Project Title: Invasive carp movement and habitat use in the Missouri River Basin to inform containment and control management actions.

Geographic Location: The study area includes Missouri River tributaries with direct connection to the lower Missouri River and periphery streams within the states of South Dakota, Iowa, Kansas, and Missouri. The lower Missouri River is the 1,305 river kilometers (rkm) of the mainstem Missouri River downstream of Gavins Point (the most downstream dam) to its confluence with the Mississippi River near St. Louis, MO. Tributaries of interest include:

- The James River joins the Missouri River approximately 18 rkm downstream of Gavins Point Dam and extends into South Dakota and North Dakota. The study area will focus on the lower 358 rkm of the James River upstream of the Missouri River confluence to Huron, South Dakota.
- The Vermillion River joins the Missouri River at approximately rkm 1,242 and extends into South Dakota. The study area will focus on the lower 192 rkm of the Vermillion River upstream to the East Vermillion Lake dam.
- The Big Sioux River joins the Missouri River at approximately rkm 1,181 and extends into Iowa and South Dakota. The study area will focus on the lower 255 rkm of the Big Sioux River upstream to the Sioux Falls in Sioux Falls, SD.
- The Little Sioux River joins the Missouri River at approximately rkm 1,077 and extends into Iowa and Minnesota by way of the Iowa Great Lakes, which are comprised of seven different waterbodies that are extremely important recreationally and economically. This study will focus on the 415 rkm from the confluence with the Missouri River to the electric barrier on the outlet of the Iowa Great Lakes and upstream to the Iowa-Minnesota border. Following flooding in 2012 that allowed invasive carps to invade the Iowa Great Lakes, the Iowa DNR, Minnesota DNR, and local partners installed the electric barrier. In December 2019, a Silver Carp was captured in the Ocheyedan River, about 100 yards from the Iowa border in southwestern Minnesota.
- The Kansas River joins the Missouri River at approximately rkm 591 and extends into Kansas. This study will focus on the area from the confluence with the Missouri River near Kansas City, MO, to Bowersock Dam near Lawrence, KS (rkm 60).
- The Grand River joins the Missouri River at approximately rkm 402 and extends north into Missouri with its headwaters in Iowa. This study will focus on the confluence with the Missouri River near Brunswick, MO.
- The Lamine River joins the Missouri River at approximately rkm 325 and extends south into Missouri. This study will focus on the confluence with the Missouri River near Booneville, MO.
- The Moreau River joins the Missouri River at approximately rkm 222 and extends south into Missouri. This study will focus on the confluence with the Missouri River near Jefferson City, MO.
- Creve Coeur Creek joins the Missouri River at approximately rkm 50 and provides access

to Creve Coeur Park Lake, a high-use recreational area with a 320-acre oxbow lake in the Missouri River floodplain owned and maintained by St. Louis County Parks and Recreation Department. This study will focus on the 3.5 rkm from the confluence with the Missouri River to the concrete spillway on the outlet of Creve Coeur Lake.

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Participating Agencies:

- Iowa Department of Natural Resources (IA DNR) & Iowa State University (ISU); Mike Weber
- Missouri Department of Conservation (MDC); Joe McMullen
- South Dakota Department of Game, Fish, and Parks (SDGFP) & University of South Dakota (USD); Tanner Davis
- USFWS – Great Plains FWCO); Dan James

Statement of Need: Containment (Goal 2 in the National Plan and Goal 3 in the Missouri River Framework) prevents invasive carp from expanding a known population confined to its current geospatial distribution. Knowing the movement range of Bighead and Silver Carp in the Missouri River basin as well as the environmental conditions associated with movements or congregations in association with deterrent barriers currently present in the Missouri River Basin will allow for the identification of locations where deterrence technologies, concentrated removal efforts, physical barriers, or other emerging technologies can be utilized for containment and control. Identification and evaluation of containment opportunities can facilitate the implementation of deterrent and/or removal systems that may limit dispersal, reproduction, or recruitment of invasive carp. A better understanding of the movement and behavior of invasive carp in tributaries and in association with barriers as outlined in this proposal is critical to devising strategies for successful containment.

As stated in National Plan Goal 6, scientifically valid research is necessary to provide accurate information for the effective management and control of Bighead and Silver Carp. This research will be used to develop criteria for deterrent barriers, harvest regulations, or other management activities. Invasive carp are well established throughout the Missouri River and tributaries downstream of Gavins Point Dam. Knowing when and under what environmental conditions adult Bighead and Silver carp are moving into the tributaries will help inform when to monitor the population as well as implement management actions. Understanding the movement range of Bighead and Silver Carp in the Missouri River basin, the environmental conditions associated with movements, and the conditions associated with congregations at deterrent barriers currently present in the Missouri River Basin will allow for the identification of locations where deterrence technologies, concentrated removal efforts, physical barriers, or other emerging technologies can be utilized for containment and control. Identification and evaluation of containment opportunities can facilitate the implementation of deterrent and/or removal systems that may limit dispersal, reproduction, or recruitment of invasive carp. A better understanding of the movement and behavior of invasive carp in tributaries and in association with barriers as outlined in this proposal is critical to devising strategies for successful containment.

Invasive carp populations extend into the interior waters of Missouri River Basin states such as Minnesota via the Little Sioux River in northwestern Iowa and North Dakota via the James River. The Little Sioux and James rivers have barriers that act as deterrents under certain conditions. Flooding in 2012 allowed invasive carps to invade the Iowa Great Lakes that are comprised of seven different waterbodies that are extremely important recreationally and economically. The IADNR, Minnesota Department of Natural Resources, and local partners responded to the invasion by installing an electric barrier on the outlet of Little Gar Lake, the most downstream lake in the Iowa Great Lakes chain with a 352 km2 watershed that includes both Iowa and Minnesota. Additionally, the Little Sioux River originates in southwestern Minnesota and in December 2019, a Silver Carp was captured in the Ocheyedan River, about 100 yards from the Iowa border in southwestern Minnesota.

The electric barrier on the outlet of the Iowa Great Lakes is 49 m wide and 8 m long and consists of eight electrodes and seven pulsers that span the width of the outlet with a gradient of electrical intensity. The barrier is only activated when water on the barrier surpasses 3”, which typically occurs in the spring when invasive carps migrate upstream for spawning but can also occur periodically during the summer and fall, albeit less frequently. While the barrier has been in place since 2013, no evaluations have occurred to determine how effective it is at slowing or stopping upstream movements of invasive carp. Invasive carp are frequently observed below the barrier and anecdotal evidence suggests that they may have passed the barrier during high water in 2018, as individuals are occasionally captured in the Iowa Great Lakes; however, it is unknown if these fish are new individuals that have recently passed the barrier or fish that were part of the initial invasion. Downstream movement of fishes past the barrier from the Iowa Great Lakes is commonly observed; thus, upstream fish passage through the barrier may also be possible.

A number of different invasive carp barrier evaluations have been conducted to date using a variety of different deterrents. However, most of these evaluations have occurred in laboratory settings due to the cost and regulations associated with installing barriers in natural environments. Electrical barriers likely hold the most promise for limiting or stopping the upstream movement of invasive carp and the barrier currently in place on the Iowa Great Lakes is only one of a few systems available in the world that provides an opportunity to test its effectiveness under natural conditions. However, no evaluations of this barrier have been conducted to date and it is currently unknown how effective the barrier is at preventing upstream movement of fish. Additionally, no information is available regarding the seasonal presence of invasive carp at the barrier or the source of these fish (e.g., Little Sioux River residents or migrants from the Missouri River). Further, the timing and frequency of invasive carp movements further upstream into Minnesota is unknown but could provide information about invasion phenology. Thus, more information regarding tributary movements of invasive carp and potential effectiveness of electric barriers at minimizing or stopping their upstream movements is needed.

Project Objectives:

1. Determine Silver Carp and Bighead Carp residence time and movement in the Missouri River and its tributaries in association with season, environmental conditions, and barriers to inform containment and control management actions.
   1.1. Determine if Silver Carp and Bighead Carp have extended presence in tributaries and directional movement into and out of Missouri River tributaries.
   1.2. Evaluate environmental factors (e.g., season, temperature, discharge) for Silver Carp and Bighead Carp movements in select Missouri River tributaries.
   1.3. Assess fish behaviors in association with an electric barrier at the outflow of the Iowa Great Lakes, a concrete spillway at Creve Coeur Lake, and dams on the Kansas River (WaterOne Dam and Bowersock Dam), particularly how fish approach, challenge, and pass the barriers.
   1.4. Evaluate seasonal congregations of Silver Carp and Bighead Carp in Missouri River tributaries, particularly as they relate to fish barriers.

Project Highlights:

- Invasive carp were commonly located downstream of the electric barrier near Milford, IA. Fish movements into tributaries were related to higher flow events.
- Tagged Silver Carp in the James River, SD, almost exclusively remained in the James River throughout the duration of the study period (with only one exception).
- Detections on telemetry receivers were recorded for 40 of the 50 tagged fish in the James River, and the average distance moved was 83.7 river kilometers.
- Stationary telemetry receiver array expanded into the Kansas River.
- Majority of carp movement limited to tributary of tagging origin or within the Missouri River system, with only 3 carp leaving the Missouri River.
- Carp that stayed within the Missouri River system traveled up to 74.5 river miles from their tagging origin.
- One carp traveled 746 river miles from the Moreau River down the lower Missouri River, down the Middle Mississippi and Lower Mississippi River, and up into the White River near St. Charles, Arkansas.

Iowa Department of Natural Resources and Iowa State University

Methods:

We deployed an array of twenty-eight VEMCO acoustic receivers (VR2W, n=26; VRTx, n=2) in spring 2022 within the Little Sioux River basin, Missouri River, and Iowa Great Lakes using a combination of bridge-mounted housings and bottom-set stands (Figure 1). Bridge mounted receivers within the Little Sioux River (16), Ocheyedan River (1), West Fork Little Sioux River (1), and Missouri River (1) were deployed in PVC housings that we attached to the downstream side of intersecting highway bridges during summer 2021. Acoustic receivers were suspended with 3-mm stainless steel cable inside the housing that allowed them to be fully submerged while being protected from floating debris in the river. Bottom set receivers were required in the West Fork Little Sioux River (1), Milford Creek (3), Ocheyedan River (1), and Lost Island Outlet (2), as there were no intersecting highway bridges at every desired receiver location (Figure 2). We conduct routine receiver maintenance at approximately 3-6 month time intervals to ensure receivers are functioning properly, download detection data, and install new batteries. We also deployed water temperature loggers (HOBO 64K Pendant data loggers; Onset Computer Corp., Bourne, Massachusetts) with each receiver that were programmed to record data at 1-hour intervals. To monitor water levels in the Little Sioux River, West Fork Little Sioux River, Milford Creek, Ocheyedan River, and Lost Island Outlet, we deployed five water level loggers (HOBO U20 Water Level Loggers; Onset Computer Corp., Bourne, Massachusetts) during June 2022 that record pressure at 1-hour intervals for each waterbody that can then be converted to water levels. We suspended loggers in PVC housing clamped to a 2.5-m T-post and pounded into the stream bed. We also deployed dissolved oxygen loggers (miniDOT Logger; Precision Measurement Engineering Inc, Vista, California) in all five systems and attached to the same PVC housings to monitor temporal fluctuations in DO (mg/l). Dissolved oxygen loggers were programmed to record measurements at 10-minute intervals.

We conducted boat electrofishing (Smith Root Model VVP- 15b, pulsed DC 170-200 V, 8-10 amps) and seining (15.0 x 2-m, 4-mm mesh) during May 2022 to capture Silver and Bighead Carp for acoustic tagging. We focused sampling efforts on the northern reaches of the Little Sioux River in the Iowa Great Lakes Region near the confluences (<5 rkm) of the West Fork Little Sioux River, Milford Creek, Ocheyedan River, and Lost Island Outlet. We seined within tributaries where boat travel was not feasible due to low water levels. Before each surgery, we measured fish for total length (mm) and weight (g) and identified sex using the presence of a rough patch on pectoral fin rays (present indicates male, absent indicates female; Wolf et al. 2018; Lederman et al. 2022) or by visually inspecting gonads during surgeries.

We implanted a number of different acoustic tags in invasive carp. The simplest transmitters (V13-1x, n=21 and V16-4x, n=40, VEMCO Inc., Halifax, Nova Scotia, Canada) provide presence/absence data at receiver locations. We also implanted V16A-6x (n=10) and V16T-4x (n=10) to transmit presence/absence data along with acceleration (V16A, m/s^2) and temperature

(V16T, °C) data for each tag transmission detected by receivers. Across all tags, transmitter weight did not exceed 2% of wet weight of fish (Winter 1996). We tagged 67 Silver Carp (male n=51, female n=16) and 14 Bigheaded Carp (male n=5, female n=9) during May 2022. We tagged a majority of Silver Carp near (<5 rkm) the confluence of the Ocheyedan River (n=5, [TL: 621-800mm, mean TL = 677mm]), Lost Island Outlet (n=17, [TL: 466-826 mm, mean TL = 639 mm]), and Milford Creek (n=16, [TL: 542-750 mm, mean TL = 659 mm]). We tagged 14 Bighead Carp (TL: 522-758 mm, mean TL = 663 mm) and 9 Silver Carp (TL: 605-949 mm, mean TL = 704 mm) within Milford Creek, approximately 300 m downstream of the electric fish barrier located at the outflow of Lower Gar Lake in May 2022. Finally, we tagged 20 (TL: 531-809 mm, mean TL = 655 mm) additional Silver Carp further downstream between Cherokee, IA, and Correctionville, IA. Acoustic receiver and fish tag data is archived and shared with partners throughout the Midwest via FishTracks (https://umesc-gisdb03.er.usgs.gov/Fishtracks) operated and maintained by USGS.

<u>Component 1.2:</u> Assess fish behaviors in association with an electric barrier at the outflow of the Iowa Great Lakes.

Invasive carp are well established throughout the Missouri River and its tributaries. Flooding in 2012 allowed invasive carps to move upstream in the Little Sioux River and invade the Iowa Great Lakes that are comprised of seven different waterbodies that are extremely important recreationally and economically. The Iowa DNR, Minnesota DNR, and local partners quickly responded to the invasion by installing an electric barrier on the outlet of Little Gar Lake, the most downstream lake in the Iowa Great Lakes chain with a 352 km^2 watershed that includes both Iowa and Minnesota. The electric barrier on the outlet of the Iowa Great Lakes is 49 m wide and 8 m long and consists of eight electrodes and seven pulsers that span the width of the outlet with a gradient of electrical intensity. The barrier is only activated when water on the barrier surpasses 7.6 cm (3”), which typically occurs in the spring when invasive carp migrate upstream for spawning but can also occur periodically during the summer and fall, albeit less frequently. While the barrier has been in place since 2013, no evaluations have occurred to determine how effective it is at slowing or stopping upstream movements of invasive carp. Invasive carp are frequently observed below the barrier and anecdotal evidence suggests they may have passed the barrier during high water in 2018, as individuals are occasionally captured in the Iowa Great Lakes; however, it is unknown if these fish are new individuals that have recently passed the barrier or fish that were part of the initial invasion. Downstream movement of fishes past the barrier from the Iowa Great Lakes is commonly observed (Jonathan Meerbeek, Iowa DNR, personal communication); thus, upstream fish passage through the barrier may also be possible.

Several different invasive carp barrier evaluations have been conducted to date using a variety of different deterrents. However, most of these evaluations have occurred in laboratory settings due to the cost and regulations associated with installing barriers in natural environments. Electrical barriers likely hold the most promise for limiting or stopping the upstream movement of invasive carp and the barrier currently in place on the Iowa Great Lakes is only one of a few systems available in the world that provides an opportunity to test its effectiveness under natural conditions. However, no evaluations of this barrier have been conducted to date, and it is currently unknown how effective the barrier is at preventing upstream movement of fish. Additionally, no information is available regarding the seasonal presence of invasive carp at the barrier or the source of these fish (e.g., Little Sioux River residents or migrants from the Missouri River). Further, the timing and frequency of invasive carp movements further upstream into Minnesota is unknown but could provide information about invasion phenology. Thus, more information regarding tributary movements of invasive carp and potential effectiveness of electric barriers at minimizing or stopping their upstream movements is needed.

To assess number of fishes and fish behavior at the electric barrier, we installed an outdoor video surveillance camera (Sunba network PTZ) at the electric barrier during June 2022 (Figure 3). We mounted the camera to a fence pole directly above the barrier and positioned it for the best possible view of fish movements on top of and below the barrier. We added a polarized 49-mm lens coupled with a UV protective lens in front of the camera lens to reduce the reflective glare on the water's surface. Additionally, we cut down vegetation below the barrier to maintain an unimpeded view of fish movements.

After the initial setup, we programmed the camera to record videos during randomly selected 15-minute intervals from each hour of the day that were saved to a hard drive on site. From these videos, we will categorize fish behaviors as avoidance (slow approach and retreat away from the base of the electrical barrier), erratic (deviation from normal swimming behavior including rapid bursts of movement), challenging (persistent attempt to swim upstream over the barrier but is unsuccessful), inhibition (swimming inhibited due to involuntary contraction and relaxation of the muscles), galvanotaxis (actively swimming toward anode due to electrical field), motionless (temporarily stunned or involuntary relaxation of muscle due to shock from barrier), tetany (severe involuntary muscle contraction, open mouth, lack of operculum movement; death), and advanced (stunned but made a successful attempt and crossed the barrier; Ostrand et al. 2009). In addition, we will document the number of Silver Carp jumps, number of fishes present, and the total amount of time each fish spends actively trying to challenge the barrier.

We recorded voltage in the electric field on and adjacent to the barrier via an oscilloscope in May 2022. We will periodically measure barrier voltage when water inundates the barrier to document any change in the electrical output. Likewise, we will periodically measure water velocity across the top of the barrier to document water flow under various conditions to develop a relationship between water depth and velocity. Finally, we are collecting water temperature data every 15 minutes below the barrier via a HOBO data logger.

Results and Discussion:
We downloaded all 28 acoustic receivers located throughout the study area at least once between early-August and mid-November. Due to low water levels during late July and much of fall 2022, multiple bridge receivers were not in service. In addition, multiple bottom set receivers were covered in sediment over unknown time periods during summer 2022 but were checked at approximately one-month time intervals to uncover from sediment, if needed.

Cumulatively, we have acquired 139,944 invasive carp detections on the three receivers located within Milford Creek between May 4th and November 14th, 2022. Most of these detections (139,748) were recorded by the acoustic receiver 250 m downstream of the electric fish barrier. Of the 23 fish (9 Silver Carp and 14 Bighead Carp) tagged in Milford Creek, all but 1 Silver Carp has been detected near the barrier. The number of fishes detected near the barrier decreased significantly from May 4th to November 14th, while detections of unique individuals at the middle and confluence receiver locations increased during June and July (Figure 4). No acoustically tagged invasive carp have been detected in the Iowa Great Lakes.

Since early May, 5 Bighead Carp and 3 Silver Carp moved from Milford Creek to the Little Sioux River. One of the 5 Bighead Carp that left Milford Creek was detected in the West Fork Little Sioux River, Ocheyedan River, and Lost Island Outlet all within a 3-day period. After its last detection in Milford Creek on July 8th, this individual was detected a total of 50 times across 14 different receivers and traveled approximately 545 km before its last detection at our Missouri River receiver located approximately 35 km downstream of the Little Sioux River confluence on July 24th (Bighead Carp 1, Figure 5). Of the 58 Silver Carp tagged in the Little Sioux River, none have been detected in Milford Creek. However, there have been multiple Silver and Bighead Carp detected moving into the West Fork Little Sioux River, Ocheyedan River, and Lost Island Outlet. The number of unique individuals detected per month appeared to be highest in these tributaries during June, followed by July (Figure 6) that corresponded with periods of increased discharge in the Little Sioux River (Figure 7) and increased water levels in tributaries (Figure 8). However, due to acoustic receivers being covered in sediment within Lost Island Outlet and the Ocheyedan River during multiple unknown time periods throughout summer 2022, the number of individuals detected in these systems may have been underestimated. Multiple gaps in detections that we observed may also imply some individuals are still present within these systems and could explain why they have not been detected anywhere in the Little Sioux River since those occasions. Finally, of the 81 fish tagged from May 4th - 18th (Silver Carp and Bighead Carp combined), we have not detected 5 Silver Carp anywhere in the acoustic receiver array.

Disregarding the 8 fish that moved from Milford Creek to the Little Sioux River, the remaining 15 appear to be highly resident and have shown very little signs of movement from their initial tagging location near the electric fish barrier. Total fish detections near the barrier dropped significantly during late-July through mid-November that coincided with declining water levels. However, large numbers of fish (primarily Bighead and Silver Carp) were observed in person on multiple occasions throughout summer 2022 approximately 300 meters downstream of the electric fish barrier (~75 meters downstream of nearest acoustic receiver). Optimal detection ranges of acoustic receivers in Milford Creek were < 50 meters (61% detection probability at 50 m) in June 2022 when water levels were relatively high, suggesting tagged fish in this area downstream of the receiver likely had lower detection probabilities. A portable hydrophone was used in this area to attempt to detect any Silver or Bighead Carp that may have been present and whether any mortalities had occurred. Five Bighead Carp and 2 Silver Carp that were initially tagged in this area were detected, but the determination of mortalities was inconclusive.

To evaluate Silver and Bighead Carp movements in the Little Sioux River and its tributaries, we classified movement events as either upstream or downstream. Directional movements were considered as sequential detections of an individual on a series of receivers that followed a unidirectional pattern. Fish we tagged on May 18th did not have as many days to move as other individuals, so movements in May were not directly compared to the other months. Since a large majority of our receivers were downloaded in the first and second week of November, detection data was only analyzed through October 31st.

Monthly movements of Silver and Bighead Carp appeared to be correlated with Little Sioux River discharge. High rainfall during June initiated both upstream and downstream movements of various magnitudes for both species. We observed Silver Carp movements were more frequent and larger during June that coincided with an extended period of high discharge in the Little Sioux River. Thirty-three of 67 Silver Carp exhibited at least 1 upstream movement (mean: 47.0 km ± 8.12 SE), and 30 individuals had 1 or more downstream movements during June (mean: 51.0 km ± 8.18 SE). In July, average Silver Carp upstream (mean = 20.6 km ± 8.38 SE) and downstream (mean = 21.2 km ± 6.38 SE) movements were smaller. Movement appeared to be very limited between August and October; only two upstream movements were observed between two individuals during August (mean = 33.75 km ± 7.35 SE) that coincided with a slight increase in Little Sioux River discharge. Across all months, the furthest downstream Silver Carp movement (225 km) exceeded the furthest upstream movement (205 km; Figure 9). Throughout much of August and all of September and October, there were no detections of Silver Carp that suggested any type of movement event.

Bighead Carp generally showed less signs of movement than Silver Carp, where only 6 of 14 fish had a movement event from June 1st to October 31st. Only one individual had an upstream movement event during June (3.5 km), while 3 individuals had downstream movements (mean = 38.8 km ± 19.78). Comparatively, Bighead Carp downstream movements (mean = 130.72 km ± 68.14 SE) were more frequent and larger than upstream movements (mean = 37.3 km ± 27.63 SE) during July. The furthest upstream Bighead Carp movement was 92 km and occurred in the beginning of July, while the largest downstream movement spanned from 3 km upstream into the West Fork Little Sioux River to 35 km downstream of the Little Sioux River/Missouri River confluence (~395 km) during mid-late July. Similar to what was observed in Silver Carp, Bighead Carp movement from August – October was very limited. In fact, we did not observe a single movement event from the end of July until our most recent data download in November. As of October 31st, 3 Silver Carp and 1 Bighead Carp have been detected at the receiver near the Little Sioux River mouth (Figure 5). Since their last detection at this receiver, we have only detected the Bighead Carp once in our array. We detected this individual in the Missouri River ~35 km downstream of the Little Sioux River confluence 4 days after its last detection in the Little Sioux River. Of the 3 Silver Carp that were last detected near the Little Sioux River mouth in mid-June and mid-July, none have been detected again within our array. However, 1 individual was detected on September 4th ~40 km upstream into the Platte River, ~160 km from the mouth of the Little Sioux River, representing a total minimum movement of 253 km from its tagging location near Correctionville, IA.

Low water levels exhibited throughout much of the Little Sioux River basin in late-July and subsequent months could potentially explain why movement was limited during this period. Drought-like conditions persisted through August, September, and October 2022 across much of the Little Sioux River basin, likely limiting movements during this time. Future detection data will allow us to assess how invasive carp movement can be affected by environmental conditions and the potential reduction in habitat connectivity among different systems on a seasonal basis. Additional years of data under variable river discharge patterns will provide insights into how movements vary interannually based on wet versus dry years.

Component 1.2: Assess fish behaviors in association with an electric barrier at the outflow of the Iowa Great Lakes.

During summer 2022, we experimented with a number of different camera configurations to assess options for evaluating fish behaviors at the Lower Gar electric barrier. Initial video analysis revealed our ability to see and identify fishes decreased with increasing distance from the camera. Similarly, we found the infrared light emitted by the LED lights on the camera at night were only illuminating a small section of our viewing frame. Therefore, we repositioned the camera to focus on visible fish movements on the north end of the barrier (Figure 10). After the installation of the surveillance camera, there were 60 days (06/14/2022 - 08/12/2022) when the barrier was active and water was flowing. Of the 60 days of flow, we captured 32 days (7/12/2022 – 8/12/2022) of viable videos. There has been no flow over the barrier between August and November 2022. On the day’s videos were viable, we did not observe any fishes trying to cross the barrier. Instead, we observed fishes downstream attempting to challenge the barrier. We will continue to monitor fish activity and their behaviors at the barrier when water levels increase. We have also been working on study logistics to assess barrier effectiveness more thoroughly once flows over the barrier resume.

Field measurements of voltage variation between electrodes resulted in strengths of 4.2 V/cm between electrodes one and two, 5.0 V/cm between electrodes two and three, 5.3 V/cm between electrodes three and four, 5.2 V/cm between electrodes four and five, 5.0 V/cm between electrodes five and six, 5.6 V/cm between electrodes six and seven, and 4.6 V/cm between electrodes seven and eight. Stray voltage 1 m below electrode one had a strength of 0.86 V/cm, while stray voltage 1 m above electrode eight had a strength of 0.6 V/cm (Figure 11).

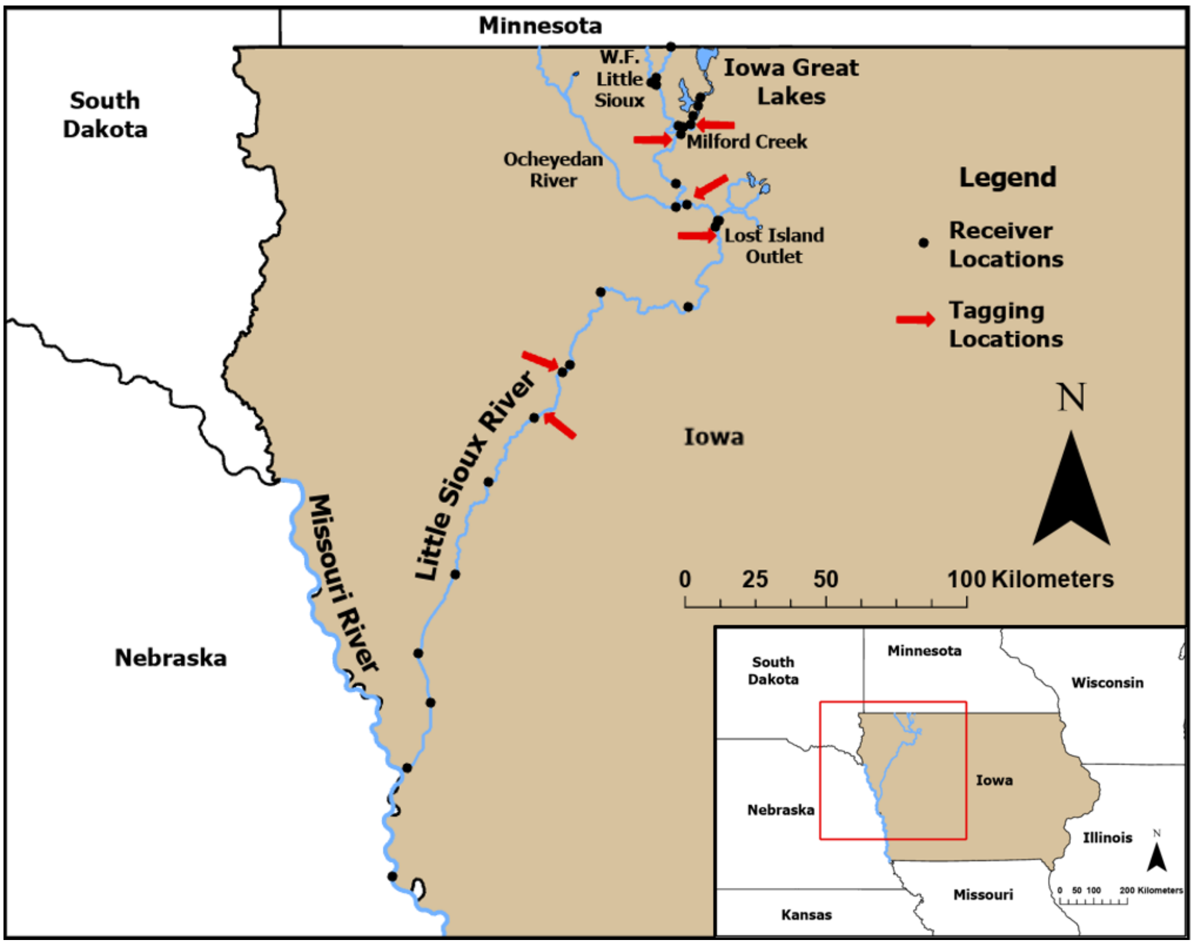


Figure 1. Little Sioux River, four of its tributaries, and the Iowa Great Lakes in Northwest Iowa. Black dots indicate acoustic receiver locations in the Missouri River (1), Little Sioux River (16), West Fork Little Sioux River (2), Milford Creek (3), Ocheyedan River (2), and Lost Island Outlet (2). Two additional acoustic receivers were deployed in the Iowa Great Lakes upstream from the electric fish barrier that will help assess its efficacy in deterring invasive carps. We acoustically tagged invasive carp at six sites (red arrows) in the Iowa Great Lakes Region and between Cherokee, IA and Correctionville, IA.

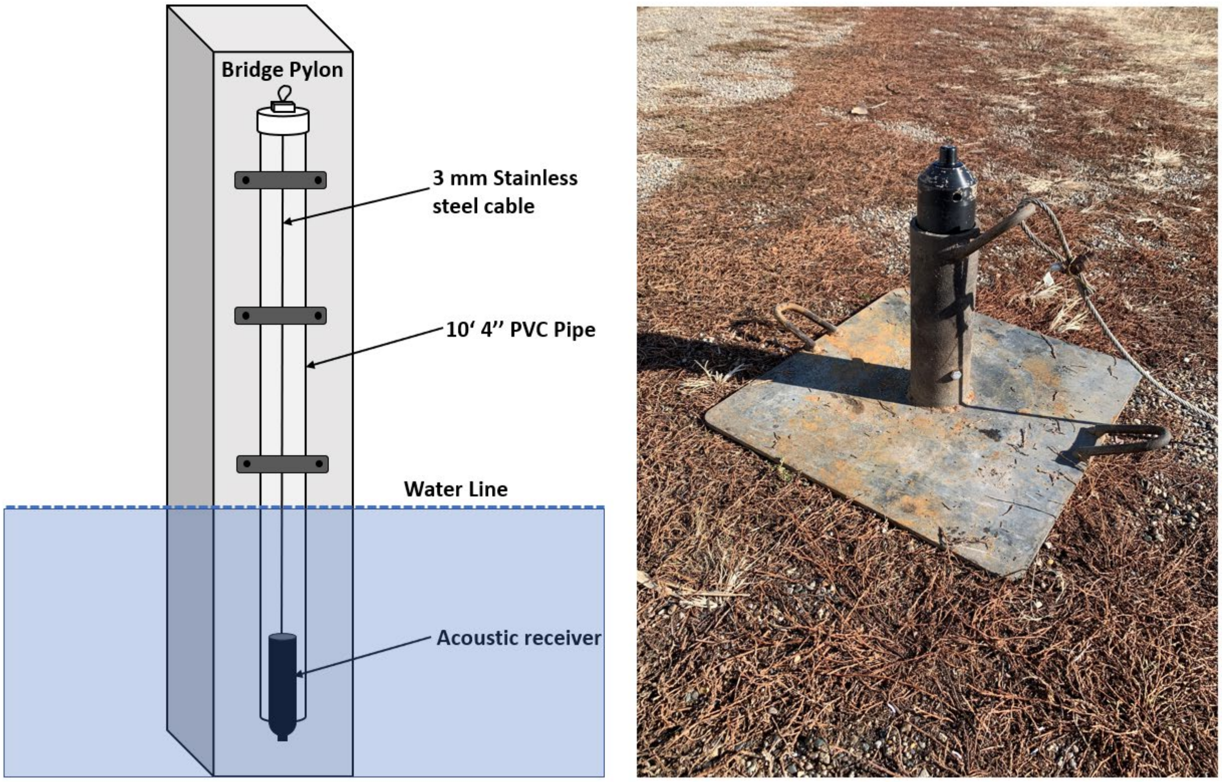


Figure 2. We deployed 19 acoustic receivers in PVC housings that were attached to the downstream side of intersecting highway bridges (left) and 9 bottom sets (right) throughout the study area (see Figure 1 for receiver locations). Bridge mounted receivers were oriented in a downward position and were placed at various areas of the water column depending on each site, whereas bottom set receivers were pointed in an upright position approximately 0.5 m above the stream/lake bed. Bottom receivers were anchored to the nearest shoreline with approximately 6.5 mm cable.

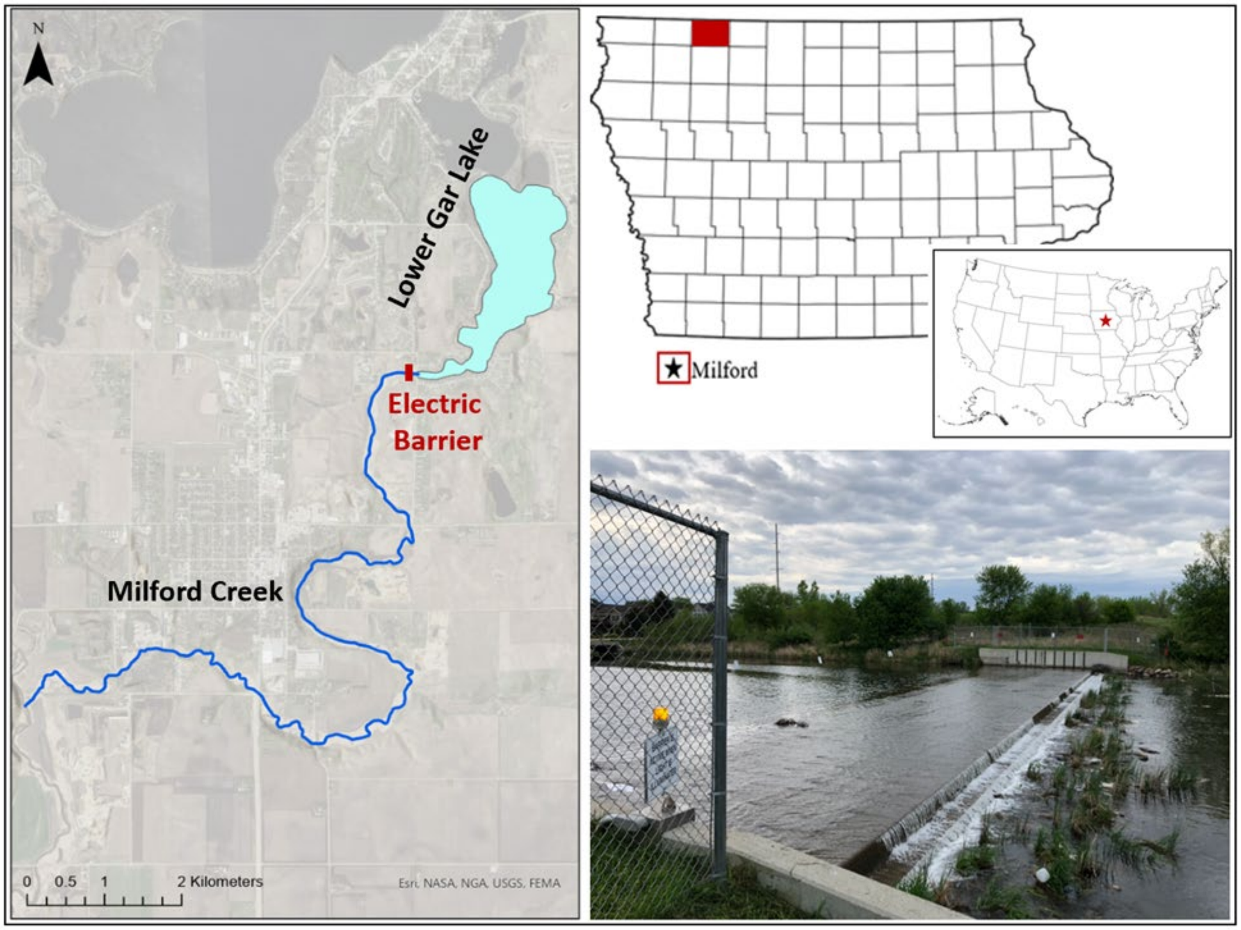


Figure 3. Electric barrier at the outlet of Lower Gar Lake and headwater of Milford Creek located in Milford Iowa, USA (43.340732, -95.132642).

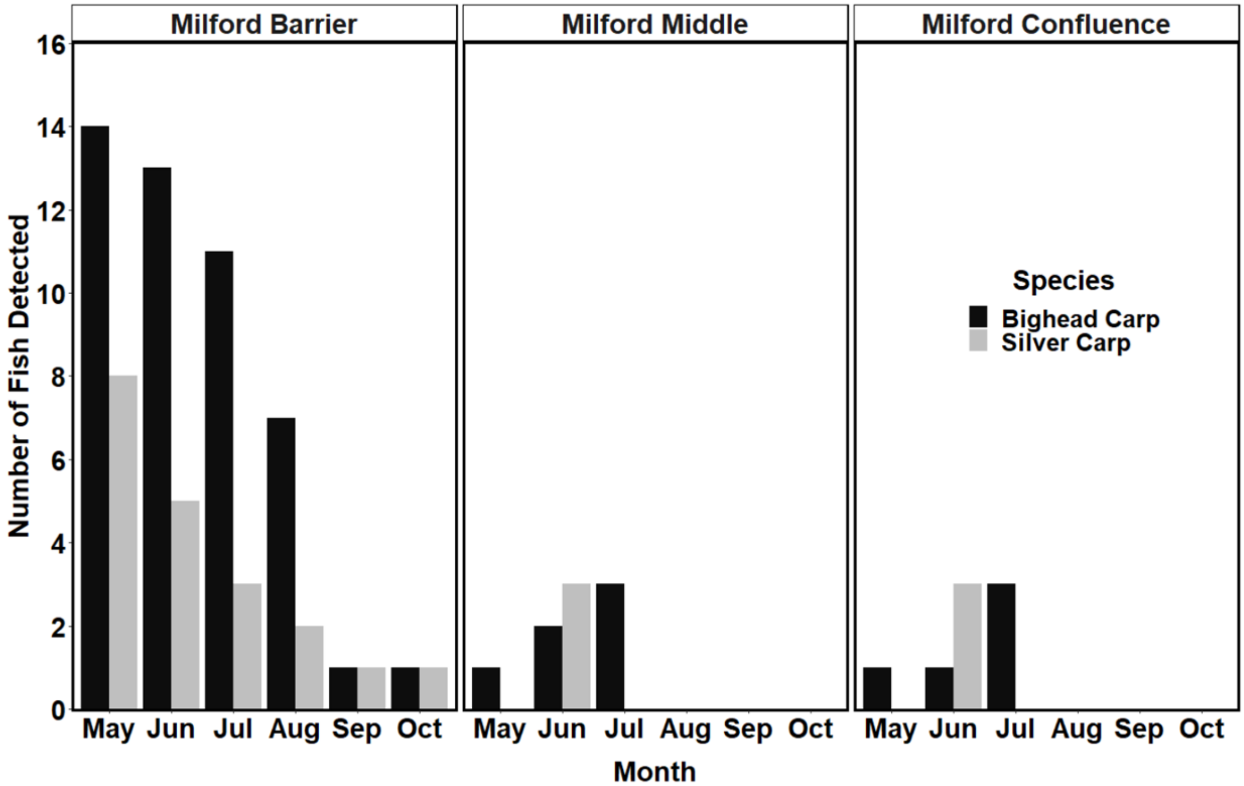


Figure 4. Number of Bighead Carp (black) and Silver Carp (grey) detected at the three receivers in Milford Creek from May-October 2022. Of the 14 Bighead Carp and 9 Silver Carp tagged in Milford Creek, only 1 Silver Carp has not been detected near the electric fish barrier (left panel). Fish detections at the middle receiver (middle panel) and confluence receiver (right panel) were highest in June and July, suggesting movements from Milford Creek to the Little Sioux River were most frequent during this time period. A total of 5 Bighead Carp and 3 Silver Carp that were tagged in Milford Creek have been detected in the Little Sioux River from May-October.

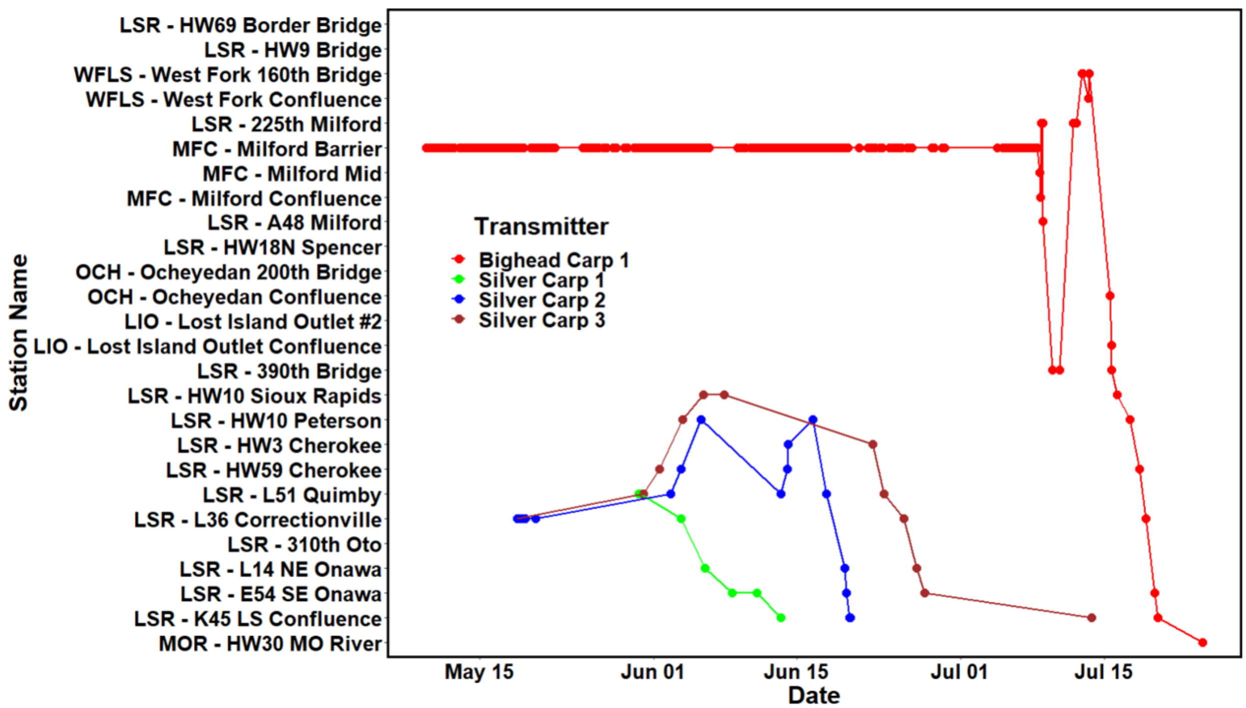


Figure 5. Abacus plot showing detection histories of 1 Bighead Carp (red) and 3 Silver Carp that have or likely have emigrated from the Little Sioux River between June 15th-July 24th, 2022. The Bighead Carp (red line) that was tagged on May 9 downstream of the electric fish barrier in Milford Creek traveled approximately 545 km before its last detection in the Missouri River, approximately 35 km downstream of the Little Sioux River confluence on July 24th. We tagged the 3 Silver Carp on May 17th-18th between Cherokee, IA and Correctionville, IA and were last detected during mid-June and mid-July near the Little Sioux River confluence with the Missouri River. Silver Carp 2 (blue line) was detected 40 km upstream into the Platte River, Nebraska on September 4th, ~255 km away from its tagging location four months prior.

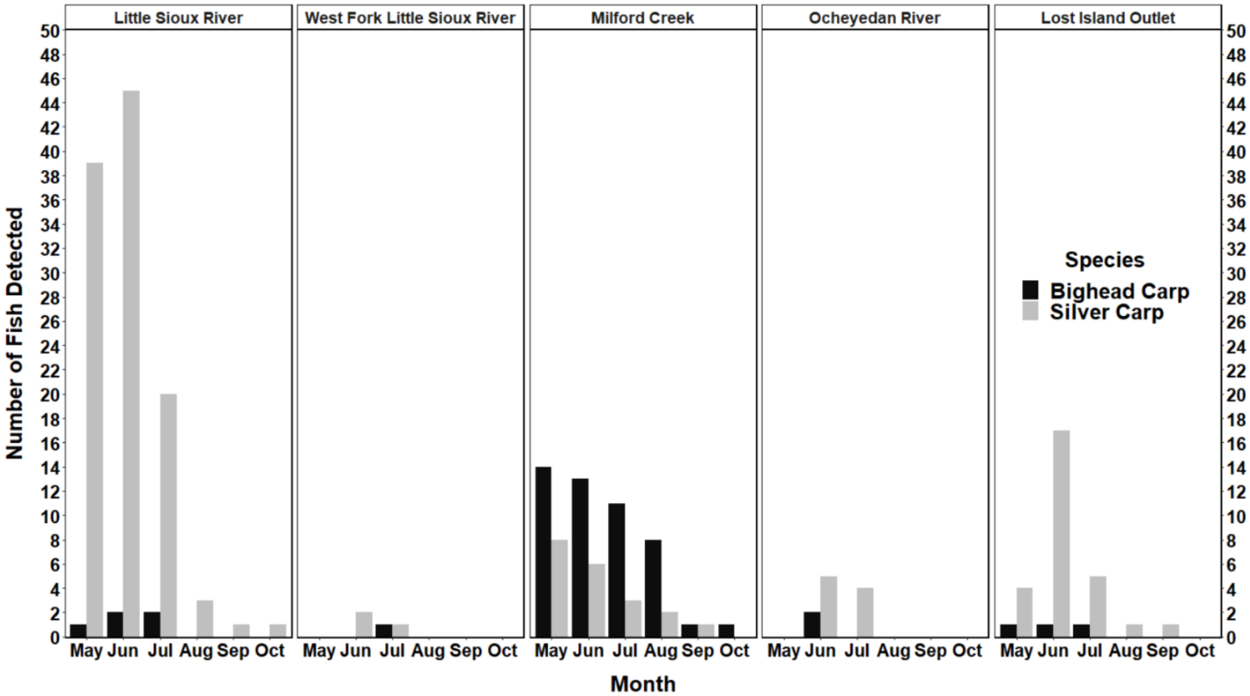


Figure 6. Number of Bighead Carp (black) and Silver Carp (grey) detected in the Little Sioux River, West Fork Little Sioux River, Milford Creek, Ocheyedan River, and Lost Island Outlet (left to right) from May-October. We captured and tagged invasive carp in Milford Creek (n=23) and the Little Sioux River near the confluence (<5 rkm) of Lost Island Outlet (n=17), Ocheyedan River (n=5), and Milford Creek (n=16). Twenty (n=20) additional invasive carp were tagged between Cherokee, IA and Correctionville, IA.

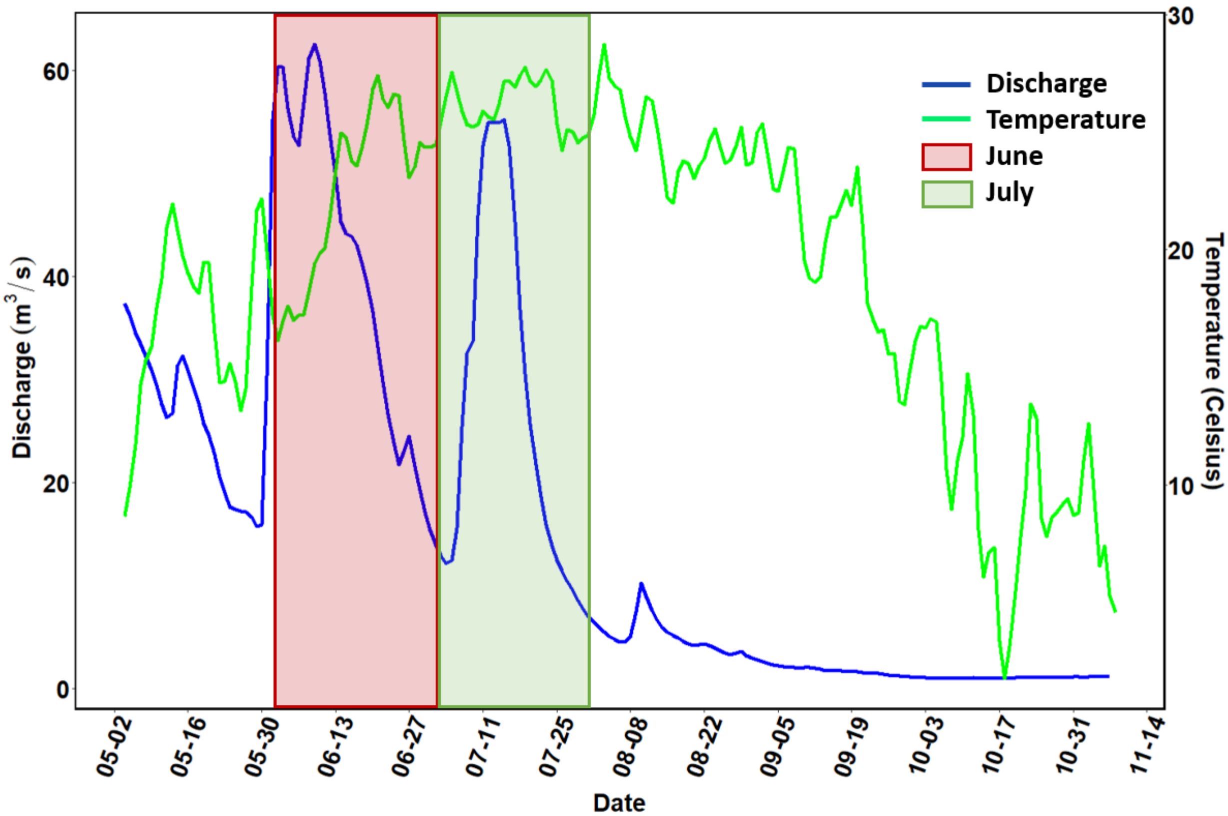


Figure 7. Hydrograph of Little Sioux River for 2022 from USGS gauging station near Linn Grove, IA (Station ID: 06605850, rkm 220) from the first day fish were tagged to the first day receivers were downloaded in November. Silver Carp movement events during June (red box) were generally more frequent and larger than movements in July (green box), whereas Bighead Carp movements were most frequent and larger in July. Discharge (m^3/s; blue line) reached its highest point during the month of June, followed by one spike that occurred in the middle of July.

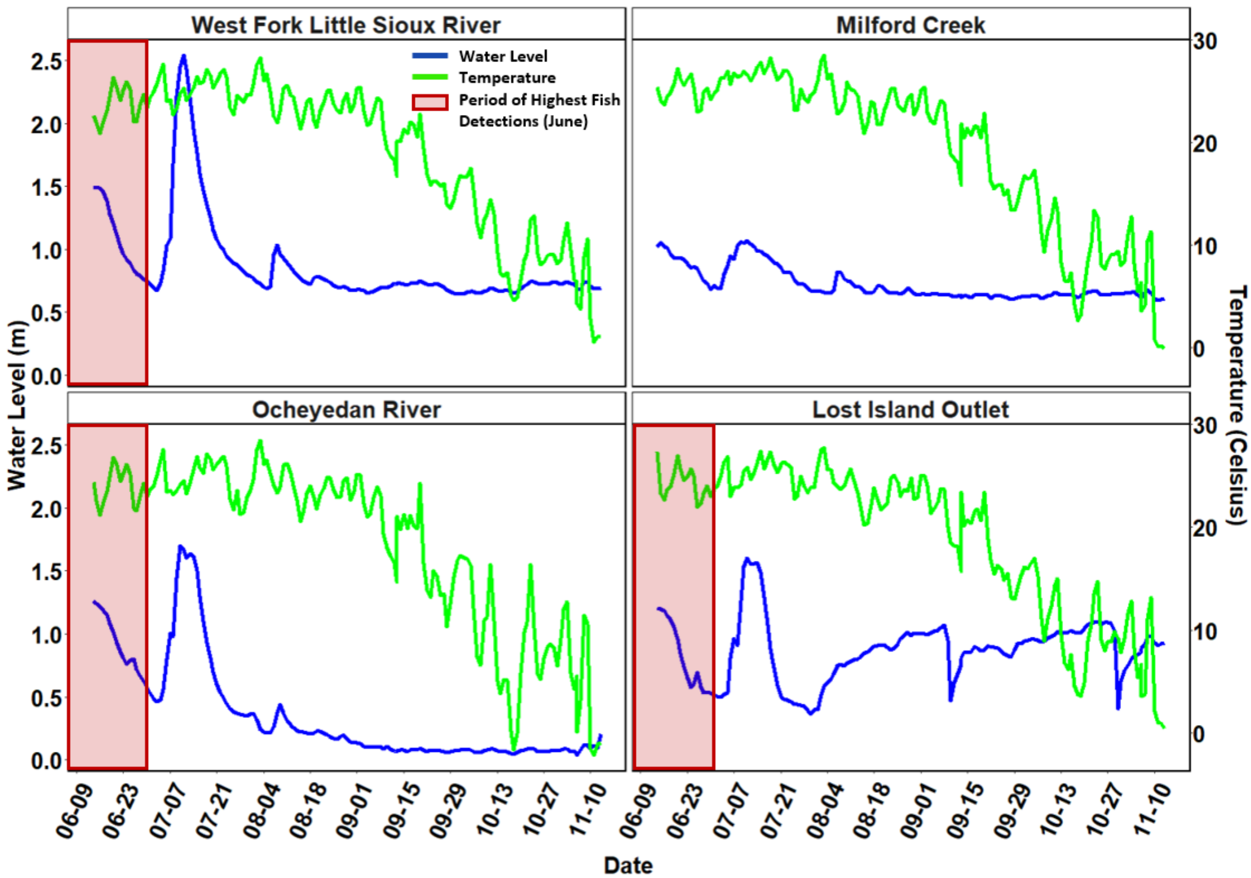


Figure 8. Water levels (m; blue line) and temperature (Celsius; green line) within the West Fork Little Sioux River, Milford Creek, Ocheyedan River, and Lost Island Outlet from mid-June through November 13th of 2022. We did not deploy water level loggers until June 13th, so water level data was not available prior to this date. Number of individuals that were tagged in the Little Sioux River and detected during June (red boxes) in the West Fork Little Sioux River (Bighead Carp: 0, Silver Carp: 2), Ocheyedan River (Bighead Carp: 2, Silver Carp: 5), and Lost Island Outlet (Bighead Carp: 1, Silver Carp: 17) were higher in comparison to all other months. To date, no Bighead or Silver Carp that were tagged in the Little Sioux River have been detected in Milford Creek.

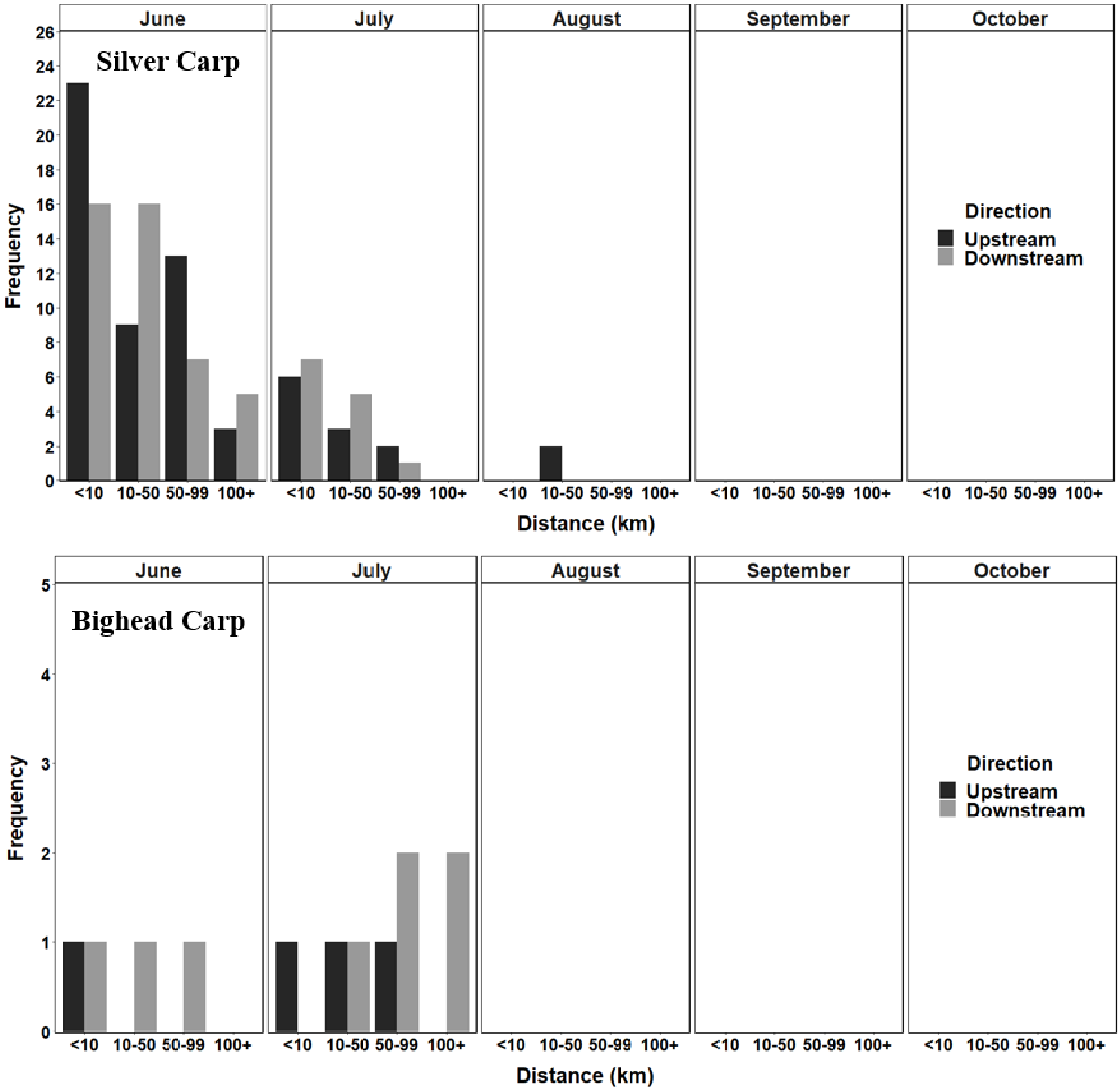


Figure 9. Directional movement event frequencies of Silver Carp (top figure) and Bighead Carp (bottom figure) from June 1st to October 31st. Note that number of individuals tagged per species was not evenly distributed (Silver Carp, n=67; Bighead Carp, n= 14), frequency of upstream/downstream movement events per month was cumulative across all individuals, and only the individuals that had at least one movement event were included in the analysis.

Figure 10. Outdoor video surveillance camera (Sunba network PTZ) installed above the electric fish barrier at the outlet of Lower Gar Lake on June 14th, 2022. The camera is positioned to allow for the best possible view of fish movements on the north side of the barrier.

Field Strength Readings
(Readings are in Volts/Centimeter)

1 meter below #1	0.86
Electrode #1 to #2	4.2
Electrode #2 to #3	5.0
Electrode #3 to #4	5.3
Electrode #4 to #6	5.2
Electrode #5 to #6	5.0
Electrode #6 to #7	5.6
Electrode #7 to #8	4.6
1 meter above #8	0.6

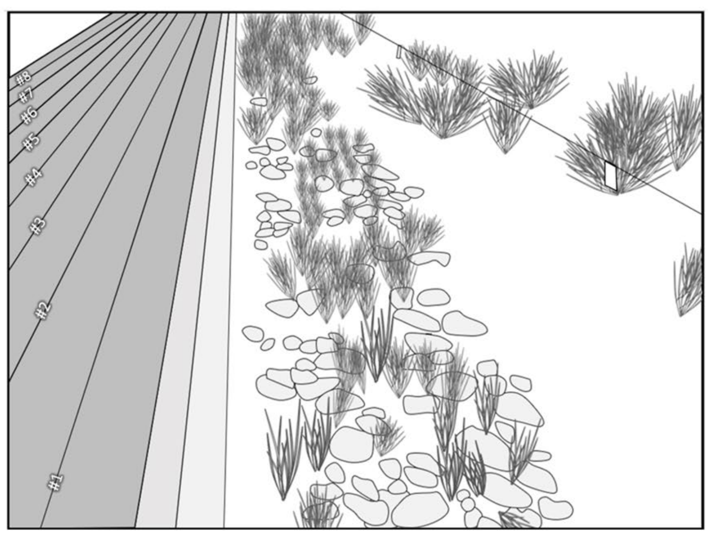


Figure 11. Field measurements collected by Smith-Root Inc. of voltage variation being emitted between electrodes on the electric barrier in Milford Creek Iowa, USA on May 4th, 2022. Stray voltage was also measured 1 meter above and below the barrier.

Agency: Missouri Department of Conservation

Methods:

During spring of 2022, additional stationary telemetry receivers were deployed in the Kansas River system to detect invasive carp movement in yet another major tributary to the Missouri River (Figure 12). Vr2Tx receivers were deployed utilizing platforms of opportunity at suitable sites (e.g., inside bend protected banklines) near notable landmarks to improve the chances of future retrieval. The receivers are further protected from damage by PVC encasement, and cable (1/8 – 3/16 inch diameter) was used to anchor receivers to platforms of opportunity. The receiver was placed away from the bankline in water depths that accounted for record drought cycles and anchored using rock bags. Each receiver was labeled with a MDC logo and property control number and has a visible tag on both bankline and anchored ends engraved with "MDC Equip." All telemetry receivers were downloaded and maintained throughout year; data was shared with the appropriate partners.

Results and Discussion:

Five stationary Vr2Tx telemetry receivers were deployed in the Kansas River system (Table 1). Other stationary telemetry receivers were downloaded and maintained throughout the year; data was shared with the appropriate partners. Invasive carp movement has been tracked on a broad scale. Of the 237 carp tagged, 186 were detected at least a single day since being tagged in late fall 2021. A total of 183 of those carp were not detected outside the lower Missouri River system, while 2 carp (tagged in Creve Coeur Creek) traveled downstream to the Mississippi River and were detected at Maple Island (Figure 13), and 1 carp (tagged in the Moreau River) traveled downstream to the lower Mississippi River before going up the White River in Arkansas (Figure 14). A total of 136 of those carp were not detected outside of their respective tributaries, meaning they were only detected within the tributary that they were originally tagged in. Five carp tagged in Creve Coeur Creek left that tributary and traveled 28.7 to 74.5 river miles (total distance from tributary, not accounting for total distance actually traveled) from Creve Coeur Creek within the Missouri River (Table 2). A total of 21 carp tagged in the Moreau River left that tributary and traveled 5.6 to 58.3 river miles from the Moreau River within the Missouri River (Table 2). A total of 19 carp tagged in the Lamine River left that tributary and traveled 7.1 to 50.8 river miles from the Lamine River within the Missouri River (Table 2). Two carp tagged in the Grand River left that tributary and traveled 49.2 to 55.1 river miles from the Grand River within the Missouri River (Table 2). Movement patterns should be assessed in depth to further assist with harvest efforts.

Table 1. Site name, date of installation, and location (latitude and longitude) of stationary telemetry receivers deployed in the Kansas River.

Site	Date	Latitude	Longitude
Below WaterOne Weir	4/21/2022	39.08443	-94.71805
Above WaterOne Weir	4/21/2022	39.05462	-94.82471
Wakarusa River	4/21/2022	38.95071	-95.09521
Below Bowersock Dam	4/21/2022	38.97104	-95.22128
Above Bowersock Dam	4/21/2022	39.00348	-95.24265

Table 2. Origin (CCC = Creve Coeur Creek, MR = Moreau River, LR = Lamine River, GR = Grand River), transmitter ID, detected locations, distance from origin (DFO), and maximum distance traveled (MDT) for each carp tagged in the lower Missouri River system.

Origin	Transmitter ID	Detected Locations	DFO	MDT
CCC	A69-1602-48950	RM2 - L&C Bridge	28.7	34.8
CCC	A69-1602-48951	RM2 - L&C Bridge	28.7	34.8
CCC	A69-1602-48952	Creve Coeur Creek	0.0	0.0
CCC	A69-1602-48954	Gasconade River - St Charles	74.5	152.7
CCC	A69-1602-48958	RM2	28.7	28.7
CCC	A69-1602-48960	RM2	28.7	28.7
CCC	A69-1602-48973	Maple Island	35.4	35.4
CCC	A69-1602-48979	Maple Island - L&C Bridge	35.4	48.0
CCC	A69-1602-48985	Creve Coeur Creek	0.0	0.0
MR	A69-1602-49117	Moreau Mouth - Moreau Upper (x8)	1.8	20
MR	A69-1602-49118	White River, Arkansas	746	746
MR	A69-1602-49119	Moreau Mouth - Moreau Upper (x3.5)	1.8	8.3

MR	A69-1602-49120	Moreau Mouth - Moreau Upper (x15.5)	1.8	39.5
MR	A69-1602-49121	Moreau Mouth - Moreau Upper (x10.5)	1.8	26.5
MR	A69-1602-49122	Moreau Mouth - Moreau Upper (x3.5)	1.8	8.3
MR	A69-1602-49123	Moreau Mouth - Moreau Upper (x7.5)	1.8	18.7
MR	A69-1602-49125	Moreau Mouth - Moreau Upper - Moreau Mouth	1.8	3.1
MR	A69-1602-49126	Osage River	17.8	17.8
MR	A69-1602-49127	Moreau Mouth	0.5	0.5
MR	A69-1602-49128	Moreau Mouth - Moreau Upper (x5.5)	1.8	13.5
MR	A69-1602-49129	Osage River - (Moreau Mouth - Moreau Upper (x5.5))	17.8	49.1
MR	A69-1602-49130	(Moreau Mouth - Moreau Upper (x2.5)) - Osage River - Moreau Mouth - Osage River	17.8	60.6
MR	A69-1602-49131	(Moreau Mouth - Moreau Upper (x1.5)) - Jeff City - (Moreau Mouth - Moreau Upper (x3.5))	5.6	23.1
MR	A69-1602-49132	Moreau Mouth - Moreau Upper - Moreau Mouth	1.8	3.1
MR	A69-1602-49134	Moreau Mouth - Moreau Upper (x14.5)	1.8	36.9
MR	A69-1602-49135	Boonville - Osage River - (Moreau Mouth - Moreau Upper (x1.5)) - Osage River	58.3	173.6
MR	A69-1602-49136	(Moreau Mouth - Moreau Upper (x9.5)) - Jeff City	5.6	30.0
MR	A69-1602-49137	Jeff City - Boonville	58.3	58.3
MR	A69-1602-49138	Moreau Mouth - Moreau Upper (x3)	1.8	7.0
MR	A69-1602-49139	Moreau Mouth - Moreau Upper (x7.5)	1.8	18.7
MR	A69-1602-49140	(Moreau Mouth - Moreau Upper (x1.5)) - (Jeff City - Moreau Mouth (x2))	5.6	27.5

MR	A69-1602-49141	Moreau Mouth - Moreau Upper (x4.5)	1.8	10.9
MR	A69-1602-49142	Moreau Mouth - Moreau Upper - Moreau Mouth	1.8	3.1
MR	A69-1602-49143	Moreau Mouth - Moreau Upper (x8.5)	1.8	21.3
MR	A69-1602-49144	Moreau Mouth - Moreau Upper (x4.5)	1.8	10.9
MR	A69-1602-49145	Moreau Mouth - Moreau Upper (x8)	1.8	20.0
MR	A69-1602-49146	Moreau Mouth - Moreau Upper (x8.5)	1.8	21.3
MR	A69-1602-49147	Moreau Mouth - Moreau Upper (x6)	1.8	14.8
MR	A69-1602-49151	Osage River	17.8	17.8
MR	A69-1602-49152	Osage River	17.8	17.8
MR	A69-1602-49153	Moreau Mouth - Moreau Upper (x11.5)	1.8	29.1
MR	A69-1602-49154	(Moreau Mouth - Moreau Upper (x3.5)) - Boonville	58.3	67.1
MR	A69-1602-49156	(Moreau Mouth - Moreau Upper (x11.5)) - Jeff City	5.6	35.2
MR	A69-1602-49157	Osage River	17.8	17.8
MR	A69-1602-49158	Jeff City	5.6	5.6
MR	A69-1602-49159	Osage River - Moreau Mouth - Osage River	17.8	54.4
MR	A69-1602-49160	Moreau Mouth - Moreau Upper - Moreau Mouth	1.8	3.1
MR	A69-1602-49161	Osage River - Jeff City	17.8	41.2
MR	A69-1602-49162	Moreau Mouth - Moreau Upper - Moreau Mouth	1.8	3.1
MR	A69-1602-49163	Moreau Mouth - Moreau Upper	1.8	1.8

MR	A69-1602-49164	Osage River	17.8	17.8
MR	A69-1602-49165	Osage River - Moreau Mouth	17.8	36.1
MR	A69-1602-49167	Moreau Mouth - Moreau Upper (x17.5)	1.8	44.7
MR	A69-1602-49168	Osage River	17.8	17.8
MR	A69-1602-49169	Moreau Mouth - Boonville	58.3	59.3
MR	A69-1602-49171	Moreau Mouth - Moreau Upper (x10.5)	1.8	26.5
MR	A69-1602-49172	Gasconade River	33.8	33.8
MR	A69-1602-49173	Moreau Mouth - Moreau Upper - Moreau Mouth	1.8	3.1
LR	A69-1602-49055	Lamine Upper - Lamine Mouth	2.1	5.4
LR	A69-1602-49056	Lamine Upper - Lamine Mouth - Lamine Upper	2.1	8.7
LR	A69-1602-49057	Lamine Upper - (Grand Mouth - Grand Upper (x7.5)) - Lamine Upper	50.8	118.9
LR	A69-1602-49058	Lamine Upper - Lamine Mouth (x2)	2.1	12.0
LR	A69-1602-49059	Lamine Upper - Lamine Mouth (x2)	2.1	12.0
LR	A69-1602-49060	Lamine Upper - Lamine Mouth - Lamine Upper	2.1	8.7
LR	A69-1602-49061	Lamine Upper - Lamine Mouth	2.1	5.4
LR	A69-1602-49062	Lamine Upper - Lamine Mouth	2.1	5.4
LR	A69-1602-49063	Lamine Upper - Lamine Mouth	2.1	5.4
LR	A69-1602-49064	Lamine Upper - Lamine Mouth - Boonville - Lamine Mouth - Lamine Upper	7.1	20.5
LR	A69-1602-49065	Lamine Mouth	1.2	1.2

LR	A69-1602-49066	(Lamine Upper - Lamine Mouth (x1.5)) - Boonville - Lamine Upper	7.1	27.1
LR	A69-1602-49067	Lamine Mouth - Lamine Upper (x3.5)	2.1	21.0
LR	A69-1602-49068	Lamine Upper - Lamine Mouth - Lamine Upper	2.1	8.7
LR	A69-1602-49069	Lamine Upper - Lamine Mouth - Boonville - Lamine Mouth	7.1	17.2
LR	A69-1602-49070	Lamine Upper - Lamine Mouth - Lamine Upper	2.1	8.7
LR	A69-1602-49071	(Lamine Mouth - Lamine Upper (x1.5)) - Grand Mouth	48.8	55.4
LR	A69-1602-49072	Lamine Upper - Lamine Mouth (x2.5)	2.1	15.3
LR	A69-1602-49073	Lamine Upper - Lamine Mouth	2.1	5.4
LR	A69-1602-49074	Lamine Upper - Lamine Mouth	2.1	5.4
LR	A69-1602-49075	Lamine Mouth	1.2	1.2
LR	A69-1602-49076	Lamine Upper - Lamine Mouth - Lamine Upper	2.1	8.7
LR	A69-1602-49077	Lamine Upper - Lamine Mouth (x3)	2.1	18.6
LR	A69-1602-49078	Lamine Mouth - Lamine Upper - Lamine Mouth	2.1	7.8
LR	A69-1602-49079	Lamine Upper - Lamine Mouth - Boonville	7.1	11.3
LR	A69-1602-49080	Lamine Upper - Lamine Mouth - Boonville	7.1	11.3
LR	A69-1602-49081	Lamine Upper - Lamine Mouth - (Boonville - Lamine Mouth (x2.5))	7.1	34.9
LR	A69-1602-49083	Lamine Upper - Lamine Mouth (x2.5)	2.1	15.3
LR	A69-1602-49084	Lamine Upper - Lamine Mouth - Lamine Upper	2.1	8.7
LR	A69-1602-49085	Lamine Upper - Lamine Mouth	2.1	5.4

LR	A69-1602-49086	(Lamine Upper - Lamine Mouth (x2)) - Boonville	7.1	17.9
LR	A69-1602-49087	Lamine Upper - Lamine Mouth - Lamine Upper	2.1	8.7
LR	A69-1602-49088	Lamine Upper - Lamine Mouth - Boonville - Lamine Mouth - Lamine Upper	7.1	20.5
LR	A69-1602-49089	Lamine Upper - Lamine Mouth	2.1	5.4
LR	A69-1602-49090	Lamine Upper - Lamine Mouth	2.1	5.4
LR	A69-1602-49091	(Lamine Mouth - Lamine Upper (x1.5)) - Grand Mouth - Lamine Mouth	48.8	103.0
LR	A69-1602-49092	Lamine Mouth	1.2	1.2
LR	A69-1602-49093	Lamine Mouth - Lamine Upper (x3)	2.1	17.7
LR	A69-1602-49094	Lamine Upper	2.1	2.1
LR	A69-1602-49095	Lamine Upper - Lamine Mouth	2.1	5.4
LR	A69-1602-49096	Lamine Upper - Lamine Mouth - Lamine Upper	2.1	8.7
LR	A69-1602-49097	Lamine Upper - Lamine Mouth - Lamine Upper	2.1	8.7
LR	A69-1602-49098	(Lamine Mouth - Lamine Upper (x1.5)) - Boonville	7.1	13.7
LR	A69-1602-49099	Lamine Upper	2.1	2.1
LR	A69-1602-49100	Lamine Upper - Lamine Mouth (x2.5)	2.1	15.3
LR	A69-1602-49101	Lamine Upper - Lamine Mouth - Lamine Upper	2.1	8.7
LR	A69-1602-49102	(Lamine Mouth - Boonville (x2.5)) - Lamine Upper	7.1	28.1
LR	A69-1602-49103	Lamine Upper - Lamine Mouth	2.1	5.4
LR	A69-1602-49104	Lamine Mouth - Lamine Upper - Lamine Mouth	2.1	7.8

LR	A69-1602-49105	Lamine Mouth - Lamine Upper - (Boonville - Lamine Mouth (x3))	7.1	43.2
LR	A69-1602-49106	Lamine Upper - Lamine Mouth (x2)	2.1	12.0
LR	A69-1602-49107	Lamine Mouth - Boonville	7.1	7.1
LR	A69-1602-49108	Lamine Upper	2.1	2.1
LR	A69-1602-49109	Lamine Upper - Lamine Mouth - Grand Mouth-Lamine Upper	48.8	103.9
LR	A69-1602-49110	Lamine Upper - Lamine Mouth (x4)	2.1	25.2
LR	A69-1602-49111	Lamine Upper - Lamine Mouth - Boonville	7.1	11.3
LR	A69-1602-49112	Lamine Upper - Lamine Mouth (x2)	2.1	12.0
LR	A69-1602-49113	Lamine Mouth - Boonville - Lamine Mouth	7.1	13.0
LR	A69-1602-49114	Lamine Mouth - Boonville	7.1	7.1
LR	A69-1602-49115	Lamine Upper	2.1	2.1
LR	A69-1602-49116	Lamine Upper - Lamine Mouth (x2)	2.1	12.0
GR	A69-1602-48988	Grand Upper - Grand Mouth (x3.5)	1.6	12.4
GR	A69-1602-48989	Grand Mouth - Grand Upper (x25)	1.6	99.6
GR	A69-1602-48990	Grand Upper - Grand Mouth (x3.5)	1.6	12.4
GR	A69-1602-48991	Grand Mouth - Grand Upper (x2.5)	1.6	9.6
GR	A69-1602-48992	Grand Mouth - Grand Upper (x10)	1.6	39.6
GR	A69-1602-48993	Grand Mouth - Grand Upper (x10.5)	1.6	41.6
GR	A69-1602-48994	Grand Upper - Grand Mouth (x16.5)	1.6	64.4

GR	A69-1602-48995	Grand Upper - Grand Mouth (x14)	1.6	54.4
GR	A69-1602-48996	Grand Upper - Grand Mouth (x9.5)	1.6	36.4
GR	A69-1602-48997	Grand Upper - Grand Mouth (x10.5)	1.6	40.4
GR	A69-1602-48998	Grand Upper - Grand Mouth (x6)	1.6	22.4
GR	A69-1602-48999	Grand Upper - Grand Mouth (x11)	1.6	42.4
GR	A69-1602-49000	Grand Upper - Grand Mouth (x13)	1.6	50.4
GR	A69-1602-49001	Grand Upper - Grand Mouth (x12.5)	1.6	48.4
GR	A69-1602-49002	Grand Mouth - Grand Upper (x3.5)	1.6	13.6
GR	A69-1602-49003	Grand Upper - Grand Mouth (x18.5)	1.6	72.4
GR	A69-1602-49004	Grand Upper - Grand Mouth (x14.5)	1.6	56.4
GR	A69-1602-49005	Grand Upper - Grand Mouth (x13.5)	1.6	52.4
GR	A69-1602-49006	Grand Mouth - Grand Upper (x14)	1.6	55.6
GR	A69-1602-49007	Grand Mouth - Grand Upper (x9.5)	1.6	37.6
GR	A69-1602-49008	Grand Upper - Grand Mouth (x17)	1.6	66.4
GR	A69-1602-49009	Grand Upper - Grand Mouth (x4) - Lamine Mouth	49.2	62.0
GR	A69-1602-49010	Grand Upper - Grand Mouth (x20)	1.6	78.4
GR	A69-1602-49011	Grand Upper - Grand Mouth (x17)	1.6	66.4
GR	A69-1602-49012	Grand Upper - Grand Mouth (x15)	1.6	58.4
GR	A69-1602-49013	Grand Upper - Grand Mouth (x18.5)	1.6	72.4

GR	A69-1602-49014	Grand Upper - Grand Mouth (x15)	1.6	58.4
GR	A69-1602-49015	Grand Upper - Grand Mouth (x15)	1.6	58.4
GR	A69-1602-49016	Grand Upper - Grand Mouth	1.6	2.4
GR	A69-1602-49017	Grand Mouth - Grand Upper (x17)	1.6	67.6
GR	A69-1602-49018	Grand Mouth - Grand Upper (x10.5)	1.6	81.6
GR	A69-1602-49019	Grand Mouth - Grand Upper - Grand Mouth	1.6	5.6
GR	A69-1602-49020	Grand Mouth - Grand Upper (x5.5)	1.6	21.6
GR	A69-1602-49021	Grand Mouth - Grand Upper (x10.5)	1.6	41.6
GR	A69-1602-49022	Grand Mouth - Grand Upper (x17)	1.6	67.6
GR	A69-1602-49023	Grand Upper - Grand Mouth (x21.5)	1.6	84.4
GR	A69-1602-49024	Grand Upper - Grand Mouth (x16)	1.6	62.4
GR	A69-1602-49025	Grand Mouth - Grand Upper - Grand Mouth	1.6	5.6
GR	A69-1602-49026	Grand Upper - Grand Mouth (x2.5)	1.6	8.4
GR	A69-1602-49027	Grand Mouth - Grand Upper (x3.5)	1.6	13.6
GR	A69-1602-49028	Grand Mouth - Grand Upper (x13)	1.6	51.6
GR	A69-1602-49029	Grand Mouth - Grand Upper (x9.5)	1.6	37.6
GR	A69-1602-49030	Grand Upper - Grand Mouth (x9)	1.6	34.4
GR	A69-1602-49031	Grand Upper - Grand Mouth (x16.5)	1.6	64.4
GR	A69-1602-49032	Grand Upper - Grand Mouth (x10)	1.6	38.4

GR	A69-1602-49033	Grand Mouth - Grand Upper (x14.5)	1.6	57.6
GR	A69-1602-49034	Grand Upper - Grand Mouth (x19)	1.6	74.4
GR	A69-1602-49035	Grand Mouth - Grand Upper (x5.5)	1.6	21.6
GR	A69-1602-49036	Grand Mouth - Grand Upper (x9.5)	1.6	37.6
GR	A69-1602-49037	Grand Upper - Grand Mouth (x3)	1.6	10.4
GR	A69-1602-49038	Grand Mouth - Grand Upper (x12.5)	1.6	49.6
GR	A69-1602-49039	Grand Upper - Grand Mouth (x6)	1.6	22.4
GR	A69-1602-49040	Grand Mouth - Grand Upper (x6.5)	1.6	25.6
GR	A69-1602-49041	Grand Mouth - Grand Upper - Grand Mouth	1.6	5.6
GR	A69-1602-49042	Grand Mouth - Grand Upper (x14)	1.6	55.6
GR	A69-1602-49043	Grand Mouth - Grand Upper (x21.5)	1.6	85.6
GR	A69-1602-49044	Grand Mouth - Grand Upper (x20.5)	1.6	81.6
GR	A69-1602-49045	Grand Mouth - Grand Upper (x4.5)	1.6	17.6
GR	A69-1602-49046	Grand Mouth - Grand Upper (x15.5)	1.6	61.6
GR	A69-1602-49047	Grand Mouth - Grand Upper (x8.5)	1.6	33.6
GR	A69-1602-49048	Grand Mouth - Grand Upper (x14.5)	1.6	57.6
GR	A69-1602-49049	Grand Mouth - Grand Upper (x18.5)	1.6	73.6
GR	A69-1602-49050	Grand Mouth - Grand Upper (x2.5)	1.6	9.6
GR	A69-1602-49051	Grand Upper - Grand Mouth (x11)	1.6	42.4

GR	A69-1602-49052	Grand Mouth - Grand Upper (x7.5) - Boonville - (Grand Mouth - Grand Upper (x8.5))	55.1	168.6
GR	A69-1602-49053	Grand Upper - Grand Mouth (x6)	1.6	22.4
GR	A69-1602-49054	Grand Upper - Grand Mouth - Grand Upper	1.6	4.4

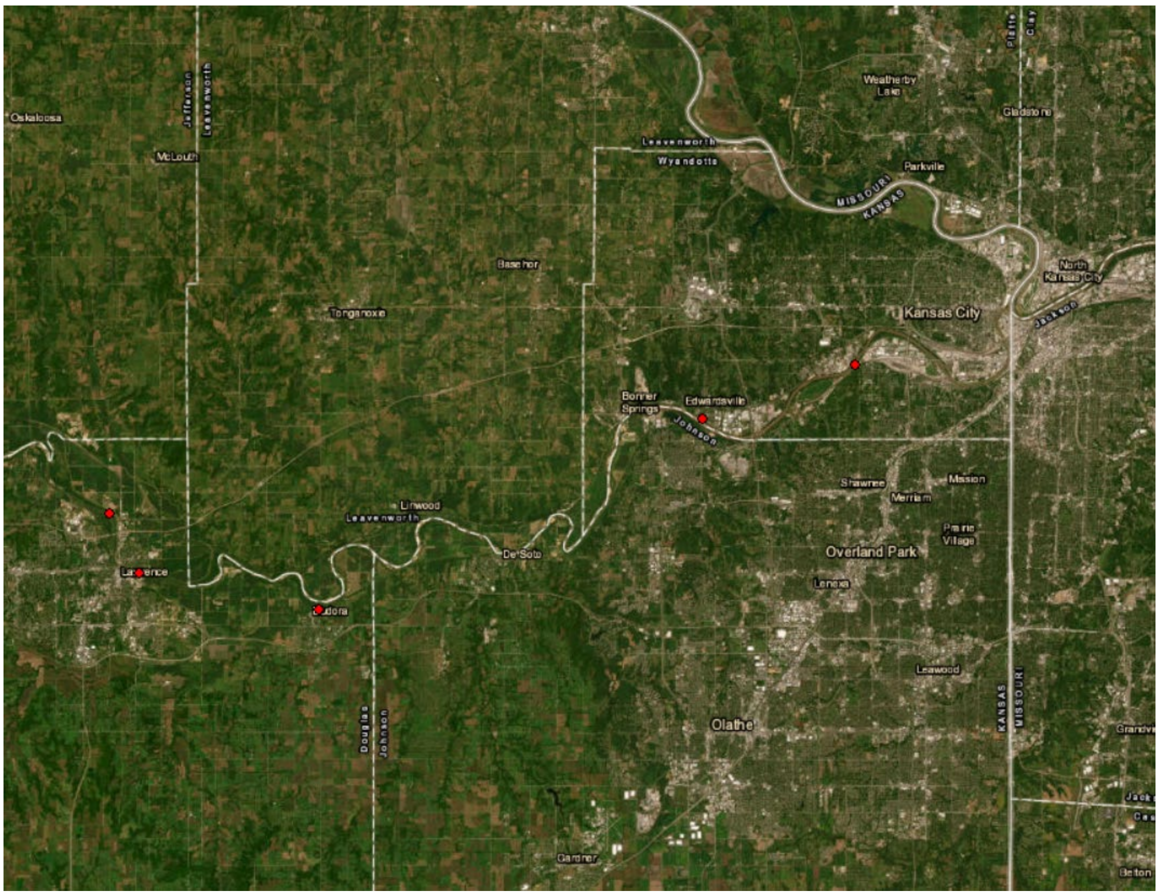


Figure 12. Stationary telemetry receiver array deployed in the lower Kansas River in late fall 2021, covering approximately 43.3 river miles between the downstream most receiver (below WaterOne Weir) and upstream most receiver (above Bowersock Dam).

Figure 13. Relative locations of the 2 carp tagged in Creve Coeur Creek (blue dot) that traveled downstream to the Mississippi River and upstream to Maple Island (red dot), approximately 35.4 river miles from the original tagging location.

Figure 14. Relative locations of the carp tagged in the Moreau River (blue dot) that traveled downstream and up into the White River (red dot) near St. Charles, Arkansas, approximately 746 river miles from the original tagging location.

Agency: South Dakota Department of Game, Fish and Parks and University of South Dakota

Methods:

A passive telemetry network spans from 1 river kilometer (rkm) above the confluence of the James River and the Missouri River (0 rkm) to rkm 358 in the James River, SD. Four HOBO temperature loggers, one dissolved oxygen (DO) sensor, and one water-level/temperature logger are located intermittently along the telemetry network for habitat data collection (Figure 15). Fifty Silver Carp were implanted with InnovaSea acoustic transmitters (model V16-4H; 69kHz, 16 mm diameter, 68 mm length, 24 g) in June 2021. Passive tracking data have been continuously collected since the date of tagging and will continue to be collected until the batteries in the tags expire.

Results and Discussion:

Tagged fish had a mean weight of 3,019 g (range: 1042 g to 5454 g) and mean total length of 625 mm (range: 452 mm to 777 mm). Of the 50 Silver Carp tagged in the James River, six fish have not been detected since the initial tagging release. Four additional fish were detected only once in a two-day window after tagging. Therefore, these 10 fish were classified as having an undetermined fate. The remaining 40 fish were detected at least once on the telemetry network after the two-day window. See Figure 16 for daily detections for all individuals tagged in the James River.

Because our receivers do not overlap in detection range, the distances are recorded as the minimum possible movement distances and provide a picture of large-scale movement patterns of Silver Carp in the James River. The mean distance moved by all tagged individuals from June 2021 to October 2022 was 83.7 rkm. The individual with the highest detected movement for any single fish tagged in the James River swam a total distance of 1,385 rkm over a period of 11 weeks, where it completed a series of upstream and downstream movements within the James River (Figure 17a). The fish with the next largest movement pattern traveled a total of 1,292 rkm and was the only tagged fish to be recorded swimming into the Missouri River and back into the James River. It first was detected travelling downstream beginning on May 14, 2022, through the James River and into the Missouri River where it was detected near Blair, NE, on May 23, 2022. The fish was not detected for a period of 22 days, and then was detected swimming back upstream in the Missouri near Blair, NE, on June 14, 2022 and then on multiple receivers in the James River until it returned to its starting point on July 5, 2022, where it remained for the duration of the detection period thereafter (Figure 17b).

Nineteen of the tagged fish were detected swimming over a total distance of 210 rkm, and 21 were detected swimming a total distance less than 40 rkm (Figure 18). All but one of the tagged individuals remained in the James River throughout the study period. When each fish did move, it almost always returned to the same spot as before movement was initiated, which suggests site fidelity to, and home ranges within, the James River (Figure 19). We are currently working on a Bayesian model to predict whether a difference exists between the group of “mover” individuals versus the “sedentary” individuals, and whether a change in discharge, temperature, or a combination of environmental factors best determine when Silver Carp will choose to begin moving. One more data offload is planned for early Spring, 2023, so that we may get an idea of winter movement patterns of our tagged fish.

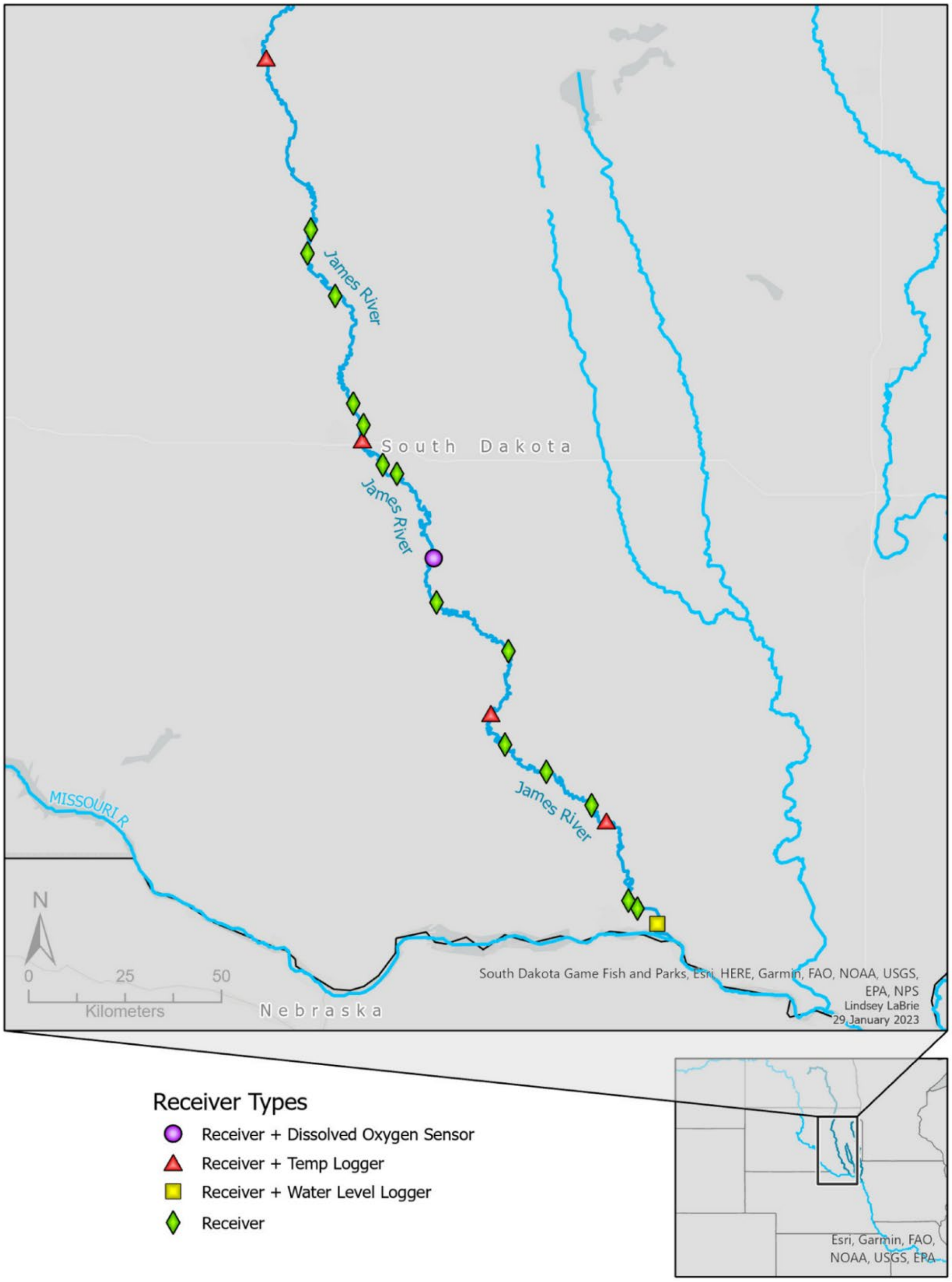


Figure 15: A map of receivers and habitat data sensors in the James River, SD.

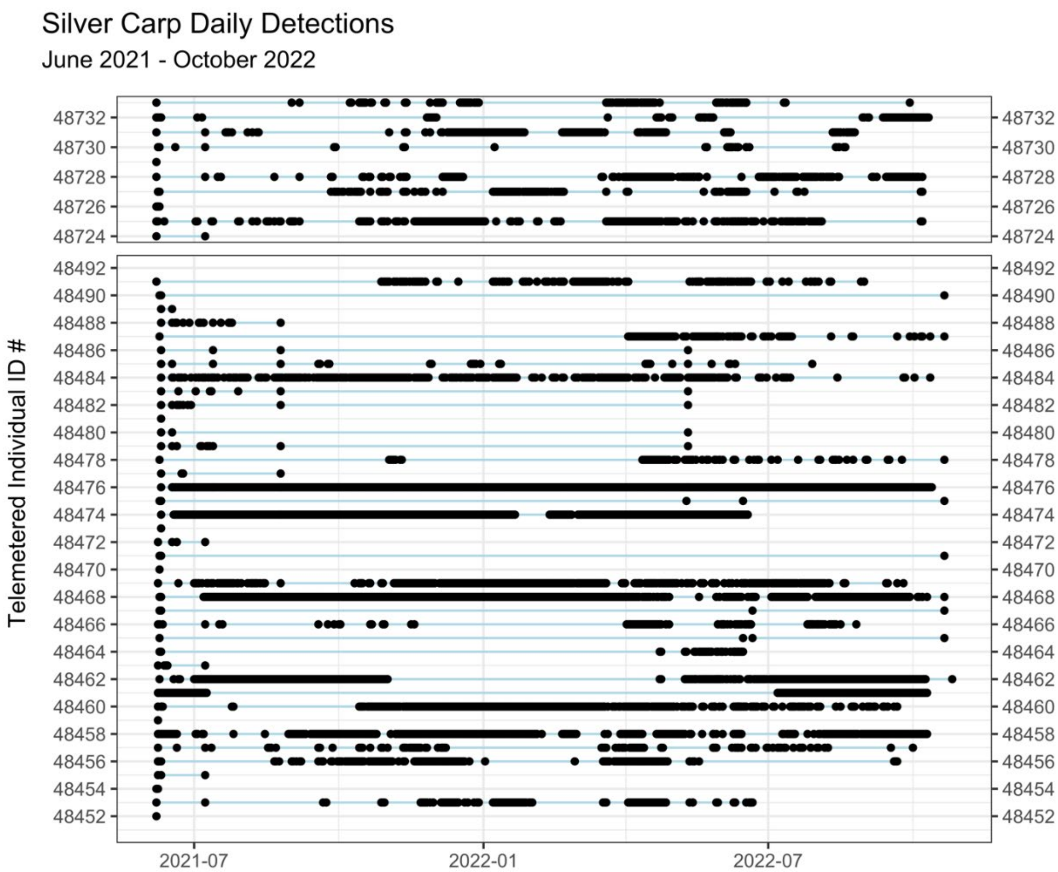
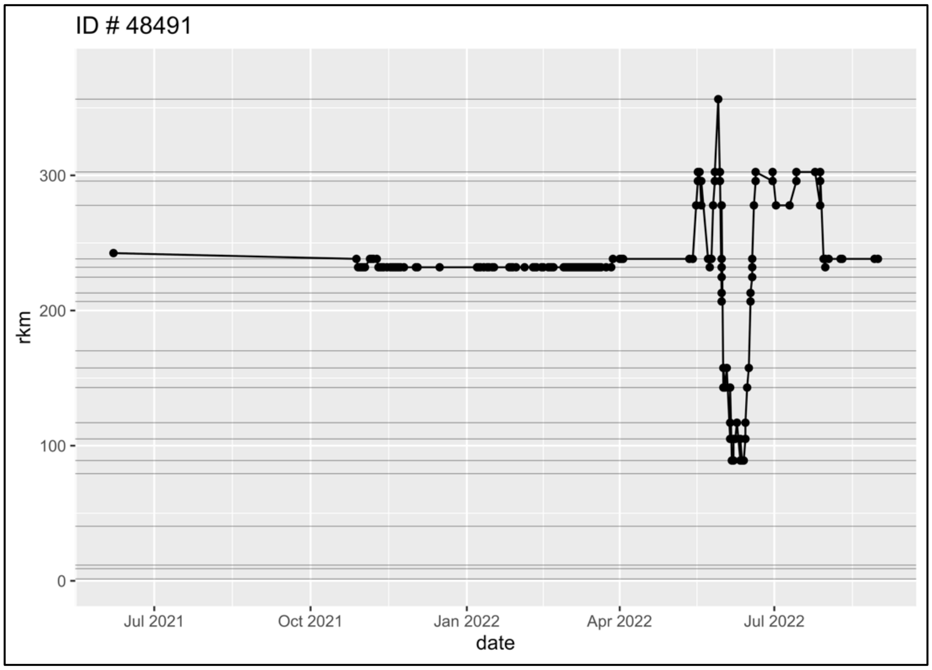


Figure 16: Daily detections for each tagged Silver Carp in the James River, SD. Black dots represent one detection per day and blue lines represent the time period between days with detections.



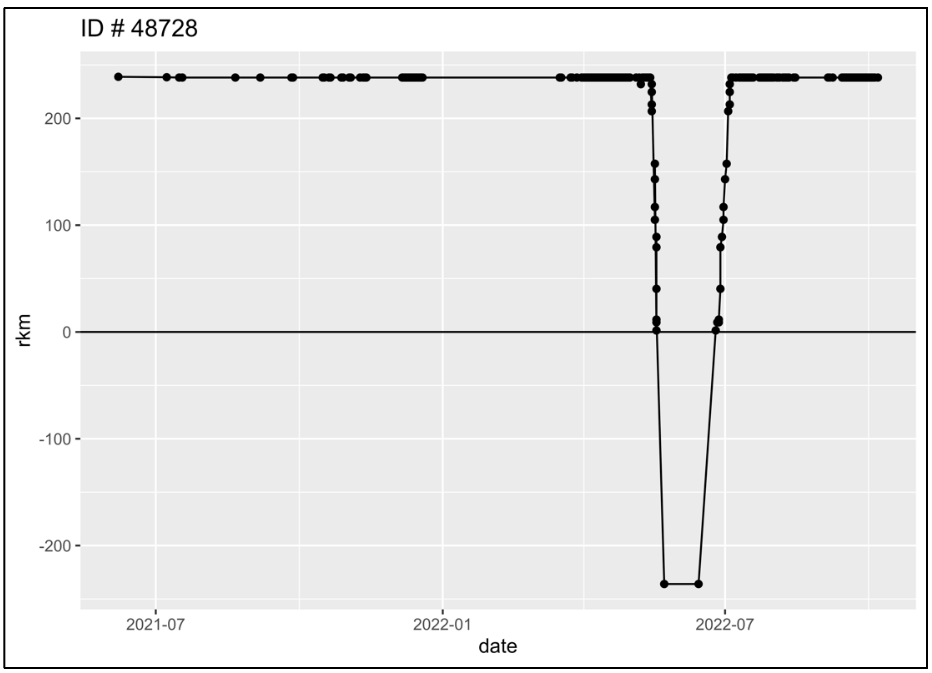


Figure 17a (top): Movement pattern for the individual Silver Carp with the greatest amount of detected movement in the James River, with the majority of the movement happening between May 14 and July 31, 2022. Time is represented on the x-axis and river kilometer on the y-axis.

Figure 17b (bottom): Movement pattern for the individual Silver Carp that swam into the Missouri River and back into the James River over a period of 52 days. Time is represented on the x-axis and river kilometer on the y-axis, where "0" indicates the confluence of the James and Missouri Rivers.

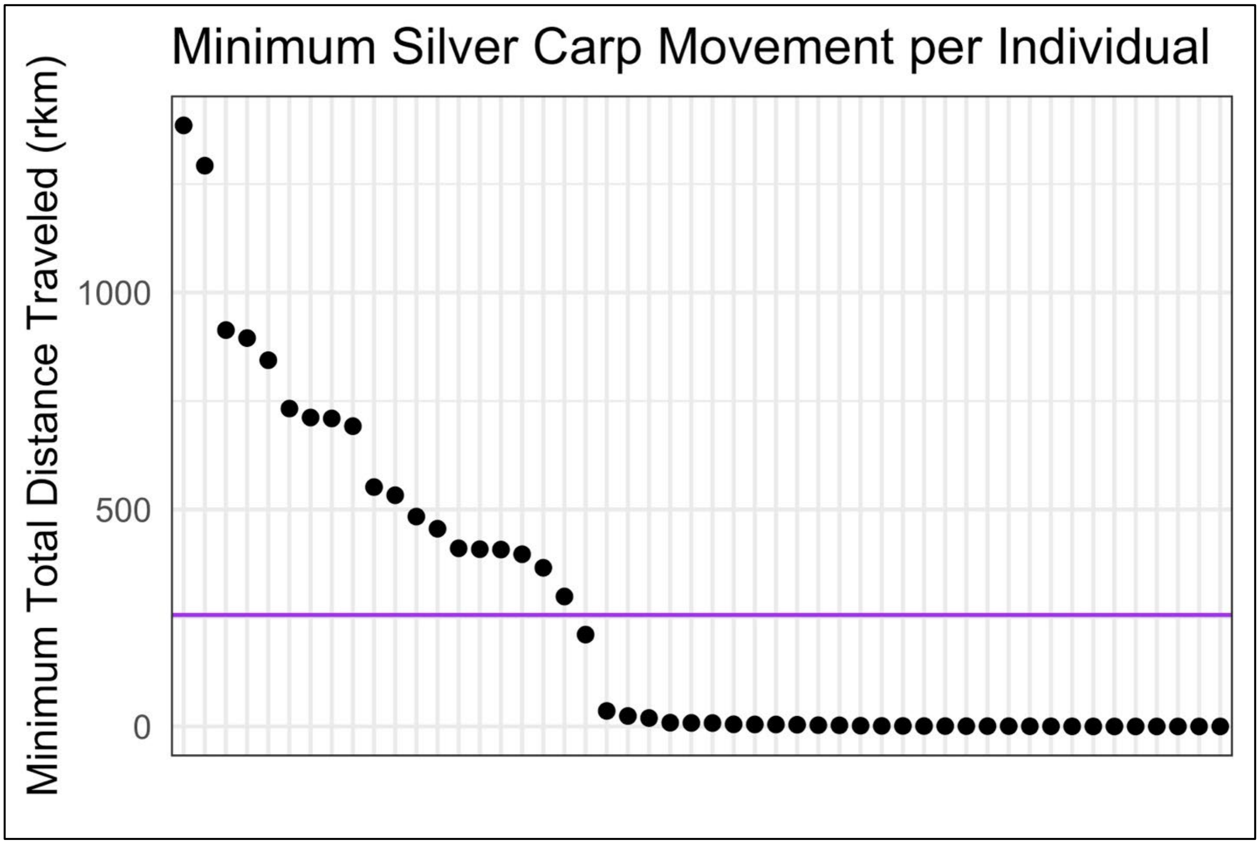


Figure 18: A graph showing the total minimum movement per individual. The mean distance traveled is denoted by a purple horizontal line. Each black dot represents one individual fish.

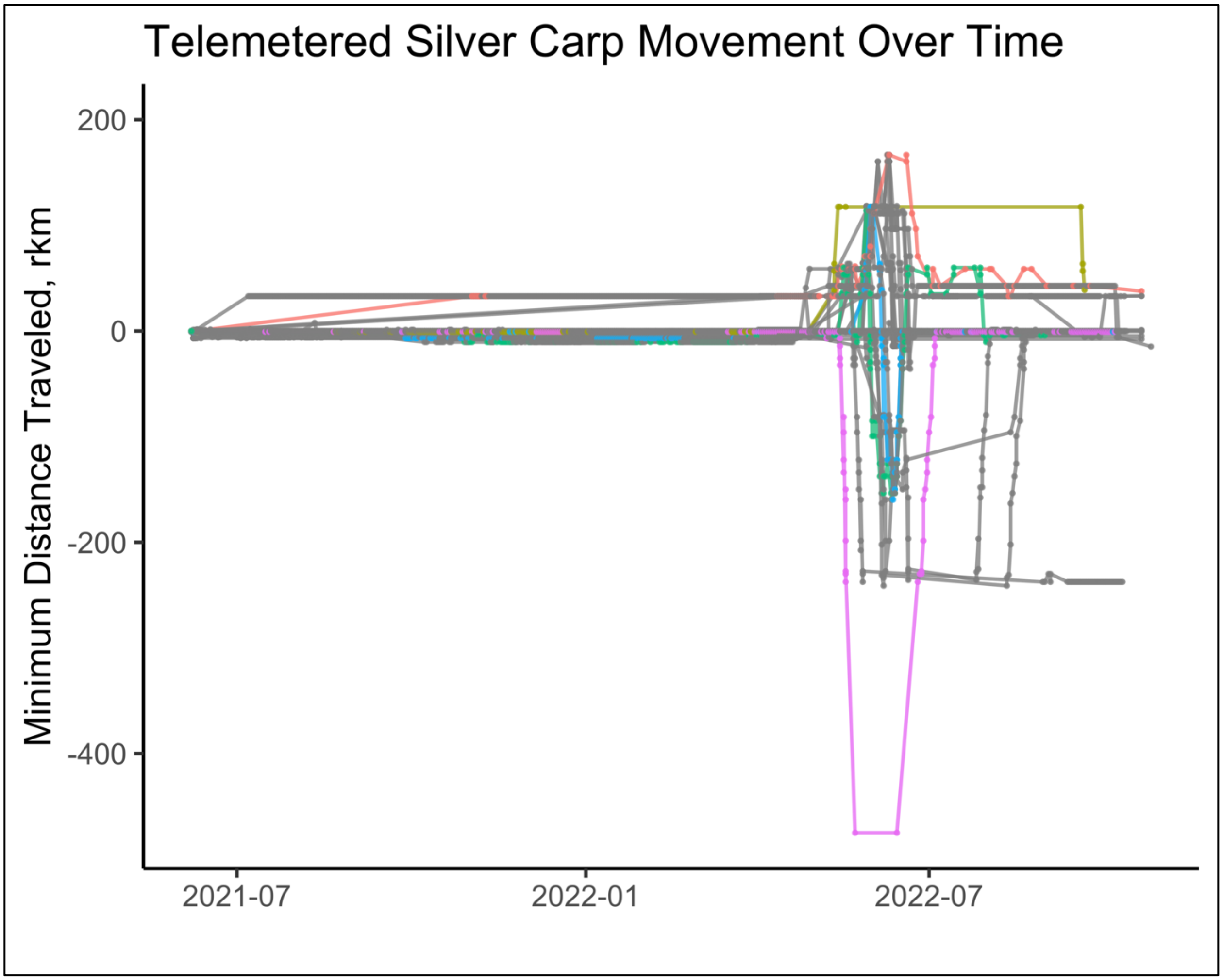


Figure 19: A graph depicting telemetered Silver Carp movement over time in the James River, SD. Movement is represented as displacement from the initial point of tagging. Negative river kilometers mean the fish swam downstream of its tagging location, and positive, upstream. A few individuals were colorized so that their movement could be discerned from the other fish movement patterns.

Agency: US Fish and Wildlife Service Great Plains Fish and Wildlife Conservation Office

Methods:

We developed a passive telemetry receiver array in the Big Sioux and Vermillion rivers to monitor movement and distribution of tagged Silver Carp (Figure 20). The array consisted of 10 Vemco VR2W acoustic receivers (n=5 per river). Each receiver was fastened to a steel frame, placed on the bottom of the river, and attached to a secure object on shore (e.g., large tree) with ⅛-inch steel cable. A HOBO temperature logger was attached to the furthest upriver and downriver receiver frames to collect water temperature data for each tributary.

In the Big Sioux River, receivers were placed from 1.2 river miles upriver from its confluence with the Missouri River to 10 river miles downriver of Falls Park, Sioux Falls, SD (i.e., impassable fish barrier), where sufficient water depth was available. Total river distance spanned was 141.8 river miles.

In the Vermillion River, receivers were placed from 0.1 miles upriver of its confluence with the Missouri River to 6.5 miles downriver of Lake Vermillion dam (i.e., impassable fish barrier) where sufficient water depth was available. Total river distance spanned was 95.9 river miles.

In 2022, 27 Silver Carp were implanted with transmitters. This, combined with the 80 transmitters implanted in 2021, resulted in a total of 107 tagged Silver Carp in the tributaries for analysis in 2022. Fish were caught in 2022 using electrofishing methods beginning at the confluence of each river, continuing upstream until 13 fish were captured in the Big Sioux River and 14 fish were captured in in the Vermillion River. Captured fish were held in a tank with a continuous flow of fresh river water. Each fish was anesthetized with Aqui-S 20E prior to surgery, weighed (g), measured for total length (mm), sexed, and implanted with acoustic transmitter tags (Vemco model V16-4H; 69kHz, 16 mm diameter, 68 mm length, 24 g). A Floy T-bar anchor tag (Model FD-94; Floy Tag & Mfg. Inc.) with a unique identification code and contact information (CARP@FWS.GOV) was attached to each fish near its dorsal fin base. Following surgery, fish were placed into a tank with a continuous flow of fresh river water until the fish was recovered enough to maintain equilibrium and swim independently. Once recovered, each fish was released near its point of capture.

Tags were implanted into 14 Silver Carp from the Vermillion River on May 31, 2022. Silver Carp in the Vermillion River had a mean total length of 603 mm (range: 560 – 648 mm) and mean weight of 2,504 g (range: 1,950 – 3,350 g). Tags were implanted into 13 Silver Carp from the Big Sioux River on June 1, 2023. Silver Carp in the Big Sioux River had a mean length of 656 mm (range: 610 – 756 mm) and mean weight of 3,035 g (range: 2,180 – 4,430 g).

Receiver and temperature logger deployment began on March 15, 2022, and receivers were retrieved from the river by November 9, 2022 to avoid equipment loss or damage during winter. Stationary receiver data were downloaded from receivers monthly from March to October. Actual dates of receiver operation varied among rivers and locations (Table 3).
Silver Carp detection data was summarized as the number of unique individuals detected at each receiver per day per 100 fish tagged. This analysis was used to account for the variability in the number of tags potentially present in the tributaries due to implanting tags in different years (i.e.,

all 107 tags were not implanted until June 1, 2022, but receivers were deployed in March 2022 to monitor the 80 tags implanted in 2021).

Two receivers in the Vermillion River (VER 4 and VER 5) and one receiver in the Big Sioux River (BSR 5) recorded no detections in 2022. One receiver in the Big Sioux River (BSR 3) was buried in shifting sediments, and data could not be recovered. Data from these four receivers were omitted from analysis in 2022. Another receiver in the Big Sioux River (BSR 4) was also buried in sediment; however, detections were recorded and downloaded prior to the loss of this receiver, so those data were included in analysis.

Results and Discussion:

- A total of approximately 1.3 million Silver Carp detections were recorded.
- A total of 7,117 individual daily detections were observed.
- River discharge in both tributaries was below the long-term average.
- Silver Carp movement patterns in both rivers generally coincided with discharge.
    - In the Big Sioux River, the number of tags detected at a receiver generally increased as discharge decreased (Figure 21).
    - In the Vermillion River, the number of tags detected at a receiver remained relatively constant as did discharge (Figure 22).
        - A single high discharge event on June 22, 2022, did result in a reduction in the number of tags detected immediately following the event across all three receivers.
- Silver Carp generally remained within the first 5 river miles of the confluence of the Missouri River for both the Big Sioux and Vermillion rivers during the entire study period (March to October).
    - General movement trends suggest that Silver Carp implanted with tags in the Big Sioux River emigrated from the river more frequently and a greater distance than those implanted in the Vermillion River (Figure 23)

Table 3. Passive receiver locations and dates of deployment and retrieval in the Big Sioux and Vermillion rivers during 2021.

River	Site	Latitude (N)	Longitude (W)	River mile	Date deployed	Date retrieved
Big Sioux	BSR1	42.4904	-96.469	1.2	3/15/2022	11/9/2022
Big Sioux	BSR2	42.5211	-96.49	4.4	4/8/2022	11/9/2022
Big Sioux	BSR3	42.7615	-96.632	39.3	3/15/2022	Unrecovered
Big Sioux	BSR4	43.0622	-96.471	80	3/24/2022	Unrecovered
Big Sioux	BSR5	43.5726	-96.6	143.1	3/26/2022	9/7/2022
Vermillion	VER1	42.7341	-96.888	0.1	3/24/2022	11/9/2022
Vermillion	VER2	42.7351	-96.886	0.3	3/24/2022	11/9/2022
Vermillion	VER3	42.7728	-96.93	4.5	3/24/2022	11/9/2022
Vermillion	VER4	43.0111	-96.995	36.7	3/26/2022	9/7/2022
Vermillion	VER5	43.4996	-97.158	96	3/26/2022	9/7/2022

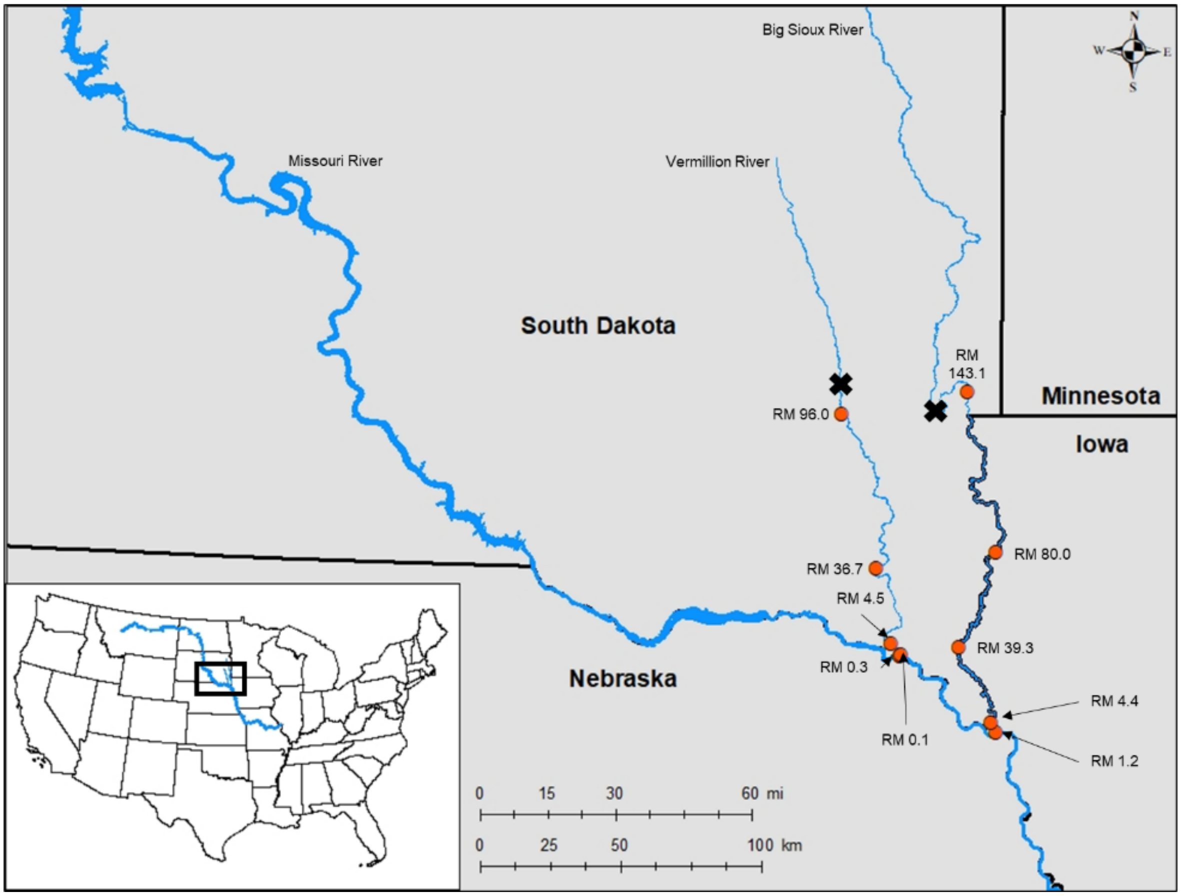


Figure 20. Location of passive receivers (orange circles) and barriers to fish movement (black "X") in the Big Sioux and Vermillion rivers during 2022. Receiver locations labeled by approximate river mile (RM).

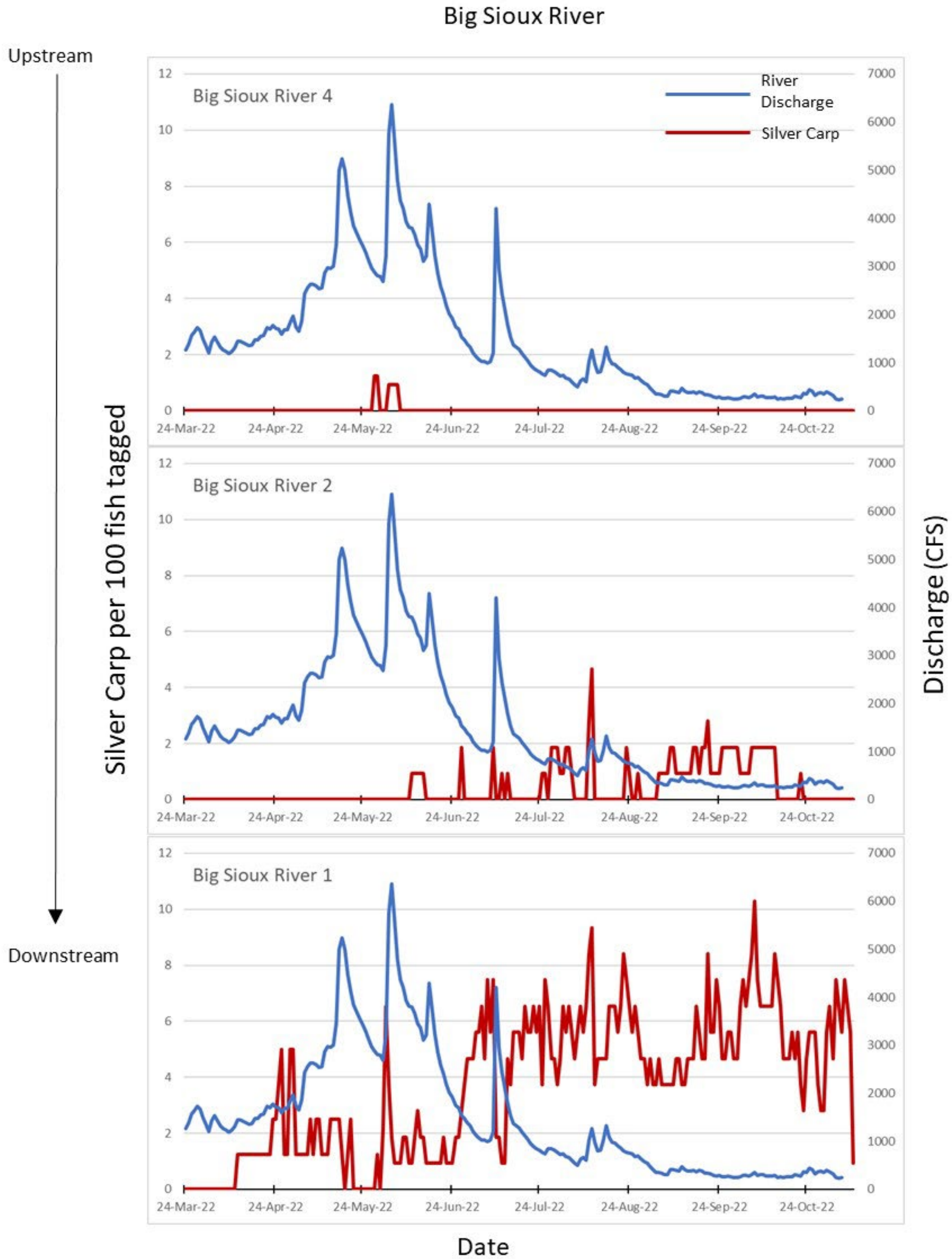


Figure 21. Number of daily detections of tagged Silver Carp per 100 fish tagged by passive receivers and discharge (cubic feet per second; cfs) in the Big Sioux River at Sioux City, IA during 2022. Graphs arranged from upstream (top panel) to downstream (bottom panel).

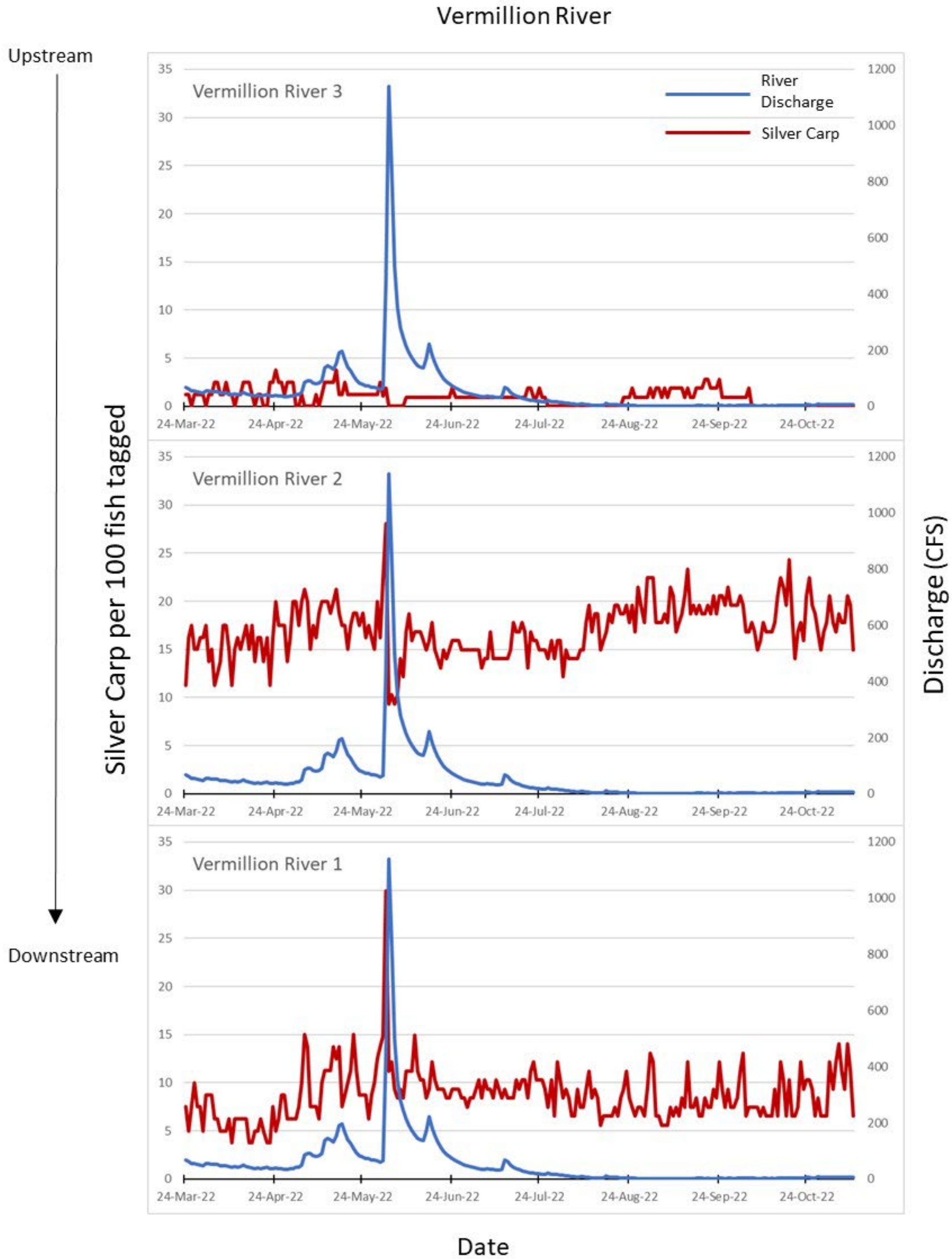


Figure 22. Number of daily detections of tagged Silver Carp per 100 fish tagged by passive receivers and discharge (cubic feet per second; cfs) in the Vermillion River at Vermillion, SD during 2022. Graphs arranged from upstream (top panel) to downstream (bottom panel).

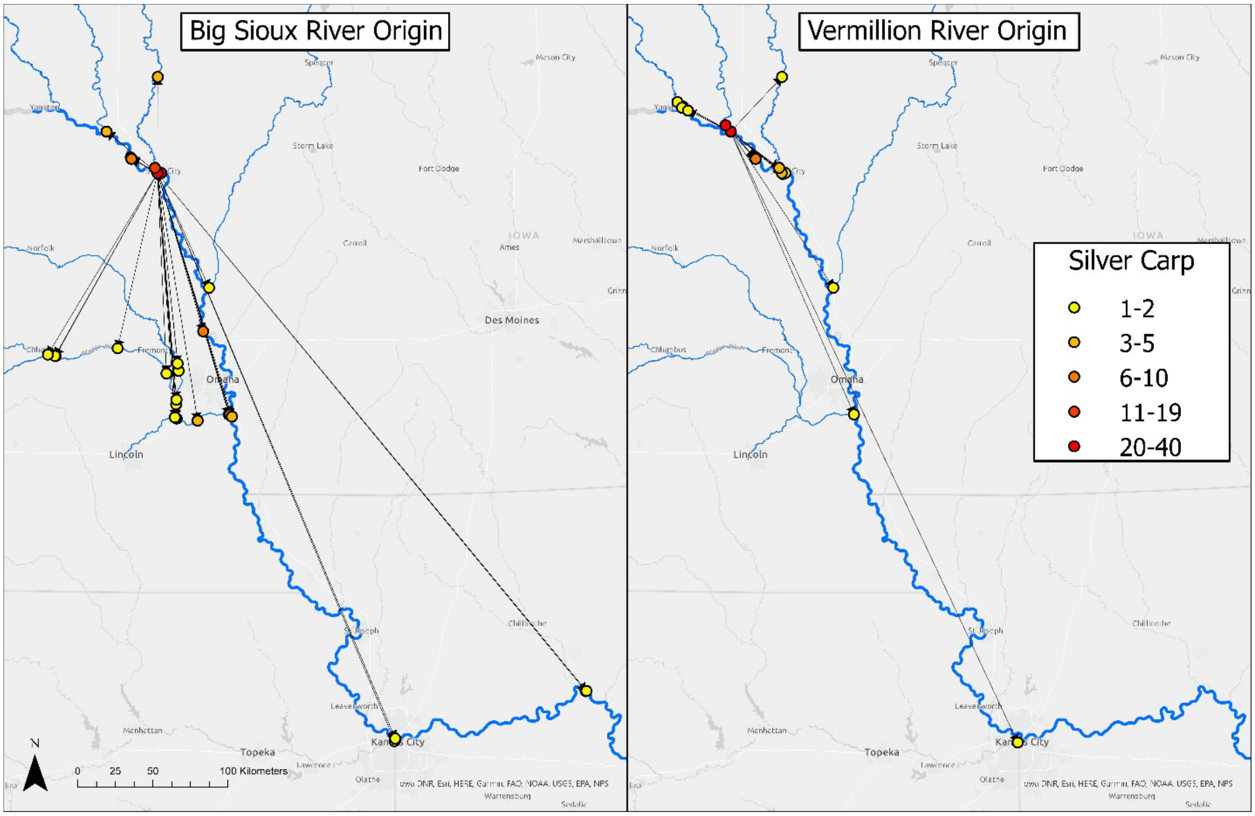


Figure 23. Dispersal of tagged Silver Carp from river of original tagging location. Records of downstream detections were obtained from receivers maintained by USGS, IA DNR, NGPC, and MDC.

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.
- Continued telemetry monitoring is recommended to encompass more river conditions and time periods.
- An expanded telemetry network would allow for more fine-scale movement pattern detections.
- Active tracking would allow for increased detections of individuals that are not located near a receiver.