Project Title: Asian Carp Movement and Assessment to Inform Management and Removal Efforts in the Lower Mississippi River (LMR) Basin

Geographic Location: Lower Mississippi River Basin

Lead Agency and Author: Louisiana Department of Wildlife and Fisheries (LDWF), Robby Maxwell (rmaxwell@wlf.la.gov)

Participating Agencies: Arkansas Game and Fish Commission (AGFC), University of Arkansas Pine Bluff (UAPB), Louisiana State University (LSU), Mississippi Department of Wildlife, Fisheries, and Parks (MDWFP), Mississippi State University (MSU), Missouri Department of Conservation (MDC), Tennessee Wildlife Resources Agency (TWRA), U.S. Fish and Wildlife Service (USFWS)

Statement of Need:

Successful containment and control of invasive species is reliant on an understanding of movements and life histories of populations in response to local conditions. Agencies involved in the LMR Asian carp movement studies are seeking to use active and passive ultrasonic acoustic telemetry and population assessments to gather data to inform efficient and effective placement of passage barriers and deterrents, as well as to guide removal efforts. Proposed projects also include monitoring of inter- and intrabasin movements in a variety of habitat types. The proposed studies will be the first collaborative tracking efforts of this scale that will be conducted on Asian carp across the LMR. Proposed networks of receiver arrays will build upon existing networks of compatible Vemco technology maintained by cooperating and partner agencies, with data sharing being of high priority. A value-added benefit of the proposed projects is expanded capability to detect fish involved in other movement studies, which coincides with the expanded detection capabilities of Asian carp in existing networks maintained by partner agencies.

The proposed studies address the "LMR Basin Asian Carp Control Strategy Framework" goals and strategies by identifying and utilizing habitat requirements, barriers, or deterrent technologies to control Asian carp. The proposed studies also address goals and strategies by using technology, methods, and capabilities necessary to monitor and control Asian carp, while opening lines of interagency cooperation and collaboration.

Project Objectives:

1. Determine intrabasin and interbasin movement to inform placement of potential deterrent technologies and removal efforts.
2. Determine feasibility of deterrent technologies by evaluating migration pathways into a natural lake.
3. Determine distribution and estimate population demographics of Asian carp in the lower Arkansas and lower White rivers to inform control measures including removal efforts.
4. Assess the contribution of Asian carp produced in the Mississippi River to populations in the lower Arkansas and lower White rivers to inform control measures including removal efforts.

Project Highlights:

- Louisiana
    - Acoustic telemetry array deployed and expanded across Louisiana (40 receivers covering over 18,000 square miles of area).
    - Capture techniques evaluated (electroshocking, nets, combination) and 107 invasive carp were tagged.
    - Receivers logged over 88,000 detections, with almost 16,000 being from nine invasive carp.
    - Collaborations with multiple state and federal agencies (USFWS, USACE, LDWF, LSU, CPRA) to achieve project goals.

- Arkansas
    - Otoliths microchemistry analyzed from 334 fish .
    - Sixty-nine Silver Carp have been implanted with acoustic transmitters.
    - Seven VR2 receivers have logged 79 transmitter encounters.
    - Five hundred ninety-two Silver Carp have been processed for population characteristics.

- Mississippi
    - Silver carp movement was limited with most tagged individuals remaining in the same spatial unit.
    - A minority of tagged individuals engaged in movement among spatial units during the spring and early summer.
    - Movement observations suggests that a barrier in Yazoo Pass may be an effective management action to minimize intrusion into Moon Lake.

- Missouri
    - One hundred invasive carp were implanted with acoustic transmitters (V16-6H) during summer/fall of 2021.
    - Eight stationary VR2Tx telemetry receivers were deployed over a 100-mile stretch of river.
    - Invasive carp averaged 676 mm in length and 3,114 grams in weight.
    - The LMR produced 1.63 male silver carp for every female silver carp.

- Tennessee
    - TWRA is working to analyze hydrologic data within the context of Reelfoot Lake Spillway operations.
    - Staff capacity and water levels limited TWRA's ability to complete electrofishing below Reelfoot Spillway – efforts are expected to commence during 2022 field season.

Lead Agency: Louisiana Department of Wildlife and Fisheries (LDWF), Robby Maxwell (rmaxwell@wlf.la.gov)

Participating Agencies: Louisiana State University (LSU); Michael Dance (mdance1@lsu.edu) and Christian Walker (cwal121@lsu.edu); US Fish and Wildlife Service, Kayla Kimmel (Kayla_Kimmel@fws.gov)

Methods:
An array of 40 acoustic receivers (Vemco VRTx) was deployed in mid-2021 between the Calcasieu River and Lake Borgne in southern Louisiana (Figure 1, Blue Points). Receivers were attached to nearby structures with the receiver near bottom in an upright orientation or just below the surface in an inverted orientation. An average detection radius of 500 m was assumed according to the standards specified by Vemco. Information on carp presence obtained from Louisiana Department of Wildlife and Fisheries from fish kill surveys, larval collections, and sighting report data was used to inform receiver locations. Receivers were placed strategically throughout the Intracoastal Waterway from the eastern to western extent of the study area, at major rivers (Mississippi River, Atchafalaya River, Mermentau River), and in connections to major estuaries of interest (Vermillion Bay, Barataria Bay, and Terrebonne Bay) to ensure a broad spatial gradient. Normal data retrieval and mooring equipment maintenance was conducted quarterly with receivers in high current or salinity areas checked more frequently to ensure the integrity of mooring equipment. One disruption to the normal download schedule occurred fall 2021 after Hurricane Ida passed over the eastern portion of the study area. The significant damage from the storm limited the use of boat launches and facilities and delayed all activities.

Additional telemetry studies conducted by partners expanded spatial surveillance of tagged invasive carp. These partner areas included: Lake Borgne (USFWS, LSU), Pearl River (USFWS, LSU), Lake Pontchartrain (USFWS, LSU), the Bonnet Carre Spillway (USACE), Rockefeller Wildlife Refuge (LSU, LDWF), Atchafalaya River (USFWS, LDWF), and the Mississippi River Delta (LSU) (Figure 1).

Invasive carp were captured during late spring, summer, and fall of 2021. Several capture techniques were employed including electroshocking, gill nets, and a combination of both. The combination of methods included the employment of electroshocking boats using both sounds generated from motors and electrical current to push carp against a structure or bank in semi-enclosed canals and bayous near main waterways. Gill nets, used as block nets, were deployed at the mouth or escape points of canals and bayous to capture fish. Opportunistically, fish were also captured using large dip nets by crew aboard the electroshocking vessel.

Captured carp were immediately transferred to a tagging cradle lined with a wet towel and ambient water was passed over the gills with a small bilge pump and hose. The fish was visually inspected to determine species, based on morphology according to the US Fish and Wildlife

Carp Identification Guide, and ensure it was in good condition and not previously tagged. Fork length (mm) was measured and recorded. Vemco V16 acoustic transmitters (Vemco, Halifax, Nova Scotia) were disinfected with an iodine solution and surgically implanted into the coelomic cavity via a 2 to 4 cm incision on the ventral side of the fish. The incision was closed with 1 -2 simple interrupted sutures (Braided Absorbable Suture, Size 3-0) and fish were released back into the water.

Results and Discussion:
Transmitters were deployed at several locations within the central region associated with the Atchafalaya River basin (n = 66), the western region (n = 20), and the eastern region associated with the Davis Pond Diversionary Canal of the Mississippi River (n = 21), which flows toward Barataria Bay. A total of 107 acoustically tagged carp (n=102 Silver, n=3 Bighead, n=2 Grass) were captured and released in the study area (Figure 1). Individuals were relatively large for all three species with a mean size of nearly a meter in length observed for each: Silver (859 ± 7.6 mm FL; mean ± SE), Grass (908 ± 3.0 mm FL), and Bighead Carp (1144 ± 48.9 mm FL) (Table1). As of December 2021, nearly 16,000 detections were recorded across the receiver array from nine unique carp (n=8 Silver, 14,539 detections and n=1 Bighead, 1,397 detections). The maximum distance traveled by both silver and bignhead carp was 16 km, while the mean distance traveled by silver carp was 8.3 km.

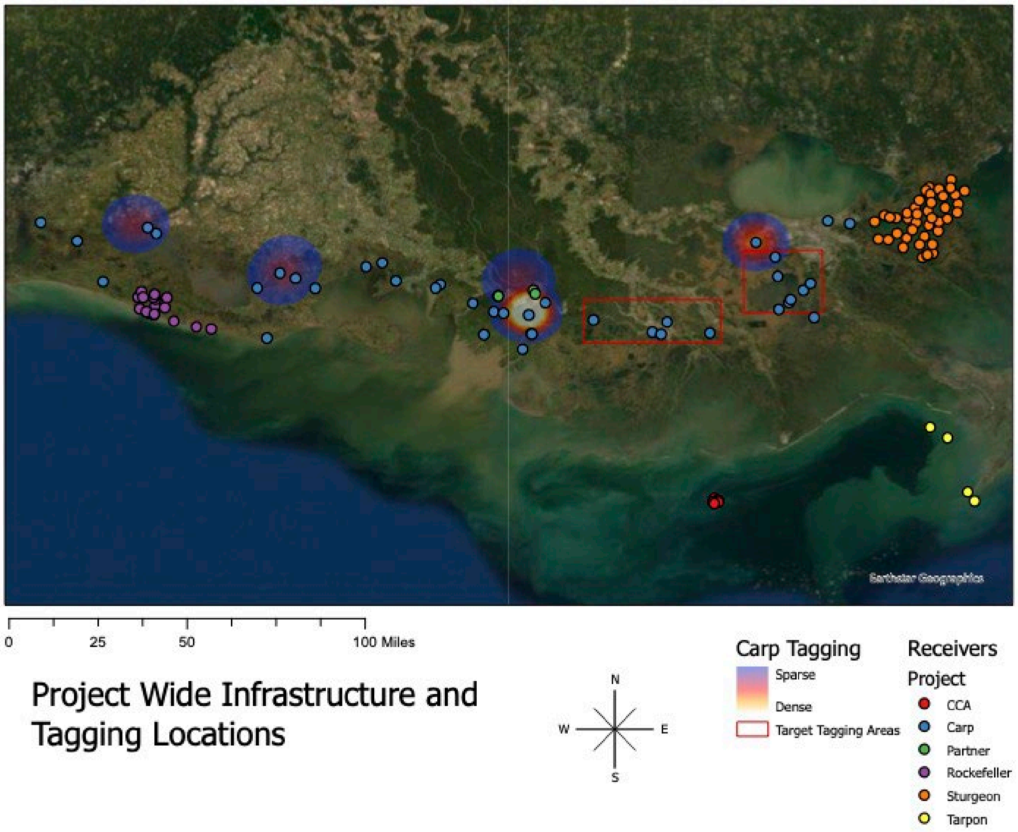

Figure 1. Map depicting location of receiver arrays in southern Louisiana used to monitor movement patterns of invasive carp. Relative spatial distribution of tagging effort is shown by heat map – whites and reds indicate a larger number of fish were tagged in this area. Blue dots represent receivers deployed for this project, while partner arrays are depicted by dots of various other colors. Red boxes indicate areas of high tagging priority for 2022.

Table 1. Summary data for Silver, Bighead, and Grass Carp tagged in the lower Mississippi River basin in southern Louisiana in 2021. Data incudes the number of individuals tagged (# Tagged), the mean fork (mm) length ± standard error for tagged individuals, the total number of detections (Detections), the number of individual fish detected (# Detected), the maximum distance traveled (km) by an individual to date (Max Dist), and the mean distance traveled (km) across all individuals (Mean Dist).

Species	# Tagged	Mean FL (mm)	Detections	# Detected	Max Dist	Mean Dist
Silver	102	859 ± 7.6	14,539	8	16	8.3
Bighead	2	1144 ± 48.9	1,397	1	16	16
Grass	3	908 ± 3.0	0	0	NA	NA

The combined use of electroshocking and gill/entanglement nets proved the most effective collection technique. Low water periods, when individuals could easily captured in backwater areas, were the most effective condition to capture carp. River levels were high into the summer of 2021, and thus the majority of transmitters were deployed during the fall when water levels were low.

Other transmitters detected on our receiver array in southern Louisiana include a Grass Carp from the northern Mississippi River basin (Iowa), a Bull Shark, American Eels, and Red Drum. Additional orphan tags were detected, but have not yet been identified.

For this reporting period, the number of detections of unique tagged carp is low. One possible explanation is that most fish were tagged in late fall and were not at large for a significant duration of this reporting period. We anticipate a greater number of unique fish will be detected at our next download in the winter of 2022 as river levels come up and fish move out into the main channels where the bulk of the receivers are located.

Recommendations:

Additional tagging efforts for 2022 will be focused on eastern regions that were impacted by Hurricane Ida in 2021, and thus resulted in reduced tagging effort. Additional transmitters will also be deployed in the western region and the Atchafalaya during 2022. Routine checking and maintenance of receivers will continue throughout 2022.

Lead Agency: Arkansas Game and Fish Commission (AGFC), Jimmy Barnett (Jimmy.Barnett@agfc.ar.gov)

Participating Agencies: University of Arkansas at Pine Bluff (UAPB), Steve Lochmann (lochmanns@uapb.edu)

Methods:

Population Assessment
In 2021, the lower Arkansas River, the lower White River, and Morgan Point Oxbow were sampled using daytime, boat-mounted electrofishing. Morgan Point Oxbow seasonally connects to the free-flowing section of the Arkansas River below Wilber D. Mills Dam. It is cut off from the Arkansas River via an embankment adjacent to Wilber D. Mills Dam. Approximately 182 Silver Carp and 2 Bighead Carp were collected in the lower Arkansas River. About 263 Silver Carp and 1 Bighead Carp were collected in the lower White River. One hundred forty-seven Silver Carp were collected from Morgan Point Oxbow. Each individual was measured for total length (mm) and weighted (kg). Sex was determined for each individual and lapilli otoliths and pectoral spines were removed. Age estimation has not yet occurred. Sampling events began in July 2021 and are ongoing.

Determination of Stock Origins Using Microchemistry
We assessed differences in Sr and Ba microchemical signatures among river systems using lapilli otoliths from 334 fish collected throughout the LMRB – namely from the Cache, Arkansas, White, Yazoo, St. Francis, L'Anguille, and Mississippi rivers.

Movement Assessment
Three Vemco VR2 acoustic receivers were deployed in the lower Arkansas River. One is near the Trulock Public Use area, another is at Pendleton Bend, and a third is below the Wilbur D. Mills Dam on the unregulated portion of the Arkansas River (Table 1). These receivers were deployed to determine movement within the lower Arkansas River. Four acoustic receivers were deployed in the lower White River. One is near De Valls Bluff, another is near St. Charles, a third is near Jack's Bay, and a final receiver is below Norrel Dam and the confluence of the Arkansas Post Canal and the White River (Table 2). These receivers were placed to monitor movement in the lower White River.

Table 1. Vemco Receivers in the lower Arkansas River			
Locations	**Lat**	**Long**	**# Carp Detections**
Trulock	34.17075 N	-91.75176 W	41
Pendleton	33.98137 N	-91.38294 W	**
Wilbur D. Mills	33.97765 N	-91.29957 W	1

** detection number unknown, receiver stuck on bottom

Table 2. Vemco Receivers in the lower White River			
Locations	**Lat**	**Long**	**# Carp Detections**
De Valls Bluff	34.78388	-91.43361	20
St. Charles	34.37928	-91.12705	3
Jack's Bay	34.0934	-91.16652	10
Norrel	34.01915	-91.18412	4

Results and Discussion:

Population Assessment
Preliminary analysis of lengths and weights from the Arkansas, White, and Morgan Point populations suggest similar size distributions (Table 3). Mean lengths of Silver Carp ranged from 735 mm to 925 mm. Mean weights ranged from 4029 g to 8805 g, with the Morgan Point population somewhat lighter than the other two.

Table 3. Lengths and Weights of Silver Carp and Bighead Carp			
System	**Species**	**Mean (SD) Length in mm**	**Mean (SD) Weight in grams**
White River	Silver	818 (51)	6460 (1437)
	Bighead	998 (N/A)	11800 (N/A)
Arkansas River	Silver	925 (106)	8805 (2040)
	Bighead	1257 (45)	20750 (550)
Morgan Point	Silver	735 (67)	4029(1227)

Determination of Stock Origins Using Microchemistry
The Sr and Ba water microchemical signatures differed among the river systems, with consistent differences detected in Sr among the Mississippi, Arkansas, and White rivers. Lapilli otolith and water microchemical signatures were linearly related. A classification and regression tree was used to assess the degree to which individuals could be assigned to the river where an individual fish was sampled. The greatest accuracy when assigning an individual back to the river from where it was sampled occurred when the three largest rivers were modeled (68%). This classification regression tree model was then used to predict early life-stage origin with

microchemical signatures sampled from spot ablations at the otolith core. The model predicted origins of Silver Carp from each river system with the greatest contribution from the Arkansas River system (56%). Limited evidence exists regarding young-of-year Silver Carp abundance, recruitment, and habitat use within the Arkansas River. Classification accuracy diminished as smaller rivers were incorporated into the model. The use of Sr and Ba can discriminate among the Arkansas, White, and Mississippi rivers but limits of their utility exist as additional smaller river systems are incorporated.

Movement Assessment

About 30 Silver Carp have been implanted with acoustic transmitters in the lower Arkansas River. Thirty-nine Silver Carp have been implanted with acoustic transmitters in the lower White River. A total of 42 transmitter receptions have occurred in lower Arkansas River. The majority of those are near Trulock, where most of the implantations occurred. A total of 37 transmitter receptions have occurred in the lower White River.

The project has also examined short-term (hours to days) movement of Silver Carp in the lower White and lower Arkansas river. Five fish were implanted with radio transmitters in each system. Fish were implanted and released near De Valls Bluff on the lower White River. Fish were implanted and released near Pine Bluff in the lower Arkansas River. Mobile tracking was conducted every four hours during three separate 24-h periods following implantation in each system. A total of 48 re-locations occurred for the five fish in the White River. A total of 39 relocations occurred for the five fish in the Arkansas River. Short-term monitoring of movements with radio telemetry and mobile tracking will continue seasonally.

Recommendations:

Continue monitoring, particularly to determine effectiveness of Arkansas River locks and dams as a deterrent to movement.

Lead Agency: Mississippi Department of Wildlife, Fisheries, and Parks (MDWFP), Dennis Riecke (Dennis.Riecke@wfp.ms.gov)

Participating Agency: Mississippi State University (MSU)

Methods:

Geographic Location
Moon Lake is an oxbow lake located outside the Mississippi River levee in the northwestern part of Mississippi (Figure 1). The lake is approximately 12 km long, 0.75 km wide, 8.9 km^2 in area, surrounded by a 166 km^2 catchment, and has a maximum depth of 10 m. Land use on the watershed is predominantly agriculture. The lake discharges into Yazoo Pass, a 22-km waterway constructed in 1863 by connecting and channelizing existing streams. Yazoo Pass joins Moon Lake with the Coldwater River which discharges into the Tallahatchie River and eventually the Yazoo River. The Yazoo River flows into the Mississippi River. Phillips Bayou connects to Moon Lake in the northern part of the lake, particularly in high precipitation months, but this bayou connects to various wetlands without direct access to a river, except perhaps during high precipitation events.

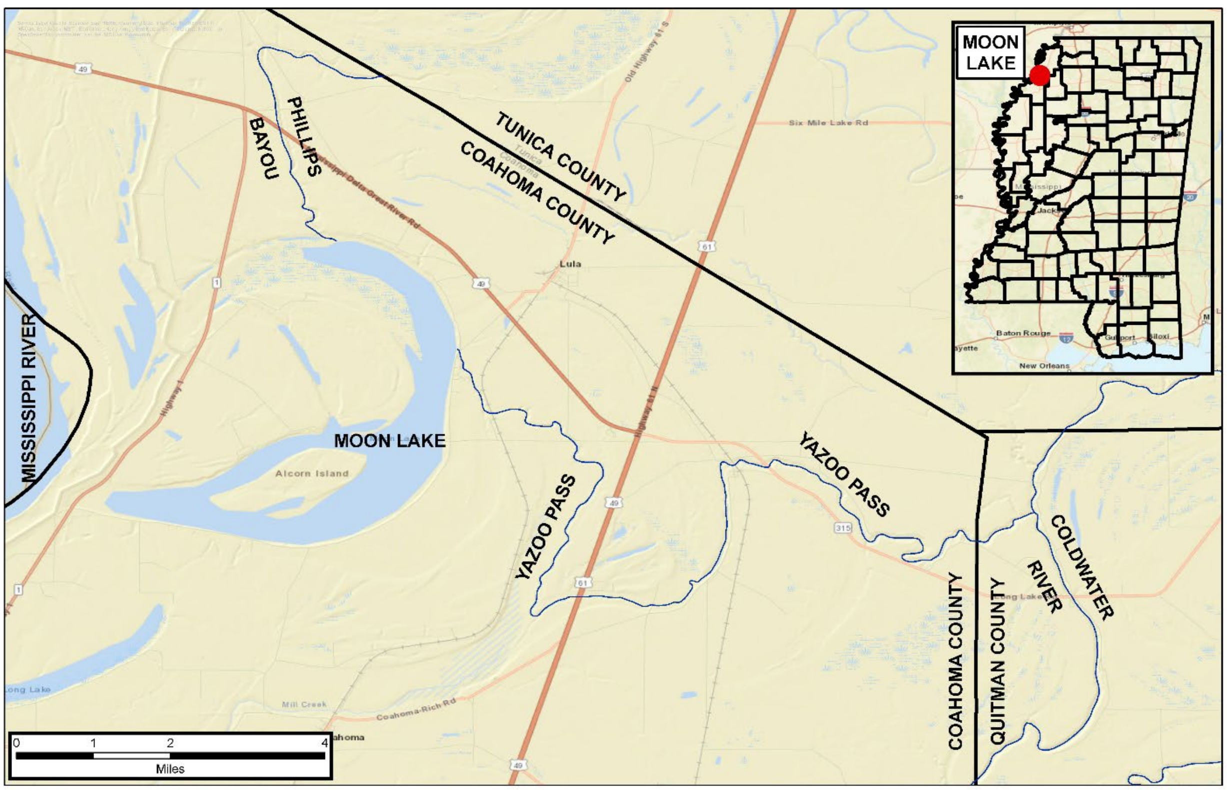

Figure 1. Study area map showing the locations of Moon Lake, the Yazoo Pass and the Coldwater River in northwest Mississippi.

Timeline

An overview of planned project activities and progress on those activities from September 2020-August 2022 is provided in Table 1.

Table 1. Project activities, planned time periods for accomplishment, and current activity status.

Activity	Time Period (Season, month/year)	Current Status
Complete IACUC protocol, select MS student, conduct recognizance of study area, contact USGS about installing a water stage station in Yazoo Pass, contact commercial fishers about fish collections, install receivers, implant tags in fish, begin mobile tracking	Sep-Dec 2020	Completed, equipment received from USFWS January 2021
Continue to implant tags in fish, continue mobile tracking, monitor receivers, monitor water level and discharge sensors	Jan-Apr 2021	Completed January 2021
Continue to implant tags in fish (if needed), continue mobile tracking, monitor receivers, monitor water level and discharge, prepare annual report	May-Aug 2021	Completed February – March 2021
Continue mobile tracking, monitor receivers, monitor water level and discharge, through GIS begin developing a classification of the types of discharge canals existing in major oxbow lakes of the MAV	Sep-Dec 2022	Ongoing throughout 2 year period, every 8-12 weeks
Continue mobile tracking, monitor receivers, monitor water level and discharge, complete classification of the types of discharge canals existing in major oxbow lakes of the MAV	Jan-Apr 2022	Tracking and Monitoring Planned
Continue mobile tracking, monitor receivers, monitor water level and discharge sensors, develop models relating hydrodynamics, temperature, and weather-related variables to carp movement, prepare final report	May-Aug 2022	Tracking and Monitoring Planned

Currently, most of the proposed activities listed in Table 1, column 1 have been accomplished or are in progress of being accomplished.

Study Area and Spatial Unit Creation

The focus of this observational study was Moon Lake. The oxbow lake has extensive hydrologic connection to the surrounding landscape when flooded above its levees. However, when the landscape is not flooded, entries and exits are limited for Silver Carp into Moon Lake. We identified Phillips Bayou and Yazoo Pass as perennial hydrologic connections to Moon Lake and created the spatial frame for this study around these waterways (Figure 2

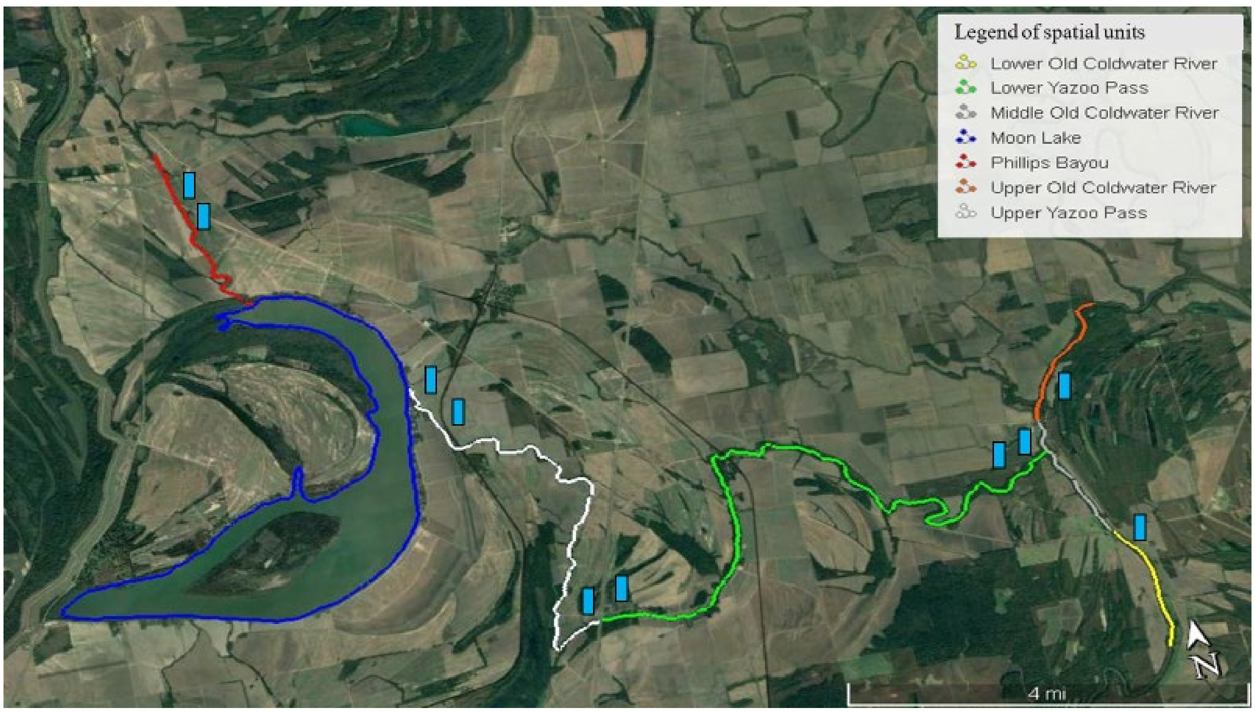

Figure 2. The study area for Moon Lake, Mississippi illustrating the spatial units, approximate acoustic receiver locations, and the bodies of water that each spatial unit represents. The light blue rectangles are the approximate receiver locations while the colored lines show either the outline or path of each water body used to create the spatial units for this study.

Seven spatial units were created within the study are to evaluate the timing and locations of tagged Silver Carp movements. Lengths of the spatial units were based on estimates of movement from previous literature. Distances traveled by invasive carp in a field setting varied from 4-6 km over a 24-hour period (Coulter et al. 2016). Lab estimates of speed for adult Silver Carp include 5.4 km/h, but speeds were held for 10 minutes before fatigue was visible (Hoover et al. 2017). The size of spatial units was approximately double the lengths of lab and field movement estimates when creating spatial units in the Yazoo Pass to account for uncertainty of how fast these Silver Carp travel when going with or against current (Table 2). The Middle Old Coldwater Spatial Unit was smaller in length than lab and field estimates to determine if fish were staying within 2 km of the confluence of Yazoo Pass and the Old Coldwater River. Spatial units were also created on boundaries of waterbodies including Moon Lake, Phillips Bayou, Yazoo Pass, and the Old Coldwater River to evaluate movement and potentially inform placement of a barrier for management of Silver Carp movement (Figure 2). Yazoo Pass and the Old Coldwater River were broken into multiple spatial units to gather more information on the movement patterns and timing of movement in these water bodies.

Table 2. The lengths and areas of spatial units. UCW = Upper Coldwater River unit; MCW = Middle Coldwater River unit; LCW = Lower Coldwater River unit; LYP = Lower Yazoo Pass unit; UYP = Upper Yazoo Pass unit; ML = Moon Lake unit; and PB=Phillips Bayou unit; km = kilometers; ha = hectares.

Spatial units	Lengths or area of spatial units
UCW	2.84 km
MCW	2.59 km
LCW	2.55 km
LYP	13.62 km
UYP	9.18 km
ML	931 ha
PB	4.15 km

Silver Carp Capture and Transmitter Implantation

Eighty-two Silver Carp were collected and tagged between January 8, 2021, and February 26, 2021. Two additional Silver Carp were collected and placed into Moon Lake May 31, 2021. We caught eight Silver Carp in 91-m long by 3-m deep experimental gill nets with mesh size transitioning from 76 mm, 101 mm, and 127 mm every 30-m of the net on January 8, 2021. Nets were placed perpendicular to the shoreline in waters ranging from 3.5-5.5m. Seventy-six Silver Carp were caught in Moon Lake by a commercial Silver Carp fisherman using 304.8 m gill nets with a mesh size of 106.7 mm on January 17, 2021. Capturing Silver Carp in Yazoo Pass and the

Old Coldwater River was not feasible with the available personnel, boats, and funding. Therefore we translocated captured Silver Carp from Moon Lake across the spatial frame of the study area.

Silver Carp were inspected before tag implantation for any physical impairments, cuts, lesions, abscesses, or other openings that could infect, hinder, or alter survivability post release. Captured Silver Carp were placed into a 25-gallon tote filled with water and immobilized chemically with a Tricaine dosage ranging from 15-200 mg/L of water (FAU IACUC 2018). The amount of Tricaine used depended on the size of the Silver Carp as well as individual responses. If a Silver Carp was large and more active in the drugged water, we then applied more Tricaine in increments of 10 mg/L. Once immobilized, lengths were measured along with the sex which was determined by feeling the first ridges along the pectoral fin (Wolf et al. 2018). The Silver Carp was placed dorsal side down into rayon gurney while a hose was placed into its mouth to circulate water over their gills during the surgery. We removed scales from a 3-5 cm section of the Silver Carp and used a scalpel to make a 3 cm incision parallel to the lateral line, between the pelvic and anal fin in the lower abdomen (Coulter et al. 2013). A sterile acoustic tag (VEMCO V16 4X, Innovasea) was inserted into the incised cavity. Tags, scissors, forceps, suture, and scalpel were placed into a 70% ethanol solution before surgery on each Silver Carp to reduce the chance of infection. A synthetic suture (Ethicon size 0 or 2) was used to close the incision with a simple interrupted suture. Tagged Silver Carp were placed into a net pen to recover after surgery. Silver Carp were monitored post release in the net pen and after translocation to evaluate motor control or if they demonstrated any form of impairment or distress. Three Silver Carp had acoustic tags removed from them based on behavior before and during release. Those Silver Carp were given back to the commercial fisherman while the tags were placed into new Silver Carp that did not display any distress or impairment. Thirty-five tagged Silver Carps were returned to Moon Lake and the remaining 49 Silver Carp were distributed among the spatial units in the study.

Silver Carp Translocation to Spatial Units

Fully recovered tagged Silver Carp were placed into a covered 100-gallon cattle tank with four aerators attached for translocation. Silver Carp have been documented to have both mobile and sedentary individuals (Pretchel et al. 2018) so we moved Silver Carp into Yazoo Pass and the Old Coldwater River to observe if they would move into or away from Moon Lake, and the times and environmental conditions that movement occurred. Silver Carp were translocated in six of seven spatial units in the study area (Table 3). Phillips Bayou was not used for translocation because due to low water level. Release locations were selected near roads for quick transfer of Silver Carp from the tank to the spatial unit. We tried to ensure that the Silver Carp that had been sitting in the pens the least would have the longest travel time to maximize survival among translocated Silver Carp.

Table 3. Locations and the number of fish translocated into the spatial unit. UCW = Upper Coldwater River unit; MCW = Middle Coldwater River unit; LCW = Lower Coldwater River unit; LYP = Lower Yazoo Pass unit; UYP = Upper Yazoo Pass unit; ML = Moon Lake unit; and PB=Phillips Bayou unit

Spatial Unit	Lat	Long	# translocated
UCW	34.418221°	-90.386664°	7
MCW	34.408051°	-90.387939°	8
LCW	34.389318°	-90.378887°	7
LYP	34.416973°	-90.438282°	20
UYP	34.423618°	-90.477309°	7
ML	34.420301°	-90.533592°	35
PB	34.479633°	-90.529302°	0

Receiver Placements

Ten stationary acoustic receivers (69 kHz VR2Tx; VEMCO, Halifax, NS, Canada) were placed into the defined spatial network of the study area. Receivers were positioned at the boundaries of spatial units to act as gates with one receiver at the end and the beginning of the next spatial unit (Figure 1). Receivers were positioned to determine movement direction and timing of movements. Receivers were attached to a flat-bottomed rectangle concrete anchor with one or two metal garden stakes protruding towards the water surface to attach the receivers to (Figure 3). Pairs of acoustic receivers were placed with physical barriers between them, or at large distances to ensure that a tag was not recorded on both receivers and to maximize location certainty. Receivers were maintained to ensure proper operation and the data were downloaded every 6-8 weeks.

Figure 3. A VR2Tx acoustic receiver attached to the concrete anchor and float lines and used to passively record movements of acoustically tagged Silver Carp *Hypophthalmichthys molitrix* that pass the receiver.

Evaluating Movement Among Spatial Units With a Multistate Model

Using the R package "markovchain", we calculated the probability of a Silver Carp to move from spatial unit to spatial unit at any given time of the study. An observation history was compiled for every hour for the location of all observed Silver Carp. The observation history was then modeled using a discrete-time Markov chain to create a transition matrix that provided the probability of movement between the spatial units. The model predicts movement as the probability a Silver Carp will remain in the same spatial unit or move to an adjacent unit. In this analysis, movement among units depends on the current location of the Silver Carp.

Results:

Tagged Silver Carp (n=84) lengths ranged from 737 to 925 mm with an average total length of 835 mm (Standard Deviation = 38.1). Thirty-eight female and 46 male Silver Carp were tagged. We collected over 850,000 observations of tagged Silver Carp from mid-January 2021 to late November 2021. Tagged Silver Carp had an average of 12,822 observations (Standard Deviation = 29,639). Receivers had an average of 64,109 observations (Standard Deviation = 95,949). Deceased Silver Carp or Silver Carp suspected of being deceased were removed from the analysis. All movement among spatial units occurred in the spring and early summer, from late March to the middle of June. Of the tagged Silver Carp that moved during this time, five of six made multiple trips to and from Moon Lake to the Old Coldwater River. One Silver Carp moved from the Upper Yazoo Pass to the Old Coldwater, then to Moon Lake, and back to the Upper Yazoo Pass. Three of the six Silver Carp returned to Moon Lake while others stayed in Yazoo Pass and the Old Coldwater River. Eighty-three percent of tagged Silver Carp remained in the same spatial unit over the study period. All Silver Carp that moved used Yazoo Pass to travel to and from the Old Coldwater River.

The results of the discrete-time Markov chain model indicate that Silver Carp are very likely to stay within their spatial unit over time (Table 4). The majority of tagged Silver Carp are also more likely to move to a spatial unit adjacent to their current unit rather than a unit that is not adjacent to their current position. We did not include Phillips Bayou in the analysis because no Silver Carp were observed moving into it. All Silver Carp that were placed into the Upper Old Coldwater River stayed in that unit and have not entered Yazoo Pass.

Table 4: Estimated transition probabilities for a Silver Carp *Hypophthalmichthys molitrix* to move (or stay in) from one spatial unit to another. The acronyms for the spatial units are the Lower Old Coldwater River (LCW), Middle Old Coldwater River (MCW), Upper Old Coldwater River (UCW), Lower Yazoo Pass (LYP), Upper Yazoo Pass (UYP), and Moon Lake (ML). The diagonal line in dark grey shows the probability of a Silver Carp remaining in the same unit.

	LCW	MCW	UCW	LYP	UYP	ML
LCW	0.999888	0.000096	0.00	0.000016	0.00	0.00
MCW	0.001002	0.997328	0.00	0.001670	0.00	0.00
UCW	0.00	0.00	1.00	0.00	0.00	0.00
LYP	0.000013	0.000050	0.00	0.999823	0.000114	0.00
UYP	0.00	0.00	0.00	0.000231	0.999308	0.000461
ML	0.00	0.00	0.00	0.00	0.000154	0.999846

Deviation from Planned Project Activities

Activities in Table 1 dealing with GIS classification of the types of discharge canals existing in major oxbow lakes of the Mississippi Alluvial Valley were not pursued and therefore not accomplished because another project using invasive carp US Fish and Wildlife funding was approved to accomplish this in federal fiscal year 2022.

Discussion:

Silver carp movement was limited with most tagged individuals remaining in the same spatial unit and a minority of tagged individuals engaging in movement among spatial units during the spring and early summer. Analysis of movement observations suggests that a barrier in Yazoo Pass may be an effective management action to minimize intrusion into Moon Lake. A sound barrier may be optimal as it would not affect the Paddlefish that spawn during the same time as we observed Silver Carp movement. Silver Carp are sensitive to sound frequencies between 750 Hz and 1500 Hz (Lovell et al. 2006). Since we observed Silver Carp only moving during the spring and early summer, barrier operations may be optimized at certain times of the year to minimize risk of Silver Carp entering Moon Lake by movements through Yazoo Pass. An important uncertainty remains for the role that juvenile Silver Carp movements pose a risk to migrations into Moon Lake.

Recommendations:

Further analyses should focus on relating movement to environmental covariates like temperature and stage.

Lead Agency: Missouri Department of Conservation (MDC), Josh Abner (Joshua.Abner@mdc.mo.gov)

Methods:
During the summer and fall months of 2021, 100 invasive carp were collected from the Lower Mississippi River (LMR) using boat electrofishing for the purpose of transmitter implantation. In addition to having an acoustic transmitter (V16-6H: 30-60s random delay; 1,460 days estimated life) surgically implanted, each fish was measured, weighed, sexed, and externally tagged using a T-bar floy tag. Capture location data as well as water quality data were also recorded. During that same time, eight stationary VR2Tx telemetry receivers were deployed over a 100 mile stretch along the LMR (Table 1).

Results and Discussion:
Lengths of silver carp captured from the LMR ranged between 590mm and 845mm, with an average length of 676mm (Table 2). Weights ranged from 1920 g to 6440 g, with an average weight of 3114 g. The LMR produced 1.63 male silver carp for every female silver carp. All data, including fish specific information, can be found in Table 3.

Figure 1. Map showing the specific locations (and river mile) of the eight VR2Tx telemetry receivers deployed in the Lower Mississippi River (LMR).

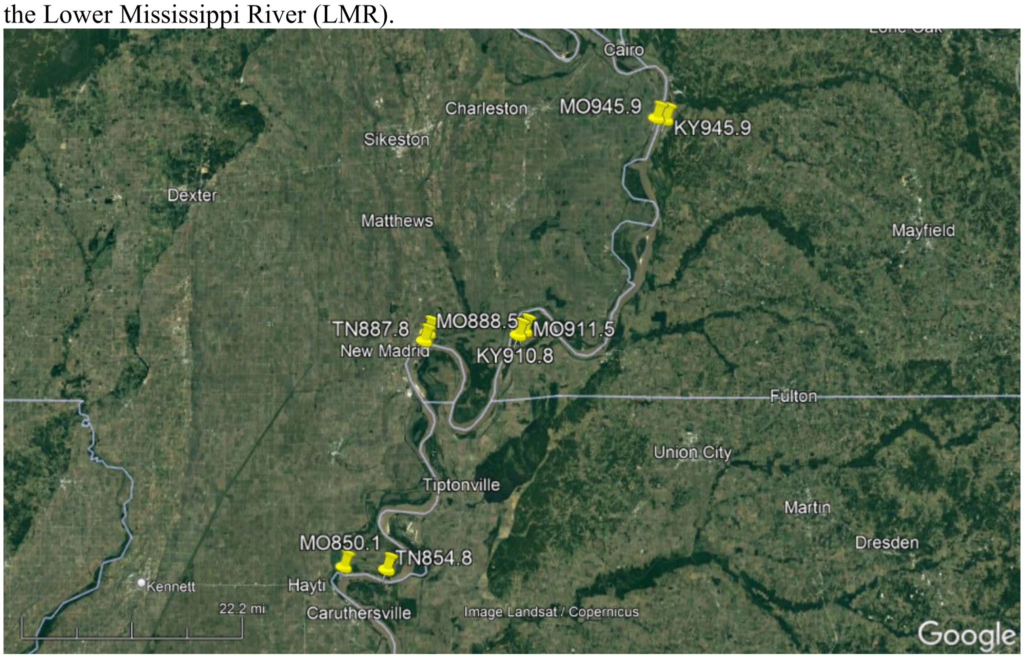

Table 1. Data related to the VR2Tx telemetry receivers in the Lower Mississippi River (LMR). Location name describes which side of the river and the river mile.

Location	Date	Latitude	Longitude
MO945.9	9/28/2021	36.88683	-89.12624
KY945.9	9/28/2021	36.88462	-89.10996
MO888.5	10/19/2021	36.57801	-89.53971

Location	Date	Latitude	Longitude
TN887.8	10/19/2021	36.56667	-89.54613
MO911.5	10/19/2021	36.58070	-89.36579
KY910.8	10/19/2021	36.57471	-89.37703
MO850.1	12/1/2021	36.24024	-89.69077
TN854.8	12/1/2021	36.23657	-89.61401

Table 2. Number of invasive carp, length range (mm), mean length (mm), weight range (g), mean weight (g), and sex ratio for the Lower Mississippi River (LMR).

LMR	Species	#	Length Range	Mean Length	Weight Range	Mean Weight	M:F Ratio
	Silver	100	590-845	676	1920-6440	3114	1.63

Table 3. Data relating to invasive carp captured in the Lower Mississippi River (LMR). All carp captured were silver carp; note length, sex, weight, transmitter, and floy data are fish specific.

Date	River Mile	Latitude	Longitude	Length	Sex	Weight	Transmitter	Floy
9/8/2021	950	36.94476	-89.09431	669	M	2620	52027	ORFS44301
9/8/2021	950	36.94476	-89.09431	645	M	3020	52028	ORFS44302
9/8/2021	950	36.94476	-89.09431	650	M	2540	52029	ORFS44303
9/8/2021	950	36.94476	-89.09431	631	M	2620	52030	ORFS44304
9/8/2021	950	36.94476	-89.09431	630	M	2860	52031	ORFS44305
9/8/2021	950	36.94476	-89.09431	615	M	2160	52032	ORFS44307
9/8/2021	950	36.94476	-89.09431	660	M	2940	52033	ORFS44308
9/8/2021	950	36.94476	-89.09431	667	F	2720	52034	ORFS44309
9/8/2021	950	36.94476	-89.09431	740	F	3760	52035	ORFS44310
9/8/2021	950	36.94476	-89.09431	638	M	2580	52036	ORFS44311
9/8/2021	950	36.94476	-89.09431	650	M	2800	52037	ORFS44312
9/8/2021	950	36.94476	-89.09431	723	F	3340	52038	ORFS44313
9/8/2021	950	36.94476	-89.09431	651	F	2640	52039	ORFS44314
9/8/2021	950	36.94476	-89.09431	654	M	2660	52040	ORFS44315

Date	River Mile	Latitude	Longitude	Length	Sex	Weight	Transmitter	Floy
9/8/2021	950	36.94476	-89.09431	670	F	2940	52041	ORFS44316
9/8/2021	950	36.94476	-89.09431	691	M	3240	52042	ORFS44317
9/8/2021	950	36.94476	-89.09431	658	M	2780	52043	ORFS44318
9/8/2021	950	36.94476	-89.09431	620	M	2240	52044	ORFS44319
9/8/2021	950	36.94476	-89.09431	626	F	2560	52045	ORFS44320
9/8/2021	950	36.94476	-89.09431	796	F	3980	52046	ORFS44321
9/8/2021	950	36.94476	-89.09431	611	M	2180	52047	ORFS44322
9/8/2021	950	36.94476	-89.09431	672	M	2840	52048	ORFS44323
9/8/2021	950	36.94476	-89.09431	626	M	2460	52049	ORFS44324
9/8/2021	950	36.94476	-89.09431	699	M	3360	52050	ORFS44325
9/8/2021	950	36.94476	-89.09431	640	M	2520	52051	ORFS44326
9/8/2021	950	36.94476	-89.09431	595	M	2200	52052	ORFS44327
9/8/2021	950	36.94476	-89.09431	659	M	2760	52053	ORFS44328
9/8/2021	950	36.94476	-89.09431	615	M	2420	52054	ORFS44329
9/8/2021	950	36.94476	-89.09431	634	M	2640	52055	ORFS44330
9/9/2021	918	36.61080	-89.31168	651	M	3240	52056	ORFS44331
9/9/2021	918	36.61080	-89.31168	775	F	4940	52057	ORFS44332
9/9/2021	918	36.61080	-89.31168	653	M	2720	52058	ORFS44333
9/9/2021	918	36.61080	-89.31168	745	F	5200	52059	ORFS44334
9/9/2021	918	36.61080	-89.31168	690	F	3440	52060	ORFS44335
9/9/2021	918	36.61080	-89.31168	645	M	3200	52061	ORFS44336
9/9/2021	918	36.61080	-89.31168	673	M	3220	52062	ORFS44337
9/9/2021	918	36.61080	-89.31168	749	F	4300	52063	ORFS44338
9/9/2021	918	36.61080	-89.31168	672	F	2900	52064	ORFS44339
9/9/2021	918	36.61080	-89.31168	673	M	3760	52065	ORFS44345

Date	River Mile	Latitude	Longitude	Length	Sex	Weight	Transmitter	Floy
9/9/2021	918	36.61080	-89.31168	660	F	3080	52066	ORFS44344
9/9/2021	918	36.61080	-89.31168	676	F	3120	52067	ORFS44342
9/9/2021	918	36.61080	-89.31168	695	F	3100	52068	ORFS44343
9/9/2021	918	36.61080	-89.31168	707	M	3600	52069	ORFS44346
9/9/2021	918	36.61080	-89.31168	718	M	3880	52070	ORFS44347
9/9/2021	918	36.61080	-89.31168	695	M	3320	52071	ORFS44348
9/9/2021	918	36.61080	-89.31168	698	M	3700	52072	ORFS44349
9/9/2021	918	36.61080	-89.31168	711	M	4000	52073	ORFS44350
9/9/2021	918	36.61080	-89.31168	676	M	3400	52074	ORFS44113
9/9/2021	918	36.61080	-89.31168	775	F	4140	52075	ORFS44114
9/9/2021	918	36.61080	-89.31168	690	M	3860	52076	ORFS44115
9/9/2021	918	36.61080	-89.31168	730	M	3860	52077	ORFS44116
9/9/2021	918	36.61080	-89.31168	712	F	3420	52078	ORFS44117
9/9/2021	918	36.61080	-89.31168	685	M	3400	52079	ORFS44118
9/9/2021	918	36.61080	-89.31168	845	M	6440	52080	ORFS44119
9/9/2021	918	36.61080	-89.31168	667	M	3040	52081	ORFS44120
9/9/2021	918	36.61080	-89.31168	657	F	2840	52082	ORFS44121
9/13/2021	850	36.24421	-89.70262	678	F	2860	52083	ORFS44122
9/13/2021	850	36.24421	-89.70262	730	M	3480	52084	ORFS44123
9/13/2021	850	36.24421	-89.70262	685	M	3100	52085	ORFS44124
9/13/2021	850	36.24421	-89.70262	646	M	2680	52086	ORFS44125
9/13/2021	850	36.24421	-89.70262	650	F	2440	52087	ORFS44401
9/13/2021	850	36.24421	-89.70262	796	M	3201	52088	ORFS44402
9/13/2021	850	36.24421	-89.70262	648	F	2740	52089	ORFS44403
9/13/2021	850	36.24421	-89.70262	721	F	3340	52090	ORFS44404

Date	River Mile	Latitude	Longitude	Length	Sex	Weight	Transmitter	Floy
9/13/2021	850	36.24421	-89.70262	701	F	3240	52091	ORFS44405
9/13/2021	850	36.24421	-89.70262	730	F	4440	52092	ORFS44406
9/13/2021	850	36.24421	-89.70262	658	M	2980	52093	ORFS44407
9/13/2021	850	36.24421	-89.70262	636	M	2500	52094	ORFS44408
9/13/2021	850	36.24421	-89.70262	710	M	3780	52095	ORFS44409
9/13/2021	850	36.24421	-89.70262	746	F	4380	52096	ORFS44410
9/13/2021	850	36.24421	-89.70262	748	F	4600	52097	ORFS44411
9/13/2021	850	36.24421	-89.70262	692	F	3380	52098	ORFS44412
9/13/2021	850	36.24421	-89.70262	691	M	3360	52099	ORFS44413
9/13/2021	850	36.24421	-89.70262	692	F	3060	52100	ORFS44414
9/13/2021	850	36.24421	-89.70262	665	M	2620	52101	ORFS44415
9/13/2021	850	36.24421	-89.70262	700	F	2940	52102	ORFS44416
9/13/2021	850	36.24421	-89.70262	648	M	2640	52103	ORFS44417
9/13/2021	850	36.24421	-89.70262	695	M	3580	52104	ORFS44418
9/13/2021	850	36.24421	-89.70262	650	M	3040	52105	ORFS44419
9/13/2021	850	36.24421	-89.70262	650	M	2860	52106	ORFS44420
9/13/2021	850	36.24421	-89.70262	698	F	3840	52107	ORFS44421
9/13/2021	850	36.24421	-89.70262	710	M	3780	52108	ORFS44422
9/28/2021	950	36.94477	-89.09436	716	F	3040	52109	ORFS44423
9/28/2021	950	36.94477	-89.09436	620	M	2400	52110	ORFS44424
9/28/2021	950	36.94477	-89.09436	651	F	2740	52111	ORFS44425
9/28/2021	950	36.94477	-89.09436	661	F	2440	52112	ORFS44426
9/28/2021	950	36.94477	-89.09436	646	M	2480	52113	ORFS44427
9/28/2021	950	36.94477	-89.09436	606	M	1920	52114	ORFS44428
9/28/2021	950	36.94477	-89.09436	637	M	2580	52115	ORFS44429

Date	River Mile	Latitude	Longitude	Length	Sex	Weight	Transmitter	Floy
9/28/2021	950	36.94477	-89.09436	670	M	2580	52116	ORFS44430
9/28/2021	950	36.94477	-89.09436	634	F	2660	52117	ORFS44431
9/28/2021	950	36.94477	-89.09436	614	M	2100	52118	ORFS44432
9/28/2021	950	36.94477	-89.09436	590	F	1920	52119	ORFS44433
9/28/2021	950	36.94477	-89.09436	694	M	3300	52120	ORFS44434
9/28/2021	950	36.94477	-89.09436	656	F	3040	52121	ORFS44435
9/28/2021	950	36.94477	-89.09436	598	M	2160	52122	ORFS44436
9/28/2021	950	36.94477	-89.09436	761	F	4220	52123	ORFS44437
9/28/2021	950	36.94477	-89.09436	618	F	2160	52124	ORFS44438
9/28/2021	950	36.94477	-89.09436	641	M	2740	52125	ORFS44439
9/28/2021	950	36.94477	-89.09436	607	M	2540	52126	ORFS44440

Recommendations:
Additional telemetry receivers will be deployed. Telemetry receivers will be downloaded to collect detection data. Periodic maintenance will be required in the future to ensure that receivers are still in place and functioning properly. Damaged or lost receivers will be repaired and/or replaced as needed and if funding is available.

Lead Agency: Tennessee Wildlife Resources Agency (TWRA), Cole Harty (Cole.R.Harty@tn.gov)

Methods:
TWRA staff have been working to gather data associated with lake and river elevations, discharge, and spillway operations at Reelfoot Lake. Data have been pulled from USGS gage stations in Reelfoot Lake. Additional data are available downstream of the Reelfoot Spillway, however the utility of these data in the absence of an understanding/description of spillway operations is limited. Staff have made contacts with other agencies and are working to gather spillway information so existing gage data can be summarized with meaningful context.

Due to water levels and personnel issues, staff were unable to conduct the planned electrofishing efforts below Reelfoot Spillway.

Results and Discussion:
Results are limited at this time. Data are still being compiled and analyzed to inform the scenarios that allow for passage of Reelfoot Spillway. We expect a significant increase in the reportable information in the next year as this project progresses and a telemetry component is implemented (see FY21 workplan).

Factors including staff availability (TWRA carp crew was recently hired and have been onboarding and training) and water levels prevented completion of electrofishing. This effort may prove difficult in future years, as river access below Reelfoot Spillway is cumbersome at both low water and wet conditions (no quality ramp; requires multiple staff, vehicles, and wenches).

Recommendations:
Given workable river conditions below Reelfoot Spillway, we will again plan to conduct electrofishing samples and we expect fewer complications with availability as new staff gain footing.

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