Research Proposal
For
Joshua D. Stafford
Master of Science
in
Wildlife, Fisheries, and Aquaculture
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PROPOSED TITLE: Seasonal Movements of Silver Carp (*Hypopthalmichthys molitrix*) in a Hydrologically Regulated Floodplain Oxbow Network

OBJECTIVES:

1. Evaluate the hydrological connectivity of Eagle Lake with the surrounding waterways.
2. Examine environmental variables coinciding with spatial and temporal movements of Silver Carp between Eagle Lake and connected waterbodies.
3. Develop an operational strategy for the water-control structures to limit Silver Carp movements into Eagle Lake.

APPROVAL:

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Introduction

Invasive carps

Invasive species have made significant detrimental impacts on biodiversity throughout history (Pimentel et al. 2005). Havel et al. (2015) defined invasive species as "an exotic species that persist in its new environment, reproduces, and spreads greatly in its distribution". The expansion of invasive species has been linked with increasing human mobility and global economic growth (Hulme 2009; Thomaz et al. 2015). The U.S. economy alone spends $120 billion annually on limiting and offsetting invasive species' effects (Pimentel et al. 2005). Specifically, accidental and intentional introduction of invasive fishes have caused billion dollars in damage to the sportfishing industry of America (Pimentel et al. 2005).

Silver Carp (*Hypophthalmichthys molitrix*) is an invasive species native to eastern Asian waterways including China, Vietnam, and Russia (Kolar et al. 2007). The species was imported to the U.S. in 1973 to control water quality in aquaculture and sewage treatment ponds (Freeze and Henderson 1982; Kolar et al. 2007). Silver Carp were likely introduced initially into U.S. waterways by releases from aquaculture facilities in Arkansas (Freeze and Henderson 1982; Kolar et al. 2007). The first confirmation of successful Silver Carp spawning in the U.S. was in Horseshoe Lake, Illinois (Burr et al. 1996). The first Silver Carp reported in Mississippi was in 1988 on the Mississippi River near Greenville (Nico et al. 2014). Silver Carp have spread throughout large portions of the Mississippi River basin, including established populations in the Illinois, Ohio, and Mississippi rivers (Schofield 2005; Kolar et al. 2007; Nico et al. 2015). An established population is one that can sustain itself with natural reproduction in its current environment.

Introduced Silver Carp have been linked to several negative impacts. Silver Carp filter feed on phytoplankton and zooplankton, which can shift the composition of biotic communities and increase some toxic cyanobacteria (Xie and Xie 2002; Jang et al. 2004; Kolar et al. 2007; Chick et al. 2020). Silver Carp can compete for food with several native planktivorous fishes including Bigmouth Buffalo (*Ictiobus* *cyprinellus*), Gizzard Shad (*Dorosoma cepedianum*), Paddlefish (*Polyodon spathula*), and many others that rely on plankton during early life stages (Irons et al. 2007; Sampson et al. 2009; Pongruktham et al. 2010; Kocovsky et al. 2012; Pendleton et al. 2017; Kinlock et al. 2020; Chick et al. 2020). There is also great concern that invasive carps (including the Silver Carp) may establish in the Great Lakes where they could compete with recreational and commercial species (Cooke and Hill 2010; Kocovsky et al. 2012; *Scientific Investigations Report* 2013; Anderson et al. 2015; Zhang et al. 2016). In addition to the biodiversity and economical threats, Silver Carp pose a threat to human safety. For example, when disturbed by boat traffic, Silver Carp can jump out of the water and hit humans (Kolar et al. 2007; Vetter and Mensinger 2016).

Silver Carp survive in a wide range of temperatures, having been observed in waters 0–40˚C and reservoirs that are frozen for prolonged periods (Kolar et al. 2007). Though some studies have shown broad salinity tolerances, Silver Carp prefer conditions with ≤ 4% salinity (Kolar et al. 2005). Silver Carp have a "laterally compressed" body shape, which is suited for low-velocity habitats. Silver Carp are slow swimmers, with burst speeds that are slower than fish with similar body shapes (Hoover et al. 2016). Adults can grow to more than 1 m total length and weigh up to 35 kg (Kolar et al. 2007). Silver Carp are planktivores with "comb-like" gill rakers, which filter phytoplankton, zooplankton, and detritus from the water column more efficiently than the closely related Bighead Carp (*H. nobilis*) (Kolar et al. 2007). This is accomplished because Silver Carp gill rakers are fused together, unlike the Bighead Carp's (Kolar et al. 2007).

Several factors influence daily fish movement distances and rates including flow, length of day, water temperature and life stage. These same factors impact when and how fish access specific habitats such as cover, water depth, and distance to bank (Albanese et al. 2004; Woolnough et al. 2009; Harris et al. 2018; Edge et al. 2020). Silver Carp daily movement is most influenced by water temperature, depth, and flow (DeGrandchamp et al. 2008; Calkins et al. 2012; Coulter et al. 2016). Water temperature (≥17˚C) and increased stage height induce Silver Carp to migrate upstream for spawning (DeGrandchamp et al. 2008; Coulter et al. 2016; Vallazza et al. 2021). During spawning, Silver Carp males move more to search for females, while females move less to save energy for egg development (Coulter et al. 2016). Smaller individuals that are sexually immature do not migrate for spawning (Coulter et al. 2016). Silver Carp inhabit large rivers, floodplain lakes, and reservoirs in their native and introduced ranges (Kolar et al. 2007). They need fast, turbid water to spawn, and their eggs need long stretches (~100 km) of river to drift during incubation (Kolar et al. 2007). Adult Silver Carp can move long distances but average 3 – 5 km per day and often aggregate in areas with slow water velocity (<0.3 m/s) and high concentrations of phytoplankton (DeGrandchamp et al. 2008; Calkins et al. 2012). Silver Carp usually aggregate behind wing dikes in main channels of rivers (Marentette et al. 2011; Calkins et al. 2012).

Oxbow lakes in Lower Mississippi Alluvial Valley

Oxbow lakes are potential refuges for native species if inaccessible to invasive carps. Oxbow lakes are formed when a river abandons a bend as a result of a natural meandering process. There are over 1300 floodplain lakes that maintain water year-around in the Mississippi Alluvial Valley (MAV) alone (Miranda et al. 2021). These oxbow lakes harbor high beta diversity, including around 100 species of fish (Miranda 2016). Silver Carp potentially compete with native species in oxbows and other backwaters (Pongruktham et al. 2010). Isolating backwaters from mainstem rivers by adding barriers or modifying operations of existing barriers could preclude Silver Carp from oxbow lakes and limit competition with the diverse native species assemblages that rely on backwater habitats (Stell et al. 2018; Kinlock et al. 2020).

Eagle Lake is an 1870-hectare oxbow lake located on the Louisiana and Mississippi border in Warren County, MS and Madison Parish, LA. 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). A levee was built in 1925 that permanently separated Eagle Lake from the Mississippi River, and a structure was completed in 1978 that controlled water flow between Muddy Bayou and Eagle Lake (hereafter, “Muddy Bayou water-control structure”; Figure 1; Miranda et al. 2001; USACE 2020). Muddy

Bayou is a 1.45 km long waterway that flows from Eagle Lake into the much larger Steele Bayou, which merges with Whittington Canal just upstream from the Yazoo River (Figure 1). Water enters or leaves Eagle Lake via Muddy Bayou. A small number of Silver Carp were probably introduced into Eagle Lake during 2011 when water managers opened the Muddy Bayou water-control structure to alleviate flood pressure on the levee around Eagle Lake (ERDC Report 2011).

My study 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 structures. My goal is to develop an operational strategy for the water-control structures in my study area. To achieve this goal, I have identified three objectives. First, I will evaluate the hydrological connectivity of Eagle Lake with the surrounding waterways. Second, I will examine environmental variables coinciding with spatial and temporal movements of Silver Carp between Eagle Lake and connected waterbodies. Third, I will use the results from objectives 1 and 2 to develop an operational strategy for Muddy Bayou water-control structure to limit Silver Carp movements into Eagle Lake. This study will strive to help inform management of invasive carps into Eagle Lake and similar waterbodies in the Mississippi Alluvial Valley.

METHODS

Overview

This study area will be split into four spatial units so that Silver Carp movements can be quantified (Figure 1). A spatial unit is considered a standalone unit. Vemco VR2W omnidirectional receivers will be placed throughout the study area to passively track tagged Silver Carp movements. Active tracking with a VR 100 will supplement these stationary receivers. Silver Carp will be 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.

Objective 1 – Evaluate the hydrological connectivity of Eagle Lake with the surrounding waterways

Waterway connectivity in the Eagle Lake study area is influenced by water-control structures and flooding. Muddy Bayou 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 flows into the Yazoo River. Whittington Canal joins Steele Bayou 600 m upstream of the Steele Bayou structure. The Steele Bayou structure is 1 km upstream of the confluence of Steele Bayou and the Yazoo River (Figures 1–3).

The operations of water-control structures on Muddy and Steele bayous could influence Silver Carp movements. When both structures are open, all spatial units are hydrologically connected. When Steele Bayou structure is closed, the Yazoo River spatial unit is disconnected from all other spatial units. When the Muddy Bayou structure is closed, Eagle Lake is disconnected from all other spatial units. Muddy Bayou structure is operated jointly by MDWFP and the U.S. Army Corps of Engineers (USACE) to manage water quality and fish habitat in Eagle Lake and to limit flooding in the Yazoo Backwater Area (Eagle Lake FMP 2021). Eagle Lake water levels are maintained by raising (opening) and lowering (closing) gates on the Muddy Bayou structure. Thus, water moves under the gates of the water-control structure. Water levels in Eagle Lake, Muddy Bayou, and Steele Bayou are monitored by stream gages placed upstream and downstream of water-control structures on Muddy and Steele bayous (USACE). Pool elevation in Eagle Lake is maintained close to 76.9 NGVD between January 1 and September 1, and 75.0 NGVD between September 1 and January 1. Water can only be released out of Eagle Lake if the water level is higher on the Eagle Lake side of Muddy Bayou structure than the Steele Bayou side of the structure. The USACE operates the structure during flooding events (Eagle Lake FMP 2021). Flooding occurs when gage height is $\geq$ 90.0 NGVD on the Steele Bayou side of the Muddy Bayou structure (USACE 2020). When the water height is $\geq$ 96.0 NGVD on Steele Bayou side, water is released into Eagle Lake from Steele Bayou to mitigate damage to the structure and surrounding roads (USACE 2020). When water elevation is less than 96.0 NGVD on the Steele Bayou side of Muddy Bayou structure, the barrier is operated to prevent invasive carps from entering Eagle Lake from Muddy Bayou by only raising the water-control structure's gate a maximum of 15 cm (Eagle Lake FMP 2021).

The USACE manages the Steele Bayou structure to limit backwater flooding in the Yazoo Backwater Area (USACE 2020). Steele Bayou water-control structure has four gates that are 6.7 m tall when completely opened. The landside elevation of Steele Bayou is maintained between 68.5– 70.0 NGVD during low flow by having two of the gates open 0.3–0.6 m (USACE 2020, D. Hanley, USACE, personal communication). These minimum levels are maintained to improve fish and wildlife habitat in the Yazoo Backwater Area (USACE 2020, D. Hanley, USACE, personal communication). When the landside of Steele Bayou approaches 73 - 75 NGVD and is a higher elevation than the Yazoo River, the structure is open to its maximum height of 6.7 m (D. Hanley, USACE, personal communication). On the landside of Steele Bayou water-control structure, minor flooding occurs at 80.0 NGVD in some low-lying areas (USACE 2020). At 87.0 NGVD, water is completely out of Steele Bayou's channel (USACE 2020). Little Sunflower River structure, which is 25 km upstream from Steele Bayou on Whittington Canal, also drains the Yazoo Backwater Area. However, Little Sunflower River structure is only opened during flood events when the Yazoo River is below the landside level of Little Sunflower River structure (USACE 2020). Neither Steele Bayou nor Little Sunflower River structures are operated to prevent movements by invasive carps.

Fish can only move between spatial units if there is hydrologic connectivity. I will use stage height gauges to monitor hydrologic connectivity and flooding in Muddy and Steele bayous. Additionally, I will place trail cameras (APEMAN, H55, China) and water level loggers (HOBO Water Level Data Logger - U20L-01 ONSET, MA, USA) in key areas to corroborate gage data (Figures 1-3). I will also add two additional water temperature loggers (Onset HOBO Pendant) in each spatial unit in case water-level loggers are lost. I will put cameras looking at Muddy and Steele Bayou structures from both upstream and downstream to validate when the structures are open, and therefore, when spatial units are connected. I will secure cameras with cable locks to either trees or structures approximately 5 m above the ground to avoid flooding. Cameras will take photos in the morning, afternoon, and evening every day and will be checked and downloaded bi-monthly. Water level loggers and Pendants will record water temperature and pressure every 15 minutes and be downloaded monthly.

I will deploy the water-level loggers in two ways. The logger that records air pressure will be attached high enough in a tree to avoid being submersed by rising water. I will use 2.5 mm stainless-steel cable and cable clamps to secure the logger to the tree. I will attach the loggers that record water pressure and temperature to cement cinder blocks. I will wire them in a PVC housing that is U-bolted to the side of the cinder blocks. I will attach one end of a rope the cinder block and put a piece of foam on the other end with project information to mark logger locations. I will measure and record the depth of the logger prior to pulling them up to download. After downloading, I will lower the logger to same place.

I will deploy Pendants in 18-cm long PVC housings. I will put an eye-bolt on one end cap of the housing. I will loop a 9-meter long, 2-mm thick stainless-steel cable through the eye-bolt and secure it with cable clamps. The other end of the cable will attach to a root or log on land. I will access the Pendant for downloading via a removable cap on the other end of the housing. I will put another eye-bolt on the inside of the removable cap. I will attach the pendant to this eye-bolt with wire. I will drill multiple holes in the PVC housing so that water can fill it and the Pendant record the water temperature.

I will relate water depths measured by water-level loggers to water depths measured by river gages on either side of water-control structures, so that water depth can be inferred if water-level loggers are temporarily lost or malfunction. to

I will correlate Silver Carp movements and water-level logger depths to USACE stage height gages on the landside and Yazoo River side of Steele Bayou, and lake and landside Muddy Bayou structures. Gage and structure data will be gathered from US Geological Survey (USGS) and US Army Corps of Engineers (USACE). I will attempt to complete this analysis early in the study and create an appendix describing how I accomplished this analysis.

Objective 2 – Examine environmental variables coinciding with spatial and temporal movements of Silver Carp between Eagle Lake and hydrologically connected waterbodies.

Receiver anchoring and placement to monitor spatial and temporal movements

I will use acoustic receivers deployed in an underwater array to detect tagged Silver Carp as they move among spatial units (Figures 1–3). I will place Vemco VR2 receivers at locations based on four criteria: accessibility, optimal read range, protection from flooding, and to minimize tampering or theft (Adams et al. 2009). I will use a daisy chain of cement and rebar anchors to hold receivers in place. I will reinforce each cement anchor's integrity with chicken wire. I will put an eye-bolt in the middle of each cement anchor. The weight (22–45 kg) of a cement anchor will depend on its location. Cement anchors will be heavier where swifter water velocities are anticipated (i.e., Yazoo River and lower Steele Bayou). I will make each rebar anchor out of 10-x-30 PVC pipe with a cap on one end. I will cut four 30-cm pieces of 13-mm rebar and slide pieces of rebar through holes in the side of a PVC pipe. I will pour 5–7 kg of cement into the PVC to hold the rebar in place. I will put an eye bolt in the top of the cement. I will use stainless-steel cable to attach buoys, cement anchors, and rebar anchors together in a daisy chain. I will use 5-mm stainless-steel cable for sites that will have slower water velocities (e.g., upper Steele Bayou and Muddy Bayou) and 6.5 mm stainless-steel cable for sites that will have swifter water velocities (i.e., Yazoo River and lower Steele Bayou). For all daisy chains, I will attach the cement anchor to the rebar anchor by looping a 10–15-m cable through the eye bolt on both anchors. I will secure both sides of the cable with cable clamps. The rebar anchor will create drag to prevent the cement anchor from being pulled downstream in swift water.

I will need to locate and access receivers to download telemetry data monthly. Therefore, I will suspend each receiver to a buoy, which will be attached to a cement anchor with a 15-m stainless-steel cable. I will use different buoy configurations depending on anticipated water velocities. For slow water, I will loop 5-mm cable through a LD-3 buoy and secure both ends with cable clamps. For swift water, I will use CC-3 buoys, which have a hole in the center that a metal pipe can slide through. I will put a metal pipe that is threaded at the top through the hole. The pipe will be long enough so that 15 cm protrudes out the bottom of the buoy. I will screw a floor flange on the top of the metal pipe to prevent the pipe from separating from the buoy. I will coat the threads of the pipe with glue to prevent theft or loss. I will drill holes on the sides of the pipe near the bottom and loop the other end of the 6.5-mm cable that is attached to the cement anchor through these holes and secure it with cable clamps. This setup reduces the chance of the buoy being ripped off the cable when there is fast water. I will put reflective tape and project information on the buoys.

I will secure a VR2 receiver 1.5 meters below the buoy on the cable between the cement anchor and buoy. The hydrophone (i.e., receiver) will point towards the substrate so the buoy will not interfere with the read range (Clements et al. 2005). I will use a 2.5-mm cable looped through the bottom hole on the VR2 and attach it to the cable with cable clamps to secure the receiver. I will place multiple zip-ties around the receiver and 6.5- or 5-mm cables to further secure the receiver. I will place receivers so their read ranges overlap (Figures 1-3). These areas of overlap are called "gates", which will allow me to determine the direction a fish is moving through each gate between spatial units (Heupel et al. 2006; Kessel et al. 2014). I will drag a test tag through these gates to ensure I can determine directional movement. Fish movements through water-control structures have the greatest management implications, so I will put two receivers on either side of Muddy and Steele bayou structures as backups. Each receiver will have separate anchor systems.

Field tests of receiver detection range

I will test the detection range of receivers within the study area before translocating tagged fish. Testing in the study area will help me configure the array (Heupel et al. 2006; Gjelland and Hedger 2013; Kessel et al. 2014). Hereafter, detection range will be “the relationship between detection probability and the distance between the receiver and tag” (Kessel et al. 2014). I will test the detection range by suspending one test tag 2 m below the surface. The test tag will be a high-output tag that will emit a delayed acoustic signal every seven seconds. The tag will be directly above a VR2 “testing” receiver, which will act as a control that should detect 100% of the tag signals (Clements et al. 2005). I picked a depth of 2 m to mimic average swimming depth of Silver Carp and a short-signal delay to increase sample size of detections (Heupel et al. 2006; MacNamara et al. 2018). I will place a VR2 receiver every 50 m away from the testing receiver and tag until 500 m away (Olsen and Moland 2011). I will test the read range for a minimum of 2 h (Espinoza et al. 2011). I will attempt to test receiver detection ranges under a variety of conditions to evaluate receiver performance (e.g., rain, wind; Kessel et al. 2014).

I will download data and use the Vemco Range Test to calculate and visualize detection range to determine placement of receivers to create gates (Vemco 2015). Detection ranges are lowest in a gate halfway between two receivers (Vemco 2015). I will aim to place receivers close enough so that their detection ranges will never be less than 50% in poor conditions (Vemco 2015). For example, if there are 1000 tag detections on the control receiver when testing during poor conditions and only 500 tag detections on the testing receiver at 200 m, I will know that there is a 50% chance of detecting a tag at 200 m in poor conditions. In this example, I would not place receivers more than 400 m apart because there would be less than a 50% chance of detecting a tag beyond 400 m.

I will conduct less-intensive read range tests every two months to maintain coverage of acoustic arrays (Heupel et al. 2006; Kessel et al. 2014). I will put the test tag at one meter below the surface over the side of the boat next to an omnidirectional VR165 acting as the control (Espinoza et al. 2011). A GPS will be used to record points where the test tag emits a signal. I will test read range out to 500 m when possible. I will evaluate detection efficiency visually via graphs using Vemco Range Test software. Bathymetry, water temperature, turbidity, and weather conditions can affect read range by blocking or attenuating tag signals (Bessudo et al. 2011; Gjelland and Hedger 2013; Kessel et al. 2014). I will consider these factors when placing receivers in the study site to minimize their effects. I will check receivers for damage and clean receivers each time I download data to avoid any interference of "biofouling" (Kessel et al. 2014).

Capturing and tagging Silver Carp

A commercial fisher will be hired to catch 100 Silver Carp in gill nets between February and March. If the fisher cannot capture 100 Silver Carp from Eagle Lake, he will catch fish from Steele Bayou and Whittington Canal. Gill nets will be 305 m long and 3.5 m deep with multi-strand 9 cm web and 18 cm stretch on the diagonal knots.

I will implant the first 80 Silver Carp with a Vemco V16 4x acoustic tag. The tag output will be 158 decibels, 69kHz and set at a random delay of 33–57 seconds. Before tagging, I will check each fish for injuries, deformities, and normal swimming behavior (Calkins et al. 2012; Byrd et al. 2019). A Silver Carp will not be tagged if the tag weighs more than 2% of its body weight (Jepsen et al. 2002). I will immobilize Silver Carp using tricaine methane sulfonate (MS-222). The suggested concentration varies from 15 to 200 mg/L (Gause et al. 2012; FAU IACUC 2014; Husen 2015). I will use a low dosage at first and increase if necessary. I will monitor and replenish water in the anesthetizing, surgery, and recovery containers to ensure water is cool and well oxygenated. I will anesthetize Silver Carp in a 378.5-liter polyresin stock tank and will consider Silver Carp sufficiently anesthetized when they lose equilibrium, are not swimming, and have slow operculum movement (Yoshikawa et al. 1988; Gause et al. 2012; Byrd et al. 2019; Edge et al. 2020). I will transport Silver Carp to a sling made of chamois cloth looped around wooden dowels. The dowels will be inserted into milk crates to hold the sling while I perform surgery. Each fish will be placed ventral side up where fresh water will constantly flow over its gills from a tube connected to a bucket.

I will clean surgical instruments and my work area with ≥ 70% ethanol alcohol between each fish surgery (Coulter et al. 2016). After I remove scales from a 3 x 5-cm area on the ventral side between the pelvic and anal fins, I will make an incision just large enough to insert a Vemco V16 tag parallel to the lateral line into the coelomic cavity (DeGrandchamp et al. 2008; Erickson et al. 2016; Coulter et al. 2016; Byrd et al. 2019). Care will be taken so that no internal organs will be damaged (Coulter et al. 2016). I will close the incision with simple interrupted sutures to minimize tag loss. I will insert a floy tag on the fish’s left side of the dorsal fin. This tag will let anyone who might catch a tagged carp know to release them for research purposes.

I will move tagged fish after surgery to another 378.5-liter polyresin stock tank with aerators where they will be observed for recovery and abnormal behavior. After a fish displays 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 will be 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). I will use the boat or vehicle to transport fish to a new site. I will place tagged Silver Carp in a net pen in water if I get ahead of vehicles transporting tagged fish. If a fish does not recover based on the above criteria, I will euthanize it by placing it in a stock tank with a lethal dose of MS-222 (IACUC-21-434). I will sanitize and insert the tag in another fish so that 80 fish exhibiting normal behavior are tagged and released.

On my field datasheet there will be columns for total length (TL), weight (g), sex, acoustic tag number, floy tag number, date released, site where it was released, location collected, and notes (Figure 5). I will determine sex by a combination of identifying gonads or expressing fish to see if eggs (female) or milt (male) are expelled (Coulter et al. 2016) and the presence (male) or absence (female) of rough patches on top of the pectoral fin (Wolf et al. 2018). Using rough patches is the most effective for Silver Carp between 300-800 mm, so extra care will be taken when identifying fish outside this range (Wolf et al. 2018).

Relocating tagged fish

I will release 20 Silver Carp in each of the four spatial units. I will make sure the groups of Silver Carp have varying sizes of adult fish. Silver Carp that are caught in Eagle Lake will be released back into Eagle Lake first. I will then capture and release fish in Steele Bayou. I will use road and boat accesses to transport tagged Silver Carp to the other release sites starting with the most downstream site, which is downstream of the Steele Bayou water-control structure (Figure 1). When stressed, fish release alarm pheromones to alert other fish to danger (Brown et al. 2000; Stensmyr and Maderspacher 2012), so releases will progress upstream to limit the effect of alert pheromones on fish movement throughout the study area.

Redundancies and failure of tag recordings

I will use a VR100 hydrophone to active track and VR2 receivers to passive track tagged Silver Carp locations and movements. If a receiver detects a fish ≥ 2 times within a 24-hour period (00:00-24:00), the last recording will determine the fish's location. I will actively track a tag that has been recorded on the same receiver for ≥ 72 hours to determine whether the fish died or the tag fell out (Goclowski et al. 2013). Fish movement can be varied temporally and spatially. I will analyze Silver Carp movement with different temporal scales to better understand course and fine scale movements.

The gate created by staggering receivers at transitions between spatial units will indicate the direction a fish is moving, thereby revealing the spatial unit where a fish is located. However, if one of the two receivers in a gate fails, a fish may pass among spatial units undetected. For example, if a fish is detected by a receiver in the upper Steele Bayou spatial unit and its next detection is on the lowest receiver in the lower Steel Bayou spatial unit, then the fish gate on the upstream end of the lower Steele Bayou either malfunctioned or failed to detect the fish when moving into the lower Steele Bayou spatial unit. For the analysis, I will treat this as missing data in my analysis. Fish may stay in the middle of a spatial unit or die before being detected by a passive receiver located at the edges of a spatial unit. Therefore, I will manually track fish in each spatial unit once per month for the duration of the study with a VH 165 (Vemco) omnidirectional hydrophone. I will use the information collected during active tracking to determine if fish are present, dead, or emigrated from the study area (DeGrandchamp et al. 2008).

Objective 3 - Develop an operational strategy for the water-control structures to limit Silver Carp movements into Eagle Lake.

I will examine environmental and biotic variables related to daily movements by Silver Carp among spatial units including total length (mm) at time of tagging, water temperature (C^o) sex (if determinable), and water stage (m) from Muddy and Steele bayou USACE and USGS gages (Table 1). I will analyze Silver Carp movements using a Cormack-Jolly-Seber (CJS) multi-state recapture model within the MARK program (Cooch and White, 2015). Movement by bigheaded carps can be sporadic immediately after tagging, called “fallback” (Frank et al. 2009). Therefore, I will exclude the first 48 hours of telemetry data from analyses (Coulter et al. 2016; Prechtel et al. 2018; Byrd et al. 2019).

The estimated responses in a multi-state model are probability of survival over a time period (S), probability of encounter such as capture and resighting (p), and probability of movement (ψ) (Powell and Gale 2015). I will model probability of movement from all combinations of aforementioned predictor variables (e.g. size at tagging, sex, water temp, etc.). Since I cannot ensure I will detect all capture probabilities, I will use a parametric bootstrap to replicate my data and estimate goodness-of-fit ($\hat{c}$) (Cooch and White 2019). I will then fit each bootstrap to my global model using RMark (Laake 2013; Cooch and White 2019). I will assess model fit with a $\hat{c}$ test, which will be calculated by dividing deviance ($-2\log_e L$) by degrees of freedom (df) (Senar and Conroy 2004; Cooch and White 2019). The likelihood (L) of a model depends on information in sample data. Degrees of freedom will be calculated by subtracting estimated parameters by one (; Senar and Conroy 2004; Powell and Gale 2015).

Sample variance can be larger than predicted by the multi-state model (i.e., overdispersion), thereby violating model assumptions. Therefore, I will use $\hat{c}$ to adjust the Akaike’s Information Criterion (AIC) for overdispersion (Cooch and White 2019) and use quasi-likelihood adjusted AIC (QAIC) for model selection. I will evaluate support for each model based on ΔQAIC (Brown et. al 2003). I will use the following equation to determine the difference in QAIC between model (i) and the best supported model (AIC_{min}) of each model: $\Delta QAIC_i = \Delta QAIC_i - \Delta QAIC_{min}$ (Senar and Conroy 2004). Next, I will calculate model weight for each model. Model weight is the probability of a model being the best-supported model among models within the candidate set and reflects model selection uncertainty (Burnham et al. 2002). I will interpret parameter estimates from the best-supported model (i.e., model with lowest QAIC) to evaluate the magnitude and direction in which predictor variables correlate to movements of Silver Carp among Eagle Lake and hydrologically connected waterbodies. If there is a pattern where Silver Carp move through water-control structures, I will try to model this movement. I will use this model to try to inform the management of water-control structures so that they can be used to deter Silver Carp movements.

Tables

Table 1**. –** Movement predictors. Variables hypothesized to influence Silver Carp (*Hypophthalmichthys molitrix*) movements among Eagle Lake (LA, MS) and hydrologically connected waterbodies.

Variable	Hypothesis	Prediction	Reference

Water temperature	Water temperature will affect Silver Carp movement. Spawning, feeding behavior, and habitat selection is influenced by temperature.	The probability of Silver Carp transitioning among spatial states will increase with warmer stream temperatures	DeGrandchamp et al. 2008; Calkins et al. 2012
Stage height	Silver Carp will move upstream on a rising hydrograph to spawn. Silver Carp will move downstream as water level drops and post spawn.	The probability of Silver Carp transitioning among spatial states will increase at higher stages.	DeGrandchamp et al. 2008; Calkins et al. 2012; Coulter et al. 2016
Length at tagging (mm)	Smaller Silver Carp may not move as much because they do not engage in broad scale movements such as spawning	The probability of Silver Carp transitioning among spatial states will increase with larger fish.	Coulter et al. 2016
Sex	Females may move less to conserve energy for egg development. Males may move more as they look for and compete for mates.	The probability of Silver Carp transitioning among spatial states will be higher for males.	Marentette et al. 2011; Coulter et al. 2016
Water connection	Silver Carp will move between spatial states more often when there is more water. Barriers in the study area will be closed at certain times. During these times, Silver Carp movements will be limited. Cameras will be used to determine when barriers are open or closed.	The probability of Silver Carp transitioning among spatial states will be higher when water-control structures are open.	Tripp et al. 2014; USACE, 2020: Hershey et al. 2021
Season	Silver Carp will move more during spring and early summer seasons due to increasing water temperatures.	The probability of Silver Carp transitioning among spatial states will be higher in the spring and summer, and lower during the fall and winter.	DeGrandchamp et al. 2008; Coulter et al. 2016
			DeGrandchamp et al. 20087

Change in Stage Height (24-hr, 1-week, etc.)	Silver Carp will move more when there is an increase in stage height.	The probability of Silver Carp transitioning among spatial states will be higher when stage height is increasing.

Table 2. – Example data sheet.

Fish Number	**Location Collected**	**TL (mm)**	**Weight (g)**	**Sex (M,F)**	**Acoustic Tag**	**Floy Tag**	**Date Released**	**Site Released**	**Notes**

Table 3. –Gannt chart showing monthly tasks during this study. "x" indicates the task will occur during that month.

2022	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
First objective defense		x										
Develop second objective	x	x	x									
Build anchors	x											
Intensive range test		x										
Test receivers and tags		x										
Deploy equipment		x										
Gather and prepare equipment	x	x										
Tag and release carp		x										
Receiver downloads		x	x	x	x	x	x	x	x	x	x	x
Water level logger and Pendant downloads		x	x	x	x	x	x	x	x	x	x	x
Camera downloads				x		x		x		x		x
Manual tracking spatial units		x	x	x	x	x	x	x	x	x	x	x
Auxiliary range test				x		x		x		x		x
Literature review	x	x	x	x	x	x	x	x	x	x	x	x
Data analysis				x	x	x	x	x	x	x	x	x
Drafting thesis						x	x	x	x	x	x	x

2023	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

Receiver downloads	x	x	x	x	x	x						
Water level logger downloads	x	x	x	x	x	x						
Camera downloads		x		x		x						
Manual tracking spatial units	x	x	x	x	x	x						
Range test		x		x								
Literature review	x	x	x	x	x	x	x	x	x			
Data analysis	x	x	x	x	x	x	x	x	x			
Drafting thesis	x	x	x	x	x	x	x	x	x			
Remove equipment						x						
Thesis Defense									x			

Figures

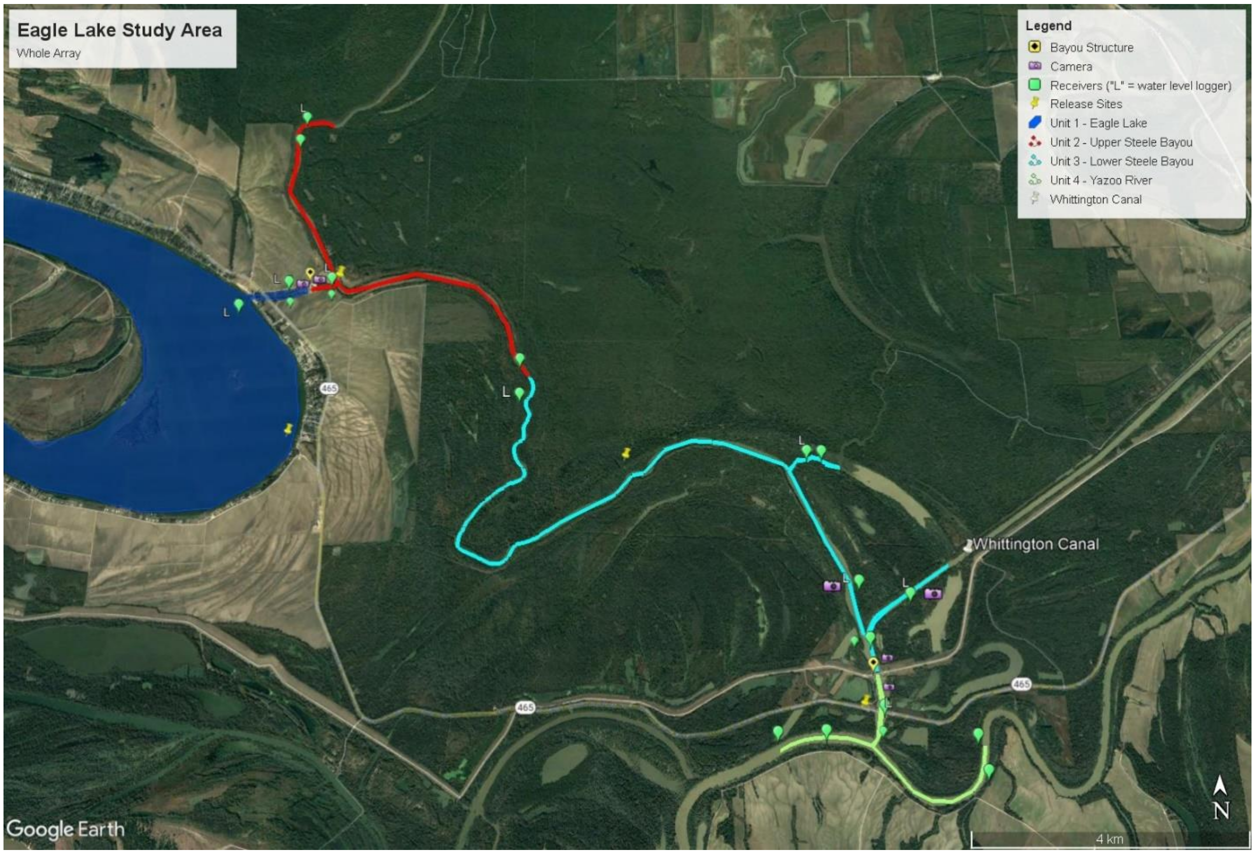

Figure 1.–Aerial view of Eagle Lake (LA, MS) study area and connected waterways. Locations of equipment are approximate.

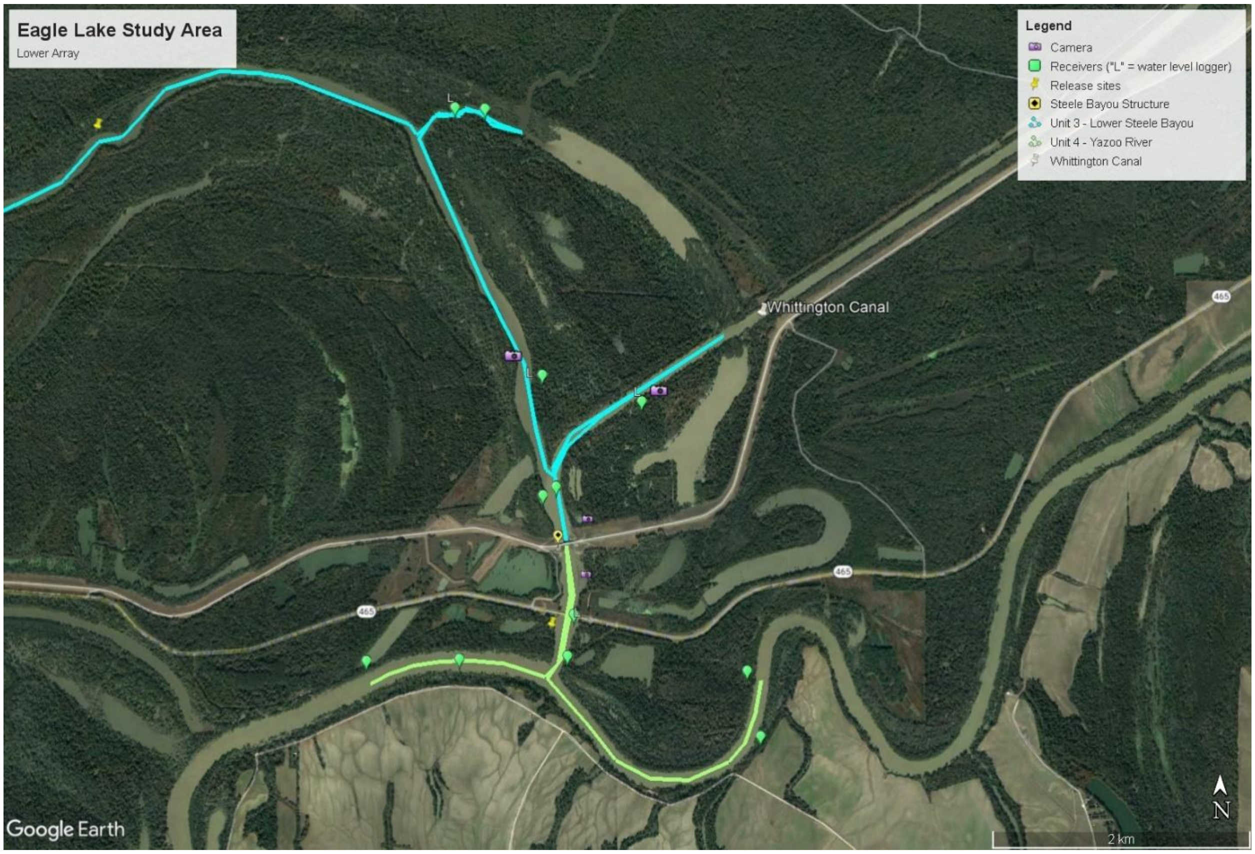

Figure 2.-Aerial view of lower Steele Bayou (blue) and Yazoo River (green), Mississippi downstream of Eagle Lake. Locations of equipment are approximate.

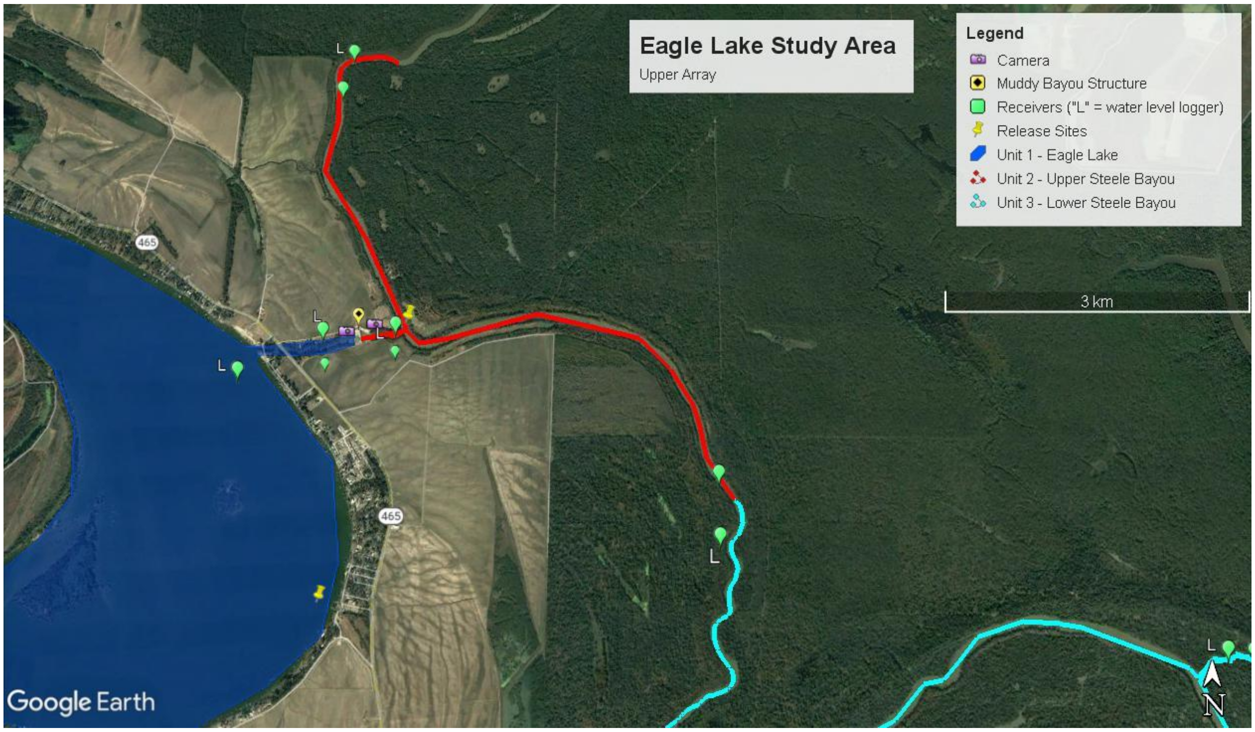

Figure 3. –Aerial view of Eagle Lake (LA, MS) and connected waterways (upper Steele Bayou, Muddy Bayou). Locations of equipment are approximate.

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