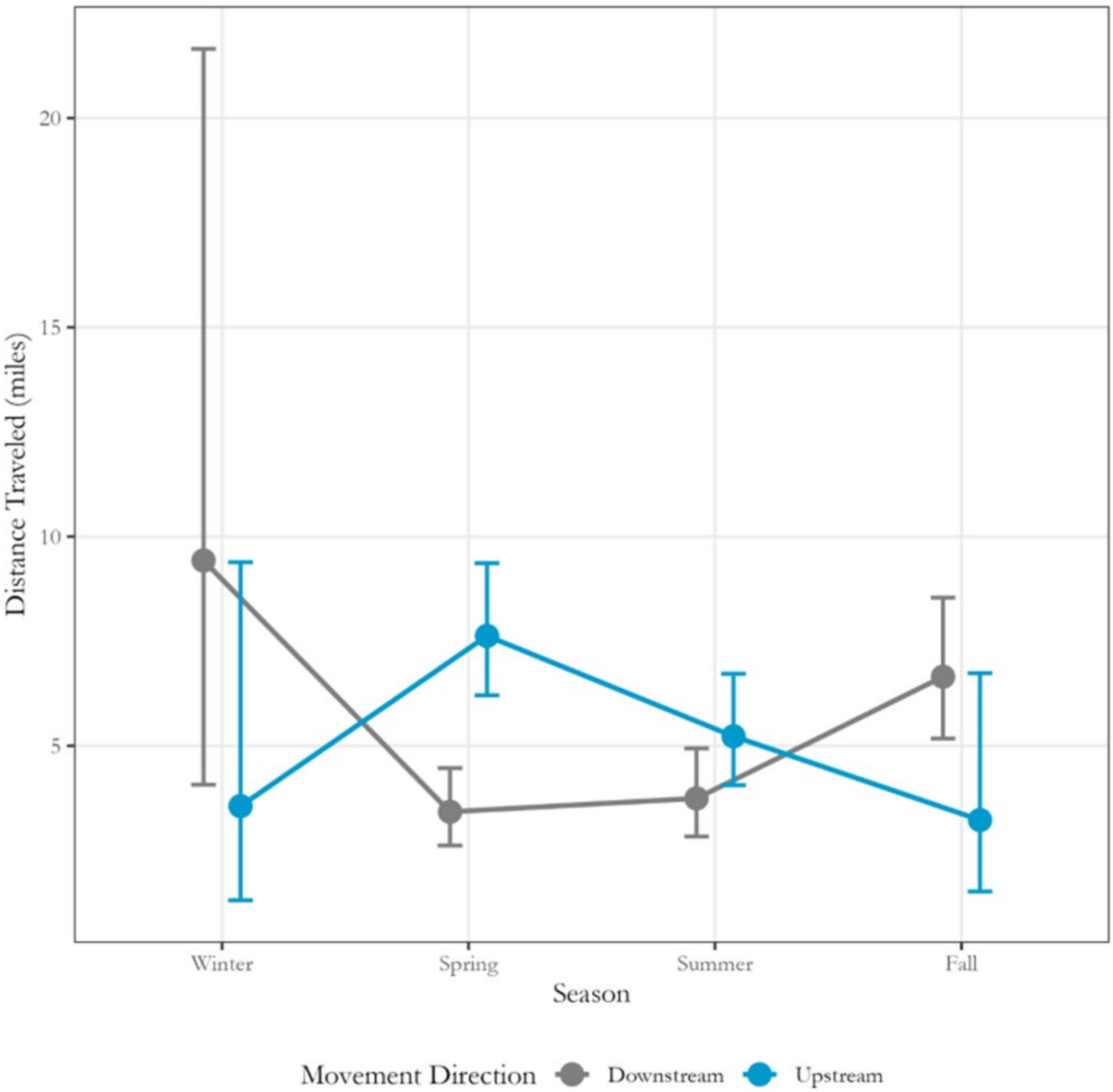

Figure 17. Estimated mean upstream (blue) and downstream (gray) seasonal movement distance (miles) of Silver Carp in the Upper Wabash River Basin. Error bars represent the 95% confidence interval of the estimated mean.

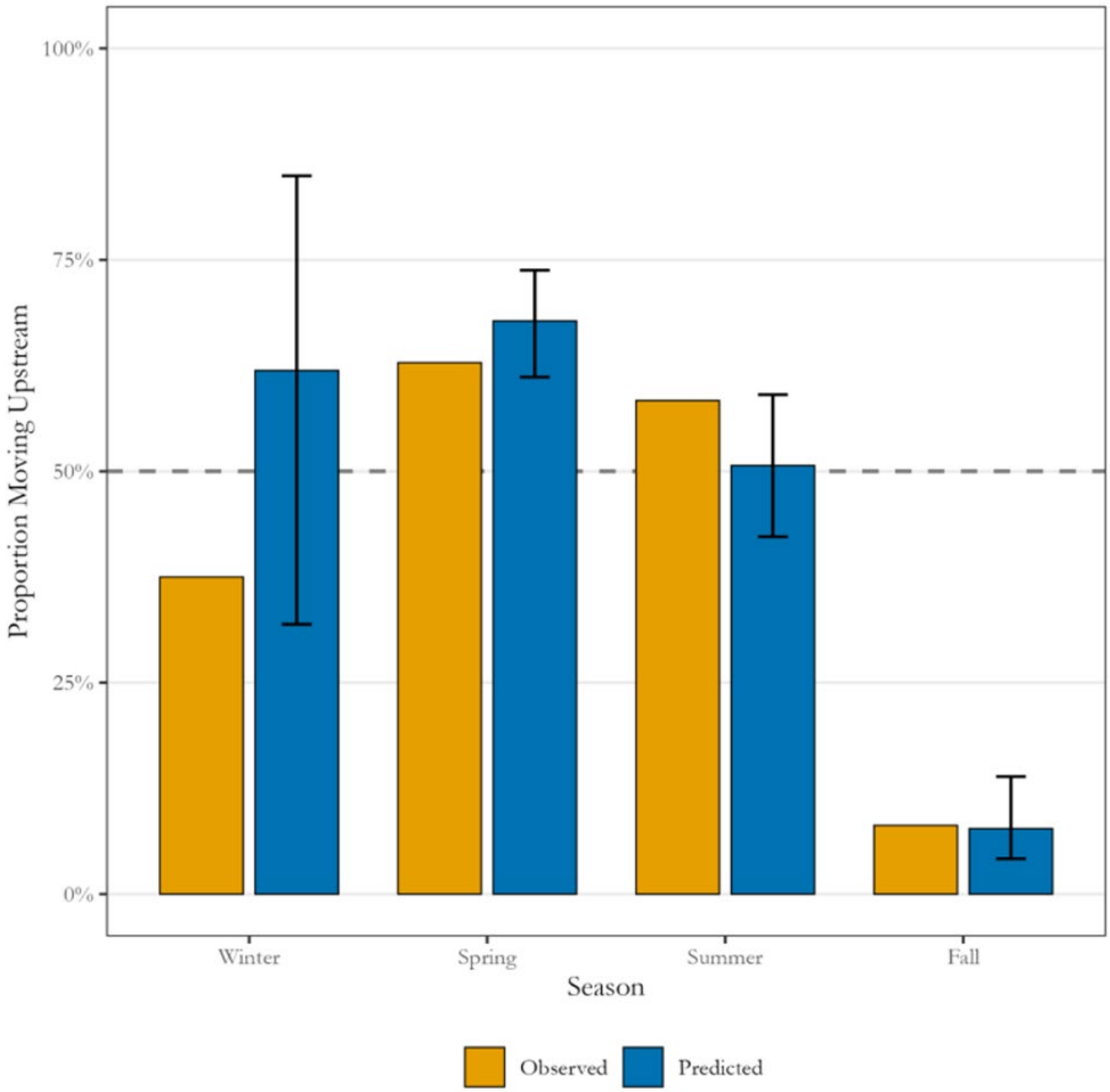

Figure 18. Observed (yellow) versus predicted (blue) proportion of movement direction during winter (December-February), spring (March-May), summer (June-August), and fall (September-November). The horizontal, dashed line denotes a break point at which fish are more likely to move upstream (>50%) or downstream (<50%). Error bars represent the 95% confidence intervals of each predicted proportion.