Project Title: Evaluation of controls on density and behaviors of invasive 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), 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 occasional reproduction and recruitment from LD 19 to LD 15 (also referred to as the intensive management or IMZ zone), and a zone above LD 15 where captures of adults occur but there is no evidence of population recruitment (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 20-25 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 density, 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 FY23 included over 252 miles of transects, counted 36,434 fish greater than 254 mm/10" TL, and ensonified over 13.3 million cubic meters of water.
- Hydroacoustic surveys of Pools 18-20 were conducted using a stratified random sampling design. Pool 21 received a comprehensive survey in FY23 and a resampling analysis to guide future levels of sampling effort for that pool is ongoing.
- Age-0 Silver Carp (N=106) were sampled with the electrified dozer trawl in the lower Skunk River (Pool 19) during fall surveys, indicating a successful spawning event occurred above LD19 in 2023.
- 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, along with partners from USGS, INHS, and MN DNR, documented a significant upstream migration of invasive carp from below LD15 into pools well above the IMZ. Most of these fish remained near the limits of their upstream migration and appear to have established new home ranges in these newly invaded habitats.
- The USFWS tagged the first invasive carp in the Wisconsin River during April 2023 plus 3 additional Silver Carp in Pool 8. 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 nearly 80,000 larval fishes from nine different families in 2023. Of these, 120 were confirmed invasive carp (90 larval bigheaded carp, 26 larval Grass Carp, and four juvenile bigheaded carp. Larval bigheaded carp were also caught in 2022, but prior to that, were last collected in 2018. Larval bigheaded carp are primarily collected in June.
- The harvest mortality model was completed. Results herein can provide managers with the information they need to make informed decisions regarding tagging studies.

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 like 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 Pool 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 18-21 of the UMR. Pools 18, 19 and 20 were previously sampled in their entirety, 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 have been used to inform stratified random sampling designs for Pools 18, 19 and 20, with ½ mile transects randomly selected from side channel, nearshore main channel border, and offshore main channel border sites. Pool 21 received a comprehensive survey of all available habitats in 2023. The Pool 21 data will undergo re-sampling analysis in FY24, and all four pools will be sampled with an SRS design in fall of 2024. The fall 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, reducing chances of double counting fish within or among pools, compared to the spring, when spawning cues can increase fish movement. Thirdly, the fall 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 13.1. 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 5 cm length groups for Silver Carp, Bighead Carp, and other fish species. Length-specific proportions were used to categorize acoustically detected fish, and relative density was estimated. All analyses were conducted using the data analysis program "R" (R Core Team 2020).

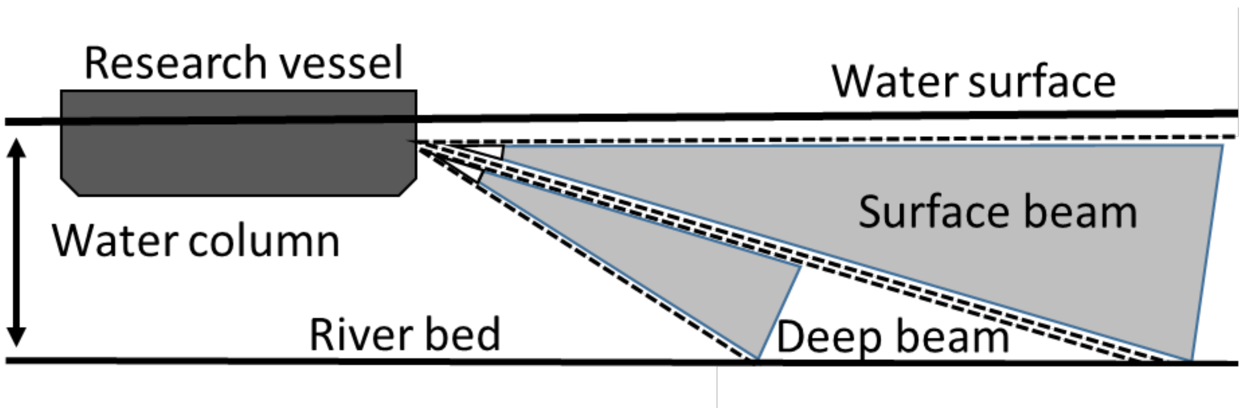

Figure 1. *Diagram showing the approximate orientation of the hydroacoustic beams during a mobile survey. The data that can be used in analysis is collected within the gray area.*

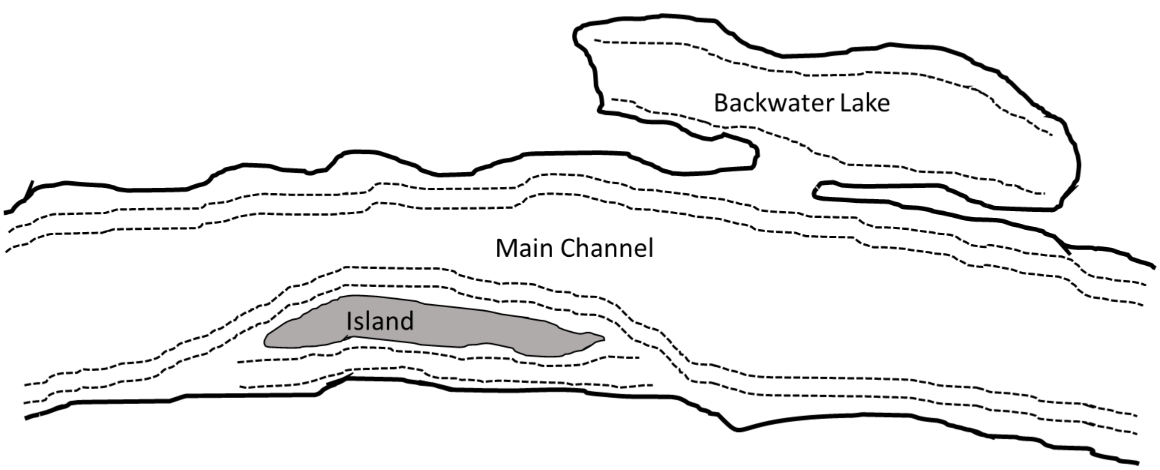

Figure 2. *Example of survey transects (represented by dotted lines) in the Upper Mississippi River; nearshore and offshore transects for each bank along the main channel, transducers pointing toward the thalweg; one transect on each bank for island side-channels and one or more transects for backwater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

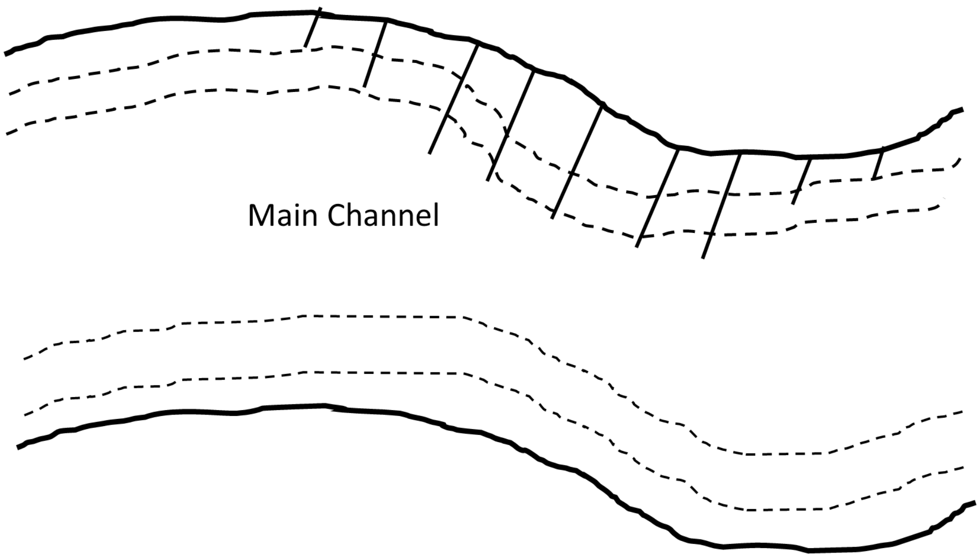

Figure 3. *Example of main channel survey transects (represented by dotted lines) in the Upper Mississippi River where wing dikes are present. Two transects for each bank along the main channel, transducers pointing toward the thalweg. When possible, transects run over the top of the dikes and as close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

Fishery Sampling

Physical fish capture data can provide demographic information and relative abundance data that can help evaluate management actions. Physical fish capture data is also needed to inform hydroacoustic surveys to generate species specific estimates of relative abundance. 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 fisheries-independent sampling 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. 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. Most age structures were collected using standardized electrified dozer trawling. However, in low-density areas, additional structures were collected using gill net catches to meet sample size requirements (about 100 individuals per sample location).

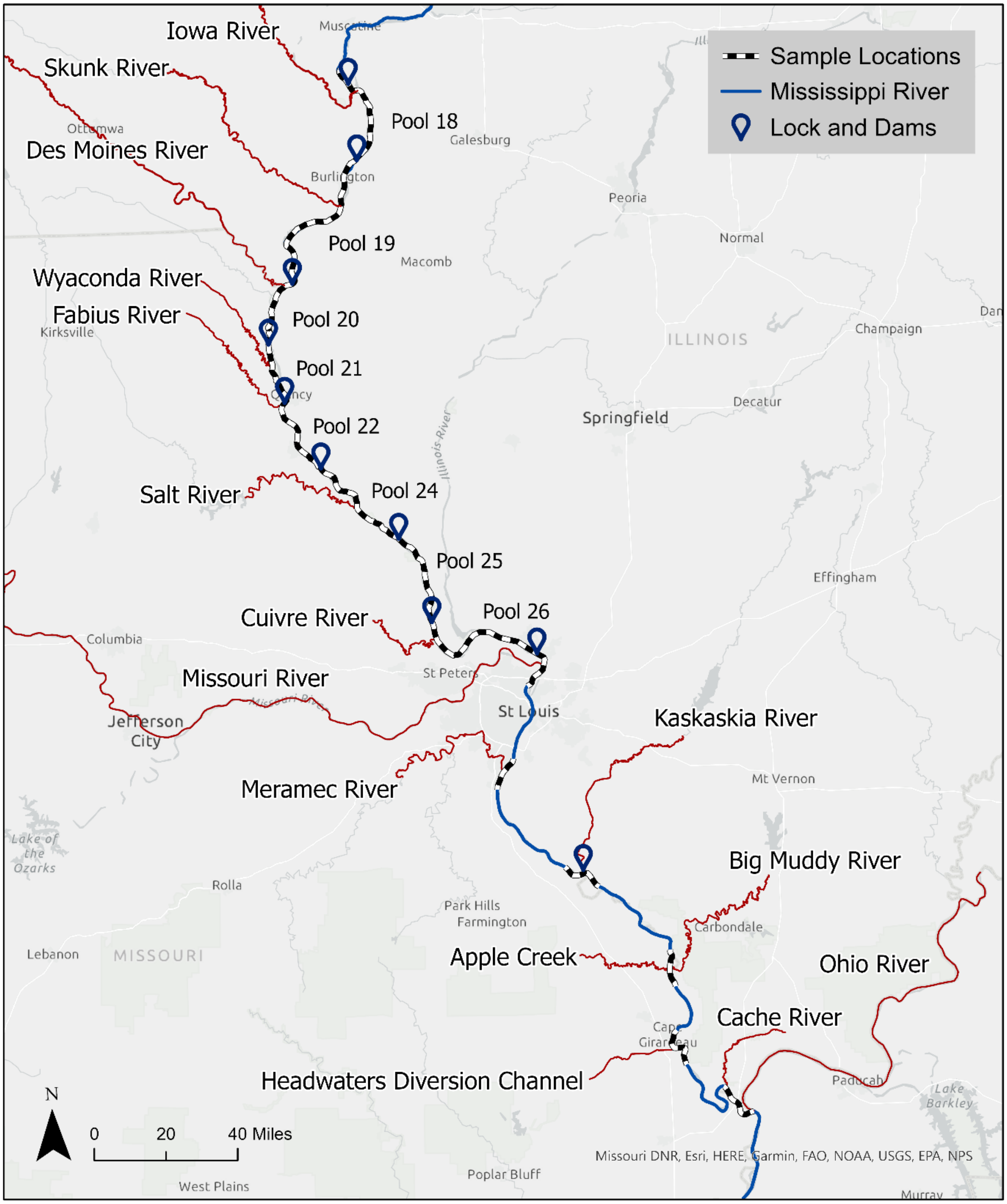

Figure 4. Map depicting fall 2023 fishery-independent sampling locations in black and white. Tributaries where sampling occurred are highlighted in red. The southernmost dam is in the Kaskaskia River, whereas all other dams are on the mainstem Mississippi River.

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.

<u>Stationary Receiver Array</u>: 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 2023, 79 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). USFWS collaborated with WI DNR and MN DNR to expand receiver coverage in the Wisconsin River and Pools 5A-8 by 19 new receivers compared to 2022 in response to growing invasive carp population density in this region. In 2023, MDC deployed 36 receivers along sites in Pools 20-26 including above and below each of the locks and dams (Figure 5), utilizing platforms of opportunity. Crews from Iowa State University deployed 31 receivers throughout the Des Moines, Iowa, and Cedar Rivers below the first barriers on each system. 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.

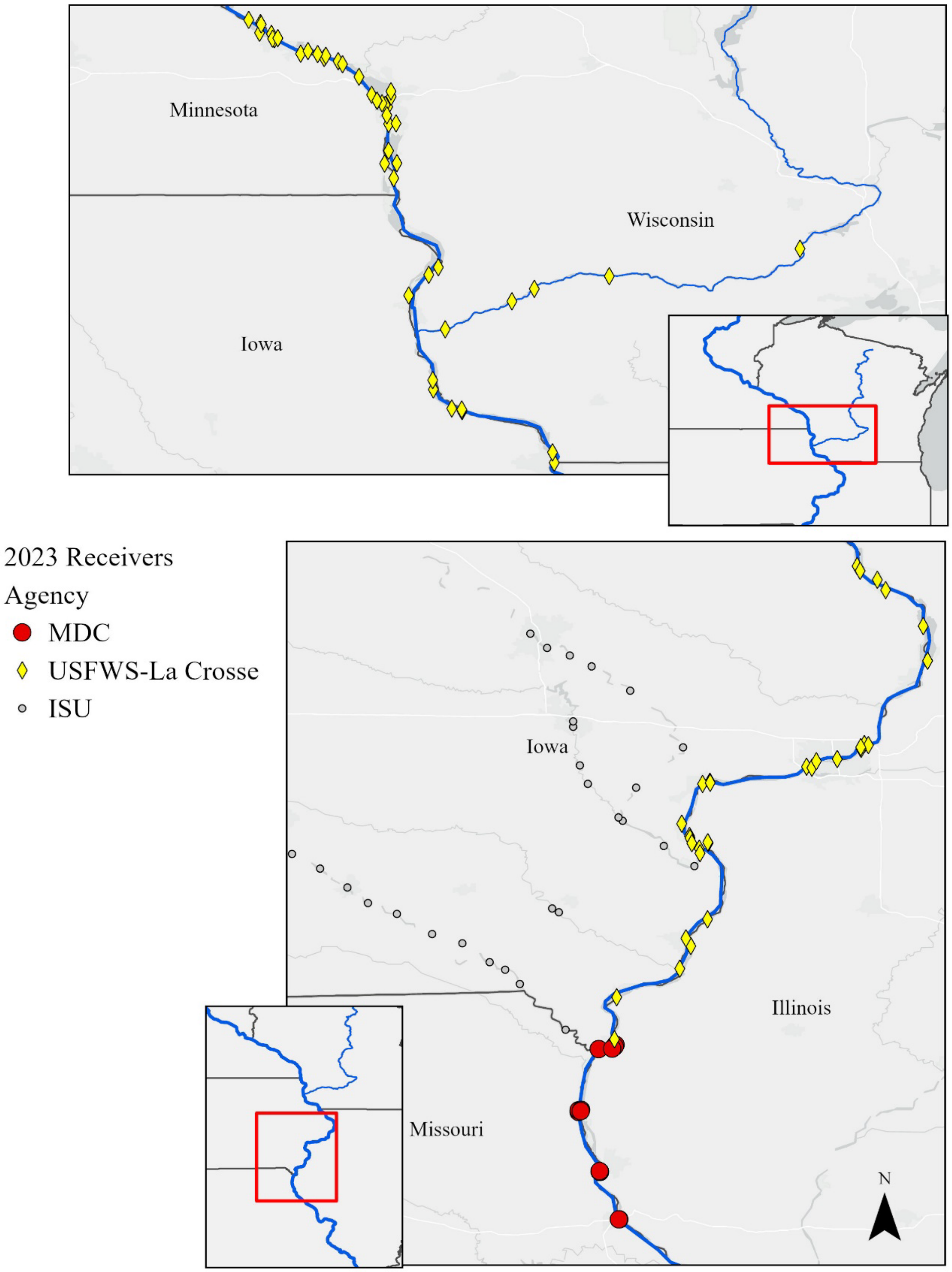

Figure 5. *Locations of stationary receivers deployed by MDC, USFWS, and INHS (diamonds) in the Mississippi River basin during 2023.*

Real Time Receivers: USFWS crews deployed and maintained four real-time receivers in Pools 16-18 from March-November 2023. Data from these receivers were shared daily with partners at INHS leading contracted removal efforts. Debris flows in spring flooding damaged the Credit Island and Cleveland Slough Receivers. USFWS crews were able to repair and redeploy the Cleveland Slough unit during early May. However, the Credit Island unit was badly damaged and required a full rebuild. This took that unit out of operation following its initial failure in early May 2023.

Acoustic Transmitter Tagging: During April and May FY23, staff from the La Crosse FWCO worked with partners at WI and MN DNRs to capture and tag 3 Silver Carp in Pool 8 and one Bighead Carp in the Wisconsin River. Iowa State University teams captured and tagged and additional 60 Silver Carp from the Des Moines, Iowa, and Cedar Rivers during Fall 2022 and an additional 50 among these three rivers during Fall 2023.

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.

To determine general, broad movements of Silver Carp in Iowa tributaries, Iowa State University staff calculated maximum displacement values for individual Silver Carp and estimated mean values based on tagging location. Maximum displacement value represents the distance (km) between most upstream and downstream detections. Individuals were classified as mobile, sedentary, or intermediate 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 sedentary, individuals with displacement values greater than 100 km as mobile, and individuals with displacement values between those thresholds as intermediate.
Frequency of transitions between the DSMR and UMR Pool 20 and transitions between IAR/CER and UMR Pool 18, were assessed to provide insights on population structure/connectivity of individuals located within the UMR tributaries and those within the mainstem UMR. Observations of both upstream and downstream passage through Ottumwa Dam were noted. Water temperature and discharge from nearby USGS gauging stations was also assessed (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 can provide 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 proportions 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 (Table 1). 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.

Table 1. *Model parameters representing a range of management decisions and environmental scenarios.*

	Scenarios	
parameter	**Constant harvest rate**	**Variable harvest rate**
Harvest rates	0.05, 0.15, 0.25, 0.35, 0.45, 0.55, 0.65 per year	Increasing Decreasing Variable Large recruitment event
Study duration	Short: 3yr tagging & 4yrs recovery Long: 9yr tagging & 10yrs recovery	Short: 3yr tagging & 4yrs recovery Long: 9yr tagging & 10yrs recovery
Number of tags	50, 100, 250, 500, 1000, 2000, 4000 per year	100, 500, 1000, 4000 per year
Tag retention	Best-case: range 0.9 – 1.0; assume 0.95 Worst-case: range 0.75 – 0.95; assume 0.85	Best-case: range 0.9 – 1.0; assume 0.95
Tag reporting	Best-case: range 0.9 – 1.0; assume 0.95 Worst-case: range 0.35 – 0.65; assume 0.5	Best-case: range 0.9 – 1.0; assume 0.95

Results:

Pool 19 hydroacoustics pre/post contract removal

From April 18 to April 22, 2023, three different backwaters were surveyed pre and post contract removal, and two backwaters were surveyed in the absence of fishing pressure as control sites. At each control site, two surveys were conducted with a 30 minute rest period in between. An additional week of scheduled fieldwork had to be canceled due to flood conditions that prevented contracted anglers from fishing. All three removal 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 58%-83% (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). At the control sites, relative fish densities increased between surveys at one site, and decreased between surveys at the other site, despite a lack of fishing pressure (Table

2). At all sites, factors like unfavorable bathymetry, fish behavior (e.g. immigration or emigration into or out of the fishing area between surveys), or other variables, likely contributed to confounding pre/post estimates. We attempted to use contract removal community data to produce species specific hydroacoutics estimates, but this was unsuccessful for the majority of fish targets. Accordingly, reported results are not species specific.

Table 2. *Hydroacoustic survey estimates of fish abundance and relative density at backwater sites in the Upper Mississippi River, pre and post contracted removals, Spring 2023.*

Site	Pool	Pre/Post	N Fish	Volume (m3)	Fish/1000 m3
Otter Bay	17	Control Pre	12	26051	0.4606
Otter Bay	17	Control Post	5	20601	0.2427
Carthage	18	Control Pre	37	74557	0.4963
Carthage	18	Control Post	48	79452	0.6041
Swamps	19	Pre	6	19810	0.3029
Swamps	19	Post	1	17844	0.0560
Carthage	17	Pre	51	79589	0.6408
Carthage	17	Post	28	104948	0.2668
Fish Lake	19	Pre	44	64020	0.6873
Fish Lake	19	Post	5	42021	0.1190

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 2023.*

Site	Fish caught	Invasives Removed	Percent Removed	Change in Density (%)
Otter Bay Control	none	none	0.0	-47.3
Carthage Control	none	none	0.0	+21.7
Swamps	411	114	27.7	-81.5
Carthage	28	10	35.7	-58.4
Fish Lake	195	55	28.2	-82.7

Pool 18-21 pool-wide hydroacoustics

During fall pool-wide hydroacoustic surveys USFWS personnel completed over 252 miles of survey transects, ensonified more than 13,332,433 cubic meters of water, and enumerated 36,434 fish greater than 254 mm (10") total length (Table 4; Table 5). Similar to 2021-2022, water levels in 2023 were too low to access any backwater habitats, only main channel border and side channel habitats were sampled.

Relative overall fish densities have increased across all habitats and pools in each of the last two years. The greatest increases occurred in Pool 20, where relative densities of fish ≥ 254 mm

(10”) TL have essentially doubled each year since 2021. Increased densities of fish in the main channel of Pool 20 drove most of this change. Trends in relative densities among habitats mirrored those observed in previous years for most pools. Relative densities of fish were greater at side channel habitats than main channel habitats in all pools and years except Pool 20 in 2023 (Table 5). This was the first time in three years of sampling that relative fish densities in the main channel of any pool, exceeded densities in the side channels. By pool, overall relative densities increased as we proceeded downstream, and were several times greater in Pool 20 (6.0416 fish / 1,000 m^3) than either Pool 18 (0.6826 fish / 1,000 m^3) or Pool 19 (0.9846 fish / 1,000 m^3). Pool 20 surveys insonified about twice as many fish as Pool 21 (3.1146 fish / 1,000 m^3; Table 5).

Community data from fall dozer trawl sampling was applied to the hydroacoustic data to produce estimates of Silver Carp relative density across pools, habitats, and years. Silver Carp exhibited trends in relative density similar to those seen in the overall fish estimates. Silver Carp were more abundant at side channel habitats than main channel habitats for all pools and years except Pool 20 in 2023, where more Silver Carp were estimated to be in the main channel. The lowest relative densities of Silver Carp occurred above LD19, and much higher estimates occurred below LD19 (Table 6). We also estimated the percentage of hydroacoustically detected fish that were likely to be Silver Carp (Table 7). This estimate does not rely on sampled volume, only the number of hydroacoustic targets and their estimated length, relative to physical capture data. When examining Silver Carp abundance as a percentage of the overall hydroacoustic sample, we saw the same habitat association trends across years as we did under the other hydroacoustic reporting metrics. Above LD19, the percentage of suspected Silver Carp in the sample trended slightly downward each year with pool-wide percentages in Pool 18 ranging from a high of 1.27% in 2021, to 0.0% in 2023. Below LD19, the percentage of suspected Silver Carp in the sample for Pool 20, dropped from 7.48% to 4.27% in 2022, and then returned to 6.81% in 2023. Pool 21 had a similar percentage of Silver Carp as Pool 20 (6.64%; Table 7).

Table 4. *Effort by pool and habitat type for pool-wide hydroacoustic surveys in the UMR, fall 2023. 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	% Sampled	0.5 mile transects (N)
18	MC	SRS	40%	77
	SC	SRS	40%	53
19	MC	SRS	20%	74
	SC	SRS	25%	25
20	MC	SRS	45%	77
	SC	SRS	35%	24
21	MC	comprehensive	100%	124
	SC	comprehensive	100%	51
Total				505

Table 5. *Number of fish ≥ 254 mm/10", total volume sampled, and relative density of fish/1,000 m³ by pool and habitat type, pool-wide hydroacoustic surveys in the UMR, fall 2022.*

		2021			2022			2023		
Pool	Habitat	N	Volume (m^3)	Fish/1,000 m^3	N	Volume (m^3)	Fish/1,000 m^3	N	Volume (m^3)	Fish/1,000 m^3
18	MC	1328	6260390	0.2121	826	3453144	0.2392	1070	2141976	0.4995
	SC	1273	1649681	0.7717	1216	1386679	0.8769	1096	1031070	1.0630
	Combined	2601	7910071	0.3288	2042	4839823	0.4219	2166	3173046	0.6826
19	MC	2925	6156423	0.4751	10707	15861319	0.6750	2147	2315512	0.9272
	SC	1850	2501569	0.7395	3594	3871264	0.9284	836	714062	1.1708
	Combined	4775	8657992	0.5515	14301	19732583	0.7247	2983	3029574	0.9846
20	MC	8753	6164736	1.4198	9987	3112277	3.2089	16117	2611705	6.1711
	SC	5046	1150818	4.3847	2270	485580	4.6748	2622	489939	5.3517
	Combined	13799	7315554	1.8863	12264	3597857	3.4087	18739	3101644	6.0416
21	MC							7528	3179142	2.3679
	SC		no survey			no survey		5018	849027	5.9103
	Combined							12546	4028169	3.1146
Total	combined	21175	23883617	0.8866	28607	28170263	1.0155	36434	13332433	2.7327

Table 6. *Relative density of Silver Carp/1,000 m^3 by year, pool and habitat type, derived from pool-wide hydroacoustic and dozer trawl surveys in the UMR, fall 2021-2023.*

Pool	Habitat	2021	2022	2023
18	MC	0.0000	0.0012	0.0000
	SC	0.0200	0.0113	0.0000
	Combined	0.0042	0.0041	0.0000
19	MC	0.0000	0.0000	0.0009
	SC	0.0028	0.0033	0.0000
	Combined	0.0008	0.0006	0.0007
20	MC	0.0911	0.1301	0.4506
	SC	0.4091	0.2440	0.2045
	Combined	0.1411	0.1455	0.4117
21	MC	NA	NA	0.1407
	SC	NA	NA	0.4549
	Combined	NA	NA	0.2069

Table 7. *Percentage of hydroacoustic targets estimated to be Silver Carp by year, pool and habitat type, derived from pool-wide hydroacoustic and dozer trawl surveys in the UMR, fall 2021-2023.*

Pool	Habitat	2021	2022	2023
18	MC	0.00	0.48	0.00
	SC	2.59	1.29	0.00
	Combined	1.27	0.96	0.00
19	MC	0.00	0.00	0.09
	SC	0.38	0.35	0.00
	Combined	0.15	0.09	0.07
20	MC	6.41	4.05	7.30
	SC	9.33	5.22	3.82
	Combined	7.48	4.27	6.81
21	MC	NA	NA	5.94
	SC	NA	NA	7.70
	Combined	NA	NA	6.64

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 conduct 361 dozer trawl samples and collect 1,837 Silver Carp in 2023 from throughout the Upper Mississippi River (Table 8). Crews removed lapilli otoliths and aged 1,110 individuals collected from the confluence of the Ohio River to

Pool 18 (> 430 river miles). Silver Carp CPUE varied spatially and temporally among sampling events during 2021-2023. Variability of CPUE values across sampling locations was expected due to the large spatial extent and population fragmentation from dams. Variability within sample locations across years is likely due to fluctuating catchability between sampling events. Over the three years of sampling, the general trend in Silver Carp CPUE's was about 100/hr or higher at locations within the open river reach, about 50/hr or lower at locations in the pooled reach, and about 1/hr for the two pools above L&D 19 (Figure 6). The only consistent exception was Pool 26 which was the only pooled location with a CPUE > 100/hr during all three years of sampling (Figure 6). Increased CPUE observed in Pool 19 in 2023 was the result of a large capture of age-0 Silver Carp. 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 7 & 8). Overall, Silver Carp were smaller and in poorer condition in the open river, and larger and in better condition in the pooled reaches. Sex ratios exhibited some variability among sites and years, but no trends were evident. Overall, observations were consistent with expectations (i.e., the proportion of each sex was near 50% for all locations).

Age-frequency histograms suggest variable recruitment of Silver Carp during the last 12 years with strong and weak cohorts represented in each population (Figure 9). Although inconsistent among river reaches, we were able to detect strong year classes from age-frequency histograms (Figure 9). Specifically, we identified strong 2018 and 2019 cohorts in the open river reach as well as portions of the pooled reach. These strong cohorts coincide with other studies that have documented a large 2018 cohort in the lower Illinois River, which intersects the UMR in Pool 26 (ICRCC 2021; Figure 4), and a large 2019 cohort in the Missouri River which intersects the UMR south of Pool 26 (MICRA 2021; Figure 4). Except for the 2018- and 2019-year classes, the population appears to be dominated by older Silver Carp (about 7-10 years; 2011–2016-year classes) at all sample locations. Furthermore, except for Pool 26, which accounted for nearly all the fish in the pooled reach < 5 years old, larger numbers of younger (< 5 years) Silver Carp were captured in the open river reach compared to the pooled reach locations (Figure 10). We suspect that spawning and/or recruitment is hindered in pooled reaches. Indeed, insufficient flow or distance for egg drift can result in ineffective spawning and recruitment of Silver Carp (George and Chapman 2013).

Although the pooled reaches may be primarily a migrant population, infrequent spawning and recruitment events appear to occur. Age data from above L&D 19 depicted a relatively large 2016 cohort (age-7 in 2023; Figure 9). Those fish likely spawned above L&D 19 and recruited to the population. Additionally, 106 age-0 Silver Carp were collected in Pool 19 in 2023 (some of these were from targeted runs and not reported in CPUE). These captures indicate that Silver Carp could intermittently spawn and recruit in the pooled reaches when conditions are ideal.

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 9). A more detailed report on USFWS fisheries-independent monitoring during 2021-2023 is available upon request.

Table 8. *Summary of sample effort (number of dozer-trawl survey sites; N), Silver Carp catch, and range of Silver Carp total length (TL) of dozer-trawl surveys across the 14 sample locations (Location) in the Upper Mississippi River during fall 2023. Note that river mile was set to 0 at the confluence of the Ohio River.*

Location	River Miles	N	Total Catch	Stock-sized	TL Range (mm)
Pool 18	410–437	29	0	0	–
Pool 19	365–410	34	61	58	90–850
Pool 20	343–365	27	76	76	575–826
Pool 21	325–343	25	77	77	600–825
Pool 22	301–325	25	45	45	619–819
Pool 24	273–301	25	43	43	627–856
Pool 25	242–273	23	60	60	631–850
Pool 26	203–242	24	204	203	158–780
Missouri River	191–198	25	307	307	407–900
Meramec River	157–164	17	341	341	480–930
Kaskaskia River	114–120	16	244	244	480–765
Big Muddy River	73–79	22	189	189	510–863
Headwaters Diversion Channel	46–52	20	89	89	550–880
Ohio River	0–8	47	101	101	576–1,004
Summary	0–437	359	1,837	1,833	90–1,004

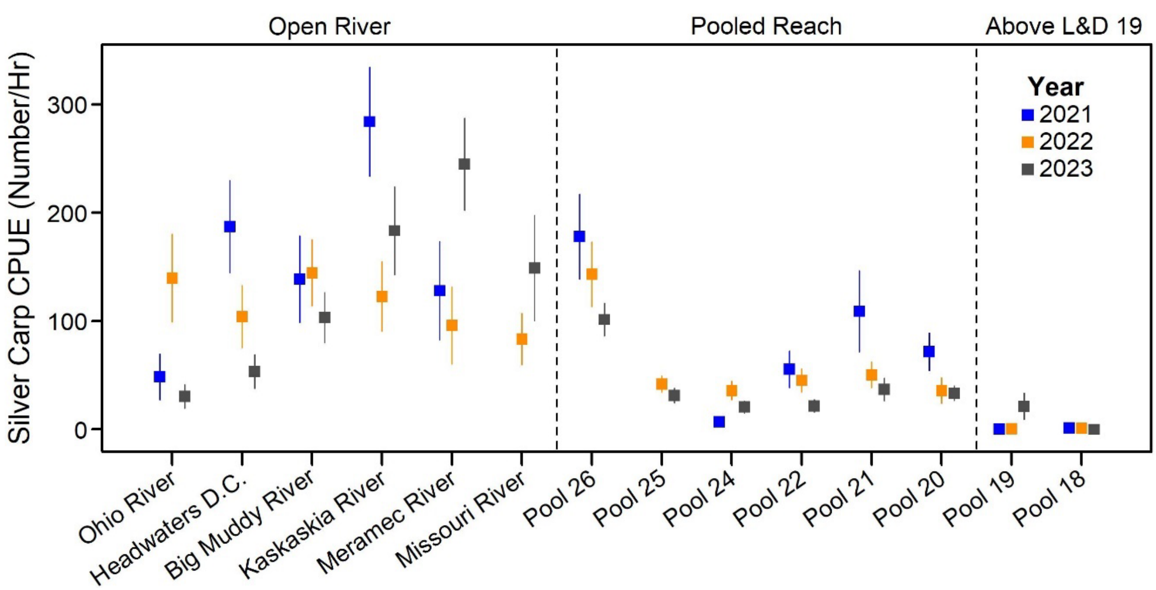

Figure 6. *Location-specific mean stock-sized catch-per-unit-effort of Silver Carp (number/hr) in the Upper Mississippi River during 2021–2023. Error bars represent one standard error. All fish were sampled using an electrified dozer trawl. Vertical dashed lines separate locations into reaches of the Upper Mississippi River.*

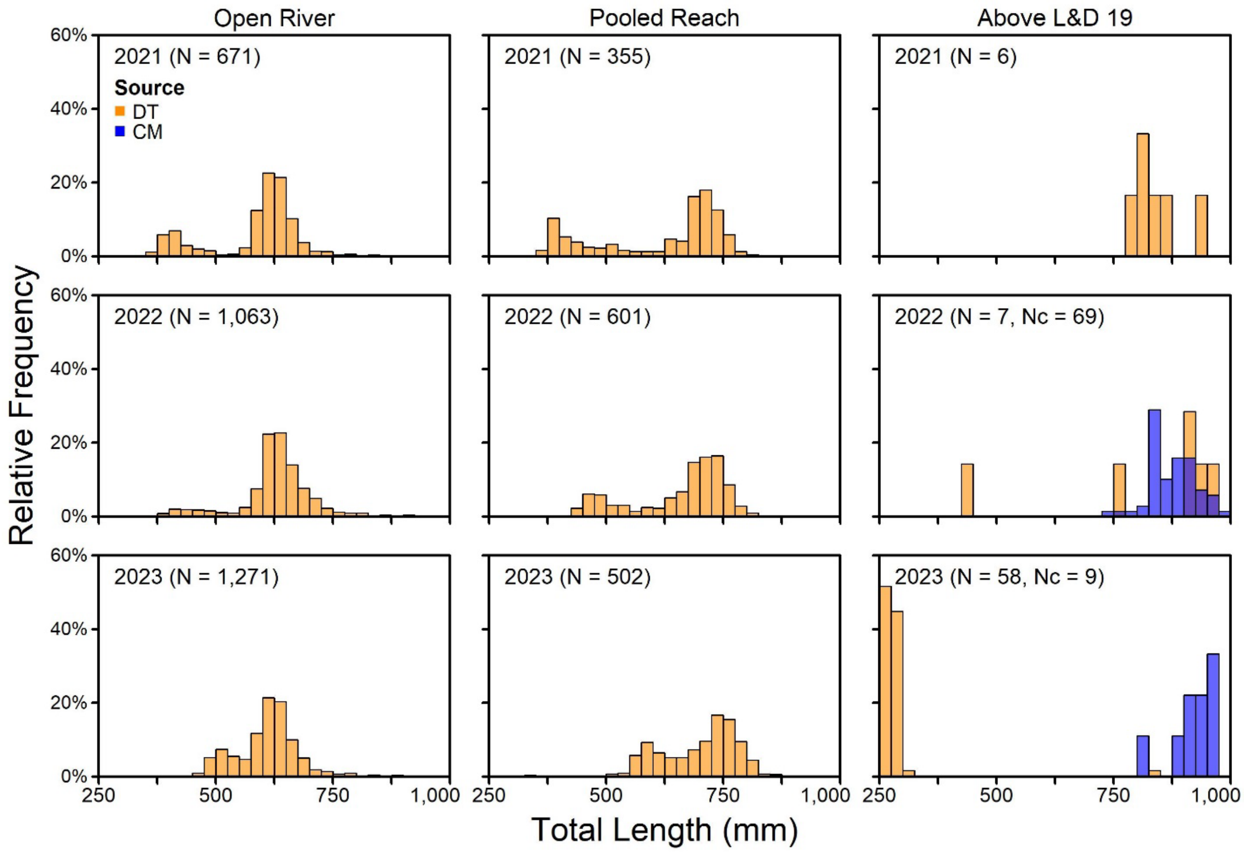

Figure 7. *Reach-specific relative length-frequency histograms of stock-sized (total length > 250 mm) Silver Carp from electrified dozer trawl surveys (DT, with a sample size of N) in the Upper Mississippi River during 2021–2023. Supplementary data from sampling commercial gill net caches (CM, with a sample size of Nc) were included for low-density locations above L&D 19 during 2022–2023.*

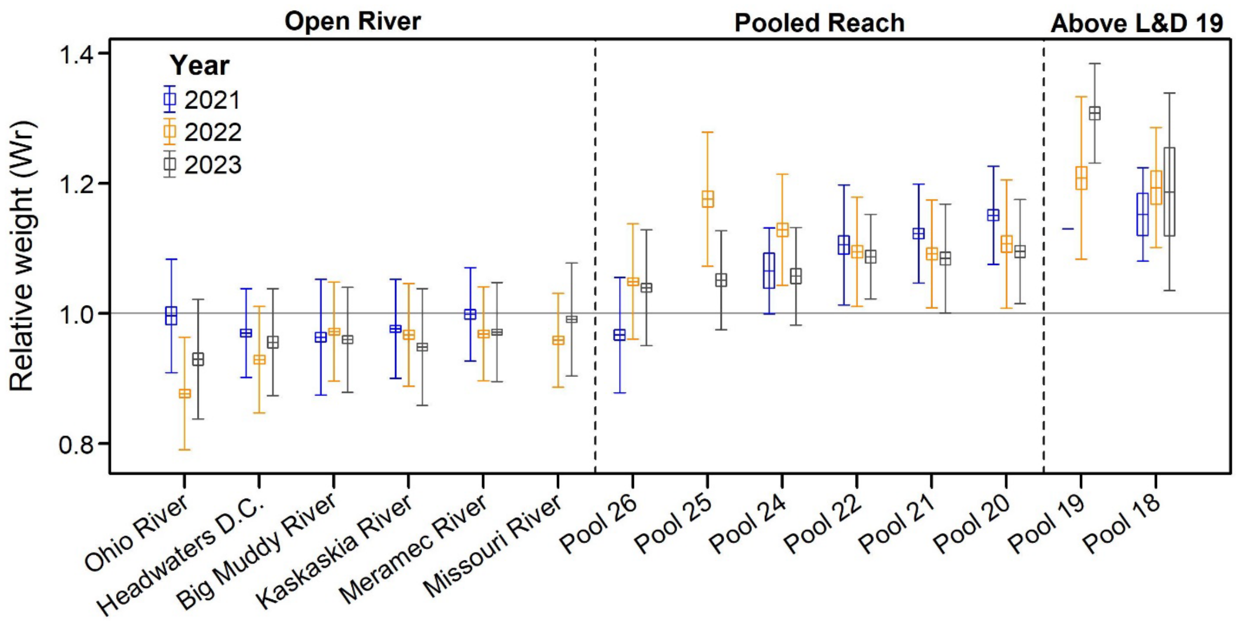

Figure 8. *Location-specific relative weights (Wr) of stock-sized Silver Carp in the Upper Mississippi River during 2021–2023. In each location, the horizontal line represents the mean Wr, the box covers mean ± SE, and the error bar represents mean ± SD. Vertical dashed lines separate locations into reaches of the Upper Mississippi River. The majority of fish were from electrified dozer trawl surveys (N = 4,523), with complemented fish from fisheries-dependent sampling (N = 79) at locations above L&D 19.*

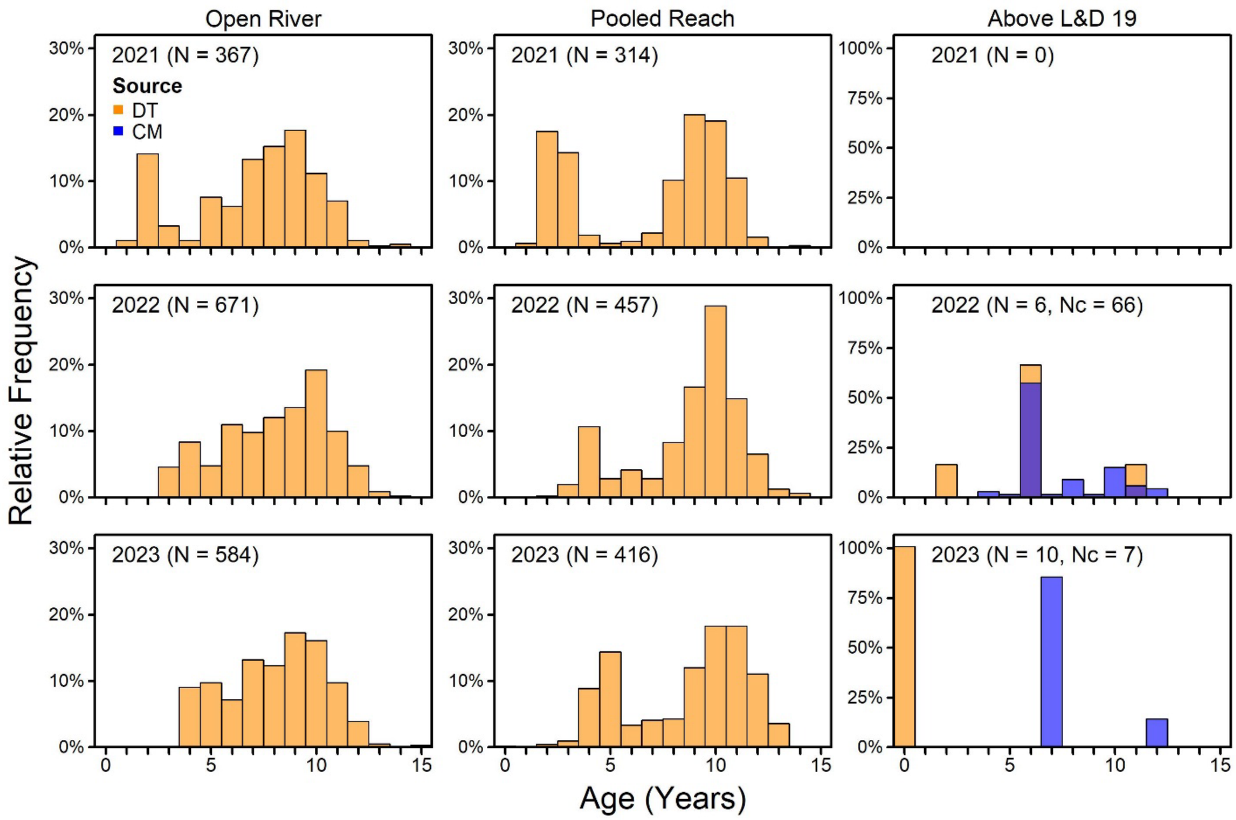

Figure 9. *Reach-specific relative age-frequency histograms of Silver Carp from electrified dozer-trawl surveys (DT, with a sample size of N) in the Upper Mississippi River during 2021–2023. Supplementary data from sampling commercial gill-net caches (CM, with a sample size of Nc) were included for low-density locations above L&D 19 during 2022–2023.*

Table 9. *The estimates of life history parameters of Silver Carp across spatial units of the Upper Mississippi River. The estimates of L∞ and K of the von Bertalanffy growth model were corresponding to a t0 estimate of −0.297. Refer to Table 2 for the explanations of table contents.*

Spatial Unit	N	L_∞ (mm)	K (Year^{-1})	M (Year^{-1})
Above L&D 19	79	946.8	0.412	0.474
Pools 20–25	827	754.9	0.362	0.465
Pool 26	357	699.3	0.341	0.456
Open river	1,618	674.3	0.385	0.504

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. USFWS staff are heading development of a peer-reviewed manuscript summarizing upstream migrations of invasive carp and paddlefish during 2022-23 This manuscript has been submitted for review and will be ready for publication during early FY25. A summary of detection events is presented in Table 10.

Table 10. *Results from residency event analysis for Silver and Bighead Carp and their hybrids in the UMR during 2023. 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 during 2023.*

2023 INDIVIDUALS DETECTED (SUM RESIDENCY EVENTS)			
UMR POOLS	**Bighead Carp**	**Hybrid Bighead x Silver Carp**	**Silver Carp**
POOL 5A	1 (15)	1 (57)	14 (4813)
POOL 6	1 (16)	1 (587)	10 (9014)
POOL 7	-	-	6 (20903)
POOL 8	2 (325)	1 (45)	43 (15971)
POOL 9	1 (14)	-	32 (4602)
POOL 10	5 (875)	2 (106)	52 (34329)
POOL 11	4 (2873)	2 (36)	51 (21621)
POOL 12	3 (104)	2 (34)	23 (3374)
POOL 13	6 (1048)	2 (40)	46 (11191)
POOL 14	4 (1990939)	1 (7)	45 (8315)
POOL 15	8 (9119)	2 (45)	84 (786511)
POOL 16	19 (54878)	6 (763)	137 (204889)
POOL 17	22 (26192)	8 (2425)	115 (44792)
POOL 18	16 (8205)	8 (3144)	118 (35262)
POOL 19	13 (6528)	3 (388)	53 (70603)

Of the 124 invasive carp tagged by MDC, 95 were detected at least a single day since being tagged in late fall 2021. Sixty-eight invasive carp were not detected outside the pooled reaches of the UMR, while five invasive carp made it to the open river and were detected at Maple Island in Pool 25, 19 invasive carp were detected in the Des Moines River, and three invasive carp were detected in the Missouri River. Eighteen of those invasive carp were not detected outside of their respective pools, meaning they were only detected within the pool they were originally tagged in. Eight invasive carp tagged in Pool 21 left that pool and traveled 2.0 to 87.0 river miles (total distance from tagging origin, not accounting for total distance actually traveled) from Pool 21 within the pooled UMR system. Nine invasive carp tagged in Pool 22 left that pool and traveled 18.0 to 85.0 river miles from Pool 22 within the pooled UMR system. Nine invasive carp tagged in Pool 24 left that pool and traveled 24.0 to 61.0 river miles from Pool 24 within the UMR system. Nineteen invasive carp tagged in Pool 25 left that pool and traveled 12.0 to 92.0 river miles from Pool 25 within the pooled UMR system. Four invasive carp tagged in Pool 26 left that pool and traveled 107.0 to 108.0 river miles from Pool 26 within the UMR system. Movement patterns should be assessed in depth to elucidate patterns and further assist with harvest efforts.

Of the Silver Carp tagged by Iowa State University below Red Rock Dam, 25 individuals were classified as sedentary, 11 individuals were classified as mobile, and 14 individuals were classified as intermediate. One individual has not yet been detected. One Silver Carp (765 mm TL, male) moved out of the Des Moines River into the UMR during Spring 2022 and was detected at a Missouri Department of Conservation receiver near Jefferson City, MO in the Missouri River during July 2022 and most recently detected further upstream in the Missouri River near Blaire, NE during June 2023, resulting in the longest observed maximum displacement of 1,433 km. Of the Silver Carp we tagged below Ottumwa Dam, we classified 16 individuals as sedentary, 25 individuals as mobile, and 12 individuals as intermediate. The longest confirmed maximum displacement of individuals tagged below Ottumwa Dam was approximately 615 km where 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. Of the Silver Carp we tagged in the Iowa River, we classified 23 individuals as sedentary, 9 individuals as mobile, and 8 individuals as intermediate. Seven individuals have not yet been detected. The longest confirmed maximum displacement of individuals tagged in the Iowa River was approximately 290 km where a Silver Carp (854 mm TL) was detected at Lock 15 in the UMR. Of the Silver Carp we tagged in the Cedar River, we classified 21 individuals as sedentary, 19 individuals as mobile, and 4 individuals as intermediate. Four individuals have not yet been detected. The longest confirmed maximum displacement of individuals tagged in the Cedar River was approximately 290 km where a Silver Carp (791 mm TL) was detected at Lock 15 in the UMR. Twelve Silver Carp tagged below Red Rock Dam transitioned downstream and successfully passed through Ottumwa Dam between October 2021 and October 2023. Two of those individuals (A69-1602-49718 and A69-9004-14226) appear to have successfully transitioned back upstream through Ottumwa Dam while nine individuals have moved downstream to the mouth of the Des Moines River. We have not observed any individuals tagged below Ottumwa Dam transitioning upstream through Ottumwa Dam. Twenty-four individuals tagged below Ottumwa Dam have transitioned downstream to the mouth of the Des Moines River as of October 2023. Of those twenty-four, sixteen have since migrated back upstream to their tagging location at some point in time. Nine individuals repeated this movement at least twice, showcasing highly mobile behavior. We observed a large movement event 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. Smaller upstream movement events were also observed during spring 2022 as both water temperature and discharge increased. Another large downstream movement event was observed during July 2022 when 15 individuals moved downstream to the mouth of the Des Moines River, followed by a smaller downstream movement between late October and early November 2022. A second series of smaller upstream movement events occurred between late March and early June 2023 where individuals moved back up into the Des Moines River, followed by a small downstream movement between late May and early June 2023. These movements typically coincided with fluctuations of discharge and temperature; however, we have experienced movements even during periods of low flow.

Ten Silver Carp tagged in the Iowa River moved downstream to the mouth of the Iowa River between April 2022 and November 2023. Of those ten individuals, four of them have made this movement two to three times. During Spring 2023, two individuals moved downstream in the Iowa River into UMR Pool 18 and then moved upstream to Lock 15. Three individuals moved from the Iowa into the Cedar River, showing some connectivity with the Cedar River cohort. Of the cohort tagged in the Cedar River, 19 individuals have moved downstream to the mouth of the Iowa River between April 2022 and Spring 2023. Each of those individuals has since moved back upstream into the Cedar River and 10 of the 19 moved back downstream a second time, showcasing some mobility. During Spring 2023, two individuals moved from the Cedar River downstream to the Iowa River and then into UMR Pool 18 where they began moving upstream and were detected as far as Lock 15. One individual (A69-1602-49655) returned to the lower portion of the Iowa River during July 2023. A single individual moved downstream from the Cedar River to UMR Pool 19 during June 2022, but has since moved back upstream into the Cedar River. These movements generally occurred during periods of increased discharge and changing temperature. A movement event was observed between mid-June and mid-July 2022 where 10 individuals between the Iowa and Cedar rivers moved downstream to the mouth of the Iowa River. A second downstream movement event was observed between early August and early September 2022 during increased discharge but still relatively low water levels. We observed a large upstream movement between late March and mid-May 2023 as water temperature began to increase from 5 - 20°C, followed by a smaller downstream movement from mid-May through early June 2023.

Larval Sampling

In 2023, sampling occurred once a week from 05/15/2023 to 09/25/2023, and a total of 142 samples were collected from 16 nights of sampling. Only larval light traps were used in 2023 to sample three streams in Pool 19 of the Upper Mississippi River where larval bigheaded carp have historically been detected: Chaney Creek, Larry Creek, Waggoner Creek (Figures 10-11). All 2023 samples have been sorted and identified. From these 2023 light trap samples, there were 79,783 larval fishes from nine different families, and Cyprinidae were the most abundant (83.2%) followed by Centrarchidae (15.7%). In 2023, there were a total of 120 confirmed invasive carp (90 larval bigheaded carp, 26 larval grass carp; 4 juvenile bigheaded carp) collected from Chaney Creek, Waggoner Creek, and Larry Creek on 05/15, 05/30, 06/05, 06/12, and 06/26/2023 (Figure 12).

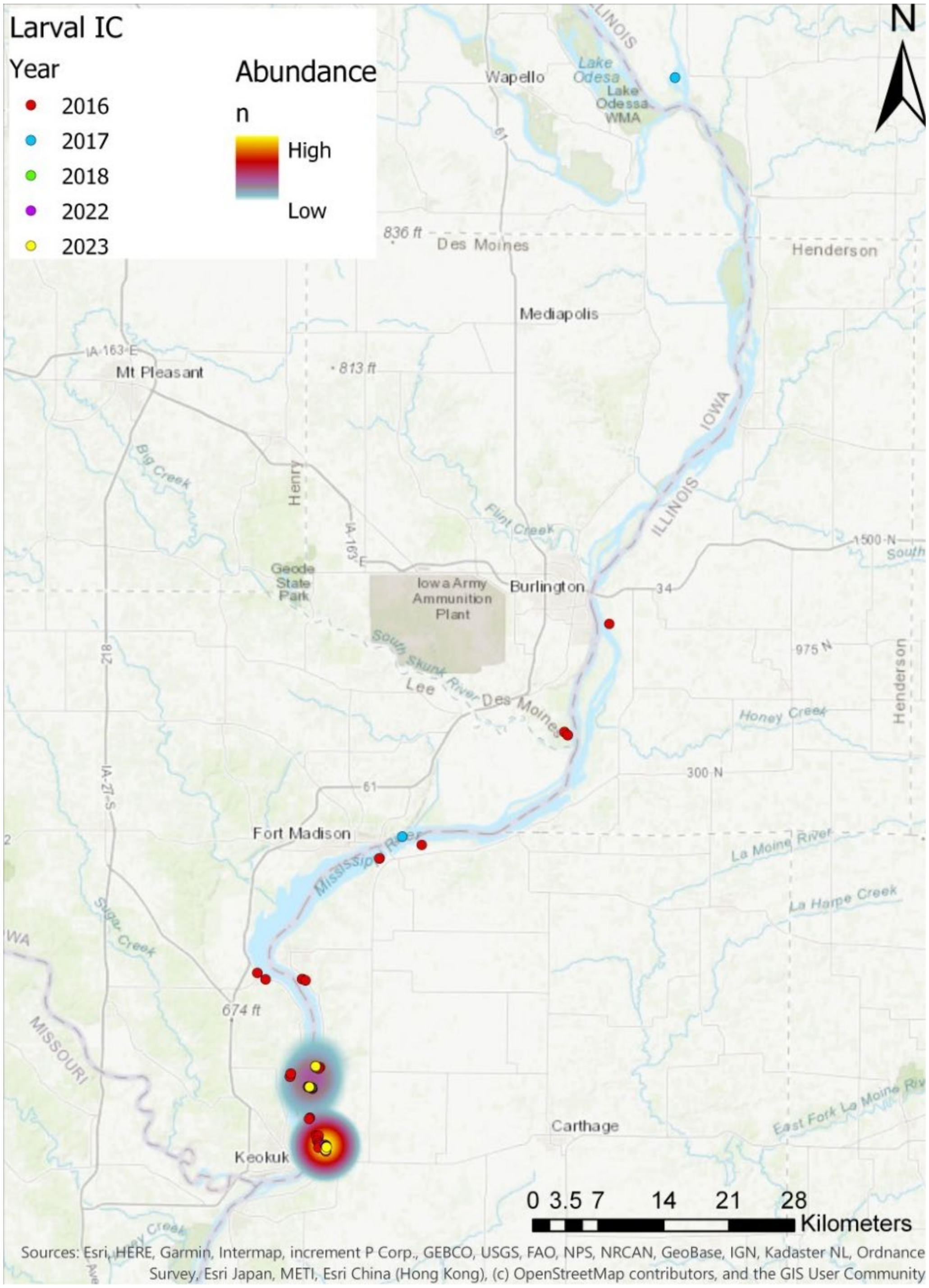

Figure 10. *Occurences of individual larval bigheaded carp (n) collected using larval light traps from 2016–2023 in Pool 19 of the Upper Mississippi River. The red circles represent areas where larval bigheaded carp were detected in 2016, the yellow squares represent areas where larval bigheaded carp 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, and the yellow circles represent areas where bigheaded carp were detected in 2023.*

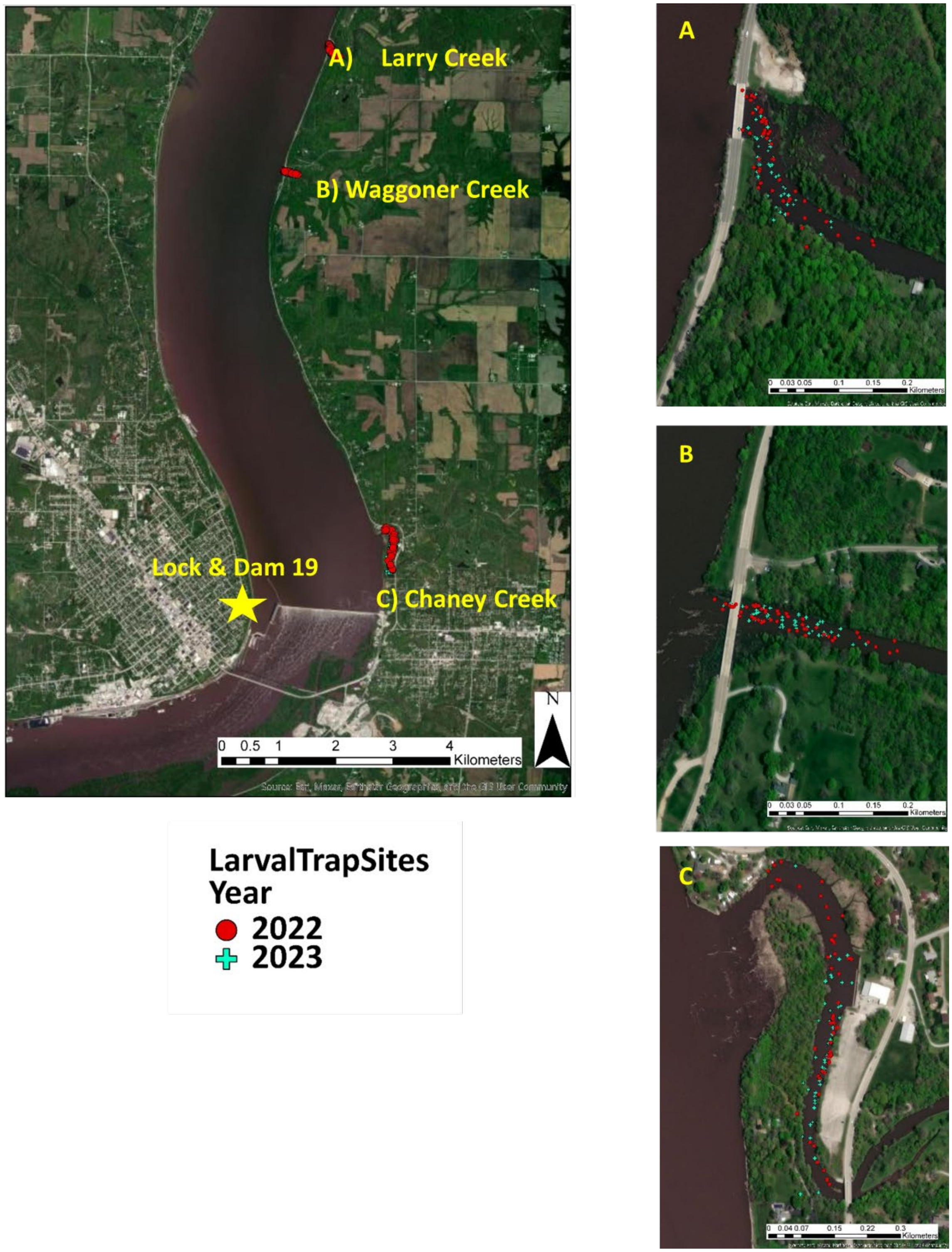

Figure 11. *Larval light trapping locations from 2022-2023 sampling seasons in lower Pool 19 of the Upper Mississippi River (left). For each creek sampled with light traps, red circles represent 2022 sites and green crosses represent 2023 sites (right).*

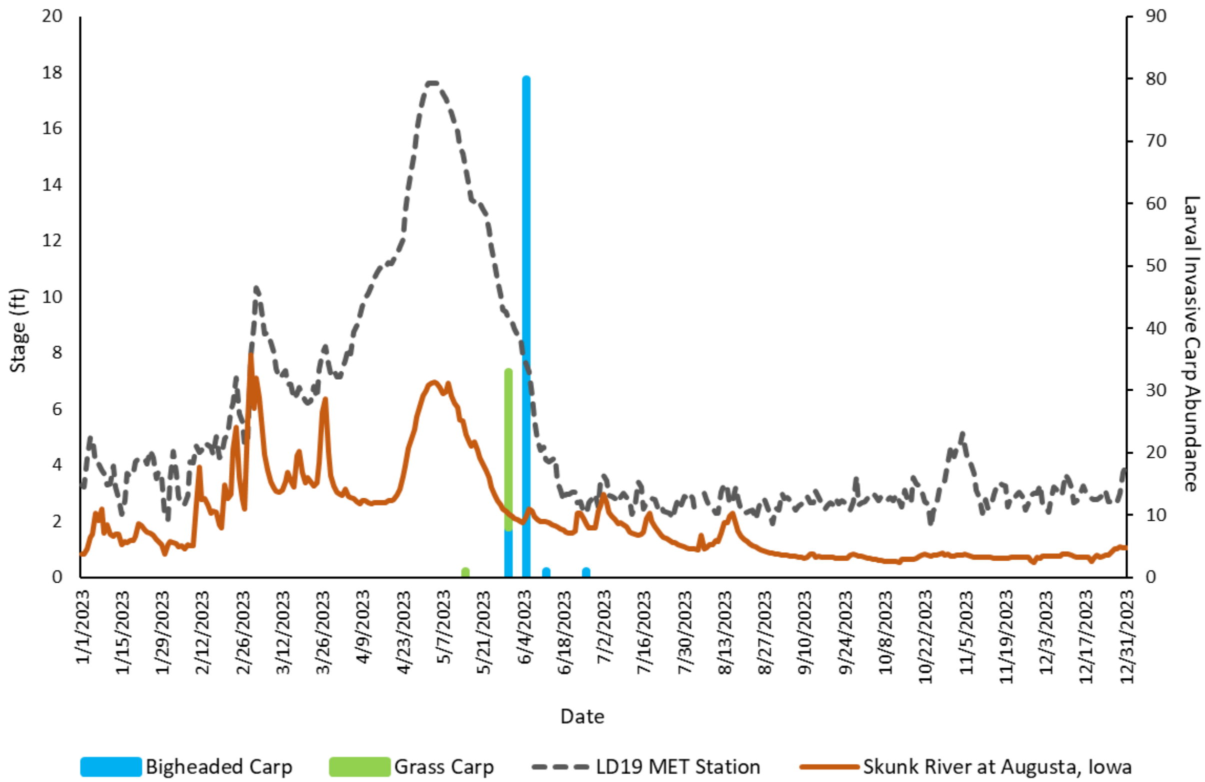

Figure 12. *Hydrological conditions in Pool 19 (P19) of the Upper Mississippi River from 01/01/2023 through 12/31/2023. Orange line represents river stage (ft) of Skunk River at Augusta, Iowa. Black dashed line represents river stage (ft) at Lock and Dam 19 (MET Station). Solid blue and green bars represent abundance of larval invasive carp (bigheaded carp and grass carp) collected in larval light traps in creeks of lower P19.*

Mortality Estimation Feasibility Study

In general, we found that the model was able to generate estimates of annual harvest mortality rates without skew or systematic bias across most of the scenarios and parameters we tested. There were, however, marked disparities in terms of the precision of modeled estimates. These findings can assist managers in making decisions about where to invest resources as they contemplate initiating a tag-return study to monitor invasive fish removals. For example, under the constant harvest rate scenarios, the model precision was very low under most of the worst-case scenarios for tag reporting, regardless of the number of tags released per year (Figure 13).

Decisions about the numbers of fish to tag per year or the length of time to run a study depends partly on the levels of annual harvest rates, the yearly variation in the harvest rate, the motivation for the study, and the level of uncertainty that is tolerable. Higher annual harvest rates had generally lower precision in terms of model estimates (Figures 13-14). This can be offset by increasing the number of tags released per year or increasing the tag reporting rate. We devised the variable harvest scenarios to assess the ability to detect this type of annual variation. The different scenarios all performed similarly in terms of their ability to estimate these changing conditions (Figures 15-16). However, we note that although the changing harvest rates may be due to changes in the total population size, the model alone does not produce an estimate of total population size. This is not estimable from returned tags alone. To estimate total population size or annual changes in population size, the total number of fish removed through harvest each year must also be available. For bigheaded carps in many of the most intensely managed areas, these numbers are generally recorded or estimated in terms of the numbers or mass of fish removed.

Increasing the duration of the study doesn't provide many gains in terms of accuracy or precision (Figure 17). Managers may have other reasons for wanting to run a study for multiple years. For example, collecting trend data, detecting recruitment events, or for correlating harvest rates to different levels of effort or different gear types. In general, single-year harvest-rate 'snap shots' should be achievable with short duration studies. However, the ability to estimate the harvest mortality rate accuracy drops beyond the tag-release years (i.e., estimating only from tagged fish released in previous years that remain at-large in the system).

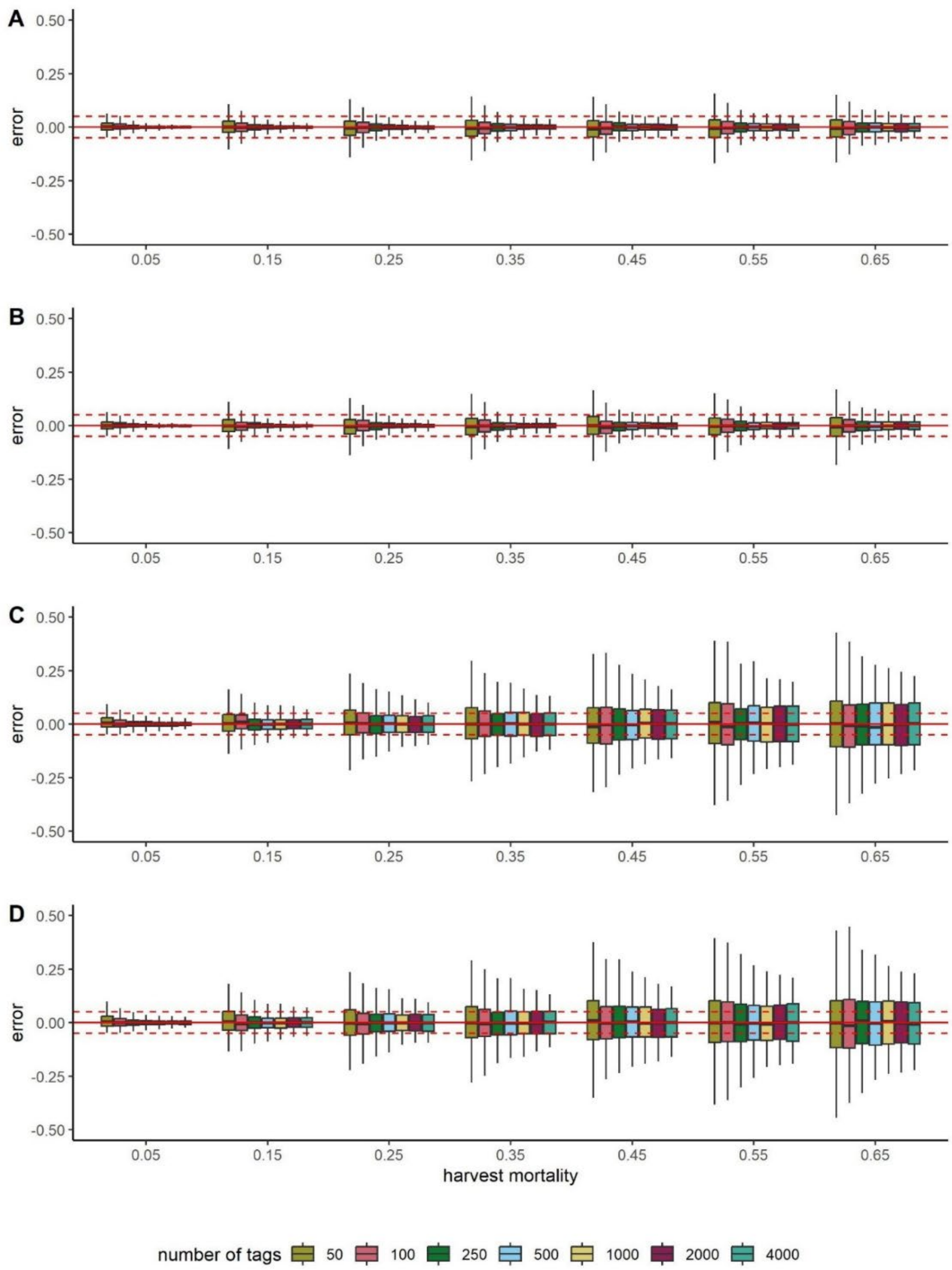

Figure 13. *Deviance of model estimated annual harvest mortality from 'true' annual harvest mortality used to simulate data for short duration studies under (A) best-case tag retention and best-case tag reporting, (B) worst-case tag retention and best-case tag reporting, (C) best-case tag retention and worst-case tag reporting, and (D) worst-case tag retention and worst-case tag reporting scenarios. Horizontal lines within shaded boxes show the median deviance values pooled over all model replicates for each scenario. Shaded boxes show the interquartile ranges (IQR) and extend to the first and third quartiles (25th and 75th percentiles), with whiskers extending to the values no farther than 1.5 x IQR from the top or bottom of the shaded box. Outlier model deviance values beyond the whiskers are not displayed. Solid red lines indicate accurate model fit to simulated 'true' annual harvest rates for each year. Dashed red lines indicate 0.1 point error tolerance range (0.05 below and 0.05 above) from the 'true' value.*

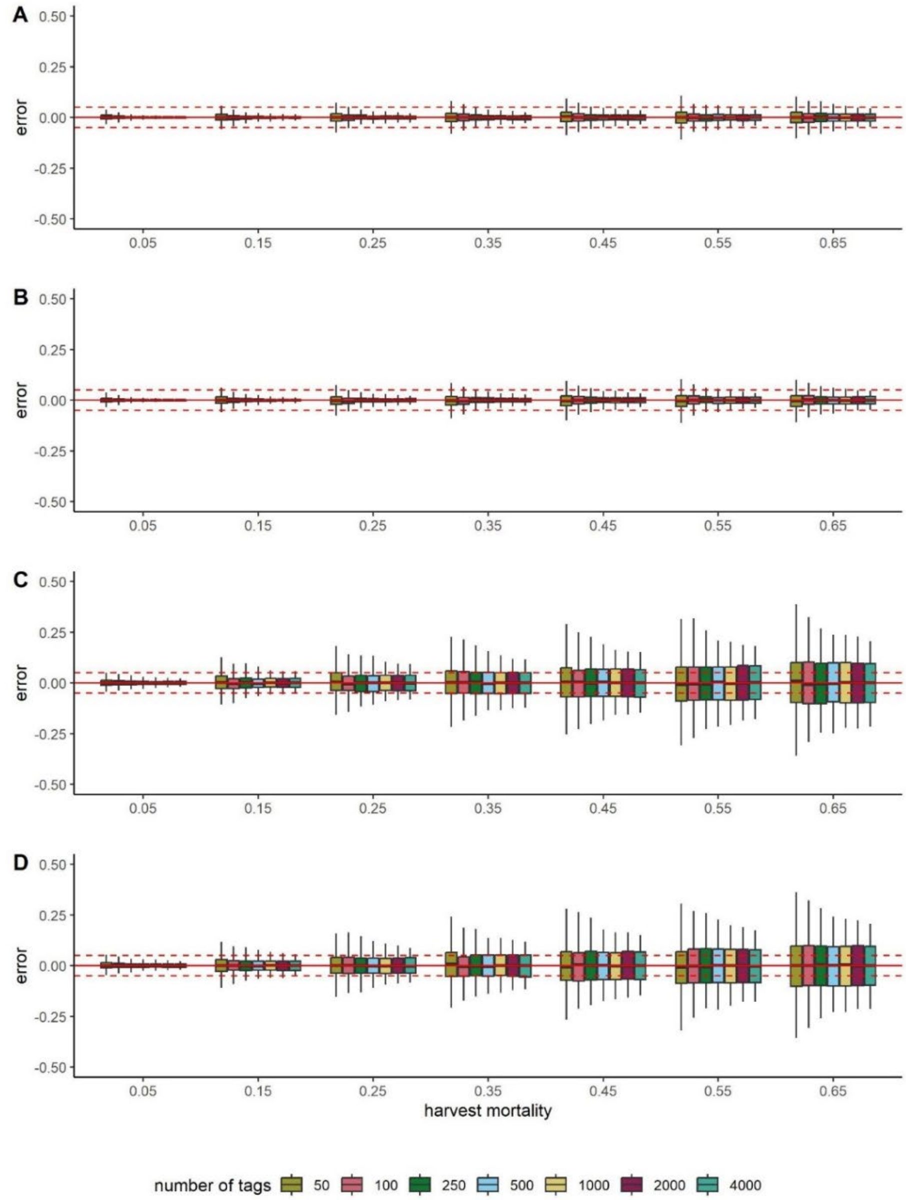

Figure 14. *Difference between 'true' and model predicted annual fishing mortality for long duration studies under (A) best-case tag retention and best-case tag reporting, (B) worst-case tag retention and best-case tag reporting, (C) best-case tag retention and worst-case tag reporting, and (D) worst-case tag retention and worst-case tag reporting scenarios. Horizontal lines within shaded boxes show the median posterior predicted fishing mortality pooled over all model replicates for each scenario. Shaded boxes show the interquartile ranges (IQR) and extend to the first and third quartiles (25th and 75th percentiles), with whiskers extending to the values no farther than 1.5 x IQR from the top or bottom of the shaded box. Outlier model estimated values beyond the whiskers are not displayed. Solid red lines indicate accurate model fit to simulated 'true' annual harvest rates for each year. Dashed red lines indicate 0.10 point error tolerance range (0.05 below and 0.05 above) from the 'true' value.*

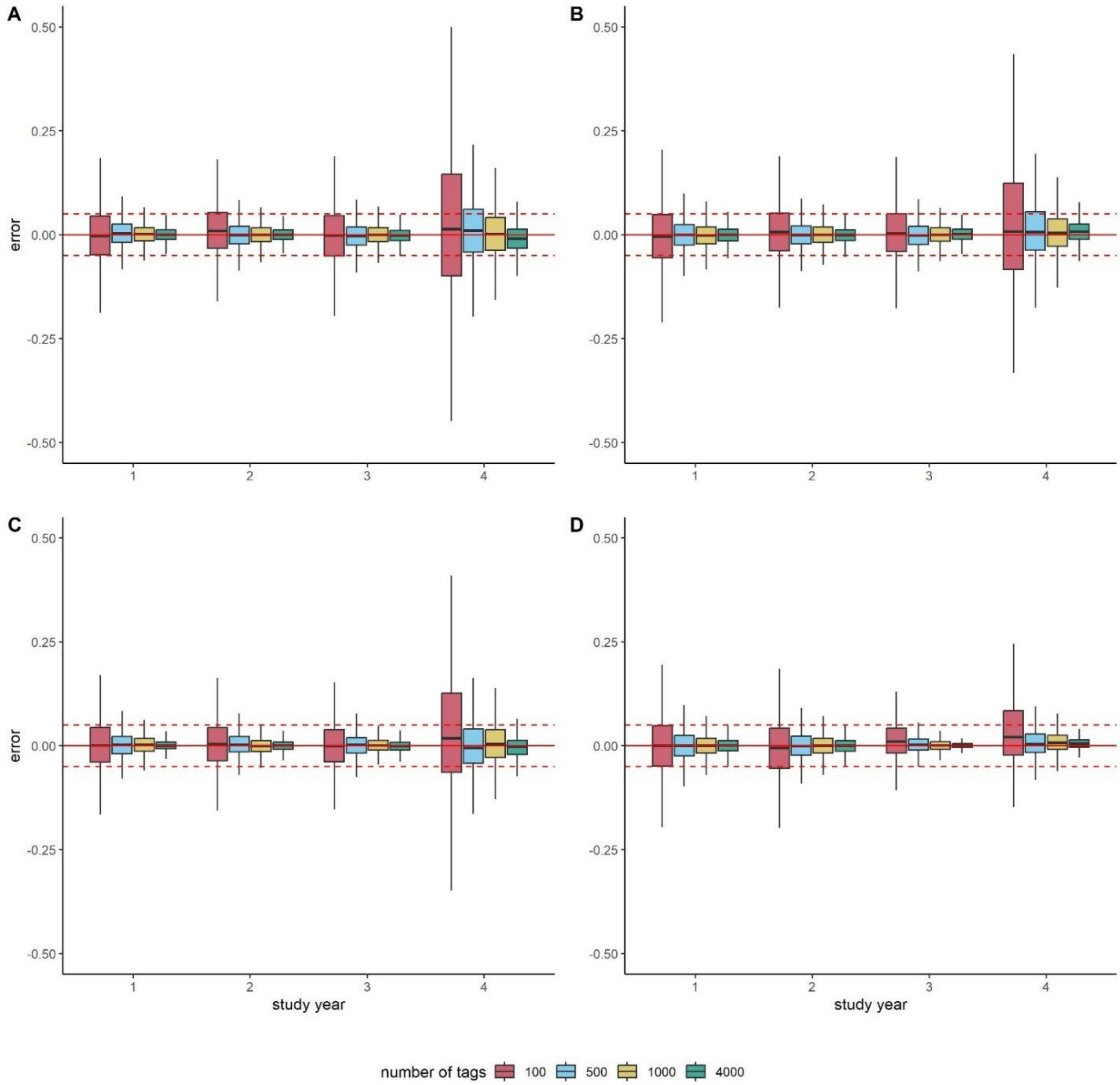

Figure 15. *Difference between 'true' and model predicted annual fishing mortality for short duration studies with annual variation under (A) Increase, (B) Decrease, (C) Variable, and (D) Recruit harvest scenarios. Horizontal lines within shaded boxes show the median posterior predicted fishing mortality pooled over all model replicates for each scenario. Shaded boxes show the interquartile ranges (IQR) and extend to the first and third quartiles (25th and 75th percentiles), with whiskers extending to the values no farther than 1.5 x IQR from the top or bottom of the shaded box. Outlier model estimated values beyond the whiskers are not displayed. Solid red lines indicate accurate model fit to simulated 'true' annual harvest rates for each year. Dashed red lines indicate 0.10 point error tolerance range (0.05 below and 0.05 above) from the 'true' value.*

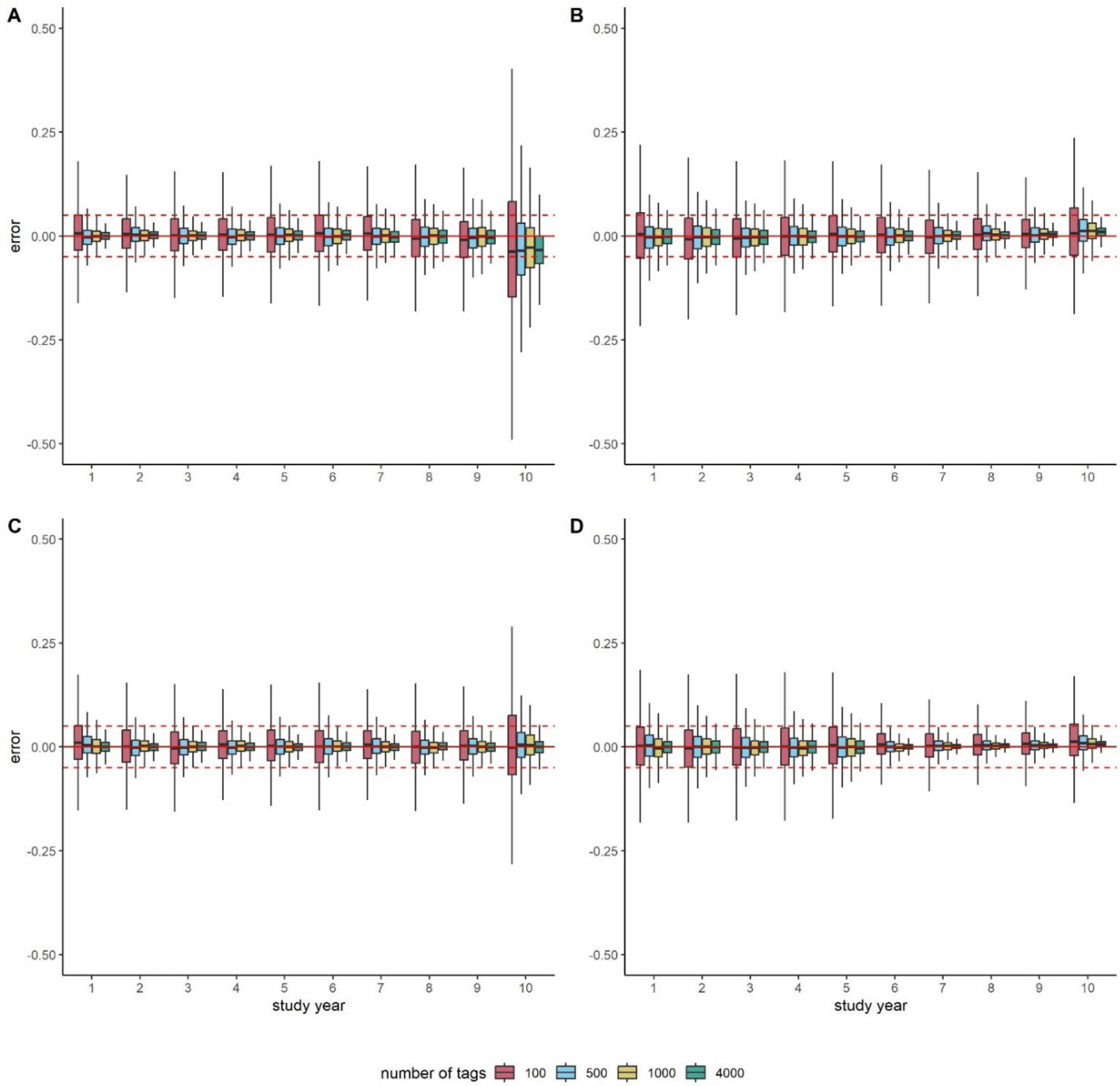

Figure 16. *Difference between 'true' and model predicted annual fishing mortality for long duration studies under (A) Increase, (B) Decrease, (C) Variable, and (D) Recruit harvest scenarios. Horizontal lines within shaded boxes show the median posterior predicted fishing mortality pooled over all model replicates for each scenario. Shaded boxes show the interquartile ranges (IQR) and extend to the first and third quartiles (25th and 75th percentiles), with whiskers extending to the values no farther than 1.5 x IQR from the top or bottom of the shaded box. Outlier model estimated values beyond the whiskers are not displayed. Solid red lines indicate accurate model fit to simulated 'true' annual harvest rates for each year. Dashed red lines indicate 0.10 point error tolerance range (0.05 below and 0.05 above) from the 'true' value.*

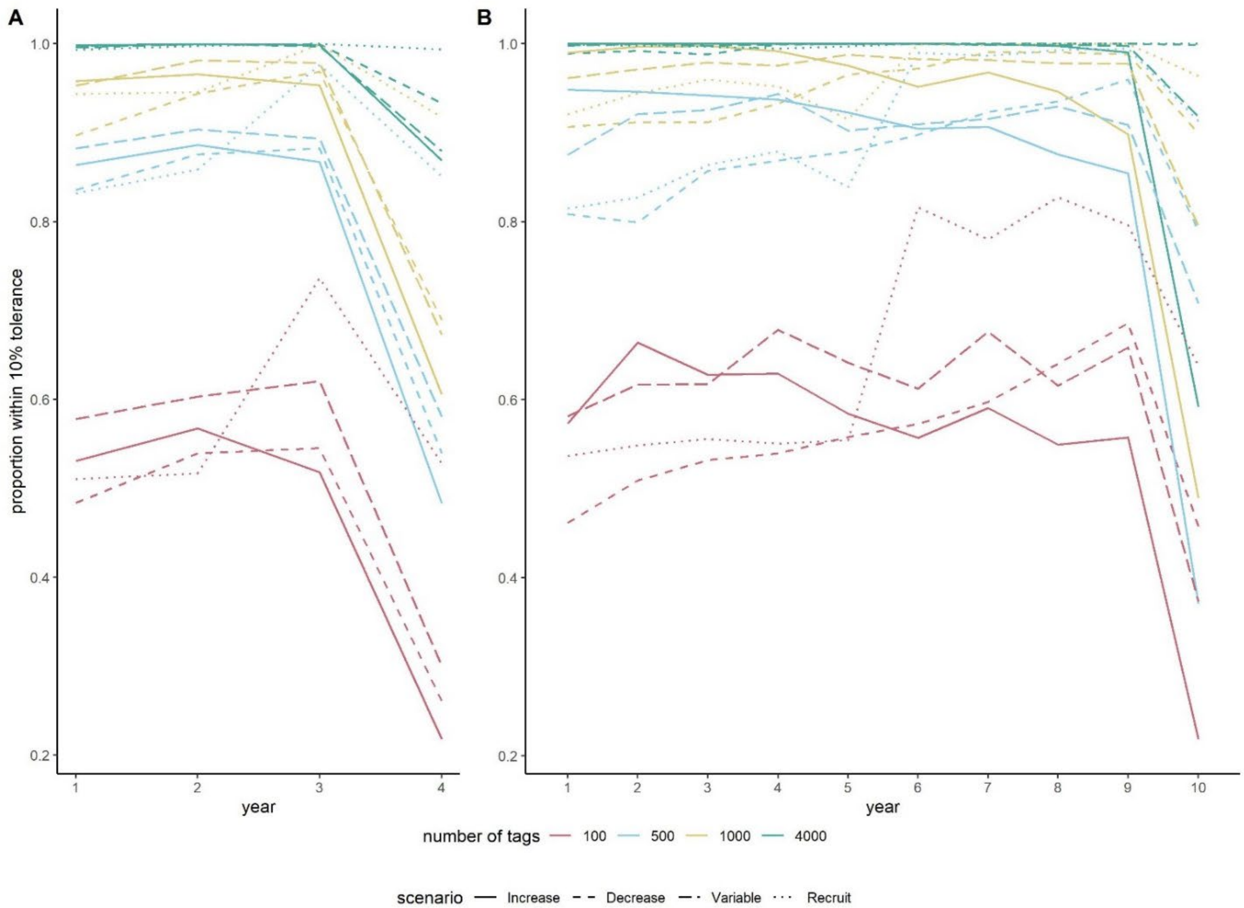

Figure 17. *Proportion of model predicted annual fishing mortality estimates that are within 10% error tolerance range for (A) short duration and (B) long duration scenarios.*

Discussion:

Spring pre/post harvest hydroacoustic surveys were generally able to document declines in fish abundance within backwaters post-harvest, but the relationship between the observed reduction in hydroacoustic densities and the associated reduction in available fish after removal of invasive carps, was variable at best. 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, fish evasion, and more. Assigning species information to hydroacoustic data collected from backwaters in the spring was difficult. Low rates of species apportionment that were observed in UMR backwaters were likely related to the 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 parallel 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, and 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). After discussions with state partners it was determined that these surveys will be suspended starting in 2024.

The pool-wide hydroacoustic survey program is continuing to expand and improve, with pool-scale survey designs ready for implementation in Pools 18-21 in 2024. Pool-wide estimates of Silver Carp relative denisty were reported (SVCP/1,000 m^3), along with the percent of hydroacoustic targets estimated to be Silver Carp. The hydrograph and the seasonal stability of water levels during survey season should be considered when deciding which of these metrics may be more appropriate for characterizing riverine fish populations. Relative density (fish/1,000 m3) could be affected by water levels (for example, more water may be sampled in a high water year, potentially reducing relative density estimates). It is also important to re-iterate that the Silver Carp hydroacoustic estimates reported here, were informed using only USFWS standardized electrified dozer trawl catch data. Especially in the low-density populations above LD19, experimenting with additional gears, using fishery-dependent information to help inform hydroacoustic estimates, or considering other ways to process and analyze the hydroacoustic data should also be considered. In Pool 18 for example, although contract anglers remove invasive carp from the pool every year with targetted gill netting, electrified dozer trawl sampling did not collect any Silver Carp in 2023. Applying that zero-catch data to the hydroacoustic output then generates an estimate of zero, an underestimate of true relative density.

Fishery-independent sampling with the electrified dozer trawl enabled the collection of some 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 than 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 rugged shore-based telemetry mounts that can withstand winter conditions in the system during 2021 and 2022 paid dividends in increased detection efficiency of the IC making upstream migrations during early 2023. Data collected during Spring 2023 provided a demonstration of the profound weakness of most UMR dams to prevent upstream IC migrations during flooding that leads to open-river conditions at these dams. Current proposals to install deterrent technologies in UMR locks aside from LD19 must consider the potential that invasive carp will simply bypass these systems in mass during flooding events. Furthermore, these data demonstrated that paddlefish, and likely other native species, also exploit open river conditions to make upstream migrations. Any attempt to block IC through dam gates should consider potential potentially detrimental effects on native species.

In the Des Moines River, maximum displacement analysis suggests a more sedentary population of Silver Carp above Ottumwa Dam with most individuals displacing less than 25 km between October 2021 and November 2023. Comparatively, individuals tagged below Ottumwa Dam appear to be more mobile, suggesting partially migratory behavior as observed in other systems (Prechtel et al. 2018). In the Iowa River, individuals appear to be relatively sedentary, with most individuals displacing less than 25 km between April 2022 and November 2023. Individuals in the Cedar River appear to be more mobile, suggesting partially migratory behavior like individuals below Ottumwa Dam in the Des Moines River.

Differences were observed in transition frequency 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. Downstream movements of individuals above Ottumwa Dam have been observed; however, only two individuals have transitioned back upstream, and no individuals tagged below Ottumwa Dam have transitioned upstream suggesting this population may be moderately isolated. The frequent transitions of individuals tagged below Ottumwa Dam suggest more potential for metapopulation interactions. Observations suggest 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 individuals throughout the Des Moines River may be residents. Differences in transition frequency were also observed between Silver Carp tagged in the Iowa River and those tagged in the Cedar River. The relatively low rates of transition shown by Silver Carp in the Iowa River may suggest this population may be more isolated; however, there does appear to be some mixing of Silver Carp tagged in the Iowa and Cedar rivers and UMR, suggesting the possibility of metapopulation interactions. The high frequency of transitions shown by Cedar River individuals suggest this cohort may be functioning as a subpopulation of a UMR metapopulation as well. Like the Des Moines River, there appears to be some individuals that have remained within the Iowa and Cedar rivers during the entire study period suggesting a portion of the population may be residents. Data collected to date has occurred during drought conditions; therefore, additional years of data collection under various flow conditions may be insightful to evaluation of how environmental conditions affect tributary movement dynamics.

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 12), and what size their recruitment potential is at the northern forefront of their reproductive range in the Mississippi River.

Tag returns alone have long been known to produce inaccurate estimates of harvest mortality rates without additional information on tag return rates (Hoenig et al. 1998). Obtaining additional information about tag return rates through high-reward tags, planted tags, or creel or processing facility surveys all require additional resources. The precision gained by allocating additional resources to assure high tag return rates can be considered by managers when making decisions about the numbers of tags, and the duration of studies.

The motivation and level of acceptable error may also play into the decision-making process. For example, if the motivation for the study is to assess what proportion of a targeted population is being removed through an intense removal effort when no prior information is available about the total population size or previous harvest levels, a larger tagging effort may be desired to assure a sufficiently precise mortality estimate. However, if the purpose is simply to assess whether a minimum harvest target is met, where a higher level of potential error in the estimate from any given year is acceptable, fewer tags may be warranted. If the purpose of the study is to monitor populations that may be highly variable in terms of changes in population size or harvest effort from year to year, higher numbers of tags may be warranted.

In terms of allocating effort and resources to estimating harvest mortality rates, we did not find evidence to support continued effort to collect and analyze tags beyond the years of fish tagging. However, this type of information could still be valuable for gaining other types of information such as movement, growth, or longevity.

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:

Pool-wide hydroacoustic 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 as needed to inform appropriate levels of sampling effort across pools with varying Silver and Bighead Carp densities. Silver Carp estimates reported herein were informed using only fisheries community data derived from standard electrified dozer trawl sampling. The use of other gears or fishery-dependent data to inform hydroacoustics should also be evaluated to determine the most appropriate suite of fishery catch data for informing hydroacoustics estimates. In the future, the relationship between hydroacoustic estimates, physical sampling, the hydrograph, and the commercial harvest should be more throroughly investigated.

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. In FY24, overall effort will be reduced. Site locations are still being determined but will focus on areas with on-going management activity such as subsidized or contracted removal operations. 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.

The harvest mortality model has provided managers with the information they need to make informed decisions regarding tagging studies. Decisions about how many tags or how long to run a study depend on the specifics of the population under examination, the ultimate goals for conducting a study, the level of tolerance for uncertainty, and the consequences for getting an erroneous estimate. We have summarized the model results in terms of the proportion of model estimates that fall within a proposed error tolerance range of 10% (Figure 17). Managers may decide that their error tolerance range is wider or narrower than our proposed ranges or is one-sided, in the case of threshold harvest targets. The consequences of getting an inaccurate estimate can be considered when deciding what error tolerance range is acceptable. These consequences could range from not meeting target harvest levels, failing to detect a change in harvest rates, or erroneously making, or failing to make, a management decision that is triggered based on harvest rates.

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.

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

George, A. E. and D. C. Chapman. 2013. Aspects of embryonic and larval development in bighead carp Hypophthalmichthys nobilis and Silver Carp Hypophthalmichthys molitrix. PloS one 8(8):73829.

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.

Hoenig, J. M., N. J. Barrowman, W. S. Hearn, and K. H. Pollock. 1998. Multiyear tagging studies incorporating fishing effort data 55:11.

Invasive carp Regional Coordinating Committee - Monitoring and Response Workgroup, (ICRCC). 2020. Monitoring and Response Plan for Invasive carp in the Upper Illinois River and Chicago Area Waterway System.

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.

Mississippi Interstate Cooperative Resource Association (MICRA). 2021. Missouri Sub-Basin Annual Summary Report. Define the spatial distribution and population dynamics of Asian carp populations and the associated fish community in the Missouri River Basin. Accessed 2/10/2023 on the MICRArivers.org website: http://www.micrarivers.org/missouri-river-sub-basin-annual-summary-reports/

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.

Then, A.Y., J.M. Hoenig, N.G. Hall, D.A. Hewitt and Handling editor: Ernesto Jardim, 2015. Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. ICES Journal of Marine Science 72:82-92.

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).