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
  - As of December 31, 2022, 167 invasive carp have been tagged in south Louisiana.
  - In 2022, there were nearly 158,000 detections from 79 unique carp across the array of 40 receivers.
  - The maximum distance traveled and recorded by receivers was 572 km, and the mean distance traveled and recorded by receivers was 31 km.

- Arkansas
  - A total of 108 transmitter receptions have occurred in lower Arkansas River, and a total of 160 transmitter receptions have occurred in the lower White River.
  - Cumulative distance traveled ranged from less than 100 km to more than 3000 km with an average (SD) cumulative distance traveled of 119.4 (143.4) km.
  - Mean lengths of Silver Carp ranged from 662 mm to 925 mm. Mean weights of Silver Carp ranged from 3387 g to 8805 g. Mean length of Bighead Carp averaged 1257 mm, while mean weight of Bighead Carp averaged 20750 g.
- Mississippi
  - Majority of carp were not detected at any stationary receiver; potentially need to manually track near original tagging locations to locate the remaining tagged carp.
  - Carp that were detected were within 4.3 to 4.8 river miles from their original tagging location.
  - *Moon Lake*
    - Silver carp movement in Moon Lake 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.
    - Silver Carp only moved during the spring and early summer, so any future barrier operations should focus on these periods to minimize risk of Silver Carp entering Moon Lake by movements through Yazoo Pass.
  - *Eagle Lake*
    - Twenty six acoustic receivers were placed in the project area.
    - Ninety five Silver Carp were implanted with acoustic tags and released.
    - No tagged Silver Carp have moved through Muddy Bayou Water Control Structure into or out of Eagle Lake .
    - Five Silver Carp passed through Steele Bayou Water Control Structure.
    - Most Silver Carp (87.5%) fish released upstream of Steele Bayou Water-Control Structure in Steele Bayou have stayed up within Steele Bayou and 12.5% have moved downstream through the structure.
    - Most Silver Carp (95%) fish released below Steele Bayou Water-Control Structure moved downstream into Yazoo River toward the Mississippi River.

- Missouri
    - The majority of carp were not detected at any stationary receiver; potentially need to manually track near original tagging locations to locate the remaining tagged carp.
    - Carp that were detected were within 4.3 to 4.8 river miles from their original tagging location.
- Tennessee
    - Fisheries staff established a telemetry array to monitor movement of tagged silver carp around Reelfoot Lake and Spillway.
    - Fifty silver carp were implanted with acoustic tags in the Reelfoot project area.
    - Silver carp tagged in this study have provided important initial data to evaluate passage across the Reelfoot Spillway; these fish have also had far reaching impressions, providing perspective to the range of silver carp by being detected on receivers in the Mississippi River near St. Louis (Lock and Dam 26), the Lower Ohio River, and even making passage into the Tennessee/Cumberland River system.
    - Initial data has provided insight as to the timing of passage and water levels that allow for passage across the Reelfoot Spillway.

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, Red 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.

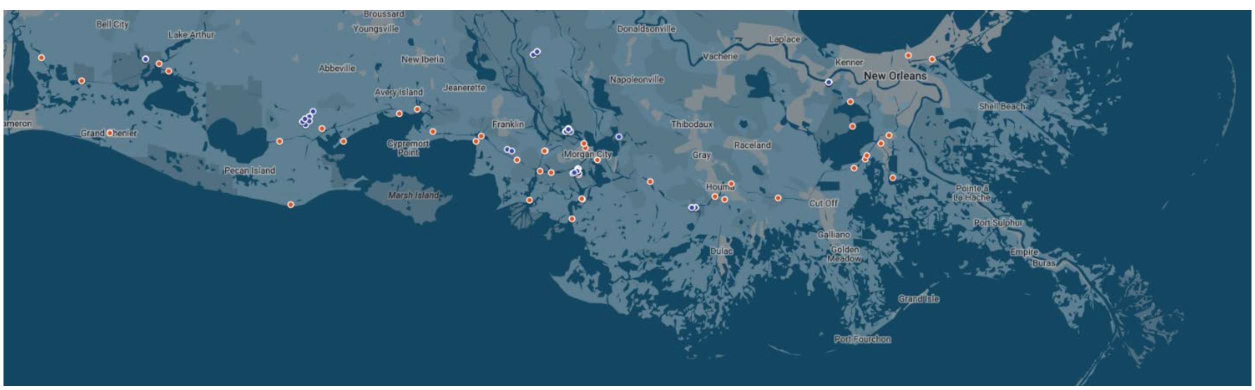

Figure 1. Map depicting receiver distribution (red points) and tagging locations (blue points) of invasive carp in coastal Louisiana.

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) .

In 2022, most invasive carp were captured primarily during late summer and fall. 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 semienclosed 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 assist capturing 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 and sex, 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 and Lake Palourde (n = 24), the western region (n = 9), and the central region near Houma (n = 22). In 2022, 60 carp were tagged. By the end of 2022, a total of 167 acoustically tagged carp (n=161 Silver, n=2 Bighead, n=4 Grass) were captured and released in the study area (Figure 2). Tagged individuals were relatively large for all three species with a mean size of nearly a meter in length observed for each: Silver (855 ± 5.6 mm FL), Grass (820 ± 94.2 mm FL), and Bighead Carp (1144 ± 3.0 mm FL) (Table1). The largest carp in the study have been tagged in the central coastal area (945 ± 11.7 mm FL), followed by the Calcasieu-Mermentau (879 ± 12.7 mm FL) and the Atchafalaya-Vermilion (817 ± 5.4) (Figure 3, Table 2). For the year 2022, nearly 158,000 detections were recorded. For the full study, over 174,000 detections have been recorded across the receiver array from 79 unique carp (n=76 Silver, 163,326 detections; n=2 Grass, 119 detections; and n=1 Bighead, 1,411 detections). The maximum distance traveled by all carp was a Silver that moved 571.95 km, while the mean distance traveled by all carp was 31.1 km (Tables 3 and 4).

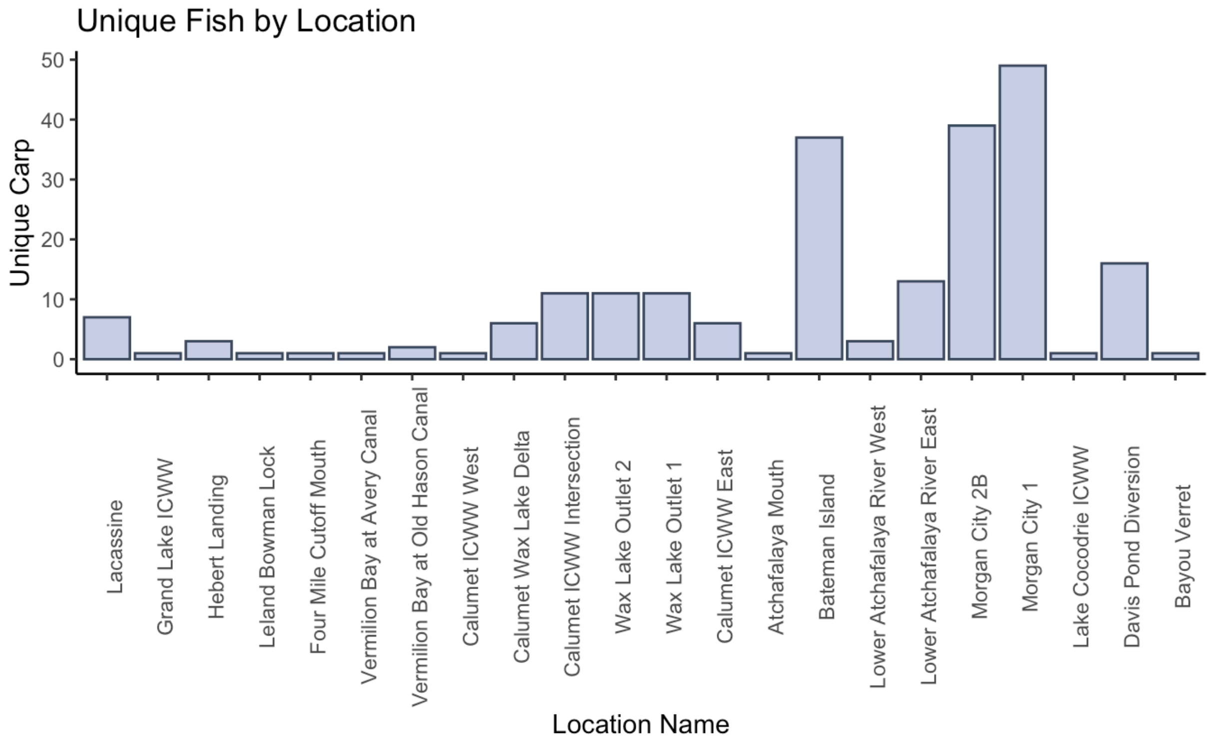

Figure 2. Unique tagged fish by location.

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 mean fork length (mean, mm), standard deviation (sd), number of individuals tagged (n), and standard error (se).

SPECIES	MEAN	SD	N	SE
BIGHEAD	1144	4.24264069	2	3
GRASS	820	188.471041	4	94.2355206
SILVER	855.763975	71.7163262	161	5.6520383

Table 2. Size of Silver, Bighead, and Grass Carp combined grouped by basin (HUC 6). Data incudes the mean fork length (mean, mm), standard deviation (sd), number of individuals tagged (n), and standard error (se).

TAGGING HUC 6	MEAN	SD	N	SE
ATCHAFALAYA-VERMILION	817.53	53.63	100	5.36
CALCASIUE-MERMENTAU	879.08	64.94	26	12.74
CENTRAL LOUISIANA COASTAL	944.80	75.04	41	11.72

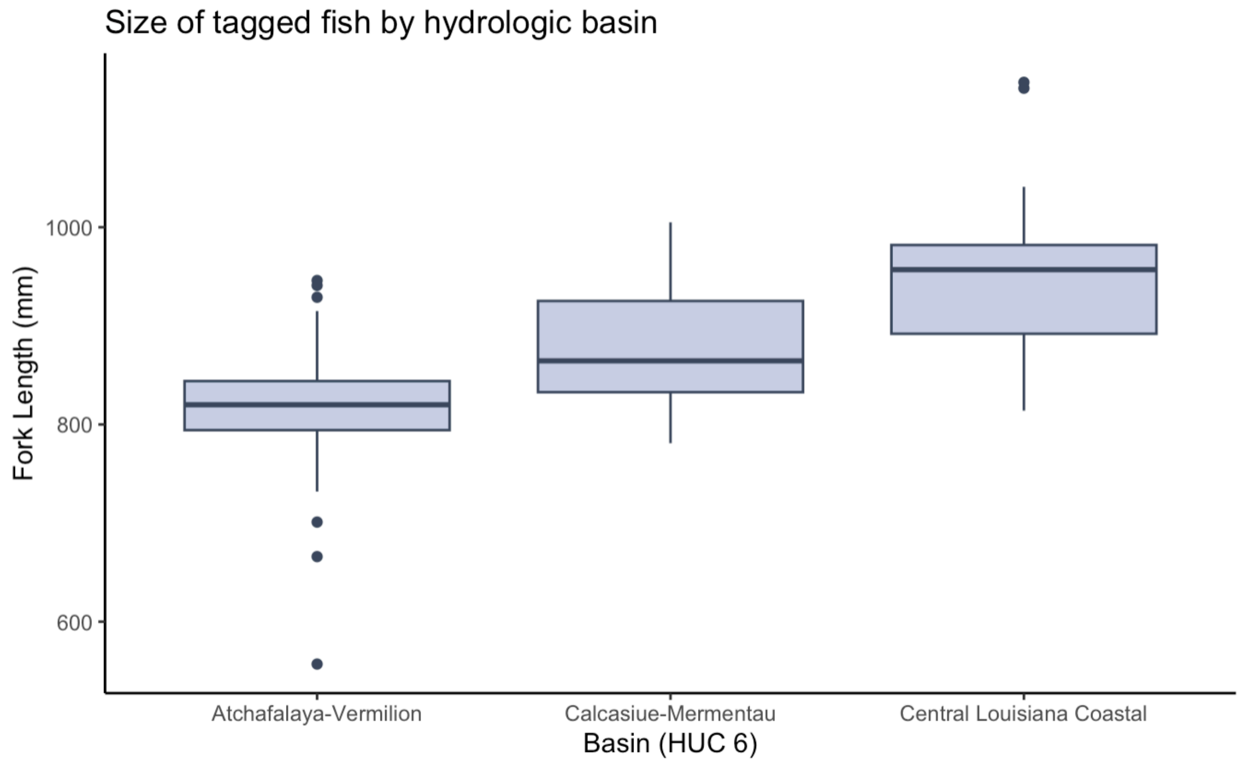

Figure 3. Tagged Fish Size by Hydrologic Basin.

Table 3. Carp Detections by Receiver.

Location Name	Rec-Serial	Latitude	Longitude	Total Detections	Unique Carp
Bateman Island	486543	29.63362	-91.244	85514	37
Morgan City 2B	106628	29.7338	-91.2256	20420	39
Four Mile Cutoff Mouth	486545	29.74152	-92.11214	18543	1
Wax Lake Outlet 2	111116	29.71085	-91.36992	17954	11
Wax Lake Outlet 1	106622	29.71033	-91.36774	15203	11
Davis Pond Diversion	486572	29.9284	-90.32095	7270	16
Morgan City 1	114980	29.71981	-91.21849	3584	49
Bayou Verret	486540	29.86908	-90.2426	1397	1
Vermilion Bay at Avery Canal	486552	29.82917	-91.90501	1362	1
Calumet ICWW Intersection	486550	29.64662	-91.38654	1009	11
Calumet ICWW East	486551	29.64082	-91.34655	637	6
Hebert Landing	486549	29.7428	-92.348	446	3
Lacassine	486537	29.98846	-92.793314	401	7
Lake Cocodrie ICWW	486553	29.61337	-90.981298	393	1
Lower Atchafalaya River East	486546	29.55575	-91.23173	357	13
Calumet Wax Lake Delta	486555	29.55356	-91.426	186	6

Location Name	Rec-Serial	Latitude	Longitude	Total Detections	Unique Carp
Lower Atchafalaya River West	486559	29.55735	-91.23359	116	3
Vermilion Bay at Old Hason Canal	486536	29.74268	-91.6229	64	2
Calumet ICWW West	486535	29.68116	-91.4714	30	1
Grand Lake ICWW	486539	29.9646	-92.75799	24	1
Atchafalaya Mouth	486541	29.4941	-91.2689	20	1
Leland Bowman Lock	486534	29.78261	-92.19248	7	1
319 Bridge ICWW	486547	29.77191	-91.78353	0	0
Argyle ICWW	486544	29.563981	-90.741449	0	0
Bayou Boeuf Lock	486533	29.6832	-91.17682	0	0
Bayou Perot	486556	29.68352	-90.187	0	0
Bourg ICWW	486565	29.56005	-90.50823	0	0
Calcasieu ICWW	486548	30.008759	-93.228216	0	0
Couba Pass	486566	29.79038	-90.23248	0	0
Creole Bridge	486554	29.9341307	-93.079709	0	0
Crown Point	486538	29.76161	-90.09938	0	0
Freshwater City	486560	29.5399	-92.3078	0	0
Grand Chenier	486567	29.769089	-92.974582	0	0
Green Bridge ICWW	486557	30.0044	-89.93908	0	0
Houma Navigation Canal	486563	29.55524	-90.70674	0	0
Inner Harbor Navigation Canal	486561	30.01619	-90.02853	0	0
Jean Laffite	486570	29.7336	-90.12783	0	0
Lafitte Dupre Cut	486571	29.62365	-90.08474	0	0
Morgan City 2	111221	29.7332	-91.22558	0	0
Mud Lake	486558	29.75741	-91.6042	0	0
North Houma ICWW	486564	29.60522	-90.68236	0	0
Salvador ICWW East	486562	29.69618	-90.18002	0	0
Salvador ICWW West	486542	29.65562	-90.22783	0	0
Seventh Ward Canal	486568	29.80377	-92.2552	0	0
Weeks Bay Channel	486569	29.84526	-91.84014	0	0

Table 4. Detections and distance traveled by fish.

Study ID	Trans-Serial	Release Location	Species	Fork Length (mm)	Detections	Unique Receivers	Distance (Km)
73	62689	Big Wax Bayou	Silver	802	6980	9	571.95
49	62640	Big Wax Bayou	Silver	735	6099	8	197.99
43	62529	Schooner Bayou	Silver	832	19993	4	143.17
67	62683	Big Wax Bayou	Silver	778	26902	7	95.91
78	62696	Big Wax Bayou	Silver	833	634	7	95.20
46	62643	Big Wax Bayou	Silver	844	5759	6	82.64
81	62663	Big Wax Bayou	Silver	840	3432	7	79.58
41	62532	Schooner Bayou	Silver	781	199	3	78.12
103	62546	Big Wax Bayou	Silver	806	453	9	77.15
72	62690	Big Wax Bayou	Silver	844	6006	6	74.40
105	62548	Big Wax Bayou	Silver	787	3535	5	66.92
65	62685	Big Wax Bayou	Silver	802	126	7	56.15
68	62688	Big Wax Bayou	Silver	816	847	2	55.75
63	62681	Big Wax Bayou	Silver	809	238	4	50.07
50	62635	Big Wax Bayou	Silver	807	945	4	46.05
84	62666	Big Wax Bayou	Silver	854	4000	5	46.05
64	62680	Big Wax Bayou	Silver	915	2207	4	46.05
53	62632	Big Wax Bayou	Silver	804	361	3	43.49
58	62631	Big Wax Bayou	Silver	832	359	3	41.48
22	62579	Big Wax Bayou	Silver	795	399	3	39.47
54	62633	Big Wax Bayou	Silver	816	628	3	39.47
80	62664	Big Wax Bayou	Silver	767	8004	3	39.47
47	62638	Big Wax Bayou	Silver	772	7693	5	39.30
71	62691	Big Wax Bayou	Silver	848	4773	4	32.90
83	62665	Big Wax Bayou	Silver	811	541	3	30.89
61	62628	Big Wax Bayou	Silver	873	141	3	26.31
100	62519	Big Wax Bayou	Grass	851	65	3	23.03
59	62626	Big Wax Bayou	Silver	832	8527	3	21.38
26	62580	Big Wax Bayou	Silver	701	408	3	17.45
77	62697	Big Wax Bayou	Silver	792	6031	3	17.17
107	62550	Big Wax Bayou	Silver	829	221	3	15.16
56	62629	Big Wax Bayou	Silver	813	308	3	15.16
86	62668	Big Wax Bayou	Silver	787	5341	3	15.16
66	62684	Big Wax Bayou	Silver	836	118	3	15.16
102	62545	Big Wax Bayou	Silver	801	666	3	13.16

Study ID	Trans-Serial	Release Location	Species	Fork Length (mm)	Detections	Unique Receivers	Distance (Km)
87	62669	Big Wax Bayou	Silver	848	2283	3	13.16
62	62682	Big Wax Bayou	Silver	804	335	3	13.16
74	62694	Big Wax Bayou	Silver	778	2709	3	13.16
8	62562	David Pond Diversion	Bighead	1147	1411	2	12.46
52	62637	Big Wax Bayou	Silver	829	13580	2	11.15
70	62686	Big Wax Bayou	Silver	888	21	2	9.87
55	62634	Big Wax Bayou	Silver	804	108	3	9.07
91	62538	Bayou Lacassine	Silver	899	27	2	6.55
60	62627	Big Wax Bayou	Silver	799	125	2	4.02
104	62547	Big Wax Bayou	Silver	805	488	2	2.01
106	62549	Big Wax Bayou	Silver	872	170	2	2.01
150	62593	Bayou Mauvais Bois	Silver	891	125	2	2.01
128	62608	Big Wax Bayou	Silver	771	111	2	2.01
134	62614	Big Wax Bayou	Silver	824	668	2	2.01
51	62636	Big Wax Bayou	Silver	902	436	2	2.01
45	62642	Big Wax Bayou	Silver	842	496	2	2.01
82	62662	Big Wax Bayou	Silver	750	300	2	2.01
76	62692	Big Wax Bayou	Silver	842	511	2	2.01
101	62520	Big Wax Bayou	Silver	825	10081	3	0.00
42	62527	Schooner Bayou	Silver	799	341	1	0.00
37	62534	Seventh Ward Canal	Silver	870	14	1	0.00
89	62536	Bayou Lacassine	Silver	902	156	1	0.00
90	62537	Bayou Lacassine	Grass	1005	54	1	0.00
93	62540	Bayou Lacassine	Silver	978	8	1	0.00
94	62541	Bayou Lacassine	Silver	1004	35	1	0.00
97	62544	Bayou Lacassine	Silver	942	44	1	0.00
7	62554	David Pond Diversion	Silver	905	21	1	0.00
1	62555	David Pond Diversion	Silver	990	531	1	0.00
3	62557	David Pond Diversion	Silver	982	540	1	0.00
4	62558	David Pond Diversion	Silver	961	154	1	0.00
10	62561	David Pond Diversion	Silver	975	84	1	0.00
11	62564	David Pond Diversion	Silver	973	2	1	0.00
13	62566	David Pond Diversion	Silver	921	1	1	0.00
14	62567	David Pond Diversion	Silver	957	2236	1	0.00
15	62568	David Pond Diversion	Silver	977	616	1	0.00
16	62569	David Pond Diversion	Silver	972	1515	1	0.00

Study ID	Trans-Serial	Release Location	Species	Fork Length (mm)	Detections	Unique Receivers	Distance (Km)
17	62570	David Pond Diversion	Silver	1041	165	1	0.00
21	62571	David Pond Diversion	Silver	994	1101	1	0.00
20	62572	David Pond Diversion	Silver	1017	222	1	0.00
19	62573	David Pond Diversion	Silver	985	32	1	0.00
18	62574	David Pond Diversion	Silver	1015	36	1	0.00
27	62578	American Lake	Silver	845	39	1	0.00
28	62581	American Lake	Silver	791	8	1	0.00
135	62615	Big Wax Bayou	Silver	874	58	1	0.00

Several notable movements have been observed thus far. The fish with transmitter 62689, a Silver Carp, showed movement that typifies fish in the Atchafalaya River Basin. Tagged in a backwater of the lower Atchafalaya River, beneath Morgan City, this fish has been detected within the basin area for over a year since its' initial capture and release in late 2021. Over the course of the year the fish has swum over 500 river kilometers, being detected on 9 different receivers, utilizing the intracoastal waterway several times to transit between Wax Lake Outlet, and the Atchafalaya River, both north and south of Morgan City, LA.

Other fish appeared to make larger movements. Fish 62529, another Silver Carp, was tagged in late 2021 in the North Prong of Schooner Bayou. This fish quickly transitioned into Vermilion Bay, at the mouth of the four mile-cutoff channel near Intracoastal City, LA. After being detected here continuously (~ 18,000 detections), the fish was next detected after a week of silence on another bay receiver – this time at the mouth of Avery Canal. Detections at Avery Canal appear in several day-long detection groupings spaced out over approximately one month. Total residence time in the bay for this fish was around three months. The next appearance occured in the Lower Atchafalaya River followed by a rapid transit (~ 18 hours) north of Morgan City.

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.

Recommendations:
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.

The remaining tags will be deployed in early 2023, and receivers will continue to be monitored as part of an extension of this study. Additionally, 15 receivers and 30 tags will be deployed up the Atchafalaya River as part of a related study. With that array in place, we will not only be able to track coastal movements of carp, but also their movements into what seem to be important spawning grounds.

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:

Large-Scale Movement

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. 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.

Table 1. Receivers in the lower Arkansas River

Locations	Lat	Long	# Carp Detections (number in parentheses are new detections this year)
Trulock	34.17075 N	-91.75176 W	83 (42)
Pendleton	33.98137 N	-91.38294 W	24 (24)
Wilbur D. Mills	33.97765 N	-91.29957 W	1 (0)

Table 2. Vemco Receivers in the lower White River

Locations	Lat	Long	# Carp Detections (number in parentheses are new detections this year)
De Valls Bluff	34.78388	-91.43361	78 (58)
St. Charles	34.37928	-91.12705	19 (16)
Jack’s Bay	34.0934	-91.16652	34 (24)
Norrel	34.01915	-91.18412	29 (25)

Small-Scale Movement

The project also examined small-scale (hours to days) movement of Silver Carp in the lower White and lower Arkansas Rivers. Five fish were implanted with radio transmitters in each system over four season (fall, winter, spring, and summer). 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 river during each season. Movement patterns varied between rivers and among seasons.

Population Characteristics

In 2021, the lower Arkansas River, the lower White River, and Morgan Point Oxbow were sampled using daytime, boat-mounted electrofishing. 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. 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.

In 2022, two bigheaded carp populations, the Mississippi River and White River, were sampled using daytime, boat-mounted electrofishing. Sampling was focused in areas with known presence of bigheaded carps, or in areas with suitable habitat. These locations included a side channel on the Tennessee section of Mississippi River, and several side channels and backwaters in the White River. 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.

Relationship Between Population Dynamics and Environmental Conditions

Despite their widespread invasional success in a variety of environments, established patterns between population demographics and environmental factors are largely lacking from the literature. We assessed the influence of a suite of environmental variables on Silver Carp population demographics across the Mississippi River Basin.

To examine the effects of environmental conditions on bigheaded carp population dynamics, a dataset of individual carp length, weight, sex, and estimated age is being compiled from populations across the Mississippi River Basin (Table 4).

Table 4. Populations from basins in the upper and lower Mississippi River included in the analysis of environmental effects on population characteristics.

Upper Mississippi River Populations	**Lower Mississippi River Populations**
Upper Mississippi main stem	Arkansas
Illinois	Cache
Ohio	Lower Mississippi main stem
Wabash	Red
Tennessee	White
Cumberland	Yazoo
Missouri	
Kansas	
Big Sioux	
James	
Vermillion	

From 2019 to 2022, Silver Carp were collected using daytime, boat-mounted electrofishing from seven rivers (Arkansas, Cache, St. Francis, Mississippi, Red, White, and Yazoo rivers) within the Lower Mississippi River Basin. In addition, raw data was compiled for populations throughout the Mississippi River Basin, including populations in the Upper Mississippi, Missouri, and Ohio river basins (Table 4).

Standard population parameters related to growth, mortality, and recruitment were estimated for each population. A dataset of environmental factors associated with temperature and hydrology was compiled for each population (Table 5).

Table 5. Environmental variables included in the analysis of environmental effects on population characteristics.

Climate Variables	**Flow Variables**
Mean annual air temperature	7-d minimum flow divided by mean flow for year
Mean growing degree days	Julian date of each annual 1-d maximum discharge
Latitude	Number of high pulses each year
Stream Order	Mean duration of high pulses within each year
Years since first detection	Means of all positive differences between consecutive daily values
	Number of flow reversals
	Mean annual flow
	Flow coefficient of variation
	Flow predictability
	Flow constancy divided by predictability

Simple linear models were used to examine relationships between population parameters and environmental variables. Significant variables were included in stepwise multiple regressions to form predictive models for each population parameter. We used an information criteria approach to determine the most parsimonious model, regardless of the number of variables included in each respective model.

Results:

Large-Scale Movement
A total of 108 transmitter receptions have occurred in lower Arkansas River. The majority of those are near Trulock, where most of the implantations occurred. A total of 160 transmitter receptions have occurred in the lower White River.

Silver Carp in the White River were picked up more times by acoustic receivers, moved greater distances, and covered larger home ranges than Silver Carp in the Arkansas River. No fish have been detected moving between rivers. Movement rates were similar between rivers. Main-channel residency periods varied based on river and season. Two fish have been observed moving upstream through a lock and dam. Four fish have been observed to have moved downstream through a lock and dam. Overall, movement patterns suggest movement of Silver Carp in the Arkansas River is limited by the numerous locks and dams of the McClellan Kerr Arkansas River Navigation System.

Analysis and interpretation of large-scale movement patterns is underway. Between June 2021 and May 2022, we quantified movement distances, rates, home ranges, and main-channel residency periods of 105 Silver Carp in the free-flowing lower White River and regulated lower Arkansas using passive acoustic telemetry arrays and internal implant acoustic transmitters.

Cumulative distance is the documented distance traveled during the study period. Cumulative distance traveled ranged from less than 100 km to more than 3000 km. Several data points identified by the Rosner test were removed as outliers. Average (SD) cumulative distance traveled was 119.4 (143.4) km. The frequency distribution of cumulative distances for fish from the Arkansas and White Rivers was significantly different according to a Fisher's Exact test, with greater cumulative distances (200-600 km) observed for Silver Carp in the White River (Figure 1).

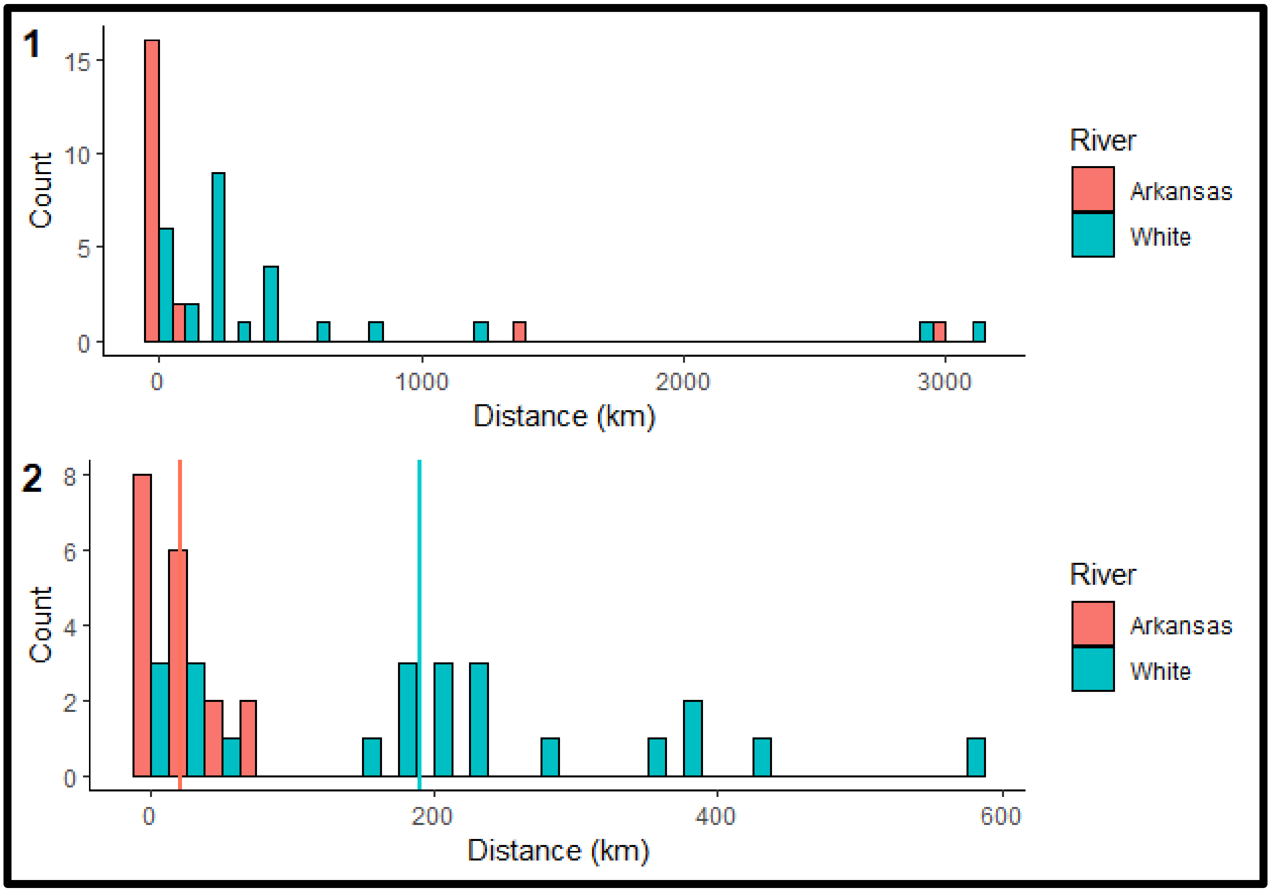

Figure 1. Cumulative distance with (top panel) and without (bottom panel) outliers for Silver Carp in the Arkansas and White Rivers. Slender vertical bars in bottom panel represent median cumulative distance for the two rivers.

Average movement rate was the distance moved between consecutive locations divided by the time elapsed. Average movement rates were calculated for individual Silver Carp. Average movement rates ranged from less than 1 km/d to 11 km/d. After removing outliers, the average of the individual average movement rates was 0.71 (0.84) km/d. The frequency distributions of average movement rates was significantly different between Silver Carp in the White and Arkansas Rivers according to a Fisher's Exact test. The median of average movement rates in the White Rivers was greater than the median of average movement rates in the Arkansas River (Figure 2).

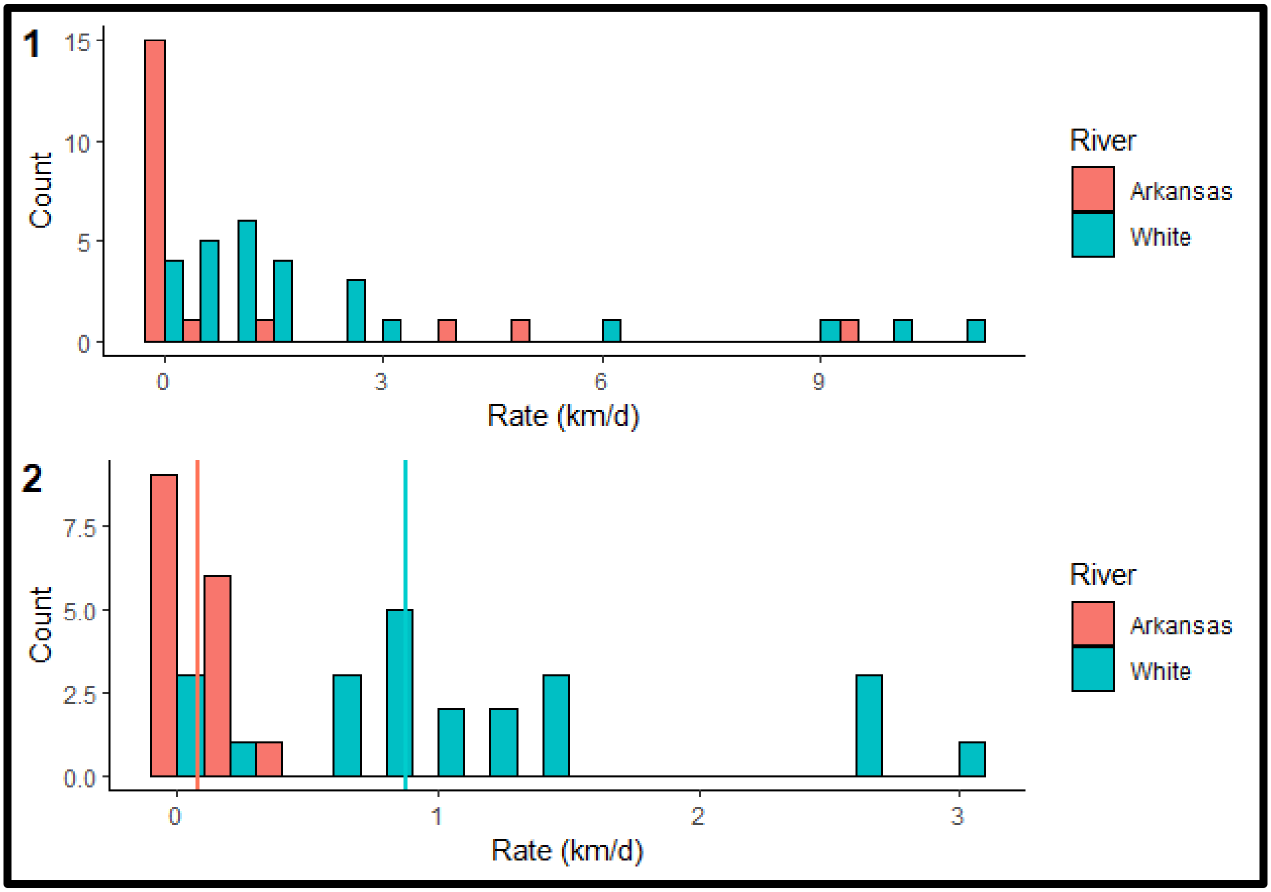

Figure 2. Average movement rates with (top panel) and without (bottom panel) outliers for Silver Carp in the Arkansas and White Rivers. Slender vertical bars in bottom panel represent median movement rates for the two rivers.

Linear home range was the distance between the upstream most and downstream most locations for individual Silver Carp. If Silver Carp transited more than one river system (e.g. White River and Mississippi River), linear home range was calculated in each system and summed across systems. Linear home range varied between less than 1 km to more than 1500 km. With outliers removed the average linear home range for Silver Carp in the study was 104.2 (123.0) km. The frequency distribution of linear home ranges for Silver Carp in the White and Arkansas Rivers were significantly different according to a Fisher's Exact test. Median linear home range in the White River was approximately 180 km, but was approximately 40 km in the Arkansas River (Figure 3).

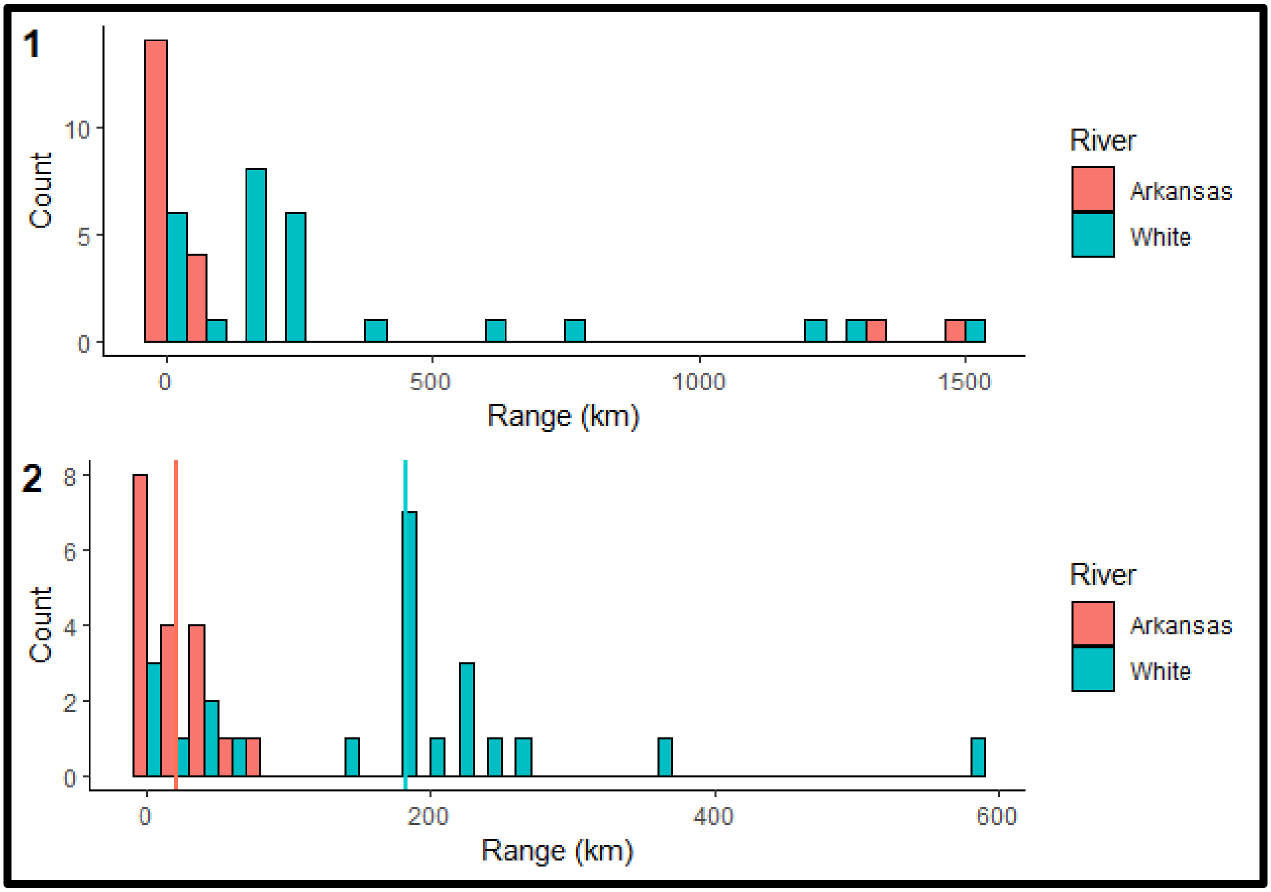

Figure 3. Linear home ranges with (top panel) and without (bottom panel) outliers for Silver Carp in the Arkansas and White Rivers. Slender vertical bars in bottom panel represent median linear home ranges for the two rivers.

Overall, Silver Carp in the White River were picked up more times by acoustic receivers, moved greater distances at faster rates, and covered larger home ranges than Silver Carp in the Arkansas River. These patterns suggest movement of Silver Carp in the Arkansas River is limited by the numerous locks and dams of the McClellan Kerr Arkansas River Navigation System.

Small-Scale Movement

Observed movement rates and movement distances indicated that movement was greater in the White River than in the Arkansas River, regardless of season. Movement was generally greater in the spring and summer than in the fall and winter, regardless of river. Habitat use varied between rivers. Silver Carp used backwater habitat more in the Arkansas River than in the White River. Silver Carp use main channel habitat more in the White River than in the Arkansas River.

Population Characteristics

In 2021, the lower Arkansas River, the lower White River, and Morgan Point Oxbow were sampled. 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.

In 2022, two bigheaded carp populations, the Mississippi River and White River, were sampled. Eight sampling events (January – October 2022) resulted in the removal of 217 Silver Carp and 0 Bighead Carp from the White River. One sampling event (September 2022) resulted in the removal of 101 Silver Carp and 0 Bighead Carp from the Mississippi River.

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 662 mm to 925 mm. Mean weights of Silver Carp ranged from 3387 g to 8805 g. Mean length of Bighead Carp averaged 1257 mm, while mean weight of Bighead Carp averaged 20750 g. Age estimation has begun, and age has been estimated for approximately 25% of collected fish.

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 Carp	817 (49)	6577 (1379)
	Bighead Carp	NA	NA
Arkansas River	Silver Carp	925 (106)	8805 (2040)
	Bighead Carp	1257 (45)	20750 (550)
Mississippi River	Silver Carp	662 (56)	3387 (891)
	Bighead Carp	NA	NA
Morgan Point	Silver Carp	735 (67)	4029(1227)
	Bighead Carp	NA	NA

The Arkansas Game and Fish Commission’s Invasive Carp Removal Program provided additional samples of Bighead Carp for this study. The Invasive Carp Removal Program has provided 37 Bighead Carp from the lower White River, 8 Bighead Carp from the lower Arkansas River, 9 Bighead Carp from the Morgan Point Oxbow, and 31 Bighead Carp from the Cache River. There are an additional 37 Bighead Carp provided by the Invasive Carp Removal Program, but location information is not yet available. All these specimens will eventually be included in the average lengths and weights listed for Bighead Carp in Table 3.

Relationship Between Population Dynamics and Environmental Conditions
The most parsimonious model predicting growth (length at age-4) was

Length at age-4 (mm) = 401.30 + 0.09(Growing Degree Days) - 178.01(Flow Predictability).

The most parsimonious model predicting condition (mean relative weight) was

Mean Relative Weight = 74.62 – 0.0008(Rise Rate) + 0.01(Growing Degree Days)

The best model predicting mortality happened to be a four variable model and was

Total Annual Mortality (A) = 0.15 – 0.0058(Years Since First Detection) + 0.63(Constancy %) – 0.00009(Growing Degree Days) + 0.002(Hydrologic Reversals)

Finally, the best model predicting recruitment variability (recruitment variability index) was

RVI= 0.85671 - 0.0043(Years Since First Detection).

It appears that while growth and condition increase with growing degree days, total annual mortality declines with increased growing degree days. Flow and climate drive population characteristics but not always in intuitive ways. The resultant predictive equations may be used by state agencies to evaluate potential management alternatives.

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

Participating Agency: Mississippi State University (MSU)

MOON LAKE

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.

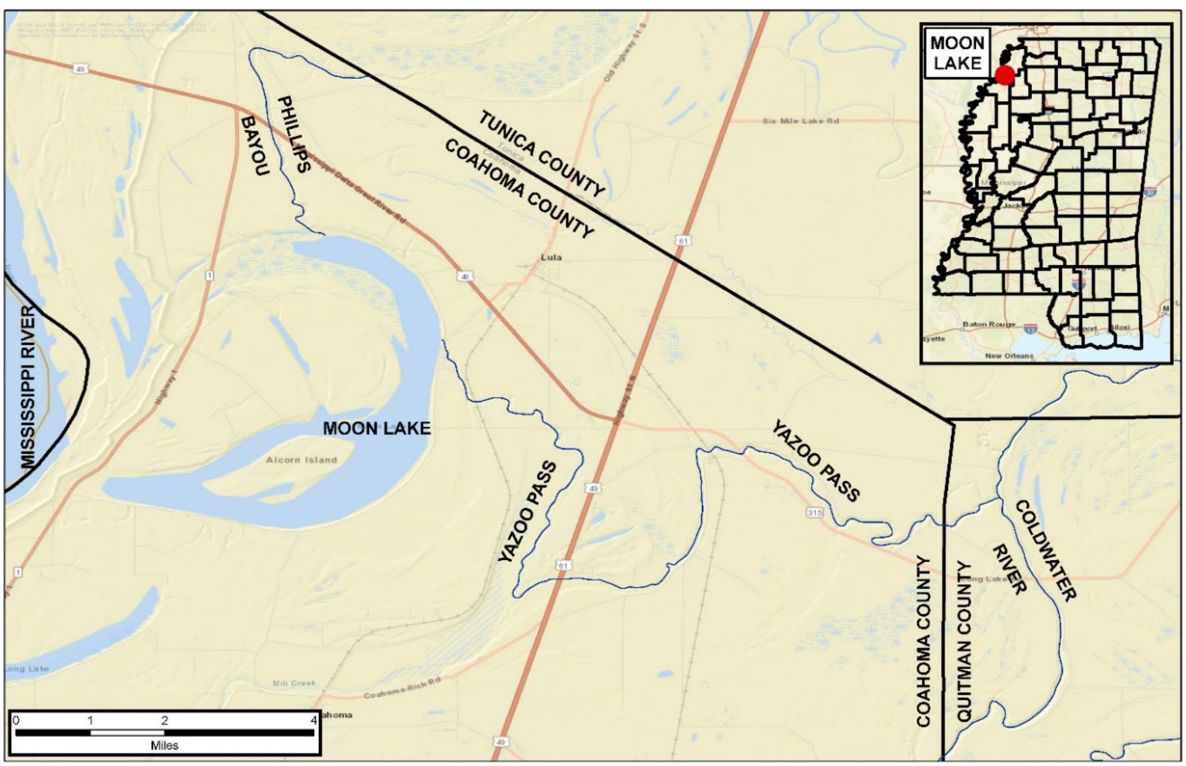

Figure 1. Study area map showing the locations of Moon Lake, the Yazoo Pass and the Coldwater River in northwest Mississippi.

All of the methods were reported in the 2021 LMR Invasive Carp Movement Interim Report. Eighty-two Silver Carp were collected and tagged between January 8, 2021, and February 26, 2021. Eighty-two Silver Carp were collected and tagged between January 8, 2021, and February 26, 2021. 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 2).

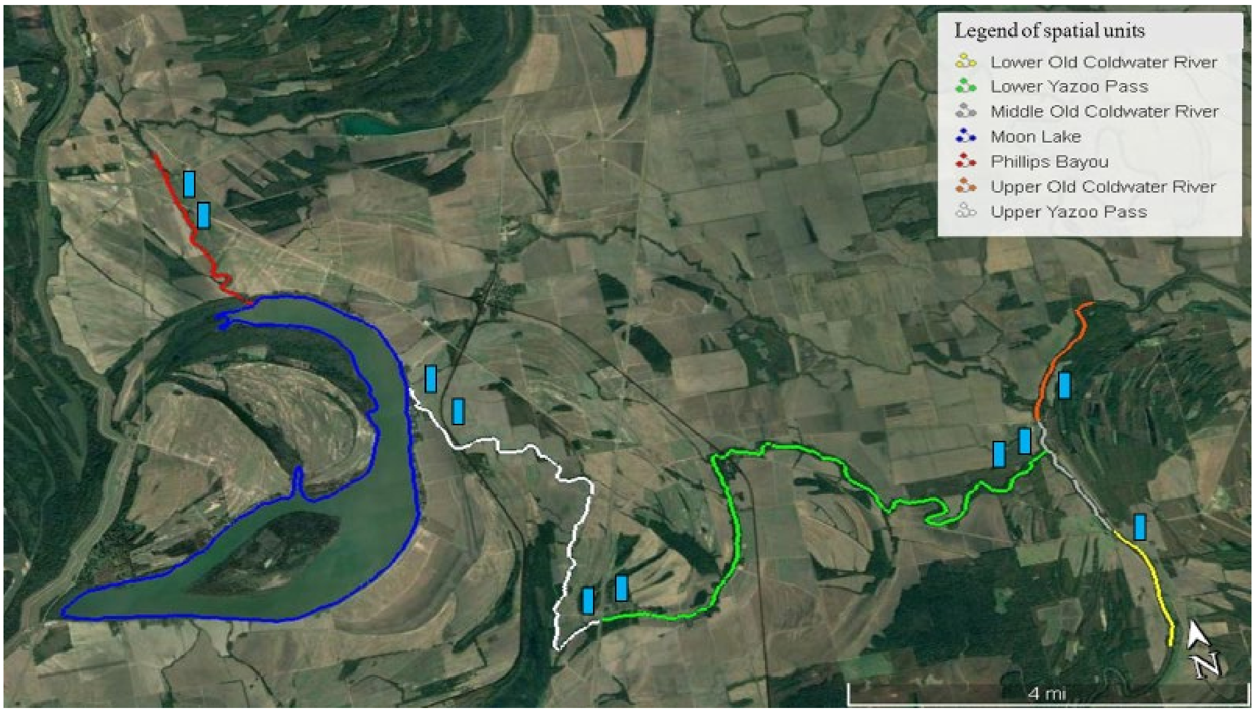

Figure 2. The study area for Moon Lake, Mississippi illustrating the spatial units, approximate acoustic receiver locations, and the bodies of water that each spatial unit represents. The light blue rectangles are the approximate receiver locations while the colored lines show either the outline or path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

Data Analysis was reported in the 2021 LMR Invasive Carp Movement Interim Report. The field work portion of this project was completed in September 2021. However a few activities were done in CY2022. Moon Lake was sampled twice from January – March to locate tagged fish and the receivers were downloaded twice during this period. Receivers were removed at the beginning of June 2022 and deployed for use on the Eagle Lake Project. Data analysis continued to inform the potential for in-lake precision harvesting and movement data to inform deterrent placement.

Results and Discussion:
Results and discussion were reported in 2021 LMR Invasive Carp Movement Interim Report and it contains much of the information in the interim performance report for the October 2020 – September 2021, submitted by MSU to MDWFP (Besson et al. 2021). Preliminary results and conclusions are in (Besson et al. 2021). Since the movement data analysis necessary for additional model development proved to be too rigorous for the graduate student to perform, his

major professor plans to complete that work. The capture-recapture analysis will provide a predictive model to evaluate risk of movement into or out of the oxbow lake. The predicted probabilities of movements can be used to inform the potential operations of a barrier if installed. For example, if environmental covariates are associated with increased probability of movement into the oxbow lake then the barrier can be operated. Alternatively, if environmental covariates are associated with increased probability of movement out of the oxbow lake then the barrier can be turned off. Varying operational rule sets can be developed to minimize the risk of silver carp moving into the oxbow lake while potentially promoting movement out of the lake.

Recommendations:
Complete Data Analysis in 2023.

EAGLE LAKE

Methods:

Geographic Location
The focal waterbody of this study is Eagle Lake (LA, MS), and this study's design resembles an ongoing project in Moon Lake, MS. However, unlike Moon Lake, the connection between Eagle Lake and surrounding waterbodies is regulated by water-control structure (WCS). Eagle Lake is an 1870-hectare oxbow lake located on the Louisiana and Mississippi border in Warren County, MS and Madison Parish, LA (Miranda et al. 2001) (Figure 1). The lake supports local economies in Jackson, MS and Vicksburg, MS and has a regionally relevant recreational fishery (Miranda et al. 2001). Eagle Lake is eutrophic and relatively shallow, with an average depth of 3 m and maximum depth of 10 m (Miranda et al. 2001). Waterway connectivity in the Eagle Lake study area is influenced by water-control structures (WCS) and flooding.

Our goal is to develop an operational strategy for the WCS in our study area to impede Silver Carp movements and range expansion. Studies have found that invasive carp movement has been blocked by physical and natural barriers already in place (Lohmeyer and Garvey 2009; Zielinski and Sorensen 2021).

Overview
This study area is split into four spatial units so that Silver Carp movements can be quantified (Figure 1). A spatial unit is considered a standalone unit. Vemco VR2 omnidirectional receivers were placed throughout the study area to passively track tagged Silver Carp movements. Active tracking with a VR 100 supplements these stationary receivers. Silver Carp were tagged with acoustic tags. Game cameras, water level loggers, and data from USGS gauges on the Muddy Bayou and Steele Bayou structures will be used to evaluate the hydrologic connectivity of the spatial units. Environmental variables will be correlated to Silver Carp movement to determine which variables coincide with fish movements.

Study Area
The focus of this study is Eagle Lake and its hydrologically connected waterways, Muddy and Steele bayous (Figure 1). Muddy Bayou is the only inflow and outflow of Eagle Lake and

therefore the only entrance and exit for fish. Eagle Lake is an oxbow lake that is permanently separated from the MS River by the levee system. Muddy Bayou is 1.45 km long and drains from Eagle Lake into Steele Bayou. There is a water control structure in Muddy Bayou 400 m upstream of the confluence of Muddy and Steele bayous. Steele Bayou merges with Whittington Canal 1.6 km upstream of the Yazoo River (Figure 1). There is another WCS on Steele Bayou (SBWCS) 1 km upstream of the confluence of Steele Bayou and the Yazoo River (Figure 1). Both structures are used to control backwater flooding and maintain fish and wildlife habitat (USACE 2020). Only MBWCS is currently operated to impede invasive carp movements (ERDC Report 2012). Silver carp did enter Eagle Lake when MBWCS was opened due to severe flooding in 2011 (ERDC Report 2012).

Spatial unit and hydrological connectivity modeling of Eagle Lake and surrounding waterways
Stage height, water depth, and water temperature data are being recorded throughout the study. Spatial unit connectivity is being calculated and modeled by comparing landside and riverside stage heights for both SBWCS and MBWCS. Stage heights are regularly downloaded from USACE rivergages.com. Water depth and temperature are recorded with water level loggers (WLL) (HOBO Water Level Data Logger - U20L-01 ONSET, MA, USA) at 15-minute intervals. We will use the data collected from the WLL to calculate water height at each spatial unit transition (Figure 1). This data will also be put into the Silver Carp movement model to see which variables coincide with Silver Carp movements.

Delineating spatial units
Spatial states were delineated to measure Silver Carp movement spatially and temporally. We wanted to measure daily movements of Silver Carp and the size of the spatial units were determined by using average daily Silver Carp movements (Degrandchamp et al. 2008, Coulter et al. 2016). Spatial units were also chosen in relation to WCS and Eagle Lake so that we could determine what variables (time of year, water temp and depth, change in stage height, sex, etc.) coincided with Silver Carp either passing through an open structure or "testing" at a closed structure. We also wanted to see when the fish were either entering or exiting each spatial unit.

Receiver anchoring and placement to monitor spatial and temporal movements
Twenty-six stationary acoustic receivers (69 kHz VR2W or VR2Tx; VEMCO Halifax, NS, Canada) were strategically placed through the study area (Figure 1). A specific "gate ID" was assigned to each location a receiver was placed. This was to keep continuity of detection data when the receivers inevitably had to be replaced due to damage or loss. The gate ID will be used during analysis rather than the receiver serial number.

Receivers were attached to a stainless-steel cable with zip ties and smaller cable and cable clamps (Figure 2). The larger stainless-steel cable was then attached to cement anchors (22-50 kg) on one end and a large buoy on the other end. Receivers were attached so they were 1-2 m below the surface of the water (Figure 2). Receivers are checked and downloaded on a bi-weekly schedule when possible (Figure 3). We also use a VR100 (VEMCO Halifax, NS, Canada) receiver box with a VR 165 (VEMCO Halifax, NS, Canada) armored omnidirectional hydrophone to active track Silver Carp locations and movements. The active tracking gives more "resolution" to the tagged fish movements and accuracy in the modeling. Each spatial unit is actively tracked once a month.

The receivers were placed at spatial unit boundaries (Figure 1) so that fish movement direction could be determined. This was accomplished by placing receivers at bends in the river so that both receivers could only detect a tagged fish when it was directly between the two receivers. Movement is determined by comparing the time between the downstream and upstream receivers. If the last detection on the upstream receiver was later and time than the last detection on the downstream receiver, then this fish movement was classified as an upstream movement and conversely for a downstream movement (Figure 4). Some fish movements were not clear or did not transition to a new unit. These movement were either classified as "tests" or "no-movement" depending on the detection patterns. Movements where the fish was detected on both receivers but did not move into a new spatial state were considered "testing" movements (Figure 5). Still other movements were when a fish was only detected on one receiver. These movements were also considered "testing" (Figure 6). An example of several months of a tagged fish movement can be found in Figure 7.

Capturing, tagging, and relocating Silver Carp

A commercial fisher was hired to net Silver Carp in Eagle Lake and in Cypress Bayou (a tributary to Steele Bayou). Gill nets were 305 m and 1000 m long and 3.5 m deep with multi-strand 9 cm web and 18 cm stretch on the diagonal knots. The rest of the fish were collected via electrofishing on several different dates with the help of USGS, MDWFP, and USACE-ERDC (Table 1). MDWFP used a Smith-Root 7.5 GPP Electrofisher and USACE-ERDC an Apex Electrofisher both set with 1000 volts of direct current (DC) at 30 pulses per second (pps) and 100% range with resulting output was ~3.5 amps in Steele Bayou. USGS had the best electrofishing catch rates with 30 hz, 80% duty cycle, and 300 volts in Steele Bayou. MDWFP was the only partner to shock Eagle Lake and they reduced to low frequency (15pps), 1000 volts, and 100% range running ~1.8 amps. Ninety-five Silver Carp were captured, tagged, and released (Table 1).

We implanted the Silver Carp with a Vemco V16 4x acoustic tag. The tag output is 158 decibels, 69kHz, and set at a random delay of 33–57 seconds. Before tagging, we checked each fish for injuries, deformities, and normal swimming behavior (Calkins et al. 2012; Byrd et al. 2019). A Silver Carp was not tagged if the tag weighed more than 2% of its body weight (Jepsen et al. 2002). We immobilized Silver Carp using tricaine methane sulfonate (MS-222) at a 150 mg/L concentration (Gause et al. 2012; Husen 2015). Water was monitored and replenished in the anesthesia and surgery containers to ensure water was cool and well oxygenated. We anesthetized Silver Carp in a 378.5-liter polyresin stock tank and considered Silver Carp sufficiently anesthetized when they lost equilibrium, were not swimming, and had slow operculum movement (Yoshikawa et al. 1988; Gause et al. 2012; Byrd et al. 2019; Edge et al. 2020). We transported Silver Carp to a wooden cradle where each fish was placed ventral side up. During surgery, fresh water was constantly flowing over the fish gills from a tube connected to a water pump.

After we removed scales from a 3 x 5-cm area on the ventral side between the pelvic and anal fins, we made an incision just large enough to insert a Vemco V16 tag parallel to the lateral line into the coelomic cavity (DeGrandchamp et al. 2008; Coulter et al. 2016; Erickson et al. 2016; Byrd et al. 2019). Care was taken so that no internal organs were damaged (Coulter et al. 2016).

We closed the incision with simple interrupted sutures to minimize tag loss. We inserted a floy tag the left side of the dorsal fin for each fish. Signs informing anglers of the tagged Silver Carp were put at boat ramps and access points asking the anglers to release any tagged Silver Carp alive back into the water body they were captured in. We cleaned surgical instruments with 70% ethanol alcohol between each fish surgery (Coulter et al. 2016).
After surgeries, we moved tagged fish to large net pen in a body of water next to the tagging station. They were observed for recovery and abnormal behavior. Once a fish displayed normal behavior of upright swimming and buoyancy with no other signs of poor health (e.g., excessive bleeding, not recovering, etc.) for at least five minutes, it was moved to a holding tank on a vehicle or boat (Peters et al. 2006; DeGrandchamp et al. 2008; Coulter et al. 2016; Byrd et al. 2019). We used the boat or vehicle to transport fish to a new site. We kept tagged Silver Carp in the net pen in water if we got ahead of vehicles transporting tagged fish. If a fish did not recover based on the above criteria (n=2), we euthanized it by placing it in a stock tank with a lethal dose of MS-222 (IACUC-21-434). In cases like this, we removed, sanitized, and inserted the tag in another fish so that 95 fish exhibiting normal behavior were tagged and released.

On our field datasheet we recorded total length (mm), weight (g), sex, acoustic tag number, floy tag number, date released, site where it was released, location collected, and notes. We determined sex by the presence (male) or absence (female) of rough patches on top of the pectoral fin (Wolf et al. 2018). This data will be used during analysis to see if size or sex influence movement.

Twenty-eight Silver Carp were released into both Steele Bayou units and the Yazoo River unit and 19 in Eagle Lake for a total of 95 (Table 1). All Silver Carp that were released into the Steele Bayou and Yazoo River units were captured in Steele Bayou or Cypress Bayou because they were easy to access and had dense populations of Silver Carp. Since Steele Bayou and the Yazoo River are connected through the SBWCS for large portions of the year, we justified it was ok to transport tagged Silver Carp from Steele Bayou to the Yazoo River. The Silver Carp that were released into Eagle Lake were also captured from Eagle Lake. We did not want to introduce anymore invasive carps into the lake and therefore didn’t transport any Silver Carp from outside Eagle Lake.

Multistate Model
We will calculate the probability of Silver Carp transitioning from one spatial unit to another at a given time using discrete-time Markov chain analysis. We plan to use hourly time steps to calculate movement probability during spawning season because Silver Carp tend to move longer distances faster compared to when they are not spawning (Degrandchamp et al. 2008). For times of year when spawning is not occurring, we plan to use 12-hour time steps. The model assumes that the next spatial unit a Silver Carp will move into or stays in depends on which spatial unit the Silver Carp is currently in. Discrete-time Markov chain analysis will be used to create the transition matrix.

Results and Discussion:
We captured 95 Silver Carp from Steele Bayou (N = 76) and Eagle Lake (N = 19) and released 95 tagged Silver Carp. Silver Carp lengths varied from 561 –1100 mm and weights 1950–11,900 g (Table 2). A little over half of the Silver Carp captured were females. The average number of

fish tag detections per receiver is 45,476 detections (SD = 63,907; see table 3 for distribution of detections per gate).

No tagged Silver Carp have moved through Muddy Bayou Water Control Structure into or out of Eagle Lake. In contrast, there have been five passage events through Steele Bayou Water Control Structure. One tagged Silver Carp from the Yazoo River unit moved upstream through Steele Bayou Water Control Structure. Three tagged Silver Carp that were released in Lower Steele Bayou unit moved downstream through Steele Bayou Water Control Structure. One tagged Silver Carp that was released into Upper Steele Bayou unit moved downstream through the Steele Bayou Water Control Structure. Despite these passage events, most (87.5%) fish released upstream of Steele Bayou Water-Control Structure in Steele Bayou have stayed up within Steele Bayou and 12.5% have moved downstream through the structure. Most (95%) fish released below Steele Bayou Water-Control Structure moved downstream into Yazoo River toward the Mississippi River. In addition to Silver Carp tagged by us, we have detected 32 tags throughout our study area that are not related to our study. So far, we confirmed one of these tags is a Paddlefish that was originally tagged and released in Lake Barkley, KY and swam 965 km to our telemetry array.

Recommendations:
Continue study for second year and complete data analysis.

Table 1. – Silver Carp *Hypophthalmichthys molitrix* (N = 95) collection methods in Eagle Lake (LA, MS) and Steele Bayou (MS) and dates released between 2/26/2022 – 12/16/2022.

Unit	Date	Collection Method	Number of Fish
Eagle Lake	2022-02-26	Gillnetted	1
Eagle Lake	2022-03-17	Electrofished	3
Eagle Lake	2022-04-15	Electrofished	15
Lower Steele Bayou	2022-03-16	Electrofished	12
Lower Steele Bayou	2022-03-17	Electrofished	6
Lower Steele Bayou	2022-04-15	Electrofished	2
Lower Steele Bayou	2022-12-16	Electrofished	8
Upper Steele Bayou	2022-02-27	Gillnetted	3
Upper Steele Bayou	2022-03-16	Electrofished	17
Yazoo River	2022-04-04	Electrofished	14
Yazoo River	2022-04-15	Electrofished	6
Yazoo River	2022-12-16	Electrofished	8

Table 2. – Summary of Silver Carp *Hypophthalmichthys molitrix* (N = 95) total lengths and weights collected in Eagle Lake (LA, MS) and Steele Bayou (MS) between 2/26/2022 – 12/16/2022.

Variable	Mean	Min	Max	SD
Weight (g)	4,490	1,950	11,900	2,440
Total Length (mm)	721	561	1,100	127

Table 3. – Tag detections per gate ID. Detections are the total number of individual tag signals that receiver has recorded from start of study (2/28/2022) to the latest download (12/18/2022).

Gate ID	Waterbody	Detections
1.1	Yazoo River	23,487
1.2	Yazoo River	985
2.1	Yazoo River	1361
2.2	Yazoo River	47,308
3.1	Yazoo River	61
3.2	Yazoo River	193
4.1	Yazoo River	276
4.2	Yazoo River	265
5.1	Yazoo River	48,109
5.2	Yazoo River	39,163
6.1	Lower Steele Bayou	88,087
6.2	Lower Steele Bayou	148,044
7.1	Lower Steele Bayou	31,611
7.2	Lower Steele Bayou	22,502
8.1	Lower Steele Bayou	17,414
8.2	Lower Steele Bayou	17,291
9.1	Lower Steele Bayou	30,354
9.2	Upper Steele Bayou	37,561
10.1	Upper Steele Bayou	8947
10.2	Upper Steele Bayou	7075
11.1	Eagle Lake	7950
11.2	Eagle Lake	6531
11.3	Eagle Lake	188,915
12.1	Upper Steele Bayou	250,094
12.2	Upper Steele Bayou	124,320
13.0	Whittington Canal	34,492

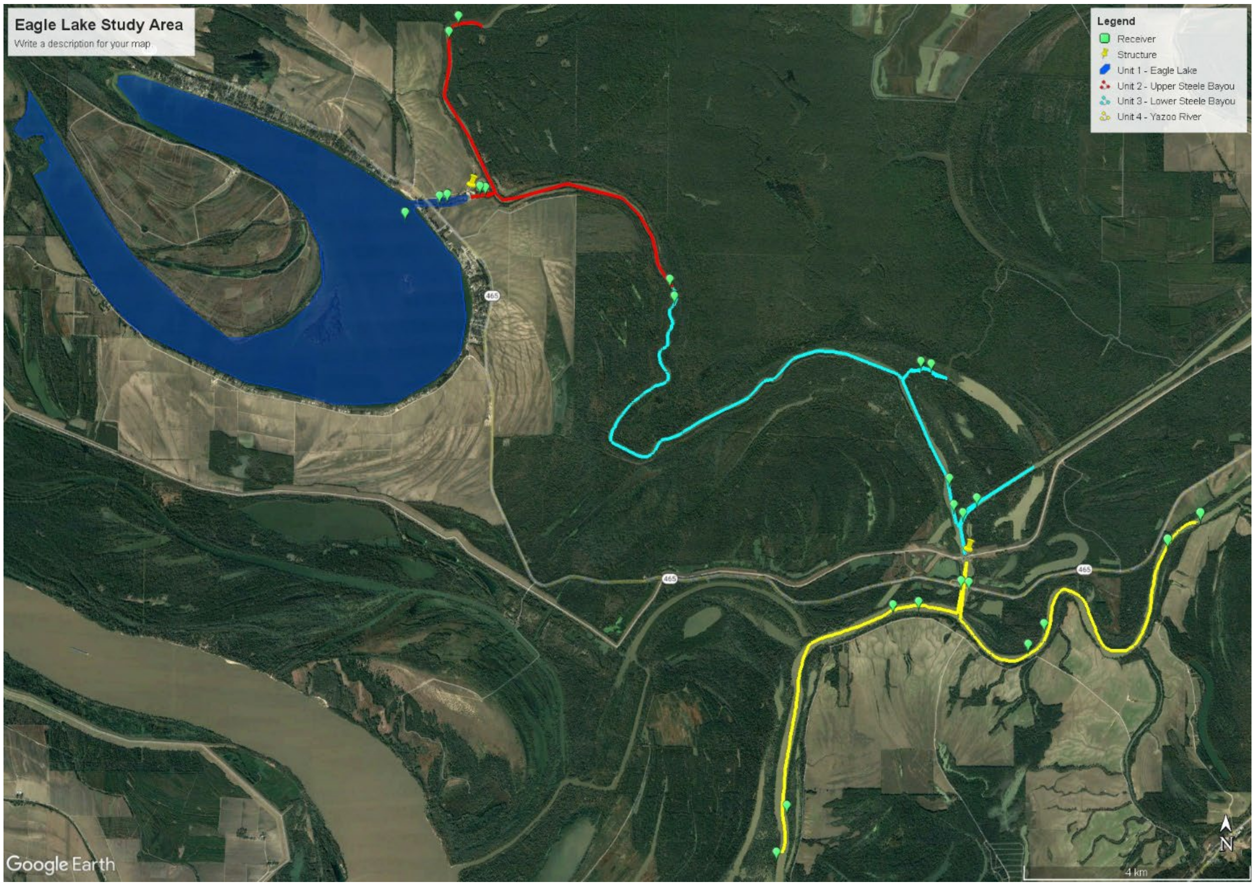

Figure 1.– Aerial view of Eagle Lake (LA, MS) study area and connected waterways. The locations of equipment are approximate.

Figure 2. – Receiver (VR2) deployment. The receiver (circled in red) is attached to the large cable that goes between the orange buoy and cement weights. The receiver is attached 1.5–2 m below orange buoy.

Figure 3. – Receiver with Bluetooth key inserted to initiate offload of tag detection data.

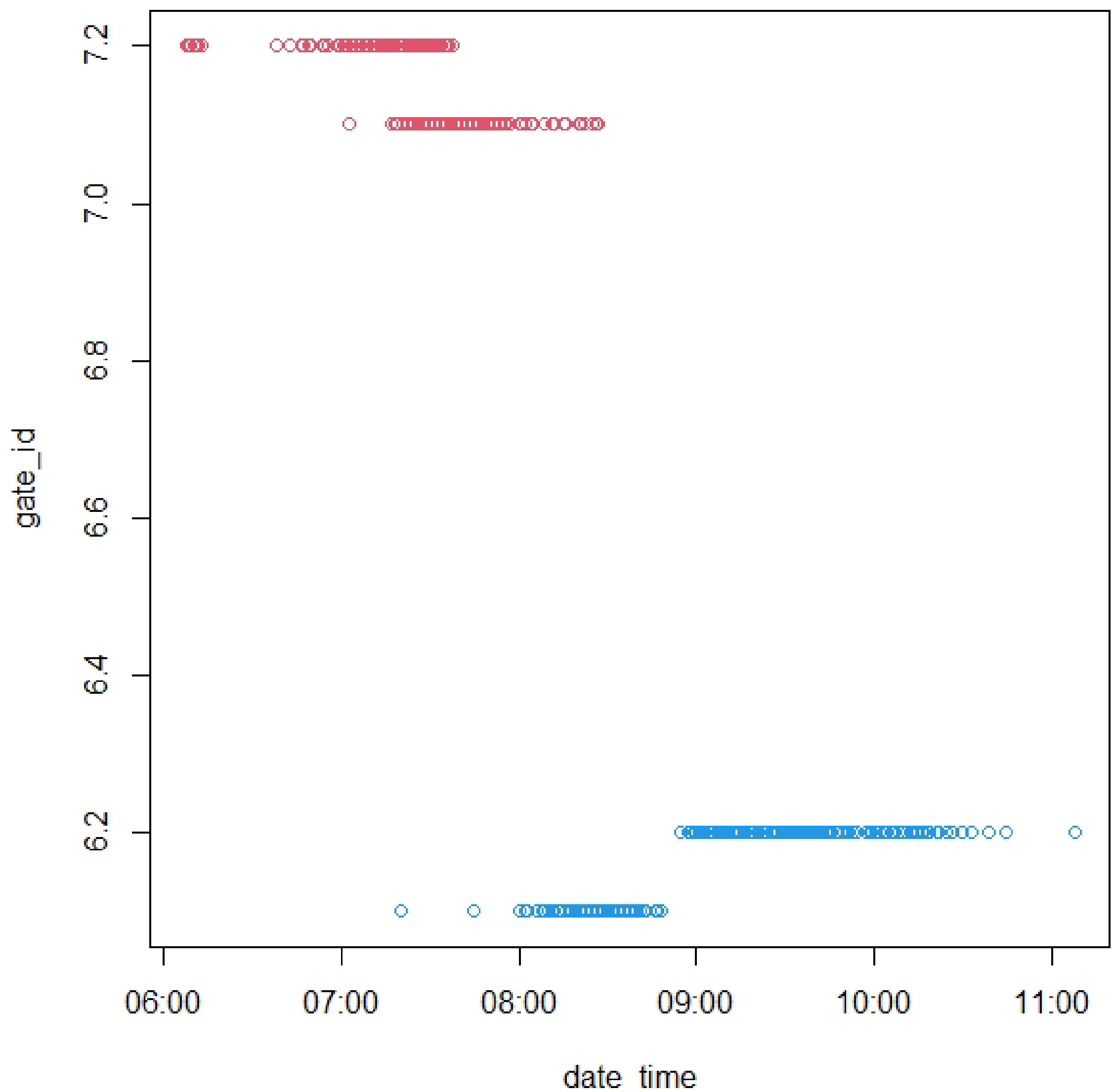

Figure 4. – Silver Carp (*Hypophthalmichthys molitrix*) (ID=59170) detected on receivers on 4/13/2022 in Steele Bayou and Whittington Canal, MS. Red group is a distinct downstream movement in Lower Steele Bayou as this fish moved past gate id 7.2 first and then 7.1. Blue group is a distinct upstream movement into Whittington Canal as the fish moved upstream past age ID 6.1 first and then by gate ID 6.2. See Figure 1 for locations of receivers.

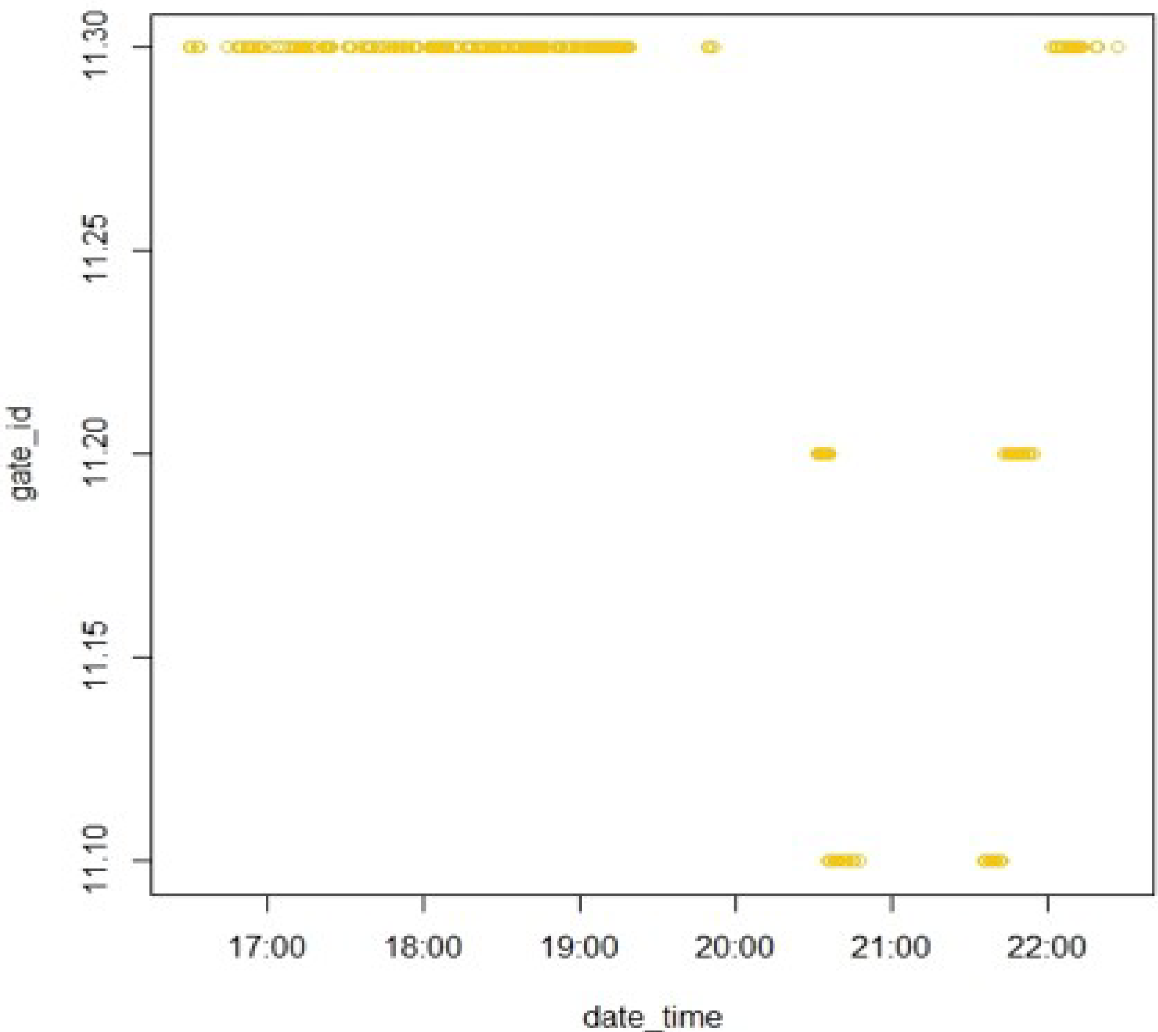

Figure 5. – Silver Carp (*Hypophthalmichthys molitrix*) (ID = 59,176) moving in a downstream movement on gate 11 5/25/2022 in Eagle Lake (LA, MS). Fish was detected on the upstream receiver (gate ID =11.3) first, then detected on downstream receivers (gate IDs = 11.2 and 11.1). However, the fish was not detected moving past gate ID 10, but went back upstream. Therefore, this movement is considered a downstream test.

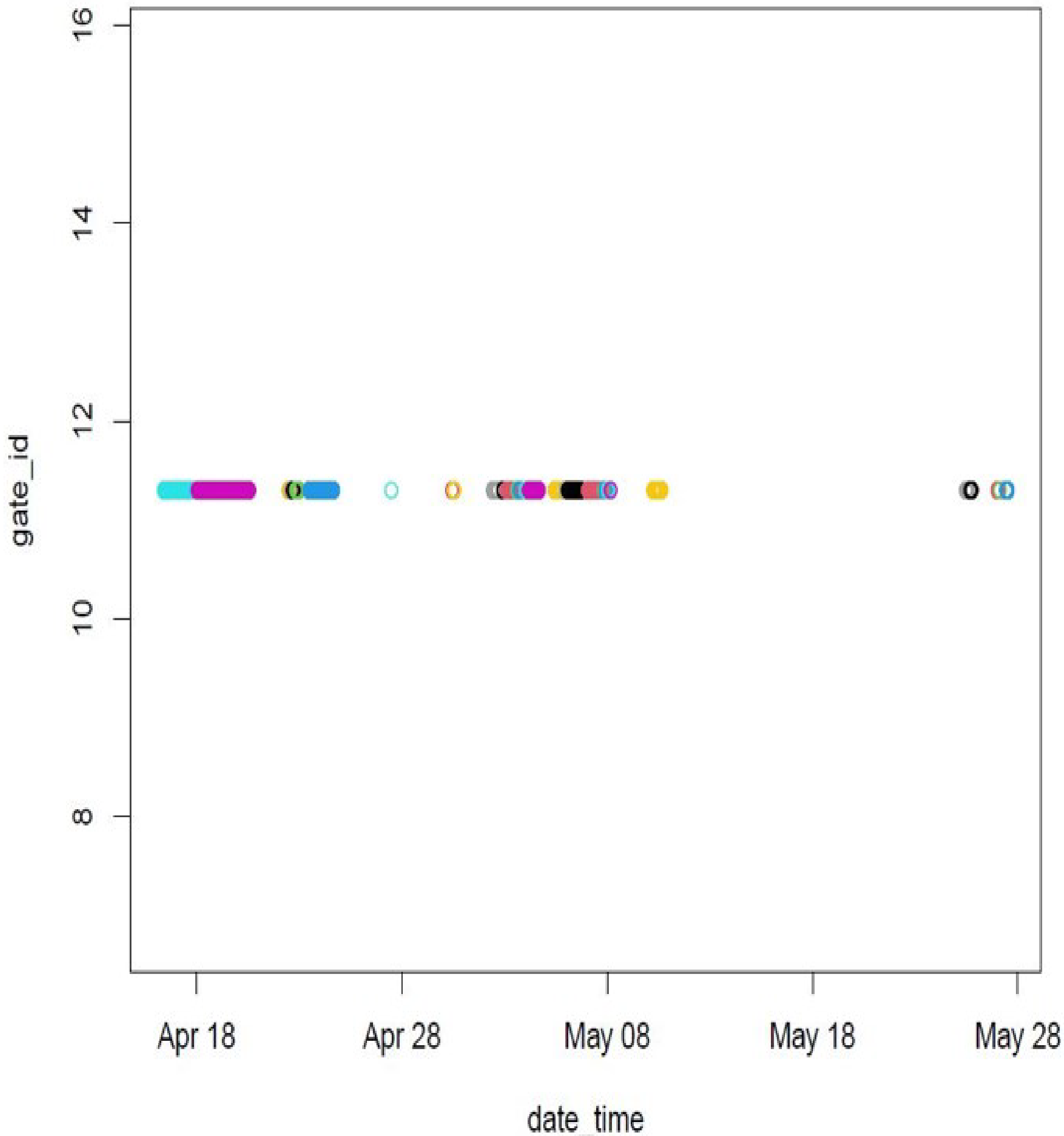

Figure 6. – Fish 59134 movement that was only detected on the upstream receiver (gate ID = 11.3) and considered "testing" 4/16/2022 - 5/27/2022 in Eagle Lake.

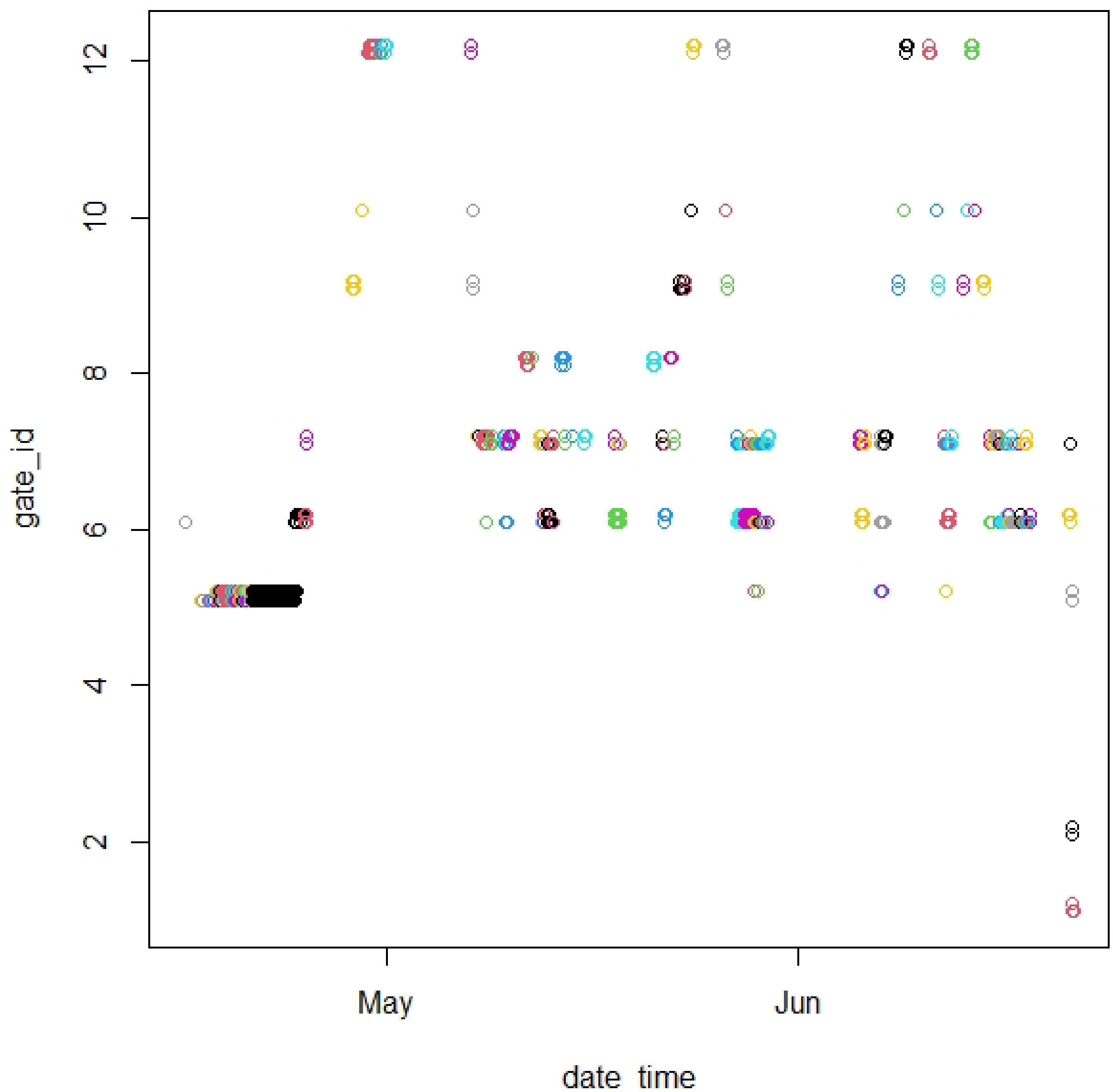

Figure 7. – All the passive detections of fish (ID = 59161) in Steele Bayou and Yazoo River 4/29/2022 – 6/21/2022. Moving from left (May) to right (June), this fish moved through Steele Bayou water control structure and then downstream passed gates 2 and then 1 towards the Mississippi River.

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

Methods:
All telemetry receivers were downloaded and maintained throughout the year; data was shared with the appropriate partners.

Results and Discussion:
Invasive carp movement has been tracked on a broad scale. Of the 100 carp tagged, four were detected at least a single day since being tagged in late fall 2021. All four of those carp were detected just outside the LMR system; three in the Ohio River at Cairo, IL, and one in the Mississippi River at Cairo, IL (Figure 1). The three carp traveled upstream approximately 4.8 river miles to the Ohio River at Cairo, while the one carp traveled upstream approximately 4.3 river miles to the UMR at Cairo (Table 1). Movement patterns should be assessed in depth to further assist with harvest efforts. Additional receivers might also be required, if logisitics allow, for increased coverage in the vast LMR system.

Tables and Figures:

Table 1. Origin (Mayfield Creek), transmitter ID, detected locations, distance from origin (DFO), and maximum distance traveled (MDT) for each fish tagged in the lower Mississippi River system.

Origin	Transmitter ID	Detected Locations	DFO	MDT
Mayfield	A69-1602-52028	Ohio River Cairo	4.8	4.8
Mayfield	A69-1602-52112	Ohio River Cairo	4.8	4.8
Mayfield	A69-1602-52119	Mississippi River Cairo	4.3	4.3
Mayfield	A69-1602-52125	Ohio River Cairo	4.8	4.8

Figure 1. Confluence of the Mississippi and Ohio Rivers near Cairo, IL, depicting relative locations of the three fish tagged at Mayfield Creek (blue dot) that traveled approximately 4.8 river miles upstream to the Ohio River (upper red dots) and the one fish that traveled approximately 4.3 river miles to the Upper Mississippi River (lower red dot).

Recommendations:

Monitoring invasive carp movement should continue until movement patterns are elucidated, at which time harvest should be the primary focus. Solidified movement patterns of invasive carp should allow for the most efficient harvest efforts to be carried out.

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

Methods:
Vemco VR2W-069k acoustic receivers (n=6) were deployed in the Reelfoot Lake area in 2022. Four receivers were placed in Reelfoot Lake, one receiver was placed below the spillway, and one receiver was placed approximately 16 km downstream of the spillway in Running Reelfoot Bayou (Figure 1). Silver carp were targeted with electrofishing boats and gill nets in April 2022. Silver carp (n=50) were implanted with Vemco 16-4x acoustic telemetry tags and organized into three separate categories: lake fish, translocated fish, and spillway fish. Lake fish were captured within Reelfoot Lake and released in Reelfoot Lake (n=13), translocated fish were captured within Reelfoot Lake and translocated below the spillway (n=25), and spillway fish were captured below the spillway and released below the spillway (n=12). Receivers were downloaded August 2022 and will be downloaded at six-month intervals.

Due to record low water levels, staff were unable to conduct the planned electrofishing efforts below Reelfoot Spillway.

Results and Discussion:
Silver carp (n=35) were detected on at least one acoustic receiver post-tagging. Spillway crossings occurred between April 11th, 2022, and May 5th, 2022, during a high-water event where water levels equalized between Reelfoot Lake and Running Reelfoot Bayou below the spillway**.** During this high-water event, gage height exceeded median daily levels below the spillway and silver carp (n=12) were able to cross the spillway, effectively entering or exiting Reelfoot Lake unimpeded (Figure 2). Spillway crossings did not occur once water levels decreased below the spillway. The spillway is an effective barrier for silver carp unless water levels equalize, usually during spring floods.

Silver carp tagged in Reelfoot Lake were detected on multiple receivers outside of Reelfoot, including receivers in the Mississippi and Ohio Rivers. Data shared by Missouri Department of Conservation documented a "lake" fish from Reelfoot over 600 river miles upstream near Lock and Dam 26 at Alton, IL. Remarkably, this fish was tagged on April 7, 2022, and detected at the aforementioned location on May 14, 2022, just 37 days post-tagging. Additionally, data shared by USGS (UMESC) and Kentucky Department of Fish and Wildlife Resources showed 11 silver carp from the Reelfoot project (4 lake, 7 translocated) were detected on Lower Ohio River receivers – most at Brookport, IL and Smithland, IL – and on lower Tennessee and Cumberland River receivers – with one appearing to have made passage into the Tennessee/Cumberland system.

Further tagging and monitoring of receivers in Reelfoot Lake was vital to understanding how silver carp move in and out of Reelfoot Lake and similar waterbodies. Further tagging efforts will be conducted in 2023 to increase numbers of tagged silver carp within Reelfoot Lake and to further explore environmental conditions that are conducive to carp passage.

Low water levels prevented completion of electrofishing efforts below Reelfoot Spillway beyond those completed for tagging purposes. As mentioned in previous reports, 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 winches). In the future, these efforts will be included only "as possible".

Tables and Figures:

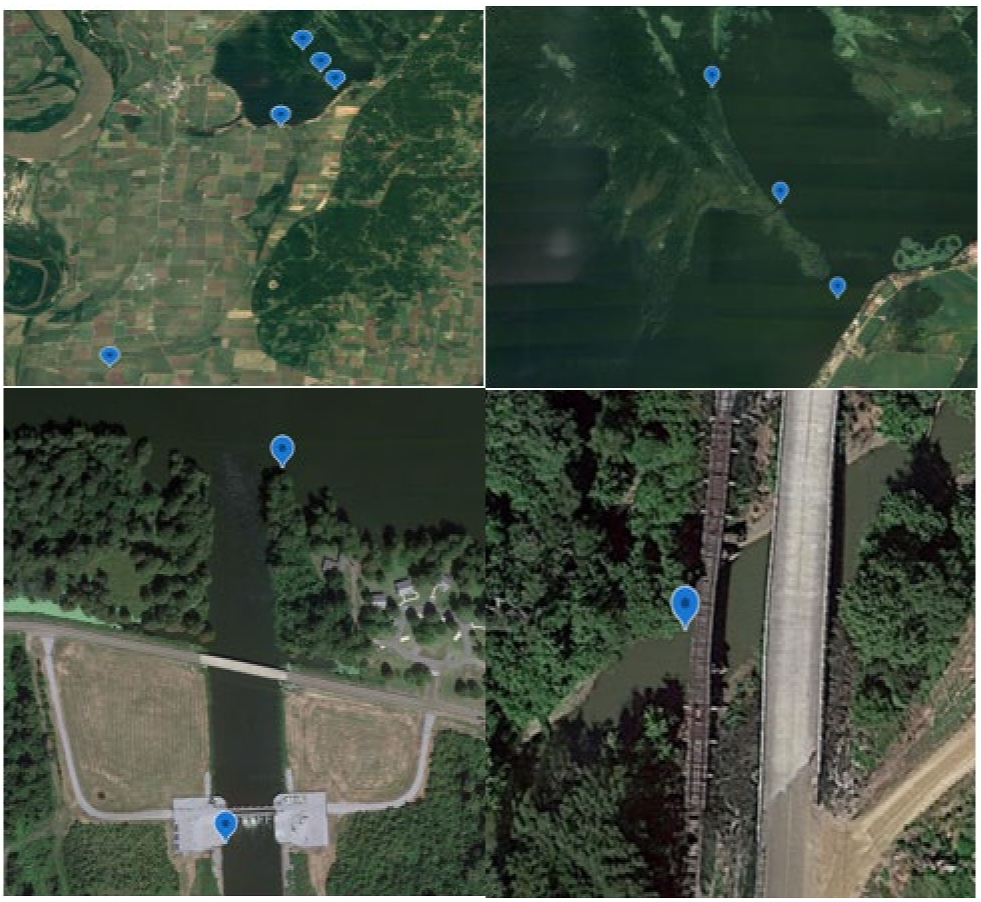

Figure 1. Receiver array at Reelfoot Lake (n=6; top left), with two receivers located at spillway (bottom left), three receivers in the lower basin including receivers at South Shore, Willow Bar Towhead Ditch, and Donelson Ditch (top right), and receiver location in Running Reelfoot Bayou (bottom right).

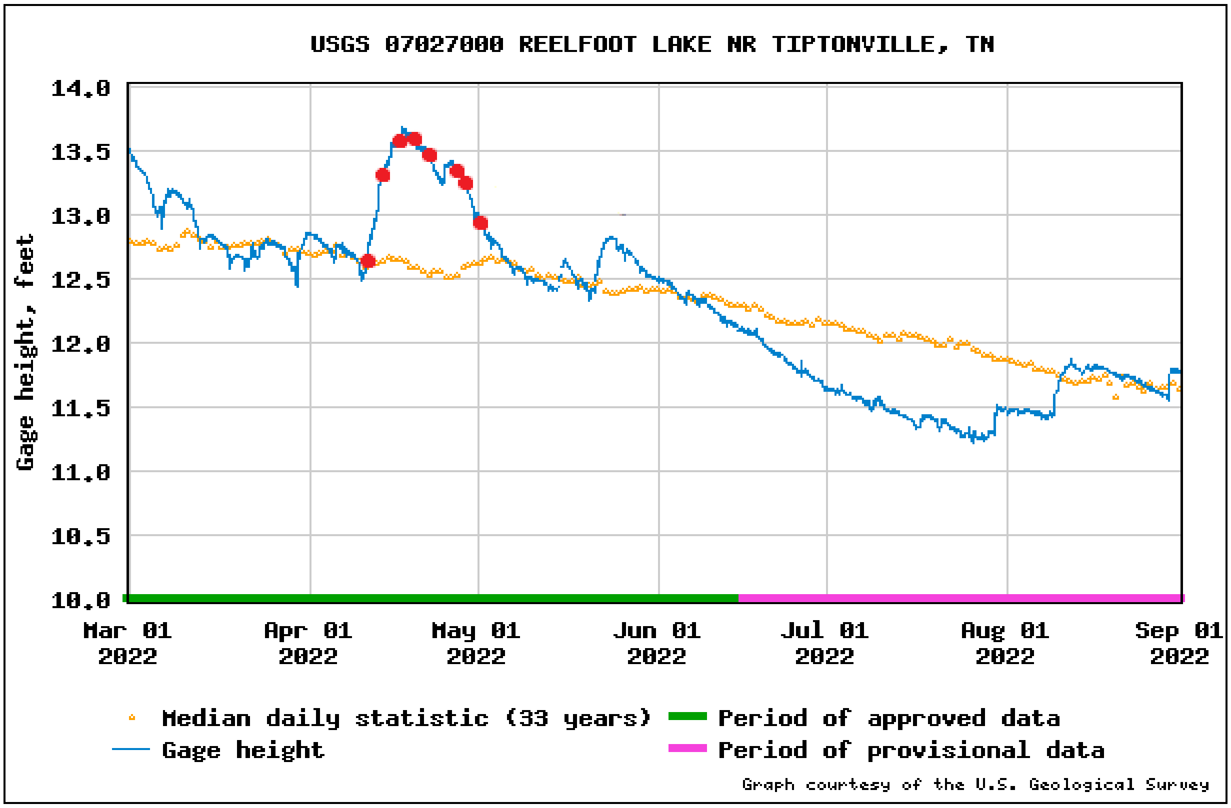

Figure 2. Gage height reading in Running Reelfoot Bayou below the Reelfoot Spillway between March 1st, 2022 and September 1st, 2022. Red dots indicate dates where Silver carp effectively crossed the spillway.

Recommendations:

- Additional tagging and expansion of the existing array is recommended.
- Further analyses and additional data are needed to continue to explore the mechanisms that drive carp passage at Reelfoot.
- Continue and expand upon collaborative efforts to track these fish as they move throughout sub-basin project areas and into other sub-basins.