Project Title: Evaluation of controls on density and behaviors of Silver and Bighead carp in the lower UMR

Geographic Location: Pool 5A through Pool 26 of the Upper Mississippi River and open river sections extending to the confluence of the Ohio River

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Participating Agencies: Minnesota Department of Natural Resources (MNDNR), Missouri Department of Conservation (MDC), Iowa State University (ISU), U.S. Army Corps of Engineers (USACE), U.S. Coast Guard (USCG), U.S. Geological Survey – Upper Midwest Environmental Sciences Center (USGS), and Illinois Natural History Survey (INHS).

Statement of Need: Populations of Silver Carp (*Hypophthalmichthys molitrix*) and Bighead Carp (*H. nobilis*) as well as hybrids (*H. molitrix x nobilis*) between these species, are advancing in the Upper Mississippi River (UMR) basin (Conover et al. 2007; Chapman and Hoff 2011; O'Connell et al. 2011). Three zones of relative abundance of Silver and Bighead Carp have been identified in the UMR; a robust core population (established) below LD 19, a transitional zone of moderately dense populations with potential reproduction from LD 19 to LD 15 (also referred to as the intensive management or IMZ zone), and a zone where individual captures of some adults have been recorded above LD 15 (USFWS 2016). Contracted removal efforts have been implemented in the transitional zone since 2016, but the impacts of those efforts are largely unknown. Furthermore, additional contract removal efforts in Pools 20-22 have recently been initiated.

A robust stock assessment program is needed to more directly evaluate how populations of Silver and Bighead Carp may be affected by current contract removals and to forecast their future response to alternative removal strategies. A robust stock assessment program should incorporate information from multiple fishery-dependent and independent sources, hydroacoustics, and telemetry, to provide the least-biased composite estimate of carp abundance, biomass, demographic distributions, recruitment, and migratory tendencies. Telemetry operations span all three management zones to help understand movement and habitat use within and among pools across these zones.

Project Objectives:

1. Establish a sampling protocol for hydroacoustic surveys in the UMR to estimate Silver and Bighead Carp relative abundance, size distribution, spatial distribution and biomass at the pool-scale, in order to inform and evaluate management actions in the UMR.
2. Use hydroacoustics to assess contracted removal operations, providing abundance estimates pre- and post-removal operations in areas within the intensive management zone (IMZ; Pools 15-19) and investigating relationships between hydroacoustic estimates and removal CPUE.

3. Conduct fishery-independent monitoring to quantify relative abundance, sex ratio, body condition, recruitment, growth, and mortality of invasive carp, support hydroacoustics surveys, and inform and evaluate management actions in the UMR.

4. Monitor spatial and temporal trends in Silver and Bighead Carp movements in response to contract removals and environmental changes using sonic telemetry in Pools 5A-26

5. Use light traps to establish an annual index of spawning activity by invasive carps in Pool 19.

6. Investigate the feasibility of a large-scale mark-recapture project for estimating Silver and Bighead Carp mortality in the UMR.

Project Highlights:

- Pool-wide hydroacoustic surveys in FY22 included over 344 miles of transects, counted 28,607 fish greater than 254 mm/10" TL, and ensonified over 28 million cubic meters of water.
- Hydroacoustic surveys of Pool 18 and Pool 20 were conducted for the first time using a stratified random sampling design. Pool 19 received a comprehensive survey in FY22 and a resampling analysis to guide future levels of sampling effort for that pool is ongoing.
- Fisheries independent data [utilizing electrified dozer trawl] depicted a separation in the UMR between the open river reach (i.e., Ohio River-Missouri River) and the pooled reaches (i.e., Pool 26-Pool 18). Silver Carp in the open river were smaller with poorer condition compared to the pooled reaches. Similarly, Silver Carp growth metrics in the open river depict decreased growth potential and higher mortality whereas those in the pooled reaches display increased growth potential and lower overall mortality estimates.
- Age data provided evidence of recruitment in the open river reach as well as Pool 26 potentially indicating more and frequent reproduction and successful recruitment in these downstream areas.
- The USFWS implanted transmitters in 261 Silver and Bighead Carp in the Pools 16-18 of the UMR. The MDC implanted 36 transmitters in Silver Carp in Pools 20-26. Iowa State University implanted transmitters in 60 Silver and Bighead Carp in the Des Moines, Iowa, and Cedar Rivers.
- Light trap sampling in Pool 19 collected 8,180 larval bigheaded carp in 2022. These are the first larval bigheaded carp collected by the light trapping program since 2018 and the highest number collected since project inception. Larval bigheaded carp are primarily collected in June.

Methods:

Hydroacoustics

Hydroacoustic surveys can provide data on the relative abundance, size distribution, and spatial distribution of fishes. When paired with physical capture data, hydroacoustics can also estimate biomass of fishes, and provide species specific estimates for these metrics. Hydroacoustics data were collected similar to that described in MacNamara et al. (2016) and Coulter et al. (2018). Surveys were conducted using two horizontally oriented split-beam transducers (200 kHz; BioSonics, Inc.) offset in angle to maximize water column coverage (Figure 1). Main channel / main channel border habitats have their sampling area divided into either nearshore or offshore transects along each bank (Figure 2). The nearshore main channel sampling area occurs at the 1 to 1.5 m depth contour with the transducers pointed out towards the thalweg. The offshore main channel sampling area is located farther from shore, picking up where the beams from the first transect would have hit the bottom and viable data collection would have stopped. In areas where wing dams extended out into the channel, transects went over the top of the dams if water depths were sufficient (Figure 3). Side channel habitats have only nearshore transects available on each shoreline. Backwater lakes and other off-channel habitats are sampled with one or more transects on each shoreline (depending on size). In the UMR, transducers are pointed towards the thalweg when sampling all habitat types.

Spring hydroacoustic surveys were conducted in portions of Pools 16-19 and coincided with the intensive harvest period in the UMR, or the period when contracted commercial removals are most effective and effort is the greatest. These surveys occurred on the same day of the removal events with a "pre" survey conducted in the morning right before commercial crews arrived. Any congregations of fish were reported to the commercial crews and then a second "post" survey was conducted after fishing was completed and commercial fishing boats had departed the area. These surveys are meant to guide removal activity, evaluate harvest efficacy, establish the relationship between hydroacoustic density estimates and harvest CPUE, and to compare length frequencies of acoustically detected and commercially harvested fishes to evaluate and refine hydroacoustic estimates and techniques.

In the fall, pool-wide population assessment surveys were conducted in Pools 18-20 of the UMR. Pools 18 and 20 were sampled in their entirety in 2021, and those data were used in a re-sampling analysis to determine the optimum transect length and amount of effort necessary to describe fish communities greater than 254 mm / 10 inches. Those results were used to pilot a stratified random sampling design for Pools 18 and 20 in 2022, with ½ mile transects randomly selected from side channel, nearshore main channel border, and offshore main channel border sites. Pool 19 received a comprehensive survey of all available habitats in 2022. The Pool 19 data will undergo re-sampling analysis in FY23, and all three pools will be sampled with an SRS design in fall of 2023. The fall time period was selected for pool-wide surveys because water levels are typically lower, concentrating fish in main channel border and side channel habitats where they are more easily surveyed with hydroacoustic equipment. Secondly, fish are generally less motile at this time period, reducing chances of double counting fish within or among pools, compared to the spring, when spawning cues can increase fish movement. Thirdly, the fall time period aligns with other comparable hydroacoustic surveys in neighboring river basins (IL River, Ohio River).

Hydroacoustic data was analyzed following MacNamara et al. (2016) using Echoview 11.2.3. Single targets were detected using parameter values from Parker-Stetter et al. (2009). Multiple targets from a single fish were grouped using Echoview's fish tracking algorithm to reduce the potential of over counting fish targets. The size of fish targets (total length; cm) were estimated from mean acoustic target strength (dB) using a function specific to side-looking hydroacoustics (Love 1971). Hydroacoustic data were informed by pool/habitat-specific fish community data. Proportions of fish were determined for each 1 cm length groups for Silver Carp, Bighead Carp, and other fish species. Length-specific proportions were used to categorize acoustically detected fish. Length-weight regressions were then used to estimate length-specific biomass for each species of interest, and relative density (numeric and mass) were estimated. All analyses were conducted using the data analysis program "R" (R Core Team 2020).

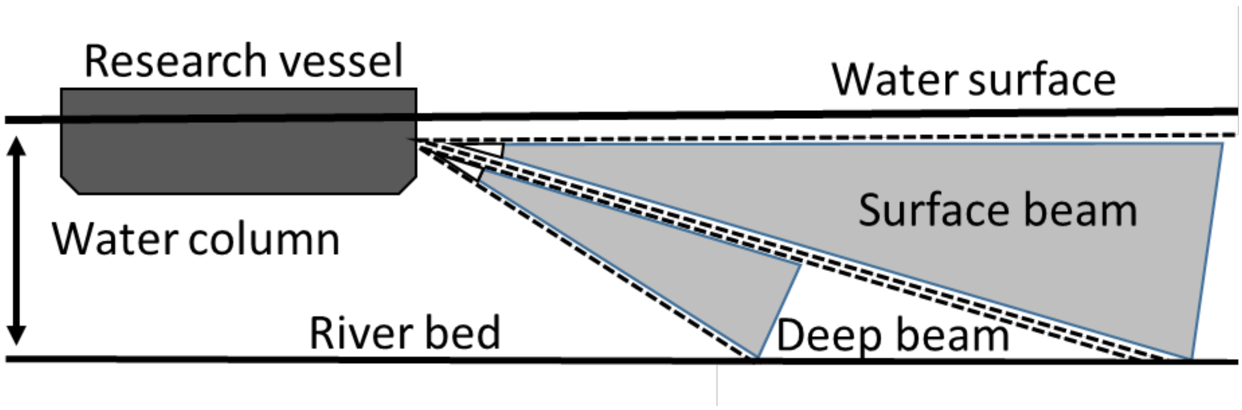

Figure 1. *Diagram showing the approximate orientation of the hydroacoustic beams during a mobile survey. The data that can be used in analysis is collected within the gray area.*

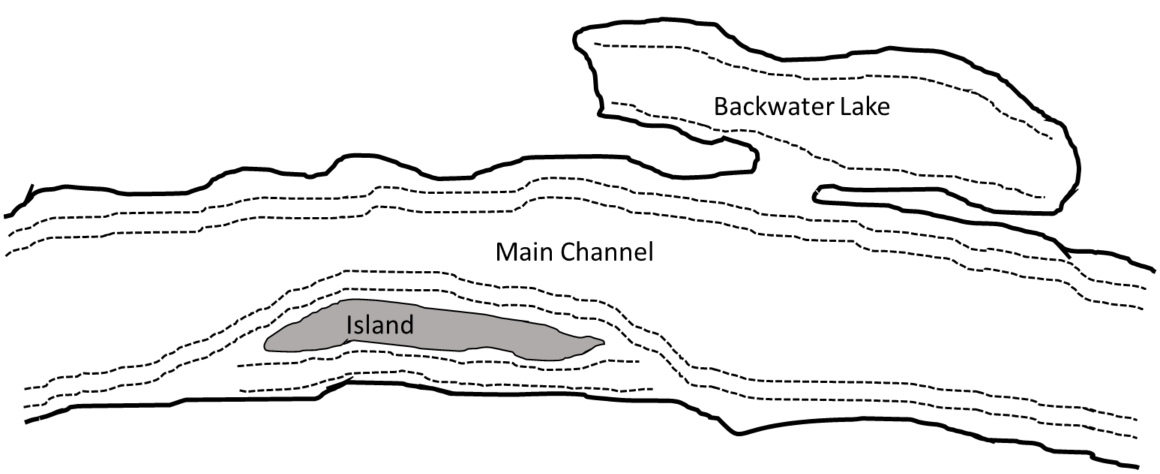

Figure 2. *Example of survey transects (represented by dotted lines) in the Upper Mississippi River; nearshore and offshore transects for each bank along the main channel, transducers pointing toward the thalweg; one transect on each bank for island side-channels and one or more transects for backwater lakes, depending on size and bathymetry.*

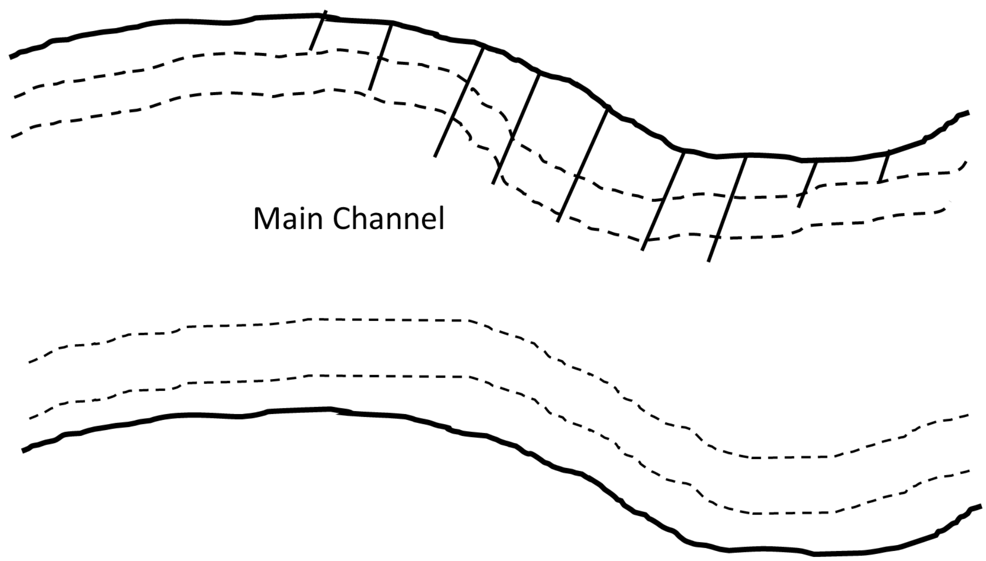

Figure 3. *Example of main channel survey transects (represented by dotted lines) in the Upper Mississippi River where wing dikes are present. Two transects for each bank along the main channel, transducers pointing toward the thalweg. When possible, transects run over the top of the dikes and as close to shore as depth allows.*

Fishery Sampling

Physical fish capture data is needed to inform hydroacoustic surveys in order to generate species specific estimates of abundance and biomass. Spring hydroacoustic surveys that were paired with intensive harvest events used only the fisheries-dependent data collected from the associated commercial removal event. Up to four commercial fishing crews entered the backwater after the initial hydroacoustics survey and sectioned the area off into cells with gill nets, then drove fish into the nets using sound (banging on the hull) and water spray from trimmed outboard motors. Collected fish were removed from the nets, identified, enumerated, weighed, and measured. All Silver Carp, Bighead Carp and Grass Carp were removed while native by-catch were processed and returned to the backwaters, away from active fishing gear to reduce re-entanglement. An effort was made to identify, weigh and measure all collected fishes during each removal event, although in some cases of high catch, some native fishes were only enumerated and returned to the water to reduce unintentional mortalities.

Fall pool-wide surveys relied on a combination of fishery-dependent (contract removal; see above) and fisheries-independent data. For the collection of fishery-dependent data, USFWS personnel partnered with INHS biologists and contracted fishermen for one week in Pool 18 and one week in Pool 19, September 2022. Contracted fishers conducted targeted netting while the biologists processed their catch, recording species, TL (mm) and weight (g) information. No contracted removals were occurring in Pool 20 during this time period. In order to get similar fishery data from all pools, USFWS conducted one week of targeted gill netting in Pool 20 during September 2022, modeled after contracted removals upriver.

Fisheries-independent sampling was conducted by the USFWS using an electrified dozer trawl (Hammen et al. 2019). Part of a larger USFWS Silver Carp demographics project, sampling occurred from the confluence with the Ohio River upstream to Pool 18 (Figure 4.). Sites were selected through a stratified random sampling (SRS) design, with effort allocated among main channel border, side channel, backwater and tributary macrohabitat types, based on availability. A minimum of 20 sites were sampled in each pool or tributary confluence location, with greater effort applied upstream of LD19 in areas with low invasive carp density (Table 1). Each dozer trawl sample was 5 minutes in duration. All captured fish were identified to species, enumerated, and total length (mm) was measured. Fish greater than 250 mm TL were also weighed. Sex was identified for all invasive carp and lapilli otoliths were removed from a sub-sample.

Table 1. Fall 2022 effort and summary data for fishery-independent dozer trawl sampling in the Upper Mississippi River. Sampled reaches listed from north to south, river mile (RM), location-specific effort (number of 5-minute transects), Silver Carp total catch (number), mean Silver Carp catch per unit effort (# stock-sized/hour) and standard error, and total length (TL) range of Silver Carp captured.

Location	RM	Effort (#)	Total SVCP	Mean CPUE (SE)	TL range (mm)
Pool 18	410-437	56	4	0.85 (0.41)	907-1050
Pool 19	365-410	81	4	0.60 (0.36)	447-948
Pool 20	343-365	21	85	48.49 (17.0)	590-815
Pool 21	325-343	20	84	50.40 (11.89)	600-908
Pool 22	301-325	22	83	45.27 (10.7)	530-770
Pool 24	273-301	22	68	35.90 (8.69)	658-840
Pool 25	242-273	20	70	41.91 (7.51)	490-810
Pool 26	203-242	20	239	141.60 (29.34)	279-800
Missouri River	195	20	139	83.40 (23.82)	364-854
Meramec River	161	20	157	95.95 (35.56)	467-901
Kaskaskia River	117	13	133	122.77 (32.07)	335-735
Big Muddy River	76	20	241	144.59 (30.47)	528-857
HW Diversion Ch.	49	20	172	104.20 (28.34)	427-1110
Ohio River	0	20	221	139.68 (40.69)	573-920
Summary	0-437	375	1700	75.39 (19.78)	279-1110

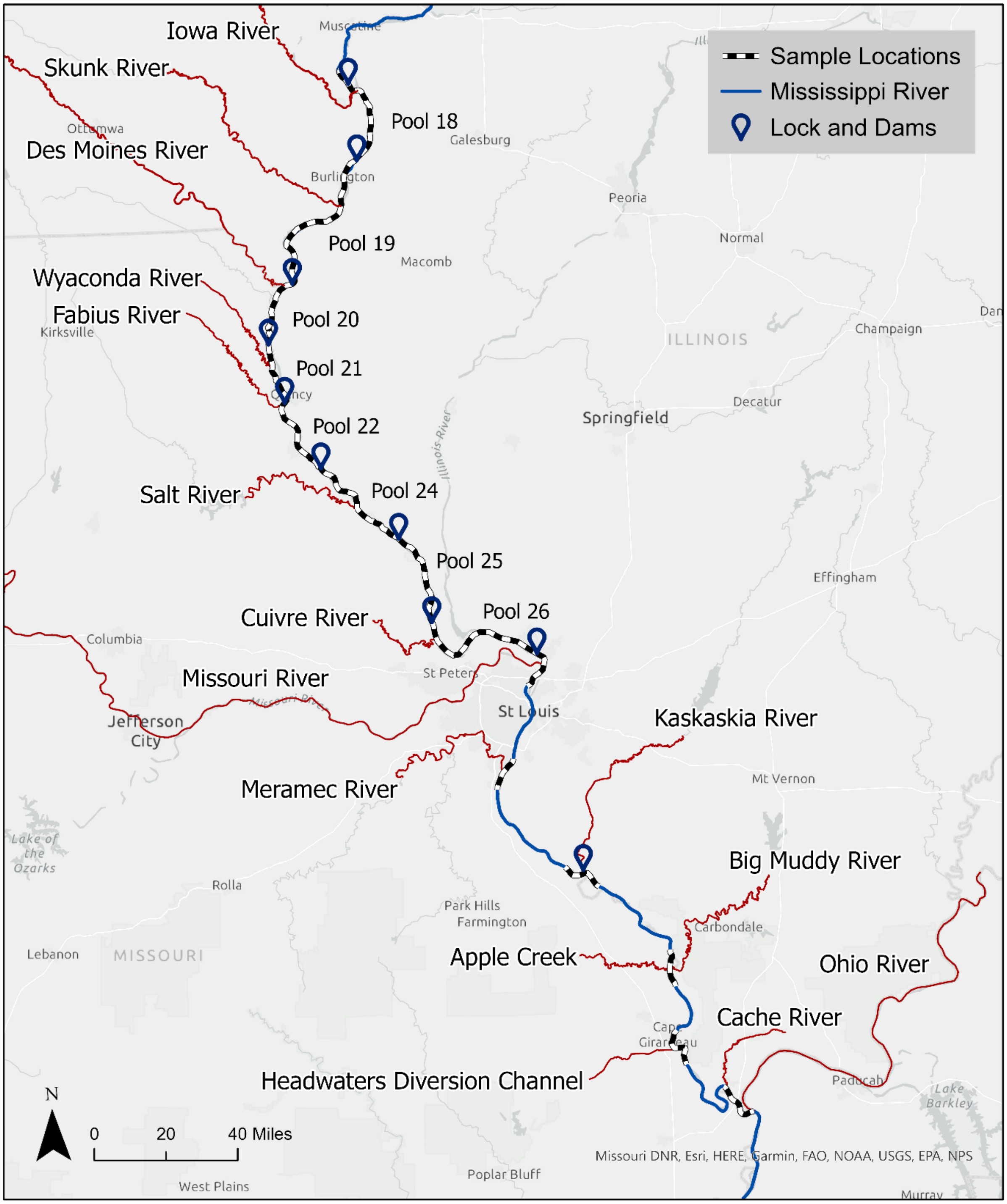

Figure 4. Map depicting fall 2022 fishery-independent sampling locations in black and white. Tributaries where sampling occurred are highlighted in red. The southernmost dam is in the Kaskaskia River, whereas all other dams are on the mainstem Mississippi River.

Telemetry

Telemetry operations span all three management zones to help understand movement and habitat use within and among pools across these zones. Telemetry infrastructure is maintained by a multi-agency cooperative with broad interests concerning the management and spatial ecology of Silver and Bighead Carp and native species whose habitats overlap with Silver and Bighead Carp. Telemetry programs serve two projects described in the *2018 Monitoring and Response Plan for Asian Carp in the Mississippi River Basin*: “Evaluation of controls, impacts and behaviors of Silver and Bighead Carp in the lower UMR” and “Evaluation of fish passage for assessment of Silver and Bighead Carp deterrents at multiple locks in the Upper Mississippi River” (Jackson and Runstrom 2018). The Missouri Department of Conservation manages the array in Pools 20-26. For most areas above LD19, personnel from USFWS manage the extended longitudinal array and real-time receivers in support of the Evaluations of Controls project (reported here). Personnel from USGS manage concentrated telemetry arrays near Locks and Dams 14, 15 and 19 in support of the Evaluation of fish passage project. A project summary for FY21 Evaluation of fish passage is included in a separate section of this report. Iowa State University continues to manage an expanded telemetry array in the Des Moines, Iowa, and Cedar Rivers initially deployed during 2021.

Stationary Receiver Array: Staff from the La Crosse FWCO have maintained an array of stationary receivers (Innovasea, (formerly Vemco) Model VR2W and VR2-Tx) in the UMR since 2013. During 2022, receivers were deployed by USFWS-La Crosse staff in Pools 5A-13 and partners with Illinois Natural History Survey deployed receivers in Pools 14-19 (Figure 5). In 2022, MDC placed deployed receivers along sites in Pools 20-26 above and below each of the locks and dams (Figure 5), utilizing platforms of opportunity. Crews from Iowa State University deployed receivers throughout the Des Moines, Iowa, and Cedar Rivers below the first barriers on each system (Figure 6). Suitable sites included locations of protected bankline (e.g., inside bend), large rock areas, and notable landmarks that improved chances of future retrieval. Data from stationary receivers were downloaded every 4-8 weeks.

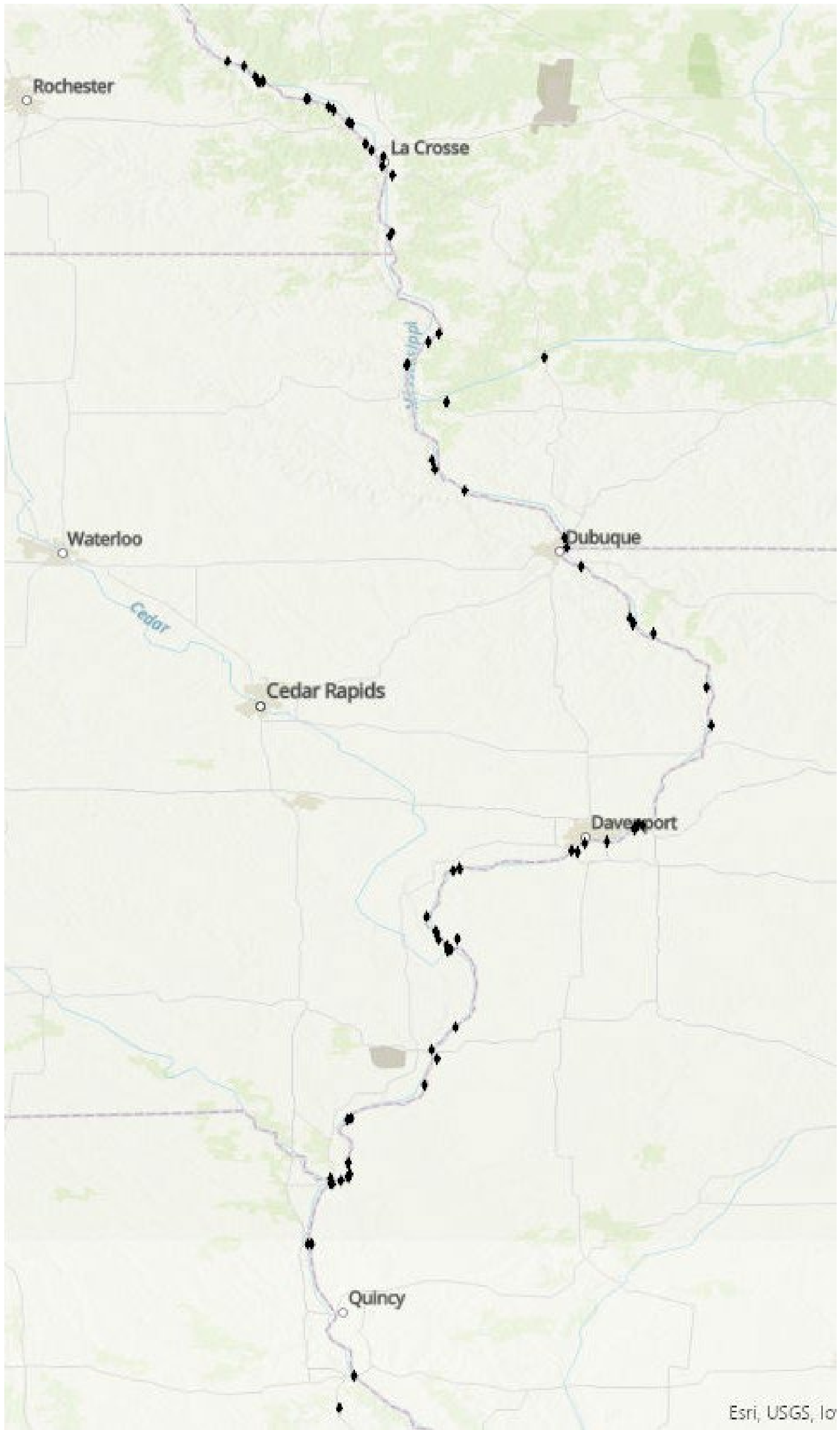

Figure 5. *Locations of stationary receivers deployed by MDC, USFWS, and INHS (diamonds) in the Mississippi River basin during 2022.*

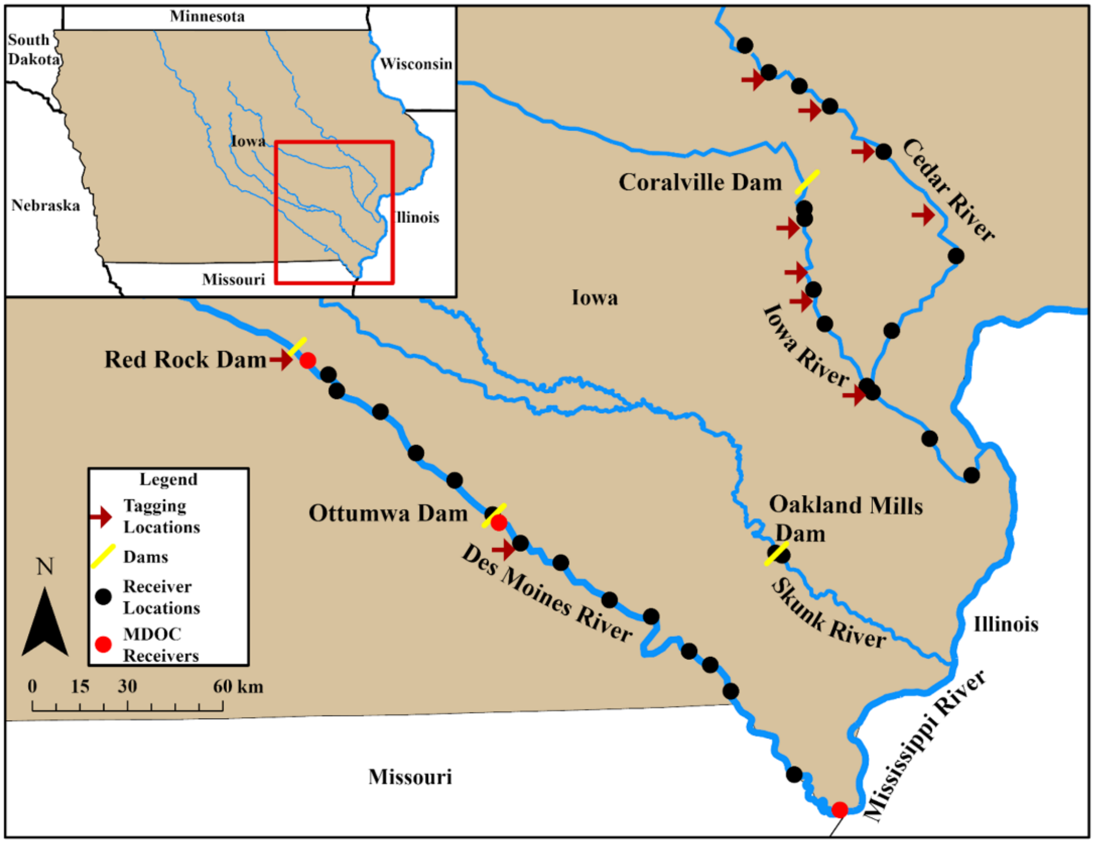

Figure 6. Upper Mississippi River and four of its tributaries (Des Moines, Skunk, Iowa, and Cedar Rivers) in southeastern Iowa. Red arrows indicate Silver Carp tagging locations, black dots represent new receiver locations, and red dots represent locations of preexisting Missouri Department of Conservation receivers. Yellow lines denote location of dams.

Real Time Receivers: USFWS crews deployed and maintained four real-time receivers in Pools 16-18 from March-November 2022. Data from these receivers were shared daily with partners at INHS leading contracted removal efforts. The real-time receivers at Credit Island in Pool 16, Cleveland Slough in Pool 17, and Boston Bay in Pool 18 experienced multiple failures during April-June. Following retrieval and receiver breakdown, USFWS crews determined that damage to solar power systems had caused these failures. These problems were fixed and the receivers functioned well from July-November.

Acoustic Transmitter Tagging: During April and May FY22, staff from the La Crosse FWCO worked with partners at INHS to capture and tag 261 invasive carp in Pools 14-18. In Pools 20-26, staff with MDC surgically implanted 36 additional Silver and Bighead Carp with transmitters. Iowa State University captured and tagged 60 additional invasive carp in the Des Moines, Iowa, and Cedar Rivers.

Data Analyses: All USFWS telemetry detections data were completed using the V-Track package in Program R (Campbell et al. 2012; R Core Team 2020). The package condensed detection records in situations where at least two detections for an individual fish within 12 hours at a fixed location (i.e., a receiver) constituted a residence event. The event was terminated/timed-out when 1) the individual was either not detected for 12 hours at a given receiver, or 2) it was detected at a new receiver. Residency events were filtered to determine the number of individual carp contributing to events in each pool. Data from both stationary and real-time receivers were incorporated into this analysis. Additionally, USGS detections data collected from receivers in their arrays at Locks and Dams 14, 15, and 19 were included in these analyses to increase spatial resolution. Residence events were later summarized by UMR pools and tributaries to examine the geographic extent of Silver Carp and Bighead Carp dispersal during 2021. In early 2022, partners from USGS also developed an extension to the V-Track package that allows the easy identification of dam passage events using data parsing and plotting functions.

Iowa State University staff calculated maximum displacement values for individual Silver Carp and estimated mean values based on tagging location to determine general, broad movements of Silver Carp tagged in the Iowa tributaries. Maximum displacement value represents the distance (km) between most upstream a, broad movements of Silver Carp and downstream detections. Individuals were then classified as migrants or residents based on thresholds used in previous studies (Prechtel et al. 2018) as well as frequency distributions of maximum displacement values at each study site. Currently, individuals with a maximum displacement value less than 25 kilometers are classified as residents, individuals with displacement values greater than 100 km as migrants, and individuals with displacement values between those thresholds as intermediate. Iowa State University partners also assessed the frequency of transitions between the Des Moines River and UMR to provide insights on population structure/connectivity of individuals located above Ottumwa Dam, below Ottumwa Dam, and in the UMR. Upstream and downstream passage through Ottumwa Dam were observed. The team also assessed water temperature and discharge from nearby USGS gauging stations (De Cicco et al. 2022) as well as HOBO temperature loggers (HOBO 64K Pendant data loggers; Onset Computer Corp., Bourne, Massachusetts) attached to the receivers to understand Silver Carp movements in relation to environmental conditions.

Larval Sampling

Evidence of Silver and Bighead Carp reproduction was detected as early as 2009 in Pool 19 of the Upper Mississippi River, indicating that areas of the UMR above LD19 are capable of providing the hydrological requirements needed for successful Silver and Bighead Carp (collectively referred to as “bigheaded carp”) spawning, egg maturation, and development. Monitoring for larval and juvenile bigheaded carp in Pool 19 is meant to detect and quantify bigheaded carp reproduction and any potential reproductive response to control strategies.

Quadrafoil larval light traps (250µm, Aquatic Research Instruments) that utilize green chemical light sticks were deployed approximately an hour after sunset and were fished for at least an hour one-three times a week. Deployment locations for each trap were selected based on proximity to shoreline, structure, and other traps. Traps were collected, and the sample filtered with the catch pan at the bottom of each trap and placed into a sample jar with a tag describing site information. Samples were preserved using 95% ethanol. Water quality measures such as dissolved oxygen, specific conductivity, conductivity, and temperature were taken using a YSI. Turbidity was measured at sampling locations using a secchi disk during the day and a portable turbidity meter at night when available.

Mortality Estimation Feasibility Study

Understanding the effects of harvest of fish populations is critical to determining their status and appropriate management measures. Although there are several ways to estimate harvest mortality (e.g., stock assessment modeling and mark-recapture methods), these methods are often data-intensive, and it can take several years to collect the necessary information to develop reasonable estimates of harvest mortality. In addition, there is little guidance available to help natural resource management agencies develop sampling plans to effectively estimate harvest mortality. This study seeks to develop guidance for mark-recapture studies to estimate the proportion of a population that is harvested. To do this, we used a series of simulations to examine the effects of different aspects of study design and assumptions on our ability to estimate fishing mortality in stochastic and information-limited environments. These simulations were designed following a Brownie model (Brownie et al. 1978) and assume that fish are affixed with an externally visible tag or marker that enables them to be identifiable minimally to the annual cohort of tagged fish.

In these simulations, we generated simulated tag-recovery datasets where a predetermined number of fish are marked with externally visible tags and some proportion of the tags are returned through annual harvest. We generated these datasets under a set of 'known' parameters with added stochasticity to explore parameters that represent a range of management decisions and environmental scenarios. We then fit the simulated datasets to a Bayesian mark-recovery model and measured the magnitude of error between the fitted model parameters and the 'known' parameters used to generate the dataset. In the simulations, we altered the study duration and the number of fish marked each year as well as assumptions about tag reporting and retention rates. For these simulations, we tested these models using a range of "known" total annual harvest rates (as a proportion of the total population) that were held constant from year to year and ranged from 0.05 to 0.65. We selected a range of annual tagging effort to provide guidance to those considering tag-recovery studies that ranged from relatively small (50 tags per year) to large (4,000 tags per year). In our simulations, a short duration study included datasets with three years of fish tagging and four years of tag recovery, whereas a long-duration study included nine years of tagging and ten years of tag recovery.

Results:

Pool 16-19 hydroacoustics pre/post contract removal

From April 26 to May 13, 2022, eight different backwaters were surveyed pre and post contract removal. Seven of those sites displayed expected reductions in hydroacoustic fish density estimates post harvest (Table 2). At these sites, reduction in the density of hydroacoustically detected fish, ranged from 39%-94% (Table 3). However, the relationship between the observed reduction in hydroacoustic densities, and the associated reduction in available fish within a backwater after removal of invasive carps, requires further examination (Table 3). There was one site (Swede Lake - Boston Bay) where post harvest hydroacoustic estimates were greater than pre-harvest (Table 2). At this site, factors like unfavorable bathymetry, low numbers of invasive carp removed, fish behavior (e.g. immigration into the fishing area between surveys), or other variables, likely contributed to confounding pre/post estimates.

Species specific estimates for Bighead and Silver Carp could only be generated for the Carthage, Fish Lake and Cleveland Slough backwaters (Table 4). Overall, only about 42% of hydroacoustically detected fishes pre-harvest, and 33% of fishes post-harvest, could be assigned to a probable species.

Table 2. *Hydroacoustic survey estimates of total fish relative abundance and density at backwater sites in the Upper Mississippi River, pre and post intensive contracted removals, Spring 2022.*

Site	Pool	Pre/Post	N Fish	Biomass (kg)	Volume (m^3)	Fish/1000 m^3	kg/1000 m^3
Big Timber	17	Pre	438	831.01	144032	3.0410	5.7697
Big Timber	17	Post	253	436.01	137346	1.8421	3.1746
Swede Lake	18	Pre	51	97.59	110477	0.4616	0.8834
Swede Lake	18	Post	64	67.76	97124	0.6589	0.6977
Carthage	19	Pre	109	186.11	85847	1.2697	2.1679
Carthage	19	Post	31	62.58	67487	0.4593	0.9273
Cleveland	17	Pre	151	277.12	116444	1.2968	2.3798
Cleveland	17	Post	29	46.29	102485	0.2830	0.4516
Fish Lake	19	Pre	130	233.29	81938	1.5866	2.8472
Fish Lake	19	Post	16	20.22	69350	0.2307	0.2916
Otter Bay	19	Pre	50	75.91	34046	1.4686	2.2298
Otter Bay	19	Post	3	1.92	35254	0.0851	0.0546
Swamps	19	Pre	12	12.02	18740	0.6403	0.6412
Swamps	19	Post	1	1.25	16901	0.0592	0.0741
Credit	16	Pre	106	297.20	79165	1.3390	3.7542
Credit	16	Post	39	138.65	86444	0.4512	1.6039

Table 3. *Number of fish caught, number of invasive carp removed, percent of caught fish that were removed, and associated percent reduction in relative density of hydroacoustically detected fish, post contracted removal, at backwater sites in the Upper Mississippi River, Spring 2022.*

Site	Fish caught	Invasives Removed	Percent Removed	Hydro Density Reduction (%)
Big Timber	253	5	2.0	39.4
Swede	78	15	19.2	-42.7
Carthage	133	46	34.6	63.8
Cleveland	90	10	11.1	78.2
Fish Lake	367	136	37.1	85.5
Otter Bay	78	14	17.9	94.2
Swamps	325	112	34.5	90.8
Credit	30	12	40.0	66.3

Table 4. *Hydroacoustic survey estimates of Silver and Bighead Carp relative abundance and density at backwater sites in the Upper Mississippi River, pre and post intensive contracted removals, Spring 2022.*

Site	Pool	Pre/Post	Species	Volume (m^3)	Fish/1000 m^3	kg/1000 m^3
Carthage	19	Pre	SVCP	85847	0.0174	0.1975
Carthage	19	Post	SVCP	67487	0.0119	0.1447
Fish Lake	19	Pre	BHCP	81938	0.0122	0.1556
Fish Lake	19	Post	BHCP	69350	0	0
Fish Lake	19	Pre	SVCP	81938	0.0041	0.0264
Fish Lake	19	Post	SVCP	69350	0	0
Cleveland	17	Pre	BHCP	116444	0.0021	0.0226
Cleveland	17	Post	BHCP	102485	0	0
Cleveland	17	Pre	SVCP	116444	0.0104	0.0915
Cleveland	17	Post	SVCP	102485	0	0

Pool 18-20 pool-wide hydroacoustics

At the time of reporting, work was ongoing to determine the most appropriate combination of fishery catch data to apply to hydroacoustic data to generate species specific estimates. As such, overall non-specific results are reported here, with species specific estimates and the results of the Pool 19 re-sampling analysis to be incorporated into a future report.

During fall pool-wide hydroacoustic surveys USFWS personnel completed over 344 miles of survey transects, ensonified more than 28,170,263 cubic meters of water, and enumerated 28,607 fish greater than 254 mm (10”) total length (Table 5; Table 6). Similar to 2021, water levels in 2022 were too low to access any backwater habitats, only main channel border and side channel habitats were sampled.

Trends in relative fish densities among habitats and pools mirrored those observed in 2021. Relative densities of fish ≥ 254 mm (10”) TL were greater at side channel habitats than main channel habitats in all pools. By pool, overall relative densities increased as we proceeded downstream, and were several times greater in Pool 20 (3.4087 fish / 1,000 m^3) than either Pool 18 (0.4219 fish / 1,000 m^3) or Pool 19 (0.7247 fish / 1,000 m^3; Table 6). The differences in relative density among the pools is most likely attributable to much higher densities of invasive carp in Pool 20 relative to pools above LD19.

Table 5. *Effort by pool and habitat type for pool-wide hydroacoustic surveys in the UMR, fall 2022. SRS design indicates the pool was subsampled with half-mile transects randomly assigned across available habitats. Comprehensive surveys sampled all available habitats.*

Pool	Macrohabitat	Survey Design	0.5 mile transects (N)
18	MC	SRS	85
	SC	SRS	49
19	MC	comprehensive	343
	SC	comprehensive	111
20	MC	SRS	76
	SC	SRS	24
Total			688

Table 6. *Number of fish ≥ 254 mm/10", total volume sampled, and density of fish/1,000 m^3 by pool and habitat type, pool-wide hydroacoustic surveys in the UMR, fall 2022.*

Pool	Habitat	N	Volume (m^3)	Fish/1,000 m^3
18	MC	826	3453144	0.2392
	SC	1216	1386679	0.8769
	Combined	2042	4839823	0.4219
19	MC	10707	15861319	0.6750
	SC	3594	3871264	0.9284
	Combined	14301	19732583	0.7247
20	MC	9987	3112277	3.2089
	SC	2270	485580	4.6748
	Combined	12264	3597857	3.4087
Total	Overall	28607	28170263	1.0155

Fishery-Independent Sampling

Staff from the U.S. Fish and Wildlife Service- Carterville, Columbia, and La Crosse Fish and Wildlife Conservation Office's coordinated to collect 1,962 Silver Carps throughout the Upper Mississippi River. Crews removed lapilli otoliths and aged 1,369 individuals collected from the confluence of the Ohio River to Pool 18 (> 430 river miles).

Invasive carp CPUE (SVCP > 250 mm TL/hr) was greatest in the open river below the Missouri River confluence (Figure 7). Length structure and condition depicted a separation in the UMR between the open river reach (i.e., Ohio River-Missouri River) and the pooled reaches (i.e., Pool 26-Pool 18; Figures 8 & 9). Overall, Silver Carp were smaller and in poorer condition in the open river, and larger and in better condition in the pooled reaches. Though sex ratios are not depicted here, they were nearly 50% male to female ratios for all locations. Age structures were similar for all sampling locations below Lock and Dam 19 (Figure 10). No age-0 Silver Carp were collected in 2022, although some smaller individuals < 500 mm TL were captured as far upstream as Pool 19. These individuals were estimated to be two years old at the time of capture, possibly indicating that invasive carp spawned in 2020 and that some of these individuals have recruited to older life stages. Additionally, 2018 and 2019 year classes (ages 3 & 4, 2022) were documented in Pool 26 and downstream (Figure 8), potentially indicating more frequent reproduction and successful recruitment in these downstream regions. Finally, growth metrics depicted increased growth potential in the pooled reaches relative to the open river as well as lower overall mortality estimates in the pooled reaches relative to the open river reach (Table 7). A detailed report on USFWS fisheries-independent monitoring during 2021/2022 is available upon request.

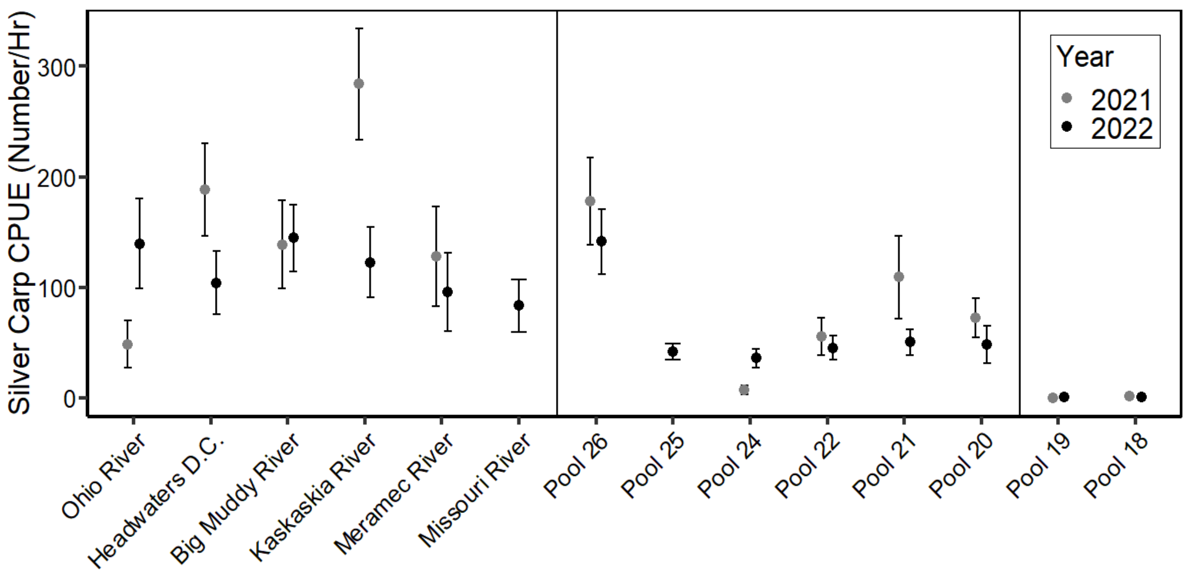

Figure 7. *Location-specific mean stock-sized catch-per-unit-effort of Silver Carps (SVCP/hour) during 2021 (gray points) and 2022 (black points). Error bars represent standard error. All fish were sampled using standardized electrified dozer trawl. Vertical black lines separate locations of Upper Mississippi River; the Ohio River-Missouri River (left) is the open river reach, Pool 26-Pool 20 (middle) is the pooled reach, and Pool 19-Pool 18 (right) is above Lock & Dam 19.*

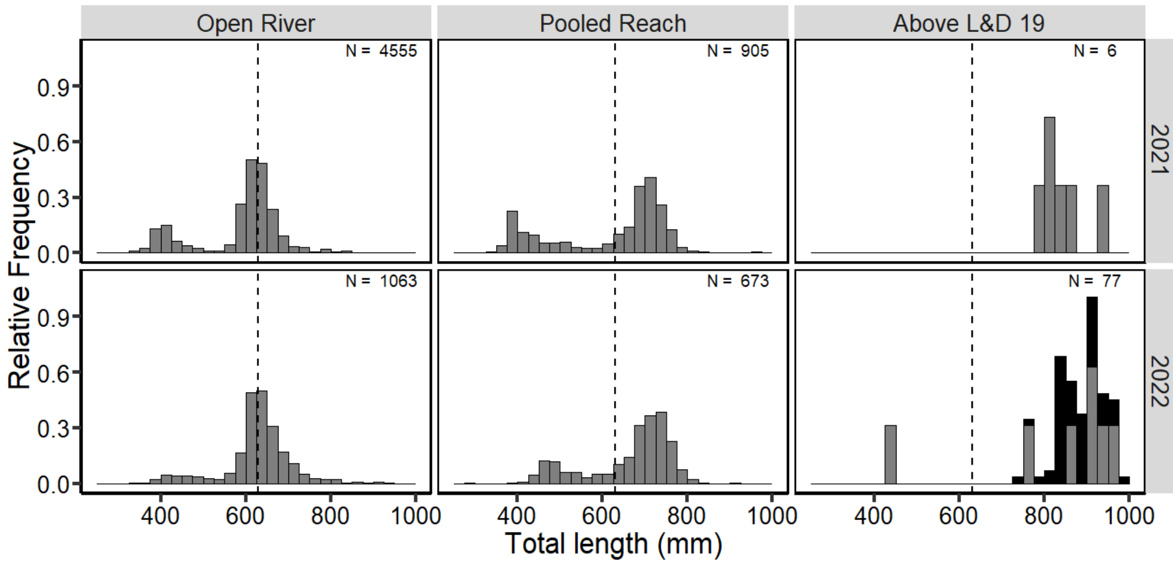

Figure 8. *Reach-specific relative length-frequency histograms and total pooled catches of Silver Carps sampled using electrified dozer trawl from all locations of the Upper Mississippi River during 2021 and 2022. Length data also include fish captured with standardized modified electrofishing during 2021. Commercial gillnet surveys were used for length distribution in low-density areas above L&D 19 during 2022. Commercial harvest is indicated in black. Vertical dashed lines represent the overall mean TL (630mm TL) of all stock-size Silver Carps sampled during 2021 and 2022.*

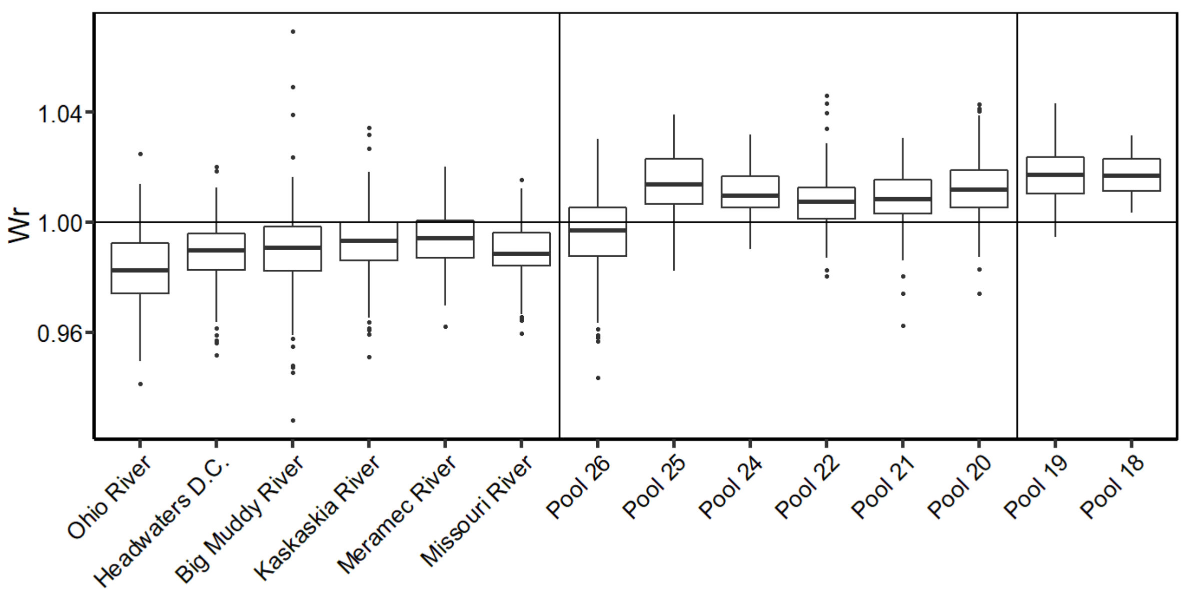

Figure 9. *Location-specific boxplots of individual stock-sized Silver Carp relative weights (Wr). The vertical black lines indicate the separation between the open river reach (left), pooled reach (middle), and locations above L&D 19 (right). Fish were sampled using the electrified dozer trawl during fall 2021-2022. Samples were supplemented with non-standardized electrified dozer trawl collections, modified electrofishing collections, and gillnet catches for areas above L&D 19.*

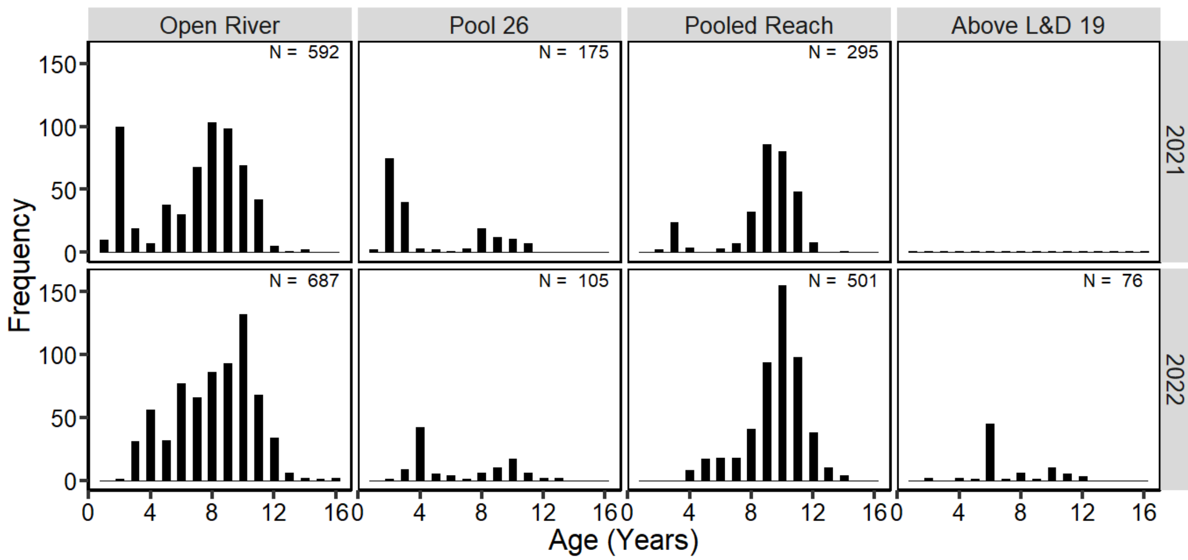

Figure 10. *Reach-specific age frequency histograms (Pool 26 separated from the pooled reach) for Silver Carp captured using electrified dozer trawl from all locations of the Upper Mississippi River in 2021 and 2022. Age samples collected from above Lock and Dam 19 were supplemented with non-standardized electrified dozer trawl collections, modified electrofishing collections, and gillnet catches during 2022.*

Table 7. *Life history parameters of Silver Carps at each study location of the Upper Mississippi River; L_∞, K, and t_0 parameters are von Bertalanffy (1938) growth coefficients, and the M parameter is the annual mortality estimate from the updated Pauly (1980) empirical equation. Fish were captured with the electrified dozer trawl during fall 2021 and 2022 and age samples were supplemented with non-standardized electrified dozer trawl collections, modified electrofishing collections, and gillnet catches.*

Location	L_∞	K	t_0	M
Ohio River	693	0.67	-0.087	NA
Headwaters D.C.	669	0.508	-0.134	0.62
Big Muddy River	655	0.489	-0.15	0.61
Kaskaskia River	652	0.363	-0.604	0.49
Meramec River	643	0.472	-0.221	0.60
Missouri River	674	0.406	0.92	0.52
Pool 26	700	0.3	-0.57	0.42
Pool 25	778	0.272	-0.516	0.37
Pool 24	759	0.33	-0.166	0.43
Pool 22	814	0.138	-4.332	NA
Pool 21	754	0.301	-1.274	0.41
Pool 20	727	0.807	1.865	NA
Pool 19	922	0.637	0.989	0.66
Pool 18	1154	0.069	-14.133	NA

Telemetry

Detection data are not reported here but transmitter(s), receiver(s), and detection(s) data were shared with multi-basin partners to improve coordination, control, and management of large river fish species (including Silver and Bighead Carp). All project data can be accessed through the multi-agency FishTracks data system administered by USGS-UMESC.

The combined arrays of USFWS and USGS in UMR Pools 5A-20 detected 1016 tagged individuals from 13 species during 2022. Sixty-eight Bighead Carp and 467 Silver Carp were detected at least once during 2022. Most Silver and Bighead Carp residency events were concentrated in Pools 14-20 where the highest densities of tagged Silver and Bighead Carp occur (Table 8).

Table 8. *Results from residency event analysis for Silver and Bighead Carp and their hybrids in the UMR during 2022. The number of individuals detected, and residency events recorded in each location provides an indication of the number of tagged individuals who occupied these locations and the duration of occupancy from March-December 2022.*

	INDIVIDUALS DETECTED (SUM RESIDENCY EVENTS)	
UMR POOLS	**Bighead Carp**	**Silver Carp**
POOL 5A	-	1 (15)
POOL 6	-	1 (5)
POOL 8	-	1 (22)
POOL 9	-	1 (1)
POOL 11	-	1 (3)
POOL 14	1 (1)	1 (61)
POOL 15	2 (32)	18 (728)
POOL 16	17 (339)	152 (2593)
POOL 17	26 (621)	153 (1656)
POOL 18	1 (5)	20 (234)
POOL 19	11 (193)	39 (213)
POOL 20	10 (193)	79 (689)

One hundred ten invasive carp were detected in the MDC array at least a single day since tagging began in late fall 2021. One hundred two carp were not detected outside the pooled reaches of the UMR, while three carp moved into the open river and were detected at Maple Island in Pool 26. Another Silver Carp was detected at Ottumwa on the Des Moines River and four other carp made it to the Peoria pool of the Illinois River.

Of the Silver Carp tagged below Red Rock Dam during fall 2021, 24 individuals were classified as resident, three individuals were classified as migrant, and 10 individuals were classified as intermediate (Figure 11). One individual has not yet been detected. The longest confirmed maximum displacement was approximately 220 km. However, we had a Silver Carp (765 mm TL) at the mouth of the Des Moines River on May 19, 2022 that was detected a single time in the UMR at L&D 26 near Alton, IL (~460 km) on June 18, 2022 by the Missouri Department of Conservation, but we have not received additional detections to verify the movement of this fish. Of the 39 Silver Carp we tagged below Ottumwa Dam, we classified 11 individuals as residents, 15 individuals as migrants, and 13 individuals as intermediate (Figure 11). The longest confirmed maximum displacement of individuals tagged below Ottumwa Dam was approximately 150 km; however, a Silver Carp (781 mm TL) was detected twelve times at a receiver in the Illinois River near Peoria, IL (~615 km) by the USFWS-Wilmington. We hope to obtain detections between the mouth of the Des Moines River and where it was detected near Peoria, IL to help confirm this movement.

Four Silver Carp tagged below Red Rock Dam transitioned downstream and successfully passed through Ottumwa Dam between October 2021 and August 2022 (Figure 12). One of those individuals (A69-1602-49718) appears to have successfully transitioned back upstream through Ottumwa Dam and two individuals have continued downstream to the mouth of the Des Moines River. We have not observed any individuals tagged below Ottumwa Dam transitioning upstream through Ottumwa Dam. Fourteen individuals we tagged below Ottumwa Dam have transitioned downstream to the mouth of the Des Moines River during this period. Of those fourteen, eleven have since migrated back upstream to their tagging location while four of eleven have migrated back downstream to the mouth of the Des Moines River a second time, showcasing highly mobile behavior (Figure 13).

A large movement event was observed between late October and early November 2021, with 13 of the 39 individuals tagged below Ottumwa Dam moving downstream to the mouth of the Des Moines River. The movement event coincided with a two week, ~350 m^3/s increase in discharge and water temperatures declining to approximately 10°C (Figure 14). Smaller upstream movement events were also observed during spring 2022 as both water temperature and discharge increased (Figure 15).

The maximum displacement analysis suggests a highly resident population of Silver Carp above Ottumwa Dam with most individuals displacing less than 25 km between October 2021 and August 2022 (Figure 11). Comparatively, individuals tagged below Ottumwa Dam appear to be more mobile, suggesting partially migratory behavior as observed in other systems (Prechtel et al. 2018; Coulter et al. 2022). It is important to note maximum displacement for all individuals detected at the mouth of the Des Moines River may be underestimated. We experienced gaps in detection histories after fish were detected at the mouth of the Des Moines River, suggesting individuals may have moved into the UMR and moved further throughout the UMR basin or beyond. We hope to obtain additional detections through the USGS FishTracks database and communication with other agencies that will fill such gaps.

Differences in transition frequency were observed between Silver Carp tagged above Ottumwa Dam and those tagged below Ottumwa Dam. Transition observations suggest Silver Carp above Ottumwa Dam may be relatively independent from those below Ottumwa Dam during low water conditions. Movements of individuals above Ottumwa Dam have yet to be observed suggesting this population may be isolated while transitions of individuals tagged below Ottumwa Dam suggest more potential for metapopulation interactions. Observations suggest that the cohort tagged below Ottumwa Dam may be functioning as a subpopulation of a UMR metapopulation due to the frequent transitions individuals have made between the receiver at the mouth of the Des Moines River and more upstream receivers. Overall, some individuals remained in the upstream portions of the study stretch below Ottumwa Dam and above Ottumwa Dam throughout the entire study period thus far, suggesting a portion of the individuals throughout the Des Moines River may be residents. However, data collected to date has occurred during drought conditions. Additional years of data collection under various flow conditions will be insightful to evaluate how environmental conditions affect tributary movement dynamics.

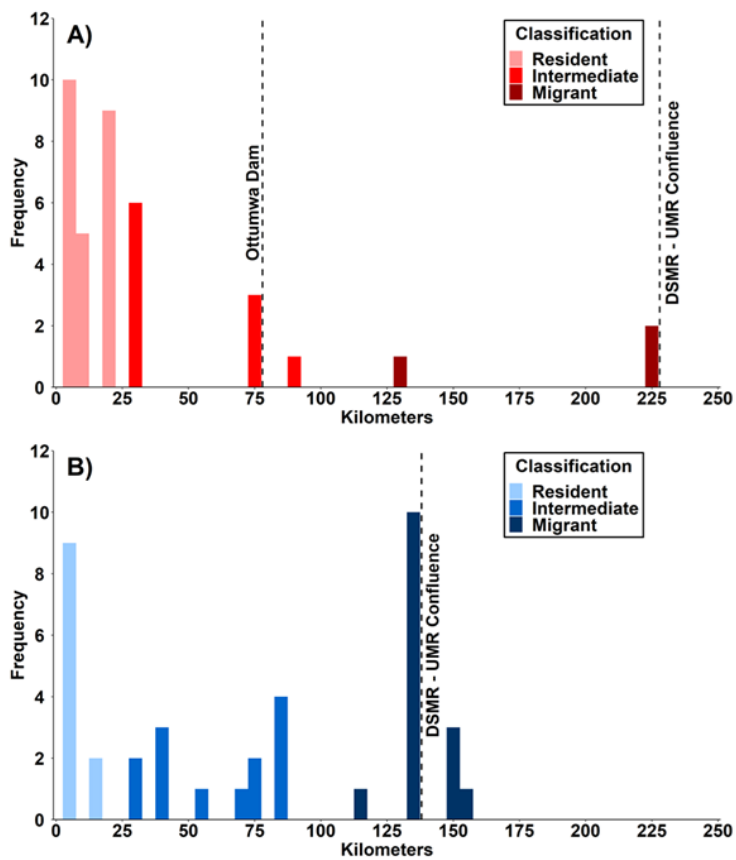

Figure 11. *Movement-frequency of maximum displacement distances (kilometers) for A) Silver Carp tagged below Red Rock Dam and B) Silver Carp tagged below Ottumwa Dam. Note that Silver Carp detected near the mouth of the Des Moines River (DSMR-HWY 136 Keokuk) may have moved further but we have not yet received detection information from other agencies conducting acoustic telemetry in the basin.*

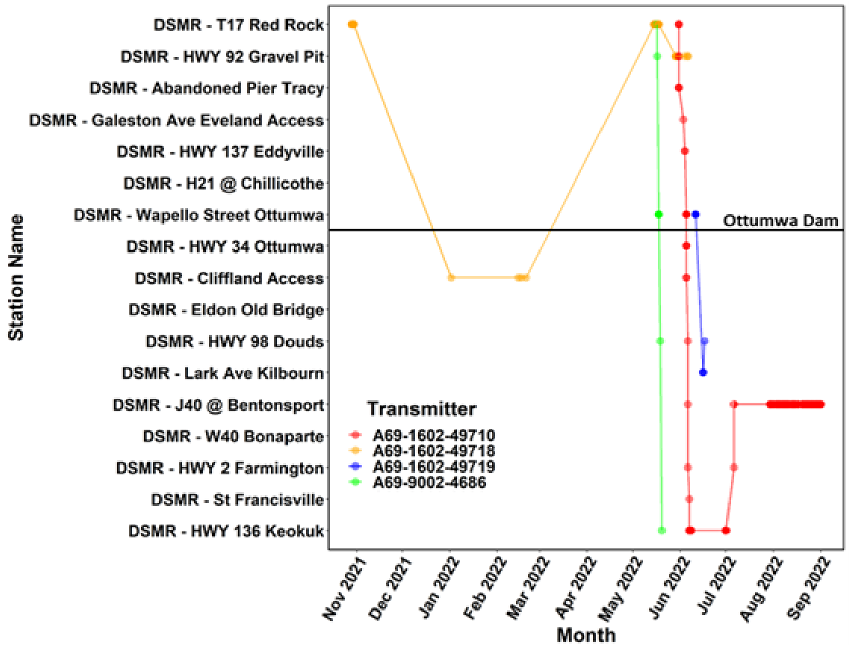

Figure 12. *Abacus plot showing detection histories of four Silver Carp that have transitioned downstream through Ottumwa Dam. Transmitter ID A69-1602-49718 (orange) successfully transitioned both downstream and upstream through Ottumwa Dam. Transmitter IDs A69-1602-49710 (red) and A69-9004-4686 (green) both transitioned downstream through Ottumwa Dam to the mouth of the Des Moines River.*

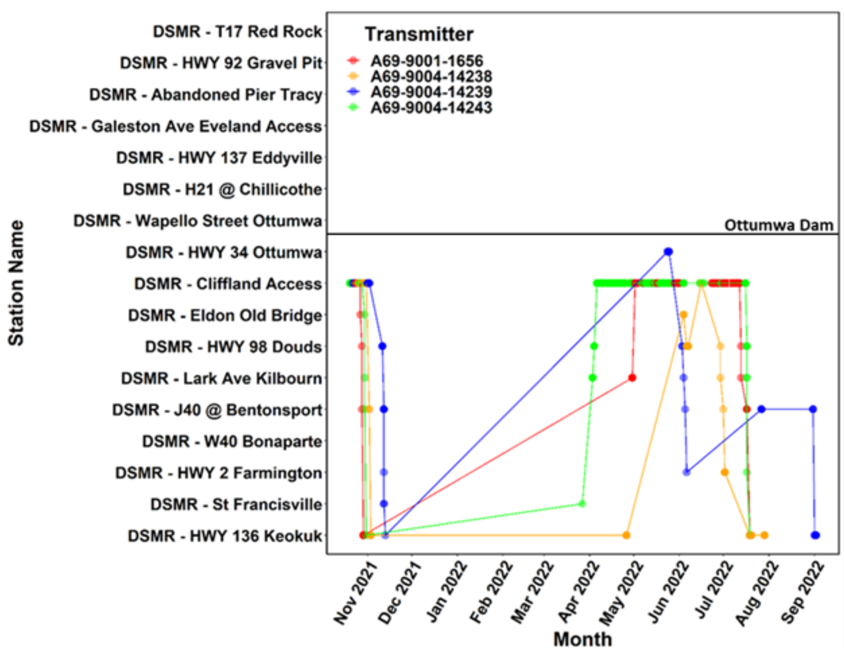

Figure 13. *Abacus plot showing detection histories of four Silver Carp that have made multiple movements between receivers near Cliffland, IA and the last receiver near the mouth of the Des Moines River. Each movement from DSMR – Cliffland access to DSMR – HWY 136 Keokuk is ~133 km. These four individuals migrated downstream, back upstream, and then back downstream between November 2021 and September 2022.*

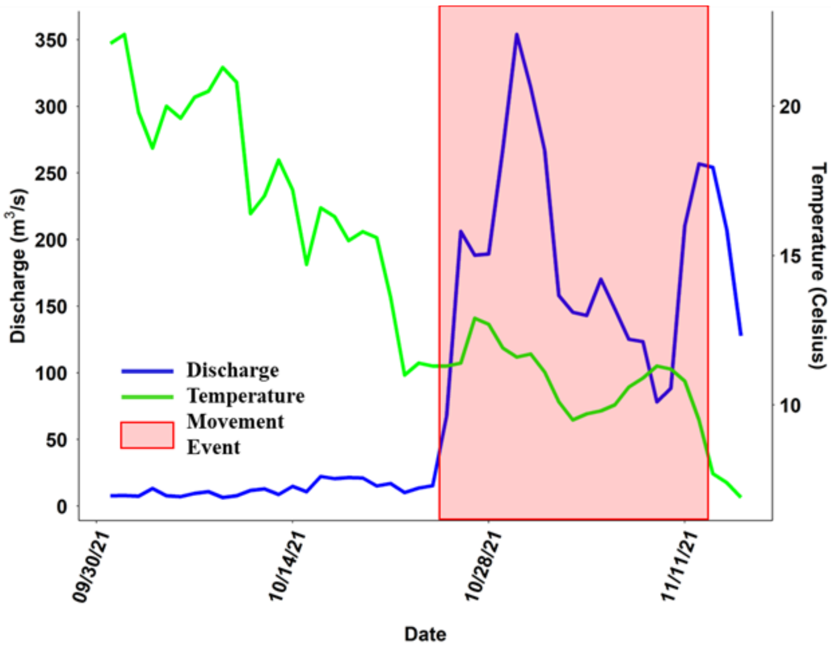

Figure 14. *Discharge (m^3/s) and water temperature (Celsius) from the USGS gauging station at Ottumwa, IA (station number 05489500) between October 1, 2021 and November 15, 2021 (https://waterdata.usgs.gov). A downstream movement event where 13 of 39 Silver Carp tagged near Cliffland, IA moved downstream to the mouth of the Des Moines River during late October-early November 2021 (red) that coincided with increased discharge and decreasing water temperature.*

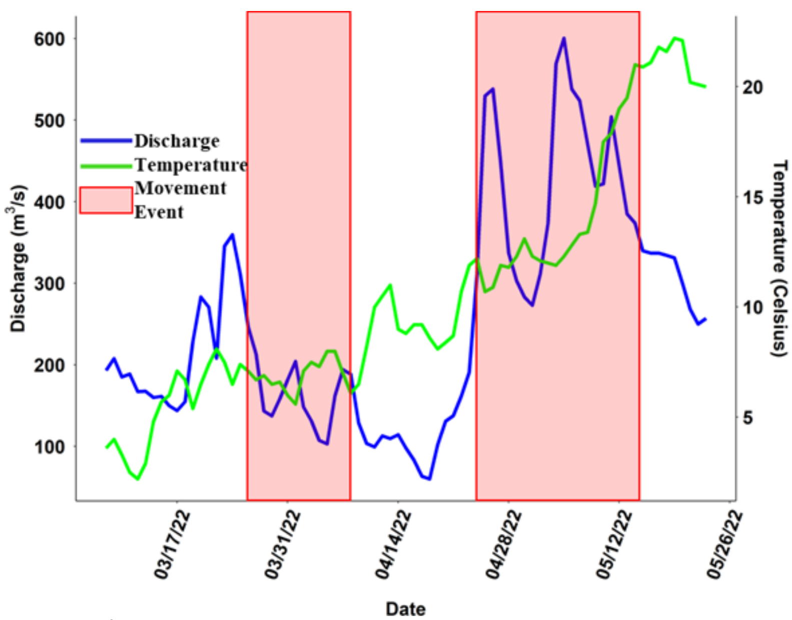

Figure 15. *Discharge (m^3/s) and water temperature (Celsius) from the USGS gauging station at Ottumwa, IA (station number 05489500) between March 17, 2022 and May 26, 2022 (https://waterdata.usgs.gov). Two separate upstream movement events (red) were recorded where Silver Carp moved upstream from the mouth of the Des Moines River to a receiver near Cliffland, IA. Four during late March-early April 2022, and six more in late April-early May. Movements coincided with increased discharge and increasing water temperature.*

Larval Sampling

In 2022, sampling occurred once a week from 05/23/2022 to 09/26/2022, and a total of 150 samples were collected from 18 nights of sampling. Only larval light traps were used in 2022. Three streams were sampled in Pool 19 of the Upper Mississippi River where larval bigheaded carp have historically been detected: Chaney Creek, Larry Creek, Waggoner Creek (Fig. 16, Fig. 17). An additional seining event was conducted on 07/20/2022 in Chaney Creek, Waggoner Creek, Sheridan Creek, and Larry Creek of Pool 19. No larval bigheaded carp were detected, but three Grass Carp were identified. All 2022 samples have been sorted and identified. From these 2022 light trap samples, there were 59,311 larval fishes from six different families identified, and Cyprinidae were the most abundant (72.4%). Larval abundances peaked in June and July. In 2022, there were a total of 8,180 confirmed bigheaded carp (8,177 larval, three juvenile) collected from Chaney Creek, Waggoner Creek, and Larry Creek on 06/27, 07/06, 07/11, 07/18, and 08/16. The majority of larval bigheaded carp (8,075) were captured on 6/27 during a descending hydrograph (Figure 18). For the rest of 2022, 105 invasive carp were captured.

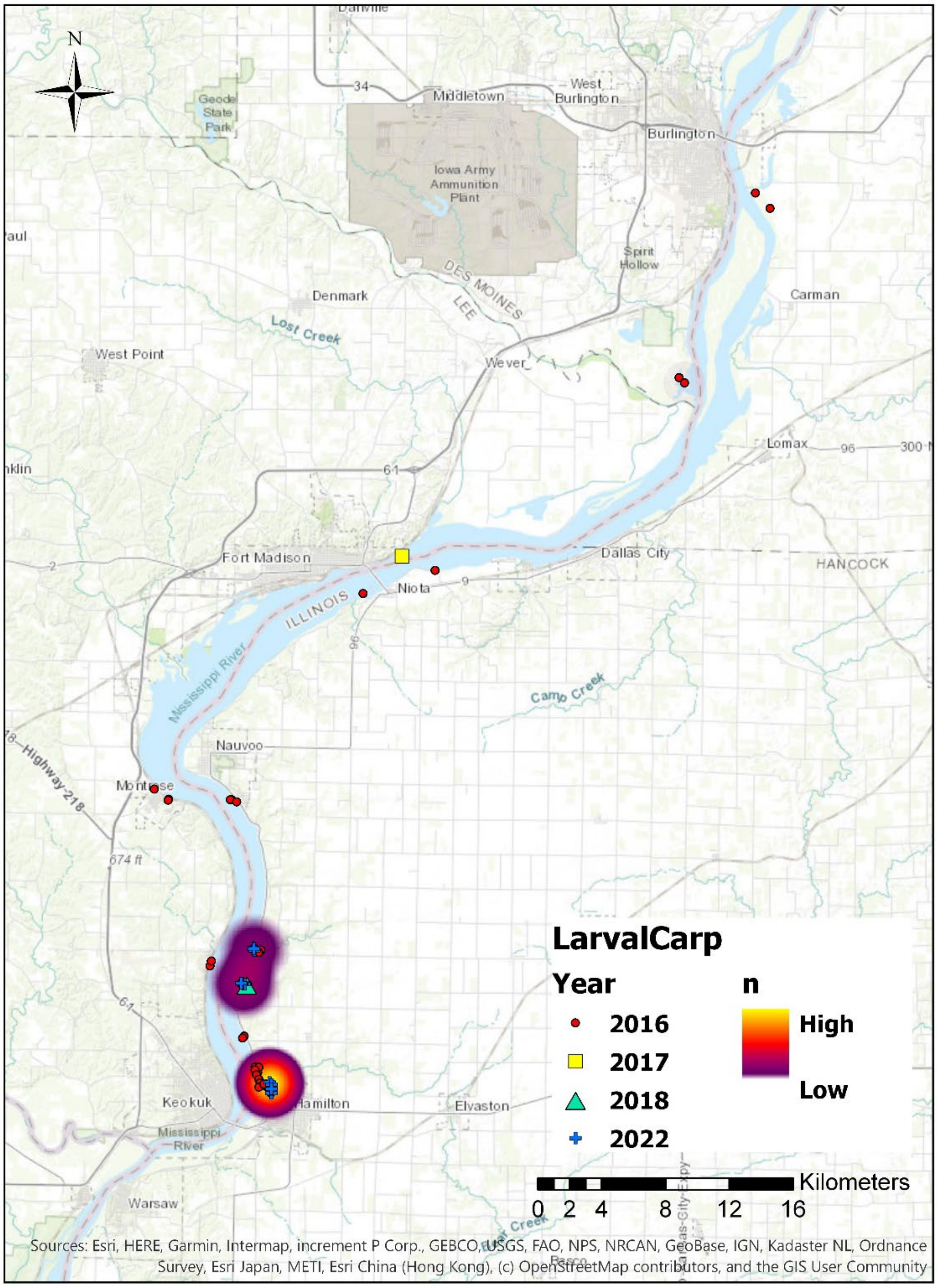

Figure 16. *Occurences of individual larval bigheaded carp (n) collected using larval light traps from 2016–2022 in Pool 19 of the Upper Mississippi River. The red circles represent areas where larval bigheaded carp were detected in 2016, the yellow squares represent areas where larval bigheaded carp were detected in 2017, the green triangles represent areas where larval bigheaded carp were detected in 2018, and the blue crosses represent areas where bigheaded carp were detected in 2022.*

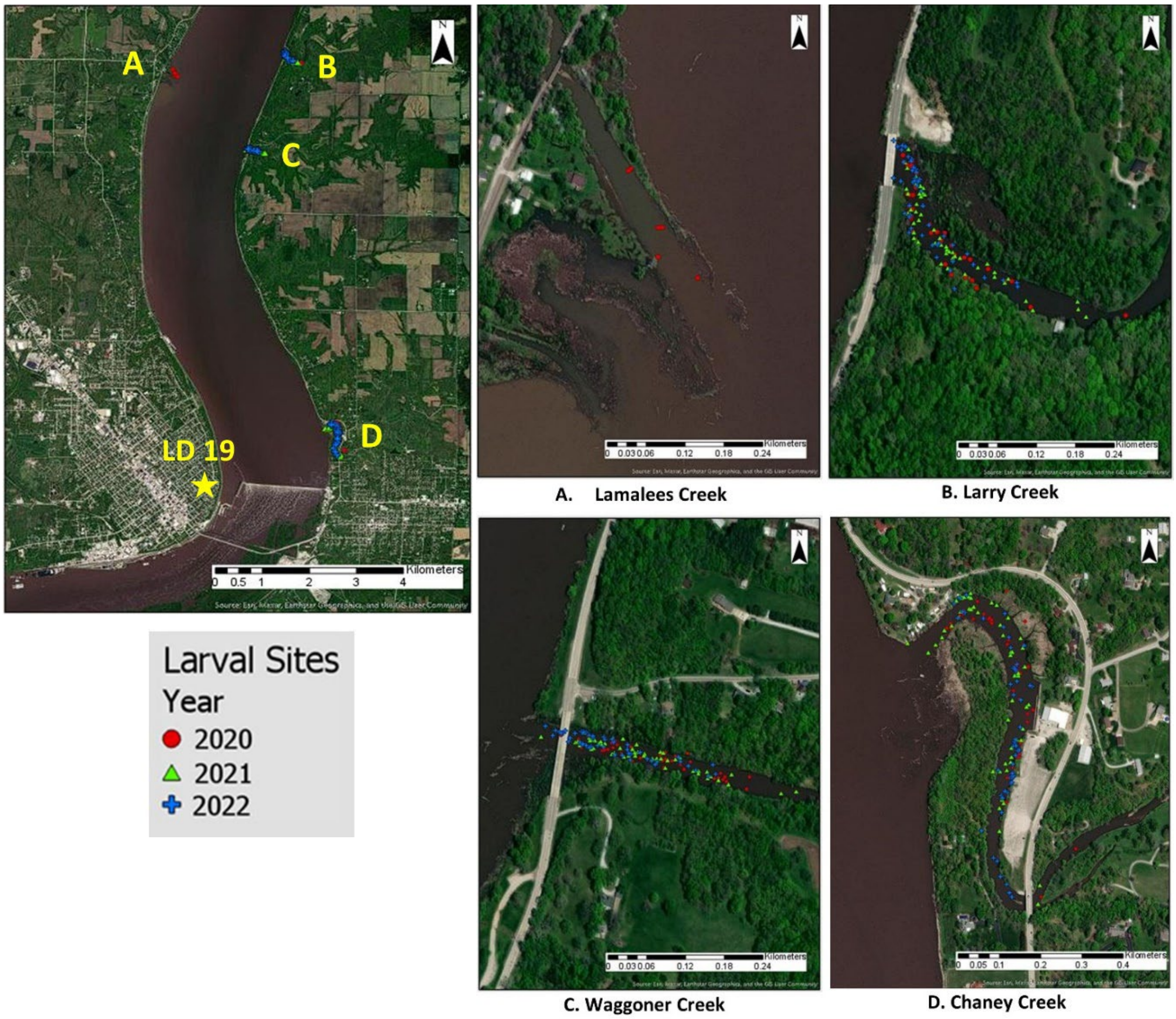

Figure 17. *Larval light trapping locations from 2020-2022 sampling seasons in lower Pool 19 of the Upper Mississippi River (left). For each creek sampled with light traps, red circles represent 2020 sites, green triangles represent 2021 sites, and blue crosses represent 2022 sites (right).*

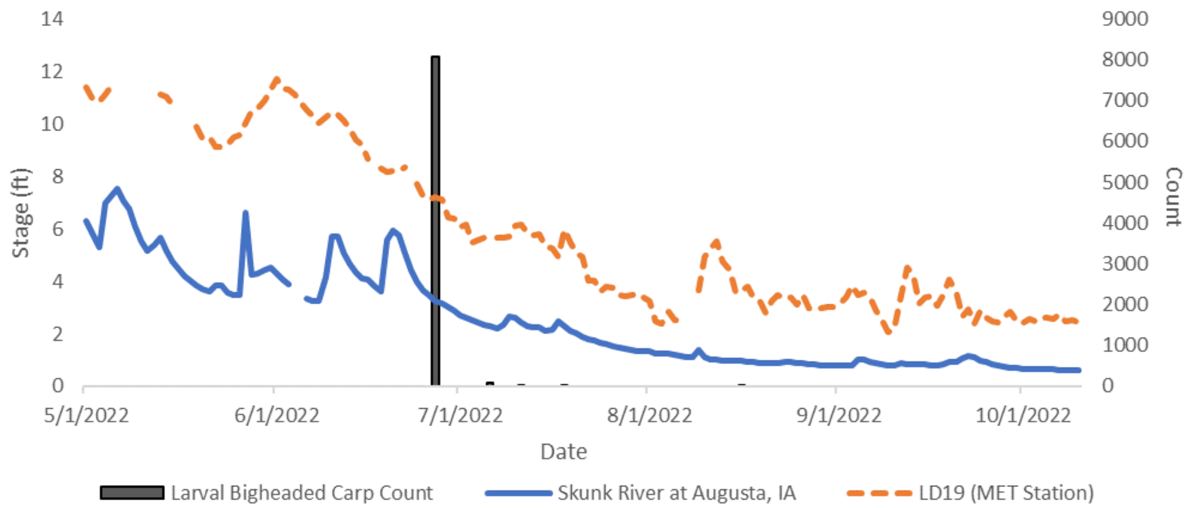

Figure 18. *Hydrological conditions in Pool 19 (P19) of the Upper Mississippi River from 05/01/2022 through 10/10/2022. Blue line represents river stage (ft) of Skunk River at Augusta, Iowa. Orange dashed line represents river stage (ft) at Lock and Dam 19 (MET Station). Solid black bars represent abundance of larval bigheaded carp collected in larval light traps in creeks of lower P19.*

Mortality Estimation Feasibility Study

In general, we found that it is possible to get reasonably accurate estimates of fishing mortality, even with relatively small studies (<200 tags/year, short duration study). If fishing mortality is low (5% of the population per year), however, a longer study duration and/or greater tagging effort (tags per year) may be needed. These simulations also indicate that it is important to have reasonable estimates of both the tag reporting and tag retention rates as these parameters are not directly estimable in the study design considered here. Specifically, the tag reporting rate can have a large effect on the precision of the harvest mortality estimate and if it is over or under-estimated could result in misleading information regarding the number of tags or duration of the study necessary to obtain a precise estimate of harvest mortality.
This study assumed that harvest rate and natural mortality were constant throughout the duration of the study. These assumptions are likely unrealistic in practice. Addressing these assumptions are, therefore, the focus of the next steps in this modelling effort.

Discussion:

The hydroacoustic program in the UMR is continuing to develop, with pool-scale survey designs developed for implementation in Pools 18-20 in 2023. In the coming years we hope to be able to detect trends in Silver and Bighead Carp abundance and density, and evaluate the impacts of management actions in the UMR. Spring pre/post harvest surveys will continue for one more year and then will be evaluated as a whole. Although hydroacoustic surveys were generally able to document declines in fish abundance within backwaters post-harvest, the relationship between the observed reduction in hydroacoustic densities and the associated reduction in available fish after removal of invasive carps, requires further examination. Factors potentially affecting these relationships include where non-invasive fish were released within a backwater, what species of fish were released, the disposition of the released fish, bathymetry of the area, water temperature and more.

Preliminary data suggests there may also be some issues with assigning species information to hydroacoustic data collected from backwaters in the spring. Factors contributing to the low rates of species apportionment that were observed in UMR backwaters include use of a target-length equation that assumes a side-aspect measurement of a fish target to estimate TL. Body orientation of fishes in backwater sites is random compared to areas with current, where fish generally orient parallell to the flow and in side-aspect to the hydroacoustics transducer. Additional factors that may have also contributed to low apportionment rates include relatively low overall numbers of commercially caught fish in some backwaters from which specific proportions could be assigned, potential limitations of hydroacoustic equipment to effectively sample the same fishes that were collected by commercial anglers (e.g. because of fish movement or habitat use, bathymetry limitations etc). Additionally, the equation that assigns species information to hydroacoustics data may need adjustment.

For pool-wide surveys, low water levels in 2021 and 2022 seemed to congregate fishes in side channels and the main channel where they could be sampled more effectively with hydroacoustics. During high water surveys in 2019, fish were more dispersed, and possibly seeking refuge from high flow in areas inaccessible to hydroacoustic sampling, like flooded timber. As more years of pool-wide sampling occur, the relationship between hydroacoustic estimates and the hydrograph will be investigated. Ongoing analyses of hydroacoustic data (the re-sampling analysis) will help determine the levels of effort needed to properly characterize the fish population of a navigation pool. This analysis will hopefully make our hydroacoustic pool-wide evaluations more efficient and eventually allow the addition of more UMR pools into the annual pool-wide sampling.

Fishery-independent sampling with the electrified dozer trawl enabled the collection of Silver Carp above LD19 in areas of low to moderate density, and was very successful at collecting Silver Carp in areas of high density (Pool 20 and downstream). Individuals from a large 2016 year-class continue to represent the most abundant age class above Lock and Dam 19. However, the presence of some younger Silver Carp (age 2+) could indicate that 1) limited reproduction has occurred in recent years above Lock and Dam 19, or 2) that young recruits from downstream pools have succcessfully passed through the lock. The presence of additional young age-classes in Pool 26 and downstream may indicate that those population segments experience successful reproduction and recruitment more often those population segments upstream. The presence of additional age classes could also be attributed to interactions with Illinois River populations entering Pool 26. Differences observed between open river and pooled reach Silver Carp demographics could be an indication of source-sink population dynamics.

Telemetry efforts continue to improve in the UMR and the addition of more receivers and tagged fish in the system in 2022 will allow for better detection of tagged fishes and more thorough understanding of spatial movements and habitat use in the UMR. The benefits of the telemetry arrays extend beyond our efforts to monitor Silver and Bighead Carp movements. During 2021, arrays monitored the movements of Paddlefish, Lake Sturgeon, and Bigmouth Buffalo throughout the UMR. All these data are regularly shared among our partnership and help support efforts to conserve and enhance native species populations.

Larval sampling has shown that bigheaded carp are capable of successfully spawning in areas of the IMZ above LD19, but that the success of these spawning events exhibits high interannual variability. Continuous larval sampling can identify potential nursery environments for bigheaded carp, as well as any future recruitment events within Pools 17–19 in the Mississippi River. Larval identification also determines what native fish families are reproducing yearly and establishes their recruitment success to the larval stage. Sampling allows for managers to diagnose if bigheaded carp are reproducing yearly, under what hydrological conditions (Figure 18), and what size their recruitment potential is at the northern forefront of their reproductive range in the Mississippi River.

The mortality estimation models found that it is possible to get reasonably accurate estimates of fishing mortality, even with relatively small studies (<200 tags/year, short duration study). If fishing mortality is low (5% of the population per year), however, a longer study duration and/or greater tagging effort (tags per year) may be needed.

Collectively, hydroacoustic, fishery-independent and dependent sampling, telemetry, and larval sampling efforts, are developing into components of a robust stock assessment program. We hope that we will soon be able to directly evaluate how populations of Silver and Bighead Carp may be affected by current contract removals and to forecast their future response to alternative removal strategies.

Recommendation:

Pre/post removal surveys in Pools 16-19 should continue in FY23 in order to gather additional data from backwater habitats, and other habitat types if available. Collecting similar data at other macrohabitats (e.g. side channels or main channel borders) would help clarify the effectiveness of hydroacoustic gear across different macrohabitat types. Further investigation into possible differences between acoustically estimated vs. collected fish lengths, and the drivers of these differences is warranted. Variables to investigate from the hydroacoustic data include fish orientation information across habitat types (which relates to the TS-Length equation), trying to improve relationships thru the development and application of alternative TS-length equations that do not assume side-aspect targets, and more focused length-frequency comparisons with consideration to fish size at gear recruitment.

Pool-wide surveys in the UMR should continue and possibly expand to be able to evaluate more pools that have contracted removal programs. The re-sampling analyses will continue to be used to inform appropriate levels of sampling effort across pools with varying Silver and Bighead Carp densities. Analysis of existing fishery-independent and dependent data will occur in FY23 to determine the most appropriate suite of fishery catch data for informing hydroacoustics estimates.

Fishery-independent surveys should continue in the UMR as a tool to monitor the demographic parameters of Silver and Bighead Carp along a broad spatial gradient, and to inform hydroacoustics surveys, both of which can help evaluate the effectiveness of management actions. These surveys also help us identify younger age classes of invasive carp that may not have recruited to commercial fishing gears. Results from the broader USFWS demographics study are being compiled and prepared for disseminated in peer-reviewed manuscripts.

Telemetry continues to be a useful tool for evaluating movements and habitat use by Silver and Bighead Carp, and for informing management actions. Maintenance of receiver arrays in the UMR should continue, with array expansion into any new locations identified by the partnership as areas of interest. Real-time receiver deployment and maintenance should also continue, and possibly expand if needed, as time and funding become available.

Continued larval sampling will help further identify the nursery environments of bigheaded carp, and document spawning events within Pools 17–19 in the Mississippi River. Future sampling should continue to refine which habitats and larval sampling gears are most appropriate to determine spawning success and recruitment potential of Silver and Bighead Carp in the IMZ.

The mortality feasibility modelling assumed that harvest rate and natural mortality were constant throughout the duration of the study. These assumptions are likely unrealistic in practice. Addressing these assumptions are the focus of the next steps in this modelling effort.

References:

Brownie, C., D.R. Anderson, K.P. Burnham, and D.S. Robson. 1978. Statistical inference from band recovery data – a handbook. U.S. Department of the Interior Fish and Wildlife Service, Resource Publication Number 125.

Campbell H.A., M.E. Watts, R.G. Dwyer, and C.E. Franklin CE. 2012. V-Track: software for analyzing and visualizing animal movement from acoustic telemetry detections. Marine and Freshwater Resources 63:815–820.

Chapman, D.C., and M.H. Hoff. 2011. Introduction *in* D.C. Chapman and M.H. Hoff, editors. Invasive Asian Carps in North America. American Fisheries Society, Symposium 74, Bethesda, Maryland.

Conover, G., R. Simmonds, and M. Whalen. editors. 2007. Management and control plan for bighead, black, grass, and silver Carps in the United States. Asian Carp Working Group, Aquatic Nuisance Species Task Force, Washington, D.C. 190 pp.

Coulter, D.P., R. MacNamara, D.C. Glover, and J.E. Garvey. 2018. Possible unintended effects of management at an invasion front: Reduced prevalence corresponds with high condition of invasive bigheaded carps. Biological Conservation 221: 118-126.

De Cicco, L.A., R.M. Hirsch, D. Lorenz, W.D. Watkins. 2022. dataRetrieval: R packages for discovering and retrieving water data available from Federal hydrologic web services, v.2.7.11, doi:10.5066/P9X4L3GE

Hammen, J.J., E. Pherigo, W. Doyle, J. Finley, K. Drews, and J. Goeckler. 2019. A comparison between conventional boat electrofishing and the electrified dozer trawl for capturing Silver Carp in tributaries of the Missouri River, Missouri. North American Journal of Fisheries Management 39:582-588.

Jackson, N., and A. L. Runstrom. 2018. Upper Mississippi River Basin Asian Carp Control Strategy Framework. Marion, IL.

Love, R.H. 1971. Measurements of fish target strength: a review. Fisheries Bulletin 69: 703-715.

MacNamara, R., D. Glover, J. Garvey, W. Bouska, and K. Irons. 2016. Bigheaded carps (Hypophthalmichthys spp.) at the edge of their invaded range: using hydroacoustics to assess population parameters and the efficacy of harvest as a control strategy in a large North American river. Biological Invasions 18: 3293-3307.

O’Connell, M.T., A.U. O’Connell, and V.A. Barko. 2011. Occurrence and Predicted Dispersal of bighead Carp ion the Mississippi River system: development of a heuristic tool. Pages 51-71 *in* D.C. Chapman and M.H. Hoff, editors. Invasive Asian Carps in North America. American Fisheries Society, Symposium 74, Bethesda, Maryland.

Parker-Stetter, S.L., L.G. Rudstam, P.J. Sullivan, D.M. Warner. 2009. Standard operating procedures for fisheries acoustic surveys in the Great Lakes. Great Lakes Fisheries Commission Special Publication 09-01.

Prechtel, A.R., A.A. Coulter, L. Etchison, P.R. Jackson, and R.R. Goforth. 2018. Range estimates and habitat use of invasive Silver Carp (*Hypophthalmichthys molitrix*): evidence of sedentary and mobile individuals. Hydrobiologia 805:203-218.

R Development Core Team. 2020. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

U.S. Fish and Wildlife Service. 2016. Annual Summary of Activities and Expenditures to Manage the Threat of Asian Carp in the Upper Mississippi and Ohio River Basins. Annual Report to Congress Pursuant to the Water Resources Reform and Development Act of 2014 (PL 113-121).