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

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Participating Agencies: Minnesota Department of Natural Resources (MNDNR), Missouri Department of Conservation (MDC), Iowa State University (ISU), Southern Illinois University (SIU), 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 hydroacoustics sampling protocol to evaluate the efficacy of Silver and Bighead Carp harvest programs and determine Silver and Bighead Carp population densities via pool-wide fall hydroacoustics surveys in Pools 18-20.

2. Conduct fishery-independent monitoring to support hydroacoustics surveys and deliver data on demographic parameters of Silver and Bighead Carp in Pools 18-20.

3. Conduct hydroacoustic surveys before and after contracted harvest events to guide removals, evaluate harvest efficacy and establish the relationship between hydroacoustic

density estimates and harvest CPUE in Pool 8 and Pools 16-20.

4. Utilize real-time and passive receivers to understand Silver and Bighead Carp movement patterns in the UMR, and identify environmental variables that influence those patterns.

5. Utilize real-time and passive receivers to increase efficiency of removal efforts by locating congregations of Silver and Bighead Carp and sharing information with removal teams in a timely manner.

6. Use larval sampling gears to establish an annual index of spawning activity by Silver and Bighead Carp in backwaters and tributaries of the lower IMZ when water temps are between 17–30°C.

Project Highlights:

- Pool-wide hydroacoustic surveys in FY21 compared to FY19 illustrated the difference in fish detection abilities at low water conditions compared to flood conditions, with nearly 4x more fish / 1,000 m^3 enumerated in FY21 (low water).
- Hydroacoustic re-sampling analysis of FY21 data is underway, and will shape survey design moving forward and improve survey efficiency.
- A newer fishery-independent gear, the electrified dozer trawl, was able to collect Silver Carp along with fish community data from low density areas above LD19. An evaluation of fishery-independent gears is ongoing and will determine the best combination of fishery-independent gears and necessary levels of effort to use in the future.
- The UMR telemetry longitudinal array was returned to its full extent during 2021 after deployments were delayed and restricted in size because of COVID-19 related travel bans during 2020.
- New transmitters implanted in 124 Silver and Bighead Carp in the Lower UMR.
- New statistical analyses have been developed for telemetry data that allow us to quickly identify and quantify upstream and downstream movements among UMR pools.
- Sampling for larval Silver and Bighead Carp collected 1,731 carp from Pool 19 backwaters in 2016. Only one larval carp was collected in Pool 19 in 2017 and 17 in 2018. Efforts shifted to Pool 19 tributaries in 2019, and no larval Silver and Bighead Carp have been collected since. Samples from 2021 are still being processed. 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. During 2021, the USFWS conducted hydroacoustic surveys on Pool 8 and Pools 16-20 of the UMR. 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). UMR transects on the main channel / main channel border consisted of two transects along each bank (Figure 2). The first set of transects was conducted near shore at the 1 to 1.5 m depth contour with the transducers pointed out towards the thalweg. The next set of transects were 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 as long as water depths were sufficient (Figure 3). Nearshore and offshore main channel transects were analyzed separately. Side channels were sampled with one transect on each shoreline, backwater lakes, marinas, and other off-channel habitats were sampled with one transect that followed around the perimeter of the entire shoreline (Figure 2).

Spring hydroacoustic sampling in Pool 8 preceded a modified unified method (MUM) removal event with survey results reported to the removal team to inform harvest locations. Spring hydroacoustic surveys were also 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.

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 (Figure 4). Pool 19 was subsampled using approximately four-mile long transects along the main channel such that a minimum of 35% of the main channel length of the pool was sampled, in addition to adjacent off-channel habitats, similar to other large river hydroacoustic monitoring programs (Coulter et al. 2018). 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 density (numeric and mass) were estimated.

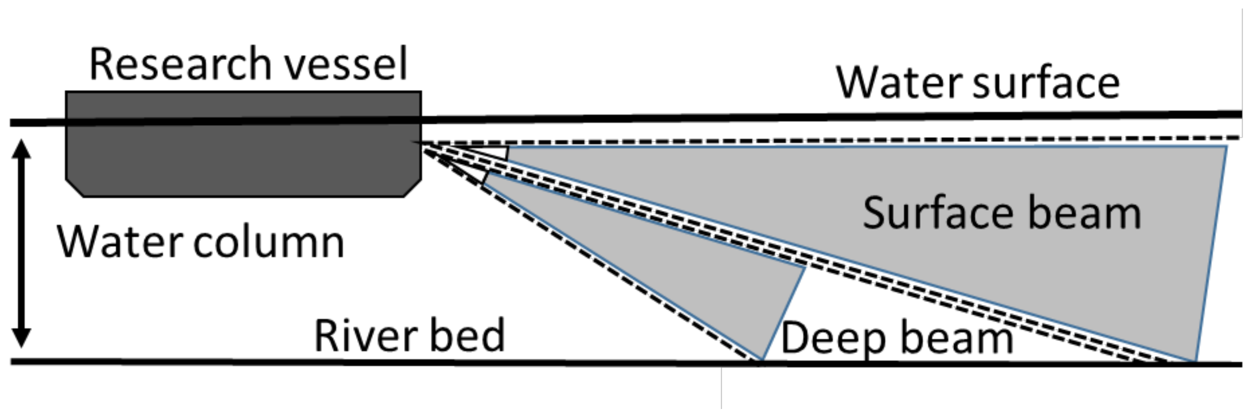

Figure 1. *Diagram showing the approximate orientation of the hydroacoustic beams during a mobile survey. The data that can be used in analysis is collected within the gray area.*

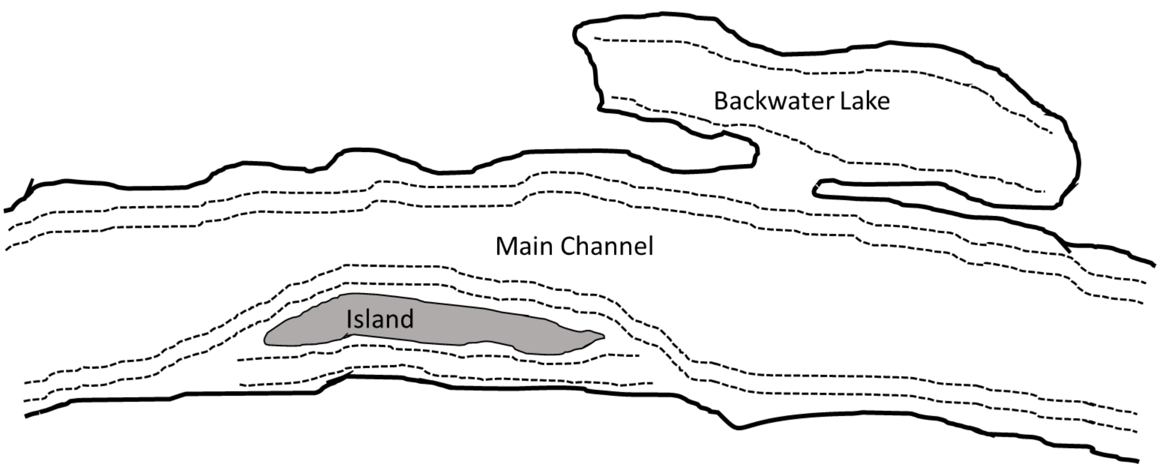

Figure 2. *Example of survey transects (represented by dotted lines) in the Upper Mississippi River; two transects for each bank along the main channel, transducers pointing toward the thalweg; one transect on each bank for island side-channels and a one transect that follows the perimeter of the shoreline for backwater lakes.*

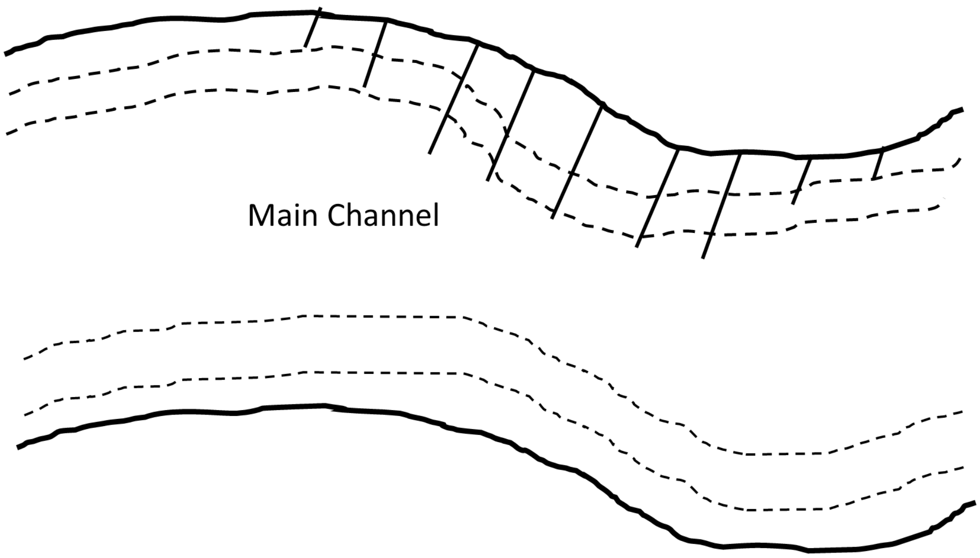

Figure 3. *Example of main channel survey transects (represented by dotted lines) in the Upper Mississippi River where wing dikes are present. Two transects for each bank along the main channel, transducers pointing toward the thalweg. When possible, transects run over the top of the dikes and as close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

Figure 4. *Map of Upper Mississippi River Pools 18, 19 and 20. Site of pool-wide hydroacoustic surveys and fishery-independent surveys in FY21 by USFWS and ILNHS.*

Fish 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 and Bighead 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. For spring pre/post-harvest surveys, length-frequency histograms were developed for pre-harvest hydroacoustic data and commercially harvested fish. Hydroacoustic data at each backwater was limited to exclude any fish targets smaller than the smallest commercially caught fish, then length-frequencies were compared using Kolmogorov-Smirnov two-sample tests with a significance level set at $p= 0.05$. All analyses were conducted using the data analysis program “R” (R Core Team 2020).

Fall pool-wide surveys relied on a combination of fishery-dependent (contract removal; see above) and fisheries-independent data. A portion of fishery-independent data came from a partnership with the Illinois Natural History Survey’s (INHS) Illinois River Biological Station, and their standardized electrofishing program called the Long-term Survey and Assessment of Large River Fishes in Illinois or the Long-term Electrofishing Program (LTEF). The program uses pulsed-direct current (DC) electrofishing to sample fish communities at randomly selected locations throughout Pools 16-21 of the Mississippi River. The program operates on an annual sampling schedule but typically limits sampling to main channel border habitats. The USFWS provided additional funding to the LTEF program in 2021 to include additional sites at backwater and side channel habitats in Pools 18-20 (Figure 4), to provide a more accurate assessment of the overall fish community in the UMR and to increase the amount of data available for use by the hydroacoustic survey. Sites were selected through a stratified random sampling (SRS) design, with effort proportionally allocated among macrohabitat types based on availability. In August and September of 2021, INHS sampled 35 sites in Pool 18, 49 sites in Pool 19, and 13 sites in Pool 20, with each electrofishing sample being 15 minutes in duration (Table 1).

The USFWS also conducted fishery-independent sampling in Pools 18-20 (Figure 4) to collect information on the relative abundance of Silver and Bighead Carp within the UMR fish community. USFWS sampling relied on an experimental gear (the electrified dozer trawl) and was meant to complement the traditional LTRM style electrofishing conducted by INHS (see section above) with the intent of increasing the capture probability of Silver and Bighead Carp (Hammen et al. 2019). Dozer trawl sites were selected through a stratified random sampling design that covered main channel border, side-channel, and backwater habitats in each pool. In August and September of 2021, the USFWS conducted fishery-independent dozer trawl surveys concurrent to, and at a similar number of sites as the LTEF surveys, although dozer trawl standard runs are only 5 minutes in duration to reduce stress on fish in the trawl (Table 1). In 2021, due to low water levels, many backwater sites were inaccessible and in those situations effort was reallocated to other nearby macrohabitats.

Table 1. *Allocation of dozer trawl (USFWS; 5 minutes of applied power per run) and standard electrofishing effort (ILNHS; 15 minutes of applied power per run), in habitats of Pools 18-20. ILNHS effort was similar but waiting on partner data to know final allocation by habitat. Gear and macrohabitat acronyms; D=dozer trawl, EF=standard electrofishing; MCB = main channel border, SC = side channel, BW = backwater.*

Pool	EF-MCB	EF-SC	EF-BW	D-MCB	D-SC	D-BW
Pool 18	11	24	0	11	25	1
Pool 19	19	30	0	17	28	5
Pool 20	7	6	0	7	5	2

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.

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 2021, the size and extent of the array was restored following spatial restrictions because of travel bans instituted after the onset of the COVID-19 pandemic. Receivers were deployed by USFWS-La Crosse staff in Pools 5A-13 and Pool 20 and partners with Illinois Natural History Survey deployed receivers in Pools 14-19 (Figure 5). Data from stationary receivers were downloaded every 4-8 weeks. In 2021 MDC placed new VR2-Tx receivers along sites in Pools 20-26 above and below each of the locks and dams (Figure 5; Table 2), utilizing platforms of opportunity. Suitable sites included locations of protected bankline (e.g., inside bend), large rock areas, and notable landmarks that improved chances of future retrieval. The receivers were further protected from damage by PVC encasement but allowing the end of the omni-directional hydrophone to be exposed. Cable (1/8-3/16-inch diameter) was used to anchor receivers to platforms of opportunity. The receivers were placed away from the bankline in water depths that accounted for record drought cycles and anchored using a rock bag. Each receiver was labeled with MDC logo/property control number and has a visible tag on the bankline and anchor ends engraved with "MDC Equip". Existing receiver stations on bridge piers (e.g., Chester, Hannibal), lock chamber (e.g., LD19) and within tributaries (e.g., Des Moines, Meramec) were maintained and data shared with sub-basin partners. These data provided information on gross movement patterns, possible spawning events, and habitat use; and in turn, inform removal and potential deterrent placement.

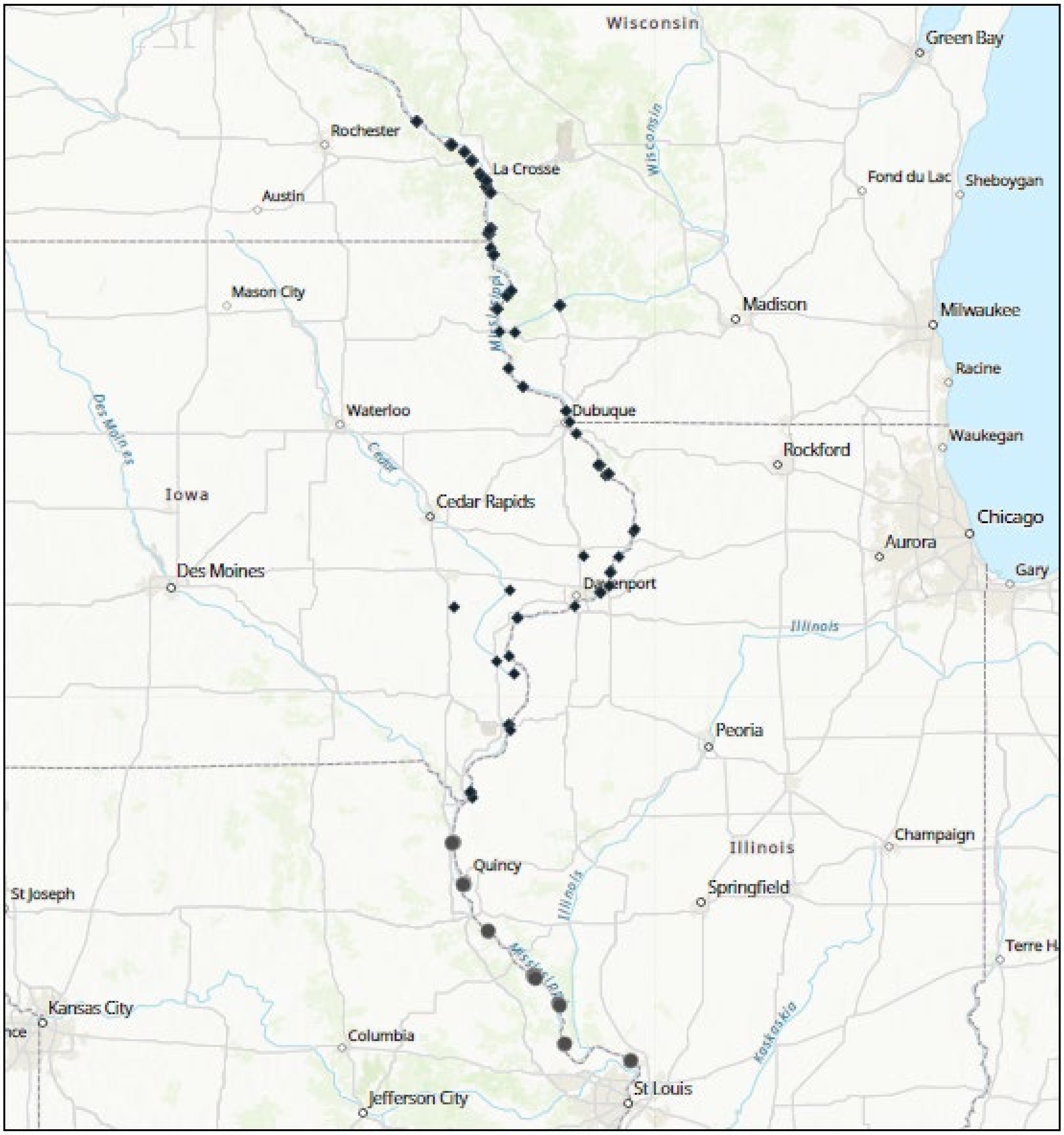

Figure 5. *Locations of stationary receivers deployed by MDC (circles), USFWS and INHS (diamonds) in the Mississippi River basin during 2021.*

Table 2. *Placement of VR2-Tx telemetry receivers deployed by MDC in the Upper Mississippi River (UMR) during 2021. Location describes state-side of the river and the river mile.*

Location	Date	Latitude	Longitude
IL325	10/25/2021	39.90712	-91.42213
MO325	10/25/2021	39.90888	-91.43408
MO343.1	10/25/2021	40.14065	-91.51545
IL343.1	10/25/2021	40.14379	-91.50684
IL343.9	10/25/2021	40.14920	-91.50557
MO343.9	10/25/2021	40.14702	-91.51626
IL324.9	10/26/2021	39.90621	-91.43231
MO324.9	10/26/2021	39.90678	-91.43272
MO301	10/26/2021	39.63343	-91.24716
IL301.2	10/26/2021	39.63833	-91.24499
MO273.8	10/26/2021	39.37848	-90.91422
IL274.0	12/2/2021	39.38648	-90.90818
IL273.5	12/2/2021	39.37745	-90.90247
MO272.7	12/2/2021	39.36602	-90.89721
MO257.8	12/2/2021	39.21764	-90.72237
IL256.7	12/2/2021	39.20487	-90.71304
MO239.7	12/14/2021	38.98219	-90.68031
IL240.0	12/14/2021	38.98604	-90.67342
MO202.6	12/14/2021	38.88087	-90.1852
IL202.6	12/14/2021	38.88504	-90.17982

Real Time Receivers: USFWS crews deployed and maintained four real-time receivers in Pools 16-18 from March-November 2021. Data from these receivers were shared daily with partners at INHS leading contracted removal efforts. The real-time receiver at Credit Island in Pool 16 stopped functioning in June. USFWS crews were unable to get the unit transmitting updates for the remainder of the year. Following retrieval and receiver breakdown, USFWS crews determined that an electrical short had caused the service disruption. These problems will be fixed ahead of the 2022 real-time receiver deployment schedule.

Acoustic Transmitter Tagging: In FY21, staff from the La Crosse FWCO participated in a three-day collaborative fishing effort with MN DNR in Pool 8 during October 2021 but were not able to tag any additional carp. In Pools 20-26, staff with MDC surgically implanted Silver and Bighead Carp with transmitters. Standardized electrofishing utilizing Long Term Resource Monitoring power goal settings was conducted to capture Silver and Bighead Carp for surgical insertion of transmitters. Up to 10 individual fish were captured at a time during electrofishing runs and placed into stock tanks with aeration, until the total goal for implanted transmitters at that location was met. Innovasea, (formerly Vemco), standardized acoustic telemetry long-term V16-6H coded transmitters were used. Transmitter specifications were: Innovasea V16-6H Power H; Random Delay: 30 to 60 seconds, Loop back to step 1. Estimated tag life 1460 days. Both transmitter and receiver operate at the acoustic signal of 69 kHz. Transmitters were surgically implanted into the abdominal cavity of invasive carp by 1) removing scales near the incision then 2) with surgical scalpel, completing a lateral incision just above the pelvic fins large enough (i.e., 1.5-2 cm in length) to accept the transmitter. Three interrupted external surgical sutures were completed on the incision to improve healing and reduce transmitter expulsion. All transmitters were checked for ping rate and coded ID prior to implantation.

All analyses of 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 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.

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.

Between 2016 and 2021, larval fish sampling was completed in Pools 17-19 using three different gear types: benthic sled sampler (2018–2019), ichthyoplankton push net (2018–2019), and larval light trap (2016–2021). During daylight hours, a benthic sled (500 µm mesh, Wildlife Supply Company, Yulee, FL) and an ichthyoplankton push net (0.5m diameter x 3 m length, 500 µm mesh, Wildlife Supply Company, Yulee, FL) were towed or pushed from the boat at a speed of 1.5 m/s for a period of five minutes. To determine the total volume sampled, a calibrated mechanical flow meter was attached to the mouth of each net. To avoid debris from entering the benthic sled from the motor, the sled was towed in a semicircle pattern. Due to the heterogeneity (woody debris, vegetation, and uneven depths) of backwater areas, deployment locations were determined based on proximity to shore and amount of structure. The sequence in which each gear type was used was selected randomly using a coin flip as to avoid biases. At the completion of each tow, samples were rinsed into sample jars, labeled with site information, and preserved with 95% ethanol.

A total of 8–12 Quadrafoil larval light traps (250 µm, 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 in conjunction with both nets and light traps. Turbidity was measured at sampling locations using a secchi disk during the day and a portable turbidity meter at night when available. Data processing (e.g., larval sorting and identification, and data analysis) occurred during the fall and winter months.

Results:

Pool 8 MUM hydroacoustics

Seven different locations in Pool 8 were identified as possible sites for MUM-type removal events in spring of 2021. Hydroacoustic surveys were conducted in late March, the week prior to the removal event, to assess densities of fish greater than 12" (305 mm) total length. A total volume of 955,440 m^3 of water, and 2,077 fish greater than 12" were sampled. Fish densities ranged from 0.32 to 5.49 fish/1,000 m^3. Results were reported to the MUM team and used in final planning (Table 3).

Table 3. *Hydroacoustic assessment results of possible MUM locations, prior to the removal event, Pool 8, Upper Mississippi River, March 2021.*

Pool 8 MUM sites	# Fish >12"	Volume sampled (m^3)	Fish/1,000 m^3
Condos	1102	200805	5.4880
I90 Bay	83	115967	0.7157
Green Island	14	43642	0.3208
Catgut Slough	38	72335	0.5253
Power Plant	70	30521	2.2935
French Slough	98	120723	0.8118
Black River / Airport Beach	331	197651	1.6747
Lauderdale marinas and Lauderdale bay	341	173796	1.9621
	2077	955440	2.1739

Pool 16-19 hydroacoustics pre/post contract removal

A total of seven different backwaters were surveyed pre and post contract removal, one backwater was surveyed on two occassions. Most sites displayed expected reductions in hydroacoustic fish density estimates post harvest, with this relationship being strongest at the sites with the highest catches of Silver and Bighead Carp. There were two sites (Boston Bay and Credit Island) where post harvest hydroacoustic estimates were actually greater than pre-harvest, but it should be noted that acoustically detected fish were also in the single digits for the both the pre and post harvest surveys (Table 4). At these sights, factors like low overall number of fish present, unfavorable bathymetry and site specific habitat features like flooded timber, or other variables, likely contributed to confounding pre/post estimates. For example, at Boston Bay, fish seemed to be holding in flooded timber and open water net sets were mostly empty. Water levels were high enough that commercial fishermen were able to effectively drive/herd and remove fish from within the flooded timber, however those fish would not have been sampleable with hydroacoustics.

Species specific estimates for Bighead and Silver Carp could only be generated for the Big Timber and Cleveland Slough backwaters (Table 5). This could be a result of relatively low overall numbers of ensonified fish in some backwaters to which specific proportions could be assigned, a limitation of hydroacoustic equipment to effectively sample the same fishes that were collected by commercial anglers (e.g. because of fish habitat use, bathymetry limitations etc), or related to the size selective nature of the removal data that was used to inform the hydroacoustic estimates.

When comparing overall length-frequency histograms, Kolmogorov-Smirnov (KS) tests indicated significant differences among acoustically detected fish and harvested fish for nearly all sites (Table 6). Investigation of the histograms shows large numbers of hydroacoustically detected fish on the small end of the spectrum that were likely not fully recruited to the gear, driving the observed differences (Figure 6). Comparisons were made again after instituting a 60 cm cut-off in both datasets, the estimated length at which fish were fully recruiting to the commercial gear. When accounting for gear recruitment, length frequencies of acoustically detected and commercially harvested fishes were more comparable (Table 6).

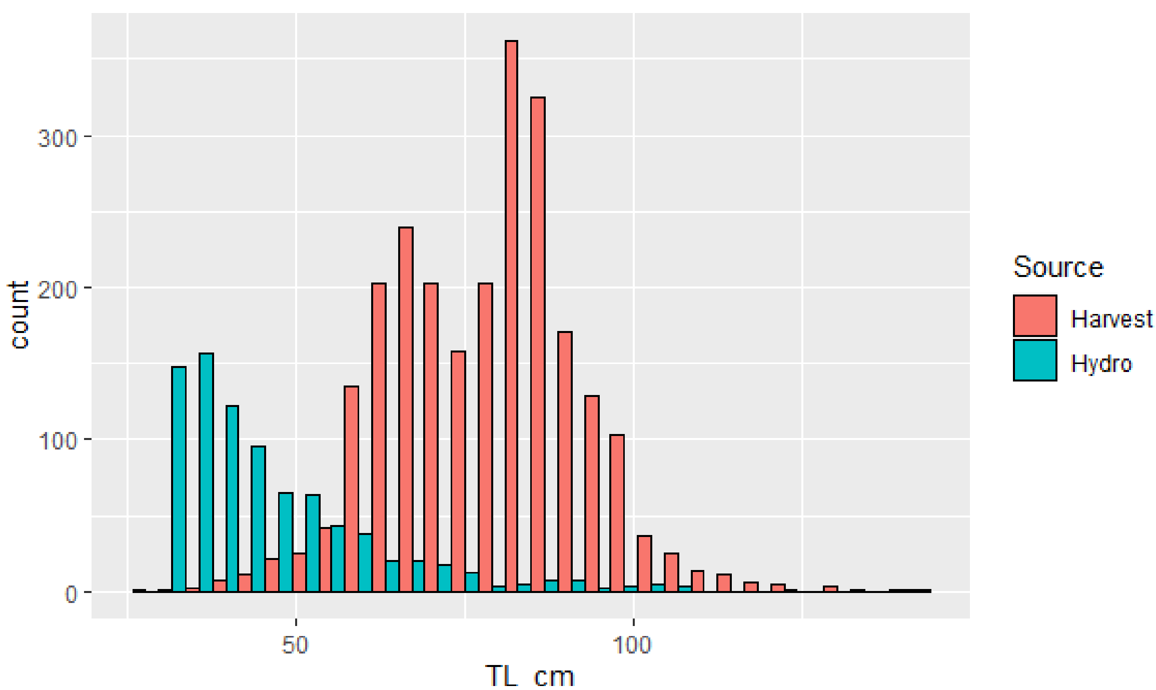

Figure 6. *Length-frequency histograms of fish hydroacoustically detected before commercial harvest, to those collected in the UMR during intensive contracted removals, April 2021.*

Table 4. *Hydroacoustic survey estimates of total fish abundance and density at backwater sites in the Upper Mississippi River, pre and post intensive contracted removals, April 2021.*

Site	Pool	Pre/Post	N Fish	Biomass (kg)	Volume (m^3)	Fish/1000 m^3	kg/1000 m^3
Big Timber	17	Pre	205	848.67	158971.14	1.2895	5.3385
Big Timber	17	Post	29	97.48	137315.09	0.2112	0.7099
Boston Bay	18	Pre	1	1.43	34399.44	0.0291	0.0417
Boston Bay	18	Post	2	3.40	28413.95	0.0704	0.1198
Carthage	19	Pre	50	61.74	75072.38	0.6660	0.8224
Carthage	19	Post	19	20.06	57863.20	0.3284	0.3467
Cleveland	17	Pre	144	467.64	153617.84	0.9374	3.0442
Cleveland	17	Post	35	79.13	140332.66	0.2494	0.5639
Credit 1	16	Pre	NA	NA	47678.02	NA	NA
Credit 1	16	Post	2	1.41	44699.58	0.0447	0.0316
Credit 2	16	Pre	1	3.01	39731.89	0.0252	0.0756
Credit 2	16	Post	2	1.35	40401.96	0.0495	0.0335
Fish Lake	19	Pre	17	60.27	43596.72	0.3899	1.3825
Fish Lake	19	Post	1	4.21	32884.34	0.0304	0.1279
Otter Bay	19	Pre	7	11.13	16219.23	0.4316	0.6860
Otter Bay	19	Post	1	0.83	16962.82	0.0590	0.0491

Table 5. *Hydroacoustic survey estimates of Silver and Bighead Carp abundance and density at backwater sites in the Upper Mississippi River, pre and post intensive contracted removals, April 2021.*

Site	Pool	Pre/Post	Species	N Fish	Biomass (kg)	Volume (m^3)	Fish/1000 m^3	kg/1000 m^3
Big Timber	17	Pre	BHCP	2.63	31.86	158971.14	0.0166	0.2004
Big Timber	17	Post	BHCP	0.00	0.00	137315.09	0.0000	0.0000
Big Timber	17	Pre	SVCP	13.50	132.54	158971.14	0.0849	0.8337
Big Timber	17	Post	SVCP	0.22	1.45	137315.09	0.0016	0.0106
Cleveland	17	Pre	SVCP	11.34	113.53	153617.84	0.0738	0.7391
Cleveland	17	Post	SVCP	0.89	7.14	140332.66	0.0063	0.0509

Table 6. *Results of Kolmogorov-Smirnov two-sample tests comparing length-frequencies of fish hydroacoustically detected before commercial harvest, to those collected by contracted fishers at backwater sites in the Upper Mississippi River during intensive contracted removals, April 2021. Comparisons were made using all fish data, and recruited (≥ 600 mm TL) data.*

		All Fish		Recruited Fish (≥ 600 mm TL)	
Site	Pool	D	p-value	D	p-value
Credit 1	16	1	0.000123	not enough data	
Credit 2	16	0.79688	0.5593	0.92727	0.3671
Big Timber	17	0.82076	< 2.2e-16	0.22487	0.005316
Cleveland	17	0.77495	< 2.2e-16	0.21497	0.08217
Boston Bay	18	1	0.005161	not enough data	
Carthage	19	0.81444	< 2.2e-16	0.70352	0.006268
Fish Lake	19	0.82825	2.88E-13	4.97E-01	0.7112
Otter Bay	19	0.94403	3.64E-07	not enough data	
Combined		0.79069	< 2.2e-16	0.28551	4.81E-08

Pool 18-20 pool-wide hydroacoustics

At the time of reporting, partner fish data for the pool-wide surveys was still being quality checked, and was not yet available. Additionally, an ongoing re-sampling analysis has not yet been completed on the fully surveyed Pools 18 and 20. This analysis will help determine the necessary levels of effort needed, and in what habitats, to appropriately characterize fish populations within a navigational pool, and determine the appropriate interval length at which to analyze data moving forward. As such, overall non-specific results are reported here, with species specific estimates and the results of the re-sampling analysis to be incorporated into a future final report.

During fall pool-wide hydroacoustic surveys USFWS personnel completed over 379 miles of survey transects, ensonified more than 23,883,617 cubic meters of water, and enumerated 21,175 fish greater than 254 mm (10”) total length (Appendix 1; Appendix 2). The last pool-wide surveys were conducted in 2019 under major flood conditions, while water levels in 2021 were below average. In 2021, water levels were so low that no backwater habitats were accessible for hydroacoustic surveys in any of the pools (Appendix 1). The benefits of sampling during low water conditions were apparent as 2021 surveys sampled about a third less water but enumerated nearly 4x as many fish ≥ 254 mm (10”) TL (Pools 16-19 in 2019 sampled 36,613,872 cubic meters of water and counted 5,559 fish ≥ 254 mm (10”) TL).

Densities of fish ≥ 254 mm (10”) TL were greater in side channel habitats than main channel habitats in all pools. Within main channel habitats, nearshore transects consistently had higher densities than offshore transects (Appendix 2). By pool, overall densities increased as we proceeded downstream, and densities in Pool 20 (1.8863 fish / 1,000 m^3) were several times greater than either Pool 18 (0.3288 fish / 1,000 m^3) or Pool 19 (0.5515 fish / 1,000 m^3; Appendix 2). This may be attributable to much higher densities of Silver and Bighead Carp in Pool 20 relative to pools above LD19.

Fishery-Independent Sampling

The USFWS conducted 101 dozer trawl samples across Pools 18-20 (Table 1). This effort resulted in the collection of over 12,334 fishes including 46 different species. Of those, 1,106 fishes were ≥ 254 mm, which is the designated length cut-off for hydroacoustic analysis (Table 7). The most common species ≥ 254 mm were Gizzard Shad (N=625), Silver Carp (N=117), Longnose Gar (N=89), Shortnose Gar (N=74), Smallmouth Buffalo (N=39) and Bigmouth Buffalo (N=36). Silver Carp were collected in all pools, but were most common in Pool 20 (N=112; Table 8).

Data from the INHS LTEF electrofishing program was still being processed, including identification of preserved specimens and quality checking of the data, at the time of this report. When those data are received it will be combined with USFWS data and applied to the hydroacoustics analysis. Additionally, we will be making comparisons among the gear types to evaluate how CPUE differs between the gears for species of interest. Results of these comparisons will be disseminated in a final report and will guide future fishery-independent sampling effort. Preliminary examination of the data shows no Silver or Bighead Carp were collected in Pools 18 or 19, while 47 Silver Carp were collected in Pool 20 (Table 8).

Table 7. *Total catch of fish by pool from USFWS dozer trawl sampling, and catch of fish ≥ 254 mm TL (these fish will inform hydroacoustics), Pools 18-20 of the UMR, Aug.-Sept. 2021.*

Pool	Total Fish	N species	Fish ≥ 254 mm TL	N species
18	3555	26	304	16
19	7185	37	448	24
20	1594	28	354	17
Total	12334	46	1106	28

Table 8. *Number of Silver Carp collected from fishery-independent sampling efforts in Pools 18-20 of the UMR, Aug.-Sept. 2021.*

Pool	Habitat	Silver Carp DT	Silver Carp LTEF
18	MC	0	0
	SC	4	0
	BW	0	0
19	MC	0	0
	SC	1	0
	BW	0	0
20	MC	43	35
	SC	54	12
	BW	15	0

Telemetry

In Pools 20-26, tagging and new receiver deployment occurred near the end of 2021. Detection data is 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). MDC implanted transmitters in 123 Silver Carp and one Bighead Carp (Appendix 3). All fish were measured, weighed, sexed, and a t-bar inserted in the dorsal fin for external ID. These captures and implants were dispersed across Pools 20-26. Mean length of implanted Silver Carp was 698 mm with mean weight of 3948 grams. The single Bighead Carp was 782 mm and 4600 grams and was female. Silver Carp sex demographic was 68 female and 55 male.

In UMR Pools 5A-20, the combined arrays of USFWS and USGS detected 645 tagged individuals during 2021. Of these, there were detections from 43 Bighead Carp, 181 Silver Carp, 5 hybrid carp, 85 Grass Carp, 171 Bigmouth Buffalo, 83 Paddlefish, 52 Lake Sturgeon, and 25 Flathead Catfish. Most Silver and Bighead Carp residency events were concentrated in Pools 16-19 where the highest densities of tagged Silver and Bighead Carp occur (Table 9). A single Silver Carp tagged in Pool 8 during October 2020 was redetected in Pool 8 throughout the field season during 2021. A second Silver Carp was redetected in Pool 11 after being detected in the same location since November 2019. This individual was initially tagged in Pool 17 during 2017 and made multiple upstream movements, reaching Lake Pepin in Pool 4 during May 2019 before heading downstream to the Wisconsin River and later to Pool 11 where it was redetected during May 2021. Thirteen upstream and 28 downstream movement events for Silver and Bighead Carp were recorded during the 2021 field season (Table 10).

Table 9. *Results from residency event analysis for Silver and Bighead Carp and their hybrids in the UMR during 2021. 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 2021.*

	Individuals detected (sum residency events)		
UMR Pools	**Bighead Carp**	**Silver Carp**	**Bighead x Silver Carp Hybrids**
Pool 8	-	1 (35)	-
Pool 11	-	1 (4)	-
Pool 14	1 (5)	1 (17)	-
Pool 15	1 (160)	21 (1243)	-
Pool 16	8 (169)	47 (1115)	1 (48)
Pool 17	6 (81)	21 (487)	1 (25)
Pool 18	6 (191)	26 (491)	1 (34)
Pool 19	14 (259)	21 (172)	2 (25)
Pool 20	7 (102)	42 (658)	-

Table 10. *Upstream and downstream movements of Silver and Bighead Carp detected in the UMR during March-December 2021.*

Direction of movements	Original location	Final Location	Detected Movements	
			Bighead Carp	Silver Carp
Upstream	Pool 17	Pool 16	-	2
	Pool 18	Pool 16	-	1
	Pool 18	Pool 17	-	7
	Pool 20	Pool 19	2	1
Downstream	Pool 14	Pool 15	1	-
	Pool 15	Pool 16	-	2
	Pool 16	Pool 17	2	4
	Pool 16	Pool 18	-	1
	Pool 17	Pool 18	2	9
	Pool 18	Pool 19	1	1
	Pool 19	Pool 20	1	4

Larval Sampling

2016 Results
A total of 391,054 larval fishes were collected in light traps representing a total of 10 different families from May to September of 2016. The highest percentage (76.9%) of larvae were from the family Cyprinidae followed by Centrarchidae (20.9%) and Clupeidae (1.1%). Most larvae (58.0%) were caught in Pool 17 of the Mississippi River with the next highest amount (21.9%) in Pool 18, followed by Pool 19 (20.1%). Larval abundances peaked in the month of June (Figure 7). A total of 1,731 bigheaded carp were detected in the 2016 sampling season. Detections of bigheaded carp larvae all occurred in Pool 19, and peak abundances occurred in the month of June (Figure 8; Figure 9).

2017 Results
A total of 413,192 larval fishes were identified from the 2017 sampling season representing 10 different families. The highest percentage (88.9%) of larvae were from the family Cyprinidae followed by Centrarchidae (9.8%) and Catostomidae (0.7%). Most larvae (67.0%) were caught in Pool 18 of the Mississippi River with the next highest amount (18.3%) in Pool 19, followed by Pool 17 (14.7%). Larval abundances peaked in the month of June (Figure 10). There was only one detection of a bigheaded carp larvae for 2017. This detection occurred in Pool 19 near Fort Madison, IA during the month of June (Figure 9).

2018 Results
A total of 48,241 larval fishes were identified from 2018 sampling season representing eight different families. The highest percentage (80.5%) of larvae were from the family Cyprinidae

followed by Centrarchidae (17.4%) and Clupeidae (1.5%). Most larvae (42.1%) were caught in Pool 19 of the Mississippi River with the next highest amount (33.5%) in Pool 18, followed by Pool 17 (24.4%). Larval abundances peaked in June (Figure 11). There were 17 bigheaded carp collected in 2018, 16 were collected in June and one was collected on September 13th. All larval bigheaded carp were collected in Pool 19 using light traps (N = 14) and push nets (N = 3; Figure 9).

2019 Results
In 2019, sampling occurred from 06/10/2019 to 09/19/2019, and a total of 202 samples were collected. Total samples collected in 2019 were lower than previous years due to lower tempertatures, flooding, and storms throughout the season. Of the samples collected, 127 were light traps, 42 were push nets, and 33 were benthic sleds (Table 11). In 2019, 70,810 larval fishes from 10 different families were identified from samples, and Cyprinidae were the most abundant (82.0%). Overall larval abundances seem to have peaked in July (Figure 12) instead of in June like previous years (2016-2018). No invasive carp were detected in the 2019 samples.

2020 Results
In 2020, sampling occurred once a week from 06/08/2020 to 09/28/2020, and a total of 129 samples were collected. Only larval light traps were used in 2020 to sample four streams in Pool 19 of the Upper Mississippi River where larval bigheaded carp have historically been detected: Chaney Creek, Larry Creek, Waggoner Creek, Lamalees Creek (Figure 9; Figure 13). Seining for juvenile bigheaded carp in small tributaries was conducted on 07/23/2020 in Chaney Creek, Lamalees Creek, Waggoner Creek, Sheridan Creek, and Larry Creek. No bigheaded carp were detected in these tributaries during the seining events. No bigheaded carp were detected in the 2020 larval light trap samples. From these 2020 light trap samples, there were 45,906 larval fishes from twelve different families identified, and Cyprinidae were the most abundant (92.0%). Larval abundances seem to have peaked in mid-July (Figure 14).

2021 Results
In 2021, sampling occurred once a week from 05/24/2021 to 10/04/2021, and a total of 165 samples were collected. Only larval light traps were used in 2021 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 (Figure 9; Figure 13). On 06/28/2021, several larval fishes were collected the same week spawning scars were observed on adult bigheaded carp females during harvest efforts in Pool 19 of the UMR. After this observation, an additional dip netting event was conducted on 07/02/2021 in Wildcat Creek and Carthage Lake of Pool 19. Samples collected from these areas were identified and did not contain invasive carp. Analysis of larval abundances is still ongoing and is expected to be completed in 2022. However, no bigheaded carp have yet been identified from the 2021 larval light trap samples.

Table 11. *Number of samples by larval sampling gear type, used in Pools 17-19 of the Upper Mississippi River from 06/10/2019–09/19/2019.*

	Pool 17	Pool 18	Pool 19
Light Trap	40	32	55
Benthic Sled	10	10	13
Push Net	11	10	21

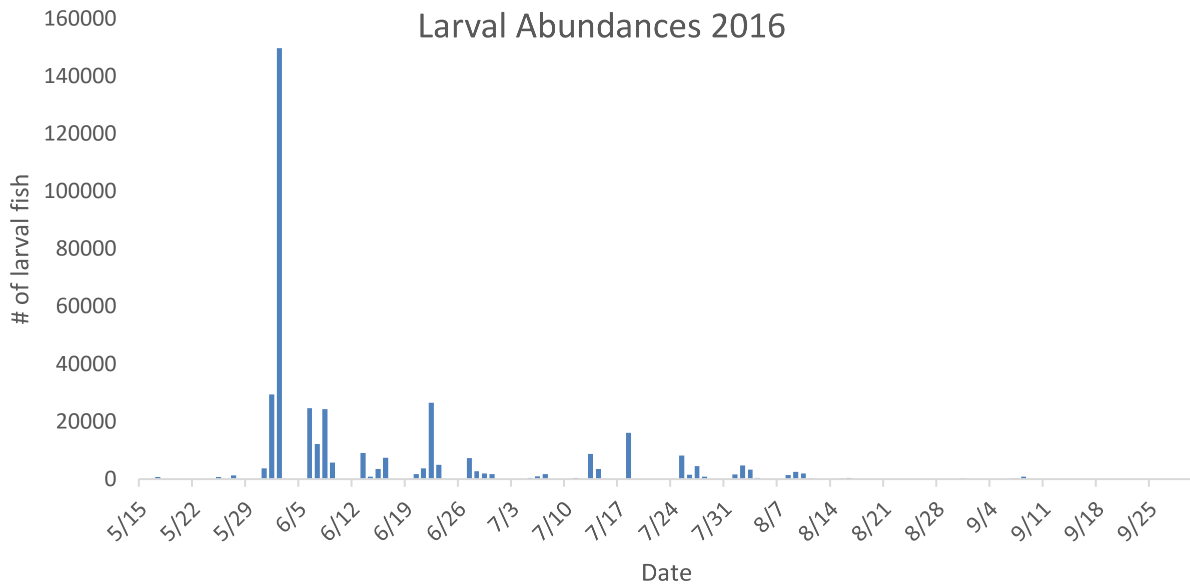

Figure 7. *Larval abundances throughout the 2016 sampling season using light traps deployed in Pools 17–19 on the Upper Mississippi River.*

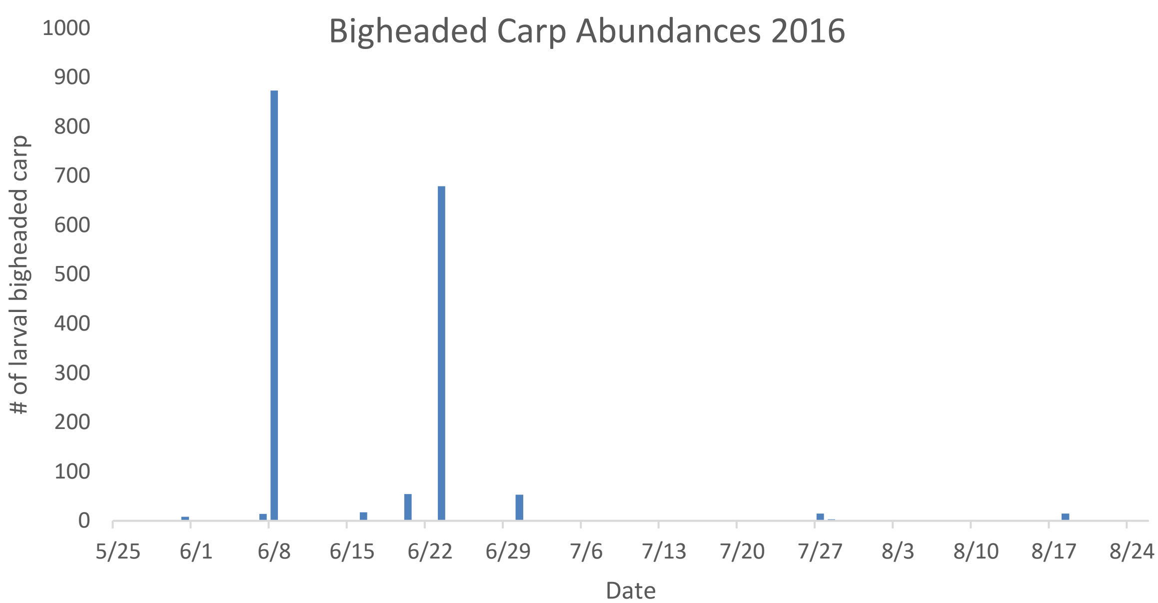

Figure 8. *Larval bigheaded carp abundances throughout the 2016 sampling season using light traps deployed in Pools 17–19 on the Upper Mississippi River.*

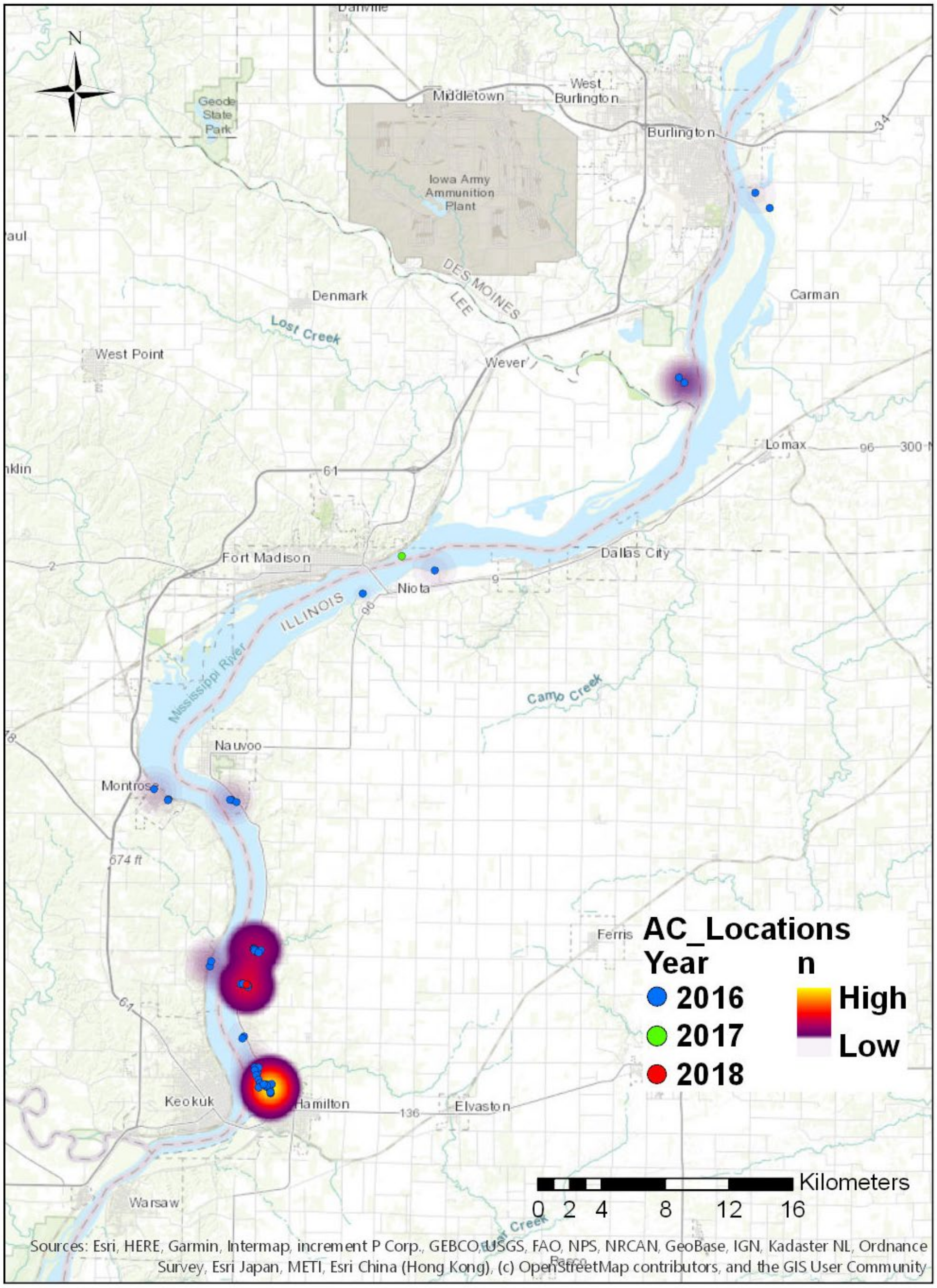

Figure 9. *Occurences of individual larval bigheaded carp (n) collected using larval light traps from 2016–2018 in Pool 19 of the Upper Mississippi River. The blue dots represent areas where larval bigheaded carp were detected in 2016, the green dots represent areas where larval bigheaded carp were detected in 2017, and the red dots represent areas where larval bigheaded carp were detected in 2018.*

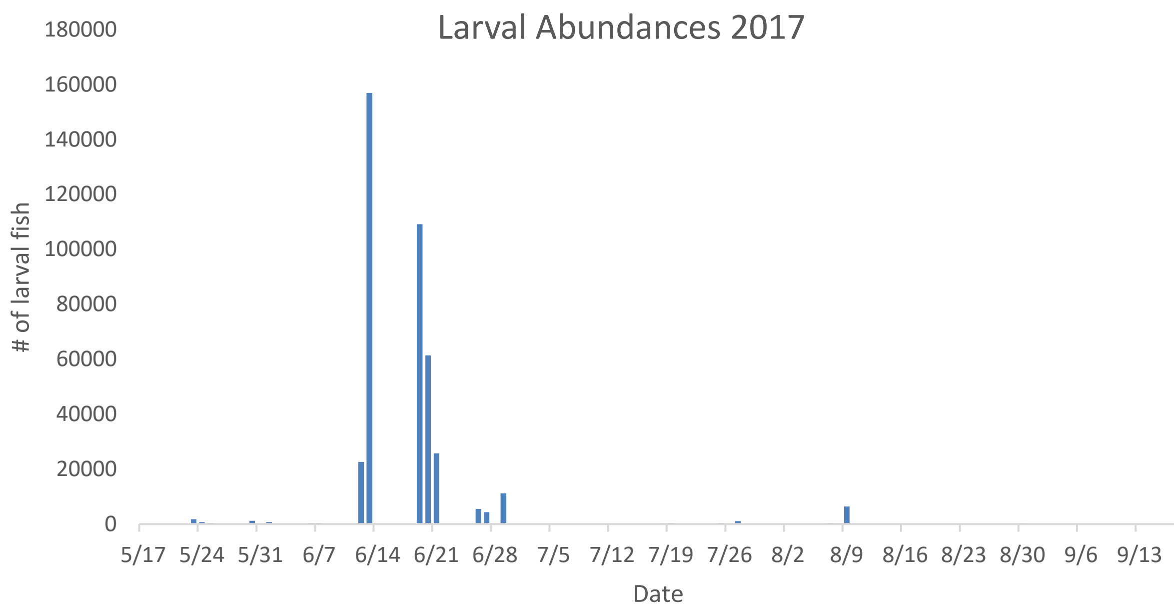

Figure 10. *Larval abundances throughout the 2017 sampling season using light traps deployed in Pools 17–19 on the Upper Mississippi River.*

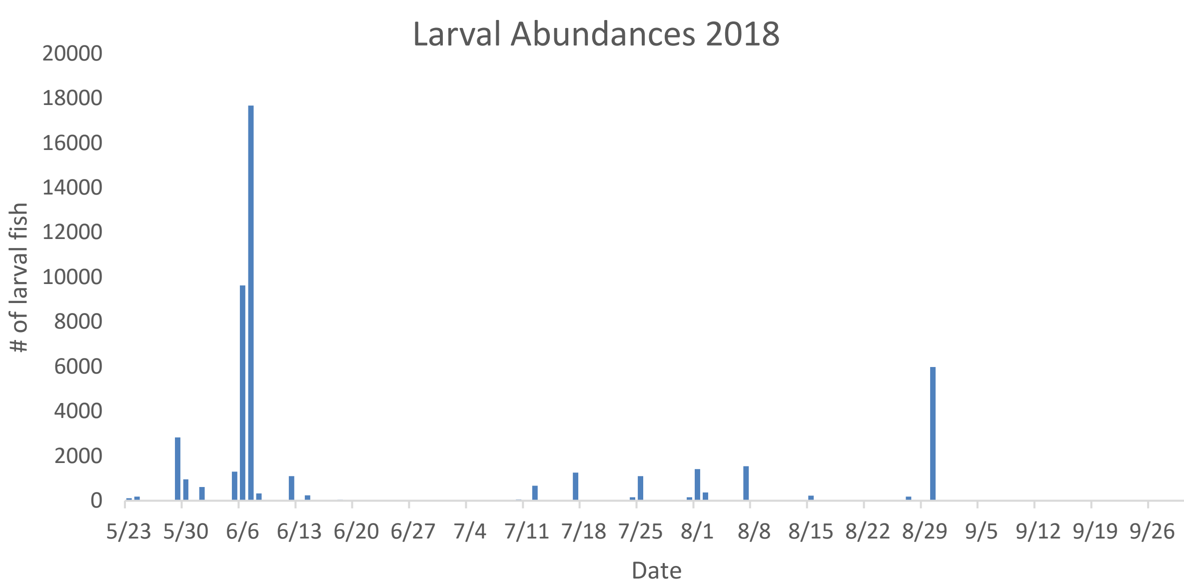

Figure 11. *Larval abundances throughout the 2018 sampling season using benthic sleds, push nets, and light traps deployed in Pools 17-19 on the Upper Mississippi River.*

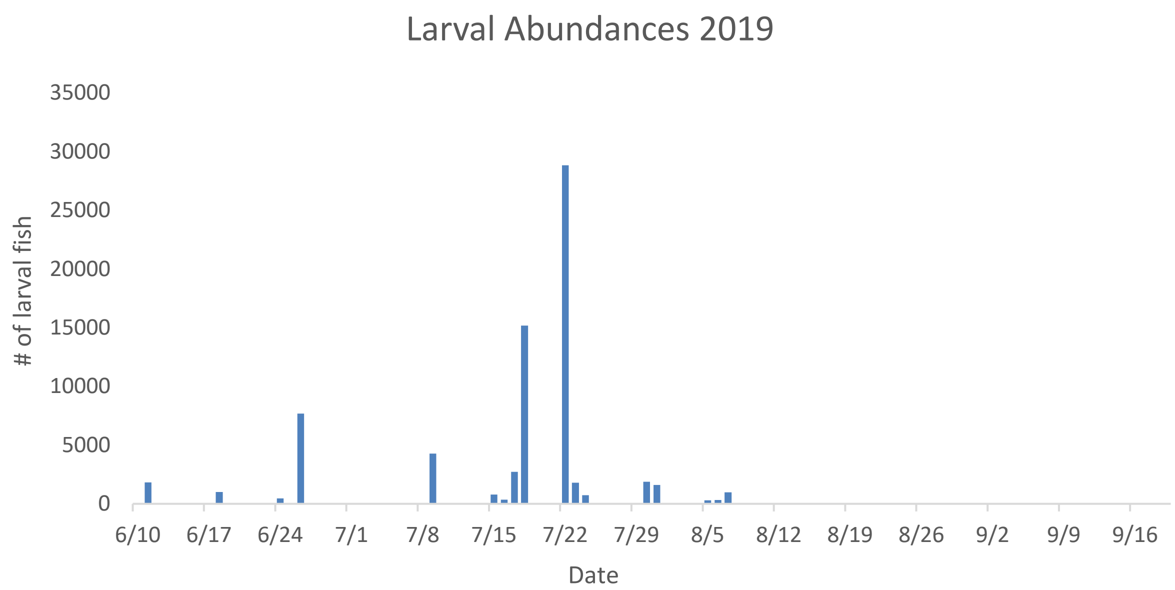

Figure 12. *Larval abundances throughout the 2019 sampling season using benthic sleds, push nets, and light traps deployed in Pools 17–19 on the Upper Mississippi River. No larval bigheaded carp were detected.*

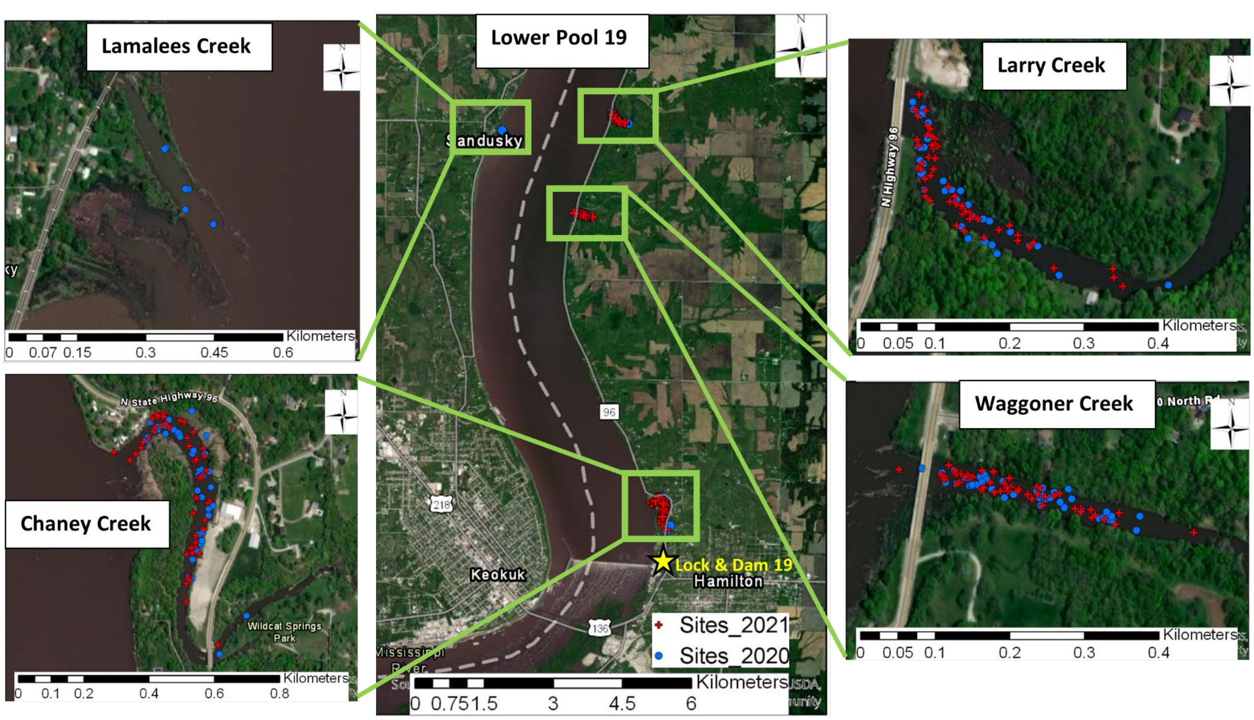

Figure 13. *Larval light trapping locations from 2020 and 2021 sampling seasons in Pool 19 of the Upper Mississippi River. Blue circles represent 2020 light trap sample sites, and the red crosses represent 2021 light trap sample sites.*

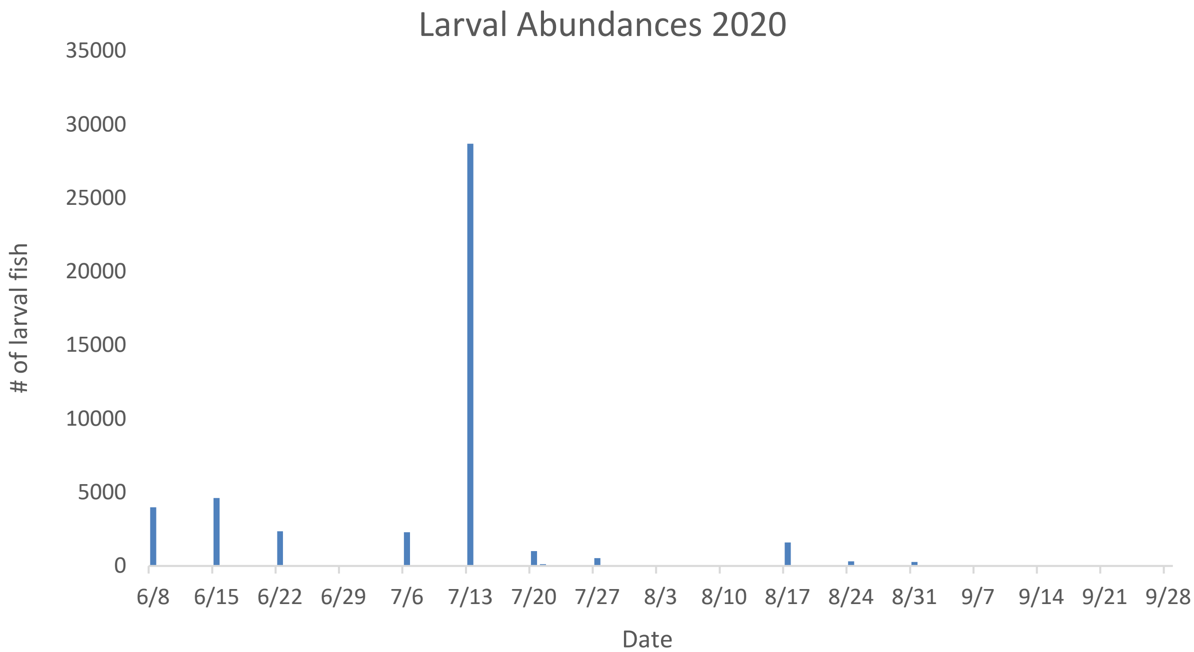

Figure 14. *Larval abundances throughout the 2020 sampling season using light traps deployed in Pool 19 on the Upper Mississippi River. No larval bigheaded carp were detected.*

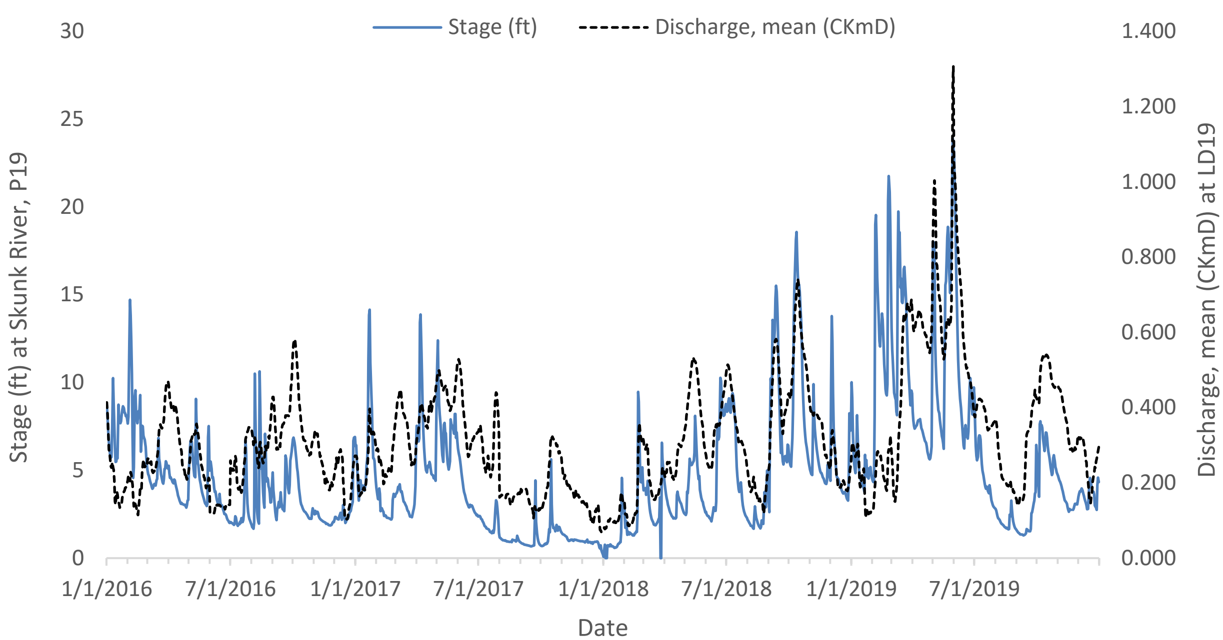

Figure 15. *Hydrological conditions in Pool 19 (P19) of the Upper Mississippi River from 01/01/2016 through 12/31/2019. Blue line represents river stage (ft) at Skunk River, and black dashed line represents mean discharge (CKmD) at Lock and Dam (LD) 19.*

Discussion:

The hydroacoustic program in the UMR is continuing to develop, and in the coming years should begin 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 should continue for at least one more year and then will be evaluated as a whole. For pool-wide surveys, 2021 was the most successful year of data collection to date, and low water levels were shown to dramatically increase the ability of the equipment to enumerate fish compared to the flood conditions that were experienced in 2019. Low water seemed to congregate fishes in side channels and the main channel where they could be sampled. During high water, fish were more dispersed, and possibly seeking refuge from high flow in areas inaccessible to hydroacoustic sampling, like flooded timber. As more years of 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 a pools fish population. 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 new 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). Data from the INHS LTEF electrofishing program was still being processed, including identification of preserved specimens and quality checking of the data, as was fishery-dependent data, at the time of this report. When those data are received they will be combined with USFWS fishery-independent data and applied to the hydroacoustics analysis. Additionally, we will be making comparisons among the gear types to evaluate how CPUE differs between the fishery-independent gears for species of interest. Ongoing analyses and comparisons of fishery-independent gears will better determine the types of gear and levels of effort needed to characterize Silver and Bighead Carp populations, especially in areas of low to moderate density. Results of these comparisons will be disseminated in a final report.

Telemetry efforts continue to improve in the UMR and the addition of more receivers and tagged fish in the system in 2021 will allow for better detection of tagged fishes and more thorough understanding of spatial movements and habitat use in the UMR. Staff from the USFWS have initiated processes to purchase 250 new Vemco transmitters during early 2022. These additional transmitters will be implanted in Silver and Bighead Carp in the IMZ in support of contracted removal efforts. An additional 25 tags will be reserved for efforts to capture and tag Silver and Bighead Carp in Pools 8-13 during spring and fall 2022. Any fish captured and tagged in these efforts upstream of the IMZ are intended to support our understanding of habitat use and the timing and frequency of movements in regions where Silver and Bighead Carp captures have increased during the last three years.

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 of 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 Silver and Bighead 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 Silver and Bighead Carp are reproducing yearly, under what hydrological conditions (Figure 15), and what size their recruitment potential is at the northern forefront of their reproductive range in the Mississippi River.

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:

In Pool 8 of the UMR, hydroacoustic surveys have thus far been used to identify congregations of large fish to help with removal event planning. Due to extremely low densities of Silver and Bighead Carp, it is difficult to make any species specific abundance or density estimates with hydroacoustics. Hydroacoustic surveys of this nature should continue on an as needed basis at the request of state partners.

Pre/post removal surveys in Pools 16-19 should continue in FY22 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), and more focused length-frequency comparisons with consideration to fish size at gear recruitment.

Pool-wide surveys should continue and expand in the UMR to be able to evaluate more pools that have contracted removal programs. Results of a re-sampling analysis should be used to inform proper levels of effort at varying Silver and Bighead Carp densities. This analysis will also help move hydroacoustic pool-wide surveys to a stratified random sampling design, and hopefully increase the efficiency of our hydroacoustic pool-wide evaluations.

Fishery-independent surveys should continue in the UMR. Quantitative comparisons of fishery-independent gears used in FY21 are being conducted, and results will inform how fishery-independent data is collected in the future. Initial results indicate the electrified dozer trawl appears to be more effective at sampling Silver Carp than traditional sampling tools like pulsed DC electrofishing, while still collecting information on the overall fish community.

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, and time and funding become available.

Continued larval sampling will help further identify the nursery environments of Silver and Bighead 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.

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Appendix 1. *Location and extent of hydroacoustic pool-wide survey sites, Upper Mississippi River, fall 2021.*

Pool	Sites	Habitat	NRM	Transect Length	Transects	Total Dist. (nmi)
18	Main Channel	MC	410.5-437	26.5	4	106
18	Keg Island	SC	435.5-436.5	1	2	2
18	Blackhawk Chute	SC	426-429	2	2	4
18	Charlie Island	SC	420-422	2	2	4
18	Corsepius Island	SC	431-432	0.5	2	1
18	Dasher Island	SC	411-412	0.75	2	1.5
18	Gun Slough	SC	422-423	0.75	2	1.5
18	Kingston Bar	SC	423-424	1.25	2	2.5
18	Mapes Chute	SC	425-427	2.25	2	4.5
18	Oquawka Chute	SC	412-415	3	2	6
18	Huron Chute	SC	420-425	5.75	2	11.5
18	Benton Slough	SC	417.5-419.5	2	2	5
19	Main Channel	MC	406-410	4	4	16
19	O'Connell Slough	SC	405-408	4	2	8
19	Shokokun Slough	SC	395-402	7.5	2	15
19	Main Channel	MC	392-397	5	4	20
19	Grape Chute	SC	391-394	3.5	2	7
19	Dallas City	SC	386-388	3	2	6
19	Main Channel	MC	378-383	5	4	20
19	Impounded SC	SC	379-382.5	3.5	2	7
19	Main Channel	MC	365-369	4	4	16
20	Main Channel	MC	343-364	21	4	84
20	Buzzard Chute	SC	349-351	1.75	2	3.5
20	Crey Chute	SC	355-358.5	3.5	2	7
20	Fox Island	SC	355.5-357	1.25	2	2.5
20	Hackley Chute	SC	352-355	3	2	6
20	Hunt/Huff/Polly	SC	346-349.5	3.5	2	7
20	Missouri Chute	SC	344.5-346.5	1.75	2	3.5

Appendix 2. *Total estimated fish densities by pool and habitat type for Upper Mississippi River Pools 18-20, fall pool-wide surveys 2021.*

Pool	Habitat	Site	# Fish ≥ 10"	Water volume sampled (m^3)	Fish/1,000 m^3
18	SC	Benton Slough	214	123012	1.7397
18	SC	Blackhawk Chute	156	104706	1.4899
18	SC	Keg Island	342	66316	5.1571
18	SC	Huron Chute	216	638712	0.3382
18	SC	Charlie Island	106	56832	1.8651
18	SC	Gun Slough	46	10052	4.5762
18	SC	Corsepius Island	7	15547	0.4502
18	SC	Dasher Island	22	57735	0.3811
18	SC	Kingston	26	46288	0.5617
18	SC	Mapes Chute	23	124488	0.1848
18	SC	Oquawka Chute	115	405993	0.2833
18	MC	RM 410.5-437 nearshore	947	2815312	0.3364
18	MC	RM 410.5-437 offshore	381	3445078	0.1106
Total	All	Combined	2601	7910071	0.3288

Pool	Habitat	Site	# Fish ≥ 10"	Water volume sampled (m^3)	Fish/1,000 m^3
19	SC	O'Connell Slough	137	203518	0.673159131
19	SC	Shokokon Slough Upper	211	448427	0.470533665
19	SC	Shokokun Slough Lower	669	336585	1.987610856
19	SC	Grape Chute	124	250306	0.495393638
19	SC	Dallas City	472	578573	0.815800253
19	SC	Impounded RM 379-382.5	237	684160	0.346410196
19	MC	RM 365-369 nearshore	221	908158	0.243349725
19	MC	RM 365-369 offshore	278	1356481	0.204942052
19	MC	RM 378-383 nearshore	188	534418	0.351784558
19	MC	RM 378-383 offshore	111	703039	0.157885978
19	MC	RM 392-397 nearshore	1746	757693	2.304363377
19	MC	RM 392-397 offshore	234	961720	0.243314062
19	MC	RM 406-410 nearshore	97	453337	0.213968858
19	MC	RM 406-410 offshore	50	481577	0.103825556
19	All	Combined	4775	8657992	0.551513561

Pool	Habitat	Site	# Fish ≥ 10"	Water volume sampled (m^3)	Fish/1,000 m^3

20	SC	Buzzard Chute	289	69863	4.136667478
20	SC	Crey Chute	2866	279622	10.24955118
20	SC	Fox Island	483	89037	5.424711075
20	SC	Hackley Chute	351	291522	1.204025768
20	SC	Hunt Island	309	297512	1.038613569
20	SC	Missouri Chute	748	123262	6.068374682
20	MC	RM 343-364 nearshore	5616	2718191	2.066079977
20	MC	RM 343-364 offshore	3137	3446545	0.910186868
20	All	Combined	13799	7315554	1.886254958

Appendix 3. *Silver and Bighead Carp implanted with transmitters by MDC during calendar year 2021.*

DATE	RIVERMILE	LAT	LONG	FISHCODE	LENGTH	SEX	WEIGHT	LBS	TRANS	FLOY
10/5/2021	342	40.12526	-85.51398	SVCP	571	F	1340	2.95	58318	ORFS44446
10/5/2021	342	40.12526	-85.51398	BHCP	782	F	4600	10.14	58316	ORFS44444
10/5/2021	342	40.12526	-85.51398	SVCP	722	F	3620	7.98	58315	ORFS44443
10/5/2021	342	40.12526	-85.51398	SVCP	749	F	3800	8.38	58314	ORFS44442
10/5/2021	342	40.12526	-85.51398	SVCP	740	F	4550	10.03	58320	ORFS44448
10/5/2021	342	40.12526	-85.51398	SVCP	745	F	4800	10.58	58313	ORFS44441
10/5/2021	342	40.12526	-85.51398	SVCP	764	F	5120	11.29	58317	ORFS44445
10/5/2021	342	40.12526	-85.51398	SVCP	651	M	2980	6.57	58321	ORFS44449
10/5/2021	342	40.12526	-85.51398	SVCP	675	M	3540	7.80	58319	ORFS44447
10/18/2021	202	38.87094	-84.18484	SVCP	481	F	1200	2.65	58325	ORFS44928
10/18/2021	202	38.87094	-84.18484	SVCP	701	F	3500	7.72	58331	ORFS44934
10/18/2021	202	38.87094	-84.18484	SVCP	681	F	3520	7.76	58330	ORFS44933
10/18/2021	202	38.87094	-84.18484	SVCP	712	F	3560	7.85	58328	ORFS44931
10/18/2021	202	38.87094	-84.18484	SVCP	701	F	3788	8.35	58337	ORFS44940
10/18/2021	202	38.87094	-84.18484	SVCP	703	F	3800	8.38	58329	ORFS44932
10/18/2021	202	38.87094	-84.18484	SVCP	711	F	3881	8.56	58322	ORFS44450
10/18/2021	202	38.87094	-84.18484	SVCP	692	F	3920	8.64	58333	ORFS44936
10/18/2021	202	38.87094	-84.18484	SVCP	694	F	3940	8.69	58334	ORFS44937
10/18/2021	202	38.87094	-84.18484	SVCP	703	F	3980	8.77	58335	ORFS44938
10/18/2021	202	38.87094	-84.18484	SVCP	698	F	4020	8.86	58338	ORFS44941
10/18/2021	202	38.87094	-84.18484	SVCP	725	F	4060	8.95	58327	ORFS44930
10/18/2021	202	38.87094	-84.18484	SVCP	753	F	4560	10.05	58324	ORFS44927
10/18/2021	202	38.87094	-84.18484	SVCP	781	F	4600	10.14	58323	ORFS44926
10/18/2021	202	38.87094	-84.18484	SVCP	627	M	2540	5.60	58326	ORFS44929
10/18/2021	202	38.87094	-84.18484	SVCP	656	M	3140	6.92	58339	ORFS44942
10/18/2021	202	38.87094	-84.18484	SVCP	680	M	3460	7.63	58332	ORFS44935
10/18/2021	202	38.87094	-84.18484	SVCP	700	M	4040	8.91	58336	ORFS44939
DATE	**RIVERMILE**	**LAT**	**LONG**	**FISHCODE**	**LENGTH**	**SEX**	**WEIGHT**	**LBS**	**TRANS**	**FLOY**
10/25/2021	327	39.93698	-85.41742	SVCP	738	F	4700	10.36	58347	ORFS44944

10/25/2021	327	39.93698	-85.41742	SVCP	748	F	4700	10.36	58346	ORFS44950
10/25/2021	327	39.93698	-85.41742	SVCP	720	F	4800	10.58	58345	ORFS44949
10/25/2021	327	39.93698	-85.41742	SVCP	780	F	5160	11.38	58340	ORFS44943
10/25/2021	327	39.93698	-85.41742	SVCP	745	F	5340	11.77	58348	ORFS43051
10/25/2021	327	39.93698	-85.41742	SVCP	743	F	5400	11.90	58350	ORFS43053
10/25/2021	327	39.93698	-85.41742	SVCP	765	F	5520	12.17	58342	ORFS44946
10/25/2021	327	39.93698	-85.41742	SVCP	785	F	5810	12.81	58343	ORFS44947
10/25/2021	327	39.93698	-85.41742	SVCP	696	M	3560	7.85	58349	ORFS43052
10/25/2021	327	39.93698	-85.41742	SVCP	740	M	4720	10.41	58344	ORFS44948
10/26/2021	301	39.63762	-85.24081	SVCP	672	F	3460	7.63	58376	ORFS43079
10/26/2021	301	39.63762	-85.24081	SVCP	676	F	3540	7.80	58389	ORFS43092
10/26/2021	325	39.90741	-85.43546	SVCP	672	F	3600	7.94	58370	ORFS43073
10/26/2021	301	39.63762	-85.24081	SVCP	698	F	3620	7.98	58387	ORFS43090
10/26/2021	301	39.63762	-85.24081	SVCP	680	F	3800	8.38	58381	ORFS43084
10/26/2021	325	39.90741	-85.43546	SVCP	692	F	3900	8.60	58363	ORFS43066
10/26/2021	325	39.90741	-85.43546	SVCP	683	F	3940	8.69	58368	ORFS43071
10/26/2021	301	39.63762	-85.24081	SVCP	691	F	3980	8.77	58385	ORFS43088
10/26/2021	301	39.63762	-85.24081	SVCP	690	F	4000	8.82	58372	ORFS43075
10/26/2021	301	39.63762	-85.24081	SVCP	705	F	4180	9.22	58380	ORFS43083
10/26/2021	325	39.90741	-85.43546	SVCP	743	F	4220	9.30	58362	ORFS43065
10/26/2021	301	39.63762	-85.24081	SVCP	725	F	4250	9.37	58377	ORFS43080
10/26/2021	301	39.63762	-85.24081	SVCP	740	F	4520	9.96	58375	ORFS43078
10/26/2021	301	39.63762	-85.24081	SVCP	750	F	4520	9.96	58386	ORFS43089
10/26/2021	301	39.63762	-85.24081	SVCP	755	F	4720	10.41	58388	ORFS43091
10/26/2021	301	39.63762	-85.24081	SVCP	752	F	4880	10.76	58379	ORFS43082
10/26/2021	301	39.63762	-85.24081	SVCP	756	F	4880	10.76	58384	ORFS43087
10/26/2021	325	39.90741	-85.43546	SVCP	748	F	5080	11.20	58360	ORFS43063
10/26/2021	301	39.63762	-85.24081	SVCP	762	F	5120	11.29	58373	ORFS43076
10/26/2021	301	39.63762	-85.24081	SVCP	612	M	2360	5.20	58382	ORFS43085
10/26/2021	325	39.90741	-85.43546	SVCP	660	M	3200	7.05	58361	ORFS43064
10/26/2021	325	39.90741	-85.43546	SVCP	665	M	3220	7.10	58354	ORFS43057
10/26/2021	301	39.63762	-85.24081	SVCP	657	M	3240	7.14	58390	ORFS43093
10/26/2021	301	39.63762	-85.24081	SVCP	679	M	3500	7.72	58383	ORFS43086
10/26/2021	325	39.90741	-85.43546	SVCP	695	M	3580	7.89	58356	ORFS43059
10/26/2021	325	39.90741	-85.43546	SVCP	698	M	3600	7.94	58357	ORFS43060
10/26/2021	325	39.90741	-85.43546	SVCP	702	M	3600	7.94	58355	ORFS43058
10/26/2021	325	39.90741	-85.43546	SVCP	682	M	3660	8.07	58366	ORFS43069
10/26/2021	301	39.63762	-85.24081	SVCP	682	M	3660	8.07	58378	ORFS43081
10/26/2021	325	39.90741	-85.43546	SVCP	670	M	3720	8.20	58352	ORFS43055
10/26/2021	325	39.90741	-85.43546	SVCP	705	M	3780	8.33	58359	ORFS43062
10/26/2021	301	39.63762	-85.24081	SVCP	680	M	3800	8.38	58374	ORFS43077
10/26/2021	325	39.90741	-85.43546	SVCP	707	M	3860	8.51	58353	ORFS43056
10/26/2021	325	39.90741	-85.43546	SVCP	692	M	4060	8.95	58364	ORFS43067
DATE	**RIVERMILE**	**LAT**	**LONG**	**FISHCODE**	**LENGTH**	**SEX**	**WEIGHT**	**LBS**	**TRANS**	**FLOY**
10/26/2021	325	39.90741	-85.43546	SVCP	695	M	4320	9.52	58367	ORFS43070

10/26/2021	325	39.90741	-85.43546	SVCP	728	M	4320	9.52	58358	ORFS43061
10/26/2021	325	39.90741	-85.43546	SVCP	728	M	4520	9.96	58351	ORFS43054
10/26/2021	325	39.90741	-85.43546	SVCP	726	M	4720	10.41	58365	ORFS43068
10/26/2021	301	39.63762	-85.24081	SVCP	765	M	5220	11.51	58371	ORFS43074
10/27/2021	236	38.92628	-84.68383	SVCP	579	F	2010	4.43	48927	ORFS43232
10/27/2021	252	39.13263	-84.71269	SVCP	630	F	2720	6.00	48916	ORFS43221
10/27/2021	236	38.92628	-84.68383	SVCP	648	F	2920	6.44	48924	ORFS43229
10/27/2021	236	38.92628	-84.68383	SVCP	640	F	3100	6.83	48931	ORFS43236
10/27/2021	236	38.92628	-84.68383	SVCP	657	F	3260	7.19	48935	ORFS43240
10/27/2021	236	38.92628	-84.68383	SVCP	664	F	3440	7.58	48929	ORFS43234
10/27/2021	236	38.92628	-84.68383	SVCP	674	F	3640	8.02	48926	ORFS43231
10/27/2021	236	38.92628	-84.68383	SVCP	672	F	3780	8.33	48936	ORFS43241
10/27/2021	252	39.13263	-84.71269	SVCP	702	F	3780	8.33	48921	ORFS43226
10/27/2021	252	39.13263	-84.71269	SVCP	723	F	4290	9.46	58404	ORFS43209
10/27/2021	236	38.92628	-84.68383	SVCP	716	F	4440	9.79	48928	ORFS43233
10/27/2021	252	39.13263	-84.71269	SVCP	738	F	4520	9.96	58402	ORFS43207
10/27/2021	252	39.13263	-84.71269	SVCP	738	F	4720	10.41	58399	ORFS43204
10/27/2021	252	39.13263	-84.71269	SVCP	712	F	5000	11.02	58409	ORFS43214
10/27/2021	252	39.13263	-84.71269	SVCP	725	F	5000	11.02	48914	ORFS43219
10/27/2021	252	39.13263	-84.71269	SVCP	738	F	5010	11.05	58405	ORFS43210
10/27/2021	252	39.13263	-84.71269	SVCP	743	F	5010	11.05	48915	ORFS43220
10/27/2021	252	39.13263	-84.71269	SVCP	740	F	5120	11.29	58410	ORFS43215
10/27/2021	252	39.13263	-84.71269	SVCP	723	F	5220	11.51	58392	ORFS43095
10/27/2021	252	39.13263	-84.71269	SVCP	784	F	5520	12.17	58395	ORFS43098
10/27/2021	252	39.13263	-84.71269	SVCP	576	M	2000	4.41	58401	ORFS43206
10/27/2021	252	39.13263	-84.71269	SVCP	582	M	2020	4.45	58406	ORFS43211
10/27/2021	236	38.92628	-84.68383	SVCP	607	M	2420	5.34	48930	ORFS43235
10/27/2021	252	39.13263	-84.71269	SVCP	598	M	2520	5.56	58403	ORFS43208
10/27/2021	236	38.92628	-84.68383	SVCP	625	M	2800	6.17	48933	ORFS43238
10/27/2021	236	38.92628	-84.68383	SVCP	633	M	3020	6.66	48932	ORFS43237
10/27/2021	236	38.92628	-84.68383	SVCP	636	M	3080	6.79	48925	ORFS43230
10/27/2021	236	38.92628	-84.68383	SVCP	647	M	3100	6.83	48934	ORFS43239
10/27/2021	252	39.13263	-84.71269	SVCP	682	M	3160	6.97	48919	ORFS43224
10/27/2021	252	39.13263	-84.71269	SVCP	675	M	3220	7.10	58400	ORFS43205
10/27/2021	252	39.13263	-84.71269	SVCP	688	M	3640	8.02	58393	ORFS43096
10/27/2021	252	39.13263	-84.71269	SVCP	686	M	3720	8.20	48923	ORFS43228
10/27/2021	252	39.13263	-84.71269	SVCP	705	M	3820	8.42	58397	ORFS43202
10/27/2021	252	39.13263	-84.71269	SVCP	694	M	3900	8.60	58407	ORFS43212
10/27/2021	252	39.13263	-84.71269	SVCP	707	M	3900	8.60	58398	ORFS43203
10/27/2021	252	39.13263	-84.71269	SVCP	703	M	4020	8.86	48917	ORFS43222
10/27/2021	252	39.13263	-84.71269	SVCP	692	M	4040	8.91	58391	ORFS43094
10/27/2021	252	39.13263	-84.71269	SVCP	707	M	4050	8.93	48918	ORFS43223
10/27/2021	252	39.13263	-84.71269	SVCP	692	M	4100	9.04	58411	ORFS43216
DATE	**RIVERMILE**	**LAT**	**LONG**	**FISHCODE**	**LENGTH**	**SEX**	**WEIGHT**	**LBS**	**TRANS**	**FLOY**
10/27/2021	252	39.13263	-84.71269	SVCP	715	M	4260	9.39	58412	ORFS43217

10/27/2021	252	39.13263	-84.71269	SVCP	720	M	4420	9.74	58408	ORFS43213
10/27/2021	252	39.13263	-84.71269	SVCP	742	M	4480	9.88	48920	ORFS43225
10/27/2021	252	39.13263	-84.71269	SVCP	724	M	4520	9.96	48922	ORFS43227
10/27/2021	252	39.13263	-84.71269	SVCP	736	M	4700	10.36	58396	ORFS43201
10/27/2021	252	39.13263	-84.71269	SVCP	738	M	4720	10.41	58394	ORFS43097