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Alexander Catalano
Southern Illinois University Carbondale, alexcatalano28@gmail.com

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INVASIVE CARP MOVEMENT, BEHAVIOR, AND HABITAT USE: EVALUATING COMMON CARP AS A SURROGATE FOR BIGHEADED CARPS

by

Alexander V. Catalano

B.S., University of Wisconsin- Stevens Point, 2018

A Thesis
Submitted in Partial Fulfillment of the Requirements for the
Master of Science Degree

Department of Zoology
in the Graduate School
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in the field of Zoology

Approved by:

Dr. James E. Garvey, Chair

Dr. Gregory W. Whitledge

Dr. David Glover

Dr. Alison A. Coulter

Graduate School
Southern Illinois University Carbondale
October 21, 2021

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Alexander V. Catalano, for the Master of Science degree in Zoology, presented on October 21, 2021, at Southern Illinois University Carbondale.

TITLE: INVASIVE CARP MOVEMENT, BEHAVIOR, AND HABITAT USE: EVALUATING COMMON CARP AS A SURROGATE FOR BIGHEADED CARPS

MAJOR PROFESSOR: Dr. James E. Garvey

Invasive species are a major concern for fish populations globally, and the ability to predict the susceptibility of ecosystems to additional invasions or range expansions is needed. Bigheaded carp [Silver Carp (*Hypophthalmichthys moltrix)* and Bighead Carp (*H. nobilis*)] pose a serious threat to the Great Lakes Basin and numerous other aquatic ecosystems, where suitable habitat for spawning could allow for the establishment of breeding populations. Evaluating a surrogate would be useful to predict how bigheaded carp behave beyond their current range. To determine whether Common Carp (*Cyprinus carpio*) is an appropriate surrogate for bigheaded carp, their potential overlap in diets, habitat selection, and behavior must be considered. Fifty-seven adult Common Carp and 7 adult bigheaded carp were acoustically tagged in the Starved Rock Pool on the Illinois River in April 2019. Active tracking occurred monthly during the summer (June-October) of 2019 and 2020, as well as with an array of passive receivers in the Illinois River. Common Carp serve as a viable surrogate for bigheaded carp in dam passage, habitat selection during summer (avoidance of main channel, and channel border while selecting for side channel habitats), and movement probability (significance for both species for weekly average discharge). However, these results should be used with caution when predicting range size (larger core ranges for Common Carp, larger total ranges for bighead carp) and movement (different environmental variables influence movement). Because bigheaded carp are likely to spread much farther and faster than common carp, a more migratory surrogate should be explored such as Paddlefish (*Polyodon spathula*) or Blue Sucker (*Cycleptus elongatus*).

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DEDICATION

I dedicate this work to my late grandfather, William Panek. You were the one who introduced me to fishing which got me started on my career path. I will always cherish the memories of fishing with you and the wisdom you passed on. Fish on.

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CHAPTER 1

INTRODUCTION

Invasive species are a major component of global change (Vitousek et al. 1996) and are often successful due to an ability to establish and outcompete native species at various life stages (Lodge 1993). Specifically, invasive species are a major concern for fish populations globally (Lowe et al. 2000, McNeely and Schutyser 2003), and the ability to predict the susceptibility of ecosystems to additional invasions or range expansions is needed. Invasive species range and success could be estimated based on previous habitat, environmental tolerances, and locations where they have been successful(Ricciardi and Rasmussen 1998, Kolar and Lodge 2002, Marchetti et al. 2004). This can cause issues as invasive species can behave different in novel environments than in historic locations, and in some cases have enhanced performances (Parker et al. 2013). Species surrogacy could help solve some of the issues related to invasives species.

Species surrogacy is used to represent one species in place of another because the target species is rare (or absent), difficult to collect, or protected by law (Caro and O'Doherty 1999b, Caro et al. 2005, Saylor et al. 2020). Surrogate species have been used to predict diets (Gosch et al. 2018), movement (NMFS 2009), habitat selection (Schofield and Ross 2003), and behavior (Buchanan et al. 2010, van Bommel and Johnson 2016). However, the selection of potential surrogates should be done carefully, as there are no universally accepted surrogates. Suitable surrogates in one ecosystem or region may not be suitable in another (Lovell et al. 2007). Although surrogate species are most often used with rare or protected species, surrogate species could potentially help understand how future invasive species may behave and interact within an aquascape.

Bigheaded carp, Silver Carp (*Hypophthalmichthys moltrix)* and Bighead Carp (*H. nobilis*) are successful invasive species due to their high fecundity (Schrank and Guy 2002), mobility (DeGrandchamp et al. 2008, Coulter et al. 2016), and tolerance of a wide range of temperatures (Herborg et al. 2007). Breeding populations now occur in the Illinois (Chick and Pegg 2001, Sass et al. 2010), Ohio (Chick and Pegg 2001), Wabash (Chick and Pegg 2001, Coulter et al. 2013, Lenaerts et al. 2015), Missouri (Chick and Pegg 2001, Hayer et al. 2014), and Mississippi rivers (Williamson and Garvey 2005, Garvey et al. 2007b). Bigheaded carp pose a serious threat to the Great Lakes Basin (Cudmore et al. 2012) and numerous other aquatic ecosystems with suitable habitat for spawning could allow for establishments of breeding populations (Hansen and Johnson 2010). However, evaluation of a surrogate would be useful to predict how bigheaded carp may behave beyond their current range.

A widespread invasive species, Common Carp (*Cyprinus carpio*), were first introduced to North America in 1831 (Lachner et al. 1970) and since have become a naturalized invasive species in many North American waterways. Due to the broader range of Common Carp relative to bigheaded carp, Common Carp could be used to make predictions about bigheaded carp dispersal and habitat use in uninvaded areas. However, there is little previous research comparing Common Carp to bigheaded carp as surrogates, but this would be valuable to better predict impacts, spread, improve early detection and movement.

To determine whether Common Carp are an appropriate surrogate for bigheaded carp, their potential overlap in diets, habitat selection, and behavior must be considered. Diet is a well understood difference between Common Carp and bigheaded carp, Common Carp directly consume macrophytes, chironomids, and other benthic inverts (Michel 1995, Batzer et al. 2000, García-Berthou 2001) and have been known to consume both zebra mussels and even fish eggs

(Marsden 1997). Conversely, bigheaded carps mainly consume phytoplankton and zooplankton (Williamson and Garvey 2005). Bighead Carp and Common Carp have shown dietary overlap in ponds, whereas Silver Carp and Common Carp diets did not overlap (Opuszyński 1981). Bigheaded carp select habitats with higher chlorophyll *a* concentrations than random sites (Calkins et al. 2012) whereas Common Carp may not select for habitats with higher chlorophyll a concentrations due to different feeding guilds.

Seasonal habitat use may be similar among the species. Common Carp and bigheaded carp show some habitat similarities in overwintering behavior; Common Carp are known to be relatively stationary during the winter and seek thermal refuges (Brown et al. 2001; Butler and Wahl 2010, Bajer et al. 2011), while bigheaded carps move into backwater and lateral habitats (Braaten and Guy 1999, Coulter et al. 2017). Spawning habitats are very different, with Common Carp spawning in shallow, non-flowing vegetated sites (Swee and McCrimmon 1966, McCrimmon 1968, Stuart and Jones 2006, Penne and Pierce 2008) and bigheaded carp spawning in turbulent, high-velocity locations (Deters et al. 2013). Butler and Wahl (2010) found that Common Carp selected for wood cover in impounded areas of the Fox River during summer and fall whereas Silver Carp have been found to select heavily for island side channels in the summer in the lower Illinois River (DeGrandchamp et al. 2008). Common Carp were selected for this surrogacy study due to the existing upriver data in the Illinois River for acoustically tagged individuals plus some apparent similarities in habitat use, movement, and broad range. All this information indicates potential overlap in habitat use or behavior at some times of the year but requires a specific evaluation of overlap.

One potential location where Common Carp could prove a valuable surrogate in understanding and managing a potential bigheaded carp invasion is in the upper Illinois River

and Chicago Area Waterway System (CAWS), including upstream areas near the entrance of Lake Michigan where bigheaded carp have not yet invaded (Mahon et al. 2013). The current invasion front for bigheaded carp in the Illinois River is Dresden Island Pool (ACRCC 2017, Stokstad 2010), less than 30 river kilometers (rkm) from the electric dispersal barrier system near the connection between the Great Lakes and the CAWS. The CAWS is the only direct and continuously open channel to the Great Lakes from the Illinois River and thus is the most likely route of future spread.

Identifying a potential surrogate species is important for identifying locations where bigheaded carp may be located, but not yet established in the CAWS and other uninvaded rivers and tributaries in the Midwest USA. Bigheaded carp and Common Carp were acoustically tagged in areas of sympatry downstream of the CAWS to compare overlap in movement and behavior. Observations of habitat selection/avoidance and movement behavior may be applicable to rivers at risk for future invasion by bigheaded carp. Expanding the knowledge base of the overlap between these two species will give fisheries managers a better target for identifying locations potentially used in uninvaded areas of the river and CAWS.

CHAPTER 2

METHODS

STUDY AREA

The Illinois River is a 439 km-long impounded river formed by the confluence of the Des Plaines and Kankakee rivers in the northern portion of Illinois that drains southwest into Pool 26 of the Mississippi River near Grafton, Illinois. The Illinois River is divided into six pools separated by five (La Grange, Peoria, Starved Rock, Marseilles, and Dresden) lock and dam structures. The lower two lock and dams (Peoria and LaGrange) are Chanoine wickets dams and the three upper lock and dams (Starved Rock, Marseilles, and Dresden) are high head (5.5-7.4 m) gated dams. The wickets at the two lower lock and dams are submerged at high water conditions allowing open navigation routes for vessels and fish passage. The Des Plaines River is connected to the CAWS which connects to Lake Michigan through one of two connections, the Chicago River and Lake Calumet. The Dresden Island Pool is bounded by Brandon Road Lock and Dam at the upstream end, and Dresden Island Lock and Dam on the downstream end. The electric barriers to inhibit upstream dispersal of bigheaded carp are located in the CAWS near Romeoville, Illinois between the confluence of the Des Plaines River and Lake Michigan. The CAWS contain four additional lock and dam structures: Brandon Road, Lockport, Thomas J. O' Brien, and the Chicago Lock. Brandon Road and Lockport dams are located on the Chicago Sanitary and Ship Canal, T.J. O'Brien is located on the Calumet River, and the Chicago Lock is located on the Chicago River. The CAWS is made largely of man-made channels which have steep embankments, lack of shade, and have a controlled flow manipulated by dams to adjust the water levels based on anticipated rain events (Rijal et al. 2011). In anticipation of potential upriver movement of bigheaded carp upstream, various agencies have acoustically tagged native and naturalized species (Common Carp (Dettmers and Creque 2004), Largemouth Bass

[*Micropterus salmoides*], Smallmouth Buffalo [*Ictiobus bubalus*], Freshwater Drum [*Aplodinotus grunniens*], Channel Catfish [*Ictalurus punctatus*] (ACRCC 2011) in the CAWS to serve as surrogates for bigheaded carp movement. Each species has different behaviors that may or may not be useful for predicting bigheaded carp habitat use and movement.

The most downstream reach in the upper Illinois River, Starved Rock Pool (SRP), starts at rkm 372 at the Starved Rock Lock and Dam (SRLD) and extends upstream for 25 rkm to the Marseilles Lock and Dam at rkm 397. Starved Rock Lock and Dam is the point between the upper and lower pools of the Illinois River, with the lower Illinois River pools being larger with lower gradient, and the upper pools being smaller with higher gradients. Due to having gated dams at both ends of the SRP, Silver, Bighead, and Common Carp must pass through either lock chambers or the dam. Based on previous studies, SRLD is known to restrict movement of fishes (Lubejko et al. 2017, Coulter et al. 2018) and Marseilles Lock and Dam likely also inhibits movement. Depth in SRP ranges from less than 0.25 m to greater than 7 m in the main channel. The pool contains several island complexes with side channels, four backwater habitats (including manmade backwaters such as harbors), and two tributaries (Fox River and Covel Creek), which comprise the lateral habitats to be examined during this study. The Peoria Pool is the most upstream pool of the lower Illinois River and extends from the Peoria Lock and Dam at rkm 253 to the SRLD at rkm 372. Upper Peoria Pool (from SRLD down to the 39 bridge) consists of the spillway below SRLD, a side channel, one tributary, and no backwaters.

Habitats in SRP were broken into five macrohabitats similar to DeGrandchamp et al. (2008): main channel (as denoted by navigational maps), channel border (area surrounding the main channel on both sides), island side channel (Sheehan Island side channel, Bull’s Island side channel, Mayo Island side channel, Delbridge Island side channel), backwaters (Heritage Harbor,

Sheehan Island backwater, backwater across the main channel from Sheehan Island, and backwater across from Bulls Island), and tributaries (Fox River up to the aqueduct near the Fox River Park in Ottawa, Illinois, Covel Creek up to the first bridge.) (Figure 1). The Peoria Pool was divided into the same macrohabitats: main channel, channel border, island side channel (Plum Island side channel), and tributary (Vermillion River up to the first bridge). Backwaters were not included as there is no backwater in upper Peoria Pool (Figure 1).

FISH TAGGING

Fifty-seven adult Common Carp (mean TL: 576mm ±78mm) and seven Silver Carp (mean TL: 604mm ± 58mm) were collected (25 above SRLD and 25 just downstream of SRLD within 5 rkm) in April 2019 using pulsed DC electrofishing and implanted with acoustic transmitters (VEMCO, Halifax, Canada; model V16 [1.6cm wide, 6.5 cm long, 150-162 dB, 10.4 g in water]) following the 2% rule of transmitter to total weight (Winter et al. 1996). An additional thirty-one Common Carp (mean TL: 618mm ± 80mm) and forty Silver Carp (mean TL: 632mm ± 45mm) were collected and tagged in Fall 2020 (early October). Fish collections were dispersed across SRP in areas where electrofishing is appropriate to distribute tags across different habitats, and fish were released within 2 km of their capture location. Released transmitters added to 24 active tagged (expire 9/14/2021) bigheaded carp (23 Silver Carp, 1 Bighead Carp) tagged with Vemco V16 from previous studies (Abeln 2018). The V16 transmitters remained active for 2,176 days (on average based on expected battery life). Each transmitter was programmed with a unique identification number and transmitted every 40-80 s (randomized to limit collisions). Detections within 48 h of tagging were omitted from data analysis due to potential influence from tagging effects (Frank et al. 2009).

Surgical procedures followed those in Lubejko et al. (2017) and Coulter et al. (2018). Upon collection, Common Carp were held in *in situ* net pens prior to surgery. To administer carbon dioxide anesthesia, individuals were moved to a tank containing river water diffused with carbon dioxide gas and buffered with sodium bicarbonate to maintain pH. After signs of equilibrium loss, the fish were placed ventral side up on a V-notched surgery board with river water pumped over the gills. An incision site was prepared posteriorly to the pelvic fins and anterior to the anus removing 5 cm by 2 cm area of scales with a sterile scalpel. After the area was descaled, it was washed with 10% providone-iodine solution to aid in prevention of infection. An incision was made lengthwise in the descaled area that was roughly three times the width of the transmitter. Transmitters were tested prior to the start of the surgery with a portable receiver (VEMCO, VR100); each transmitter was soaked in ethanol for at least two minutes. Transmitters were air dried then pushed through the incision and forward so that the transmitter did not press on the incision. The incision was closed with 3-4 interrupted sutures (Ethicon Inc. Somerville, NJ; vicryl CP-1 absorbable, monofilament). Common Carp were then tagged using a Floy Tag T-Bar Anchor tag after surgery and bigheaded carp were tagged with a jaw tag (National Tag and Band Company #28 jaw tag). Fish were placed in a different *in situ* pen and released once they regained normal swimming behavior. All tools were sterilized in 70% ethanol between each surgery.

TELEMETRY/TRACKING

Tagged fish were tracked using both passive and active gears during April 2019 through September 2020. Passive tracking occurred using Southern Illinois University's acoustic telemetry array of stationary acoustic receivers (VEMCO, model VR2W and VR2Tx) located within SRP and Peoria Pool. There were 20 receivers located within the SRP and 5 within the

upper Peoria Pool (Figure 2). Most receivers were ranged tested in 2017 (Abeln 2018). Receivers were set either as bottom or fixed set. Bottom set refers to receivers that were attached to rebar stands on the bottom of the river with the hydrophone pointed upward. The rebar stands were attached to an upstream anchor and each stand had a downstream trailing cable attached to allow for retrieval. Each anchor weighed 36 kg and were made of a concrete base with a rebar eyelet extending upward. The rebar stand (0.5 m x 0.5 m x 0.75 m) was made of rebar with an extension from the top to allow the receiver to be bolted to the stand. The hydrophone of the receivers was above the top of the rebar extension to avoid any signal interruptions. The anchor was attached together with 15m of 0.64-cm coated cable and the stand had an extra 15 m of trailing cable with a loop for retrieval from river bottom. Each complete setup was deployed parallel to shore, with the anchor placed upstream and the trailing cable downstream. Fixed sets were also employed at some locations and were attached to stationary objects like mooring cells, trees, lock chamber walls, or docks. Receivers attached to mooring cells or lock chambers were attached to lengths of rebar that were set behind the ladder recess, attached to one of the ladder rungs, with the hydrophone of the receiver pointing down. Lock chamber sets were attached to a pulley system that had the receiver attached to a cable that was used to raise and lower the receiver out of the water. Receivers attached to docks were deployed with a short length of cable that kept the receiver under the dock, away from boats, and with the hydrophone pointed down. Fixed sets attached to trees had the receiver attached to an anchor and a cable connecting the anchor to a tree on shore. One receiver set in each lateral habitat and several main channel sets spread out maximized coverage throughout the pool and prevented overlap in signal coverage.

Active tracking occurred monthly during the summer (June-October) of 2019 and 2020 by drifting downstream in a boat starting just downstream from the Marseilles Lock and drifting

down to the SRLD. Active tracking also occurred monthly (June-October) during 2019 and 2020 starting at the SRLD and drifting downstream to the I39 Bridge in Peoria Pool. A total of 2-3 days per month were spent active tracking on SRP, while an additional 1-2 days were spent active tracking on the upper Peoria Pool. Backwaters, side cuts, or side channel of the main channel were entered for tracking as they were reached during tracking drifts. Tracking occurred using a portable receiver (VEMCO, VR100 Receiver and Deck Box) using both omni-directional (VEMCO, VHTx-69k Transponding Hydrophone) and directional (VEMCO, VH110 69 kHz) hydrophones. The omni-directional hydrophone was used to located fish presence in an area, then the directional hydrophone was used as the boat drifts towards the fish until hydrophone signal strength is the same in all directions, or over 100kdb (DeGrandchamp et al. 2008). If a signal was not fully picked up, then the boat was held in the same location until the tag was detected again. When a fish was located, the GPS location was recorded, and habitat was assessed. Habitat structure (i.e., logs, manmade debris, barge, etc.) was recorded at each fish's location. Habitat was classified into side channel, main channel, channel border (inside the main channel but outside of the navigational channel, [Figure 3]), backwater, or tributary. Sediment was also noted at fish's locations. A GPS-logging YSI EXO1 sonde was towed under the boat as it drifted downriver (0.8-5.6kph) at 30cm depth to collect temperature (°C), dissolved oxygen (percent saturation, milligrams/liter), specific conductance (uS/cm), and total dissolved solids (milligrams/liter). Water quality and GPS location were taken at 60 second intervals in order to quantify fish habitat, as well as areas not used by common carp or bigheaded carp. The YSI sonde was calibrated every other month following manufacturer's instructions to ensure accuracy. Water quality data was used to aid in the making of a habitat selection index described below.

HOME RANGE AND MOVEMENT

Home range is an important metric to compare between bigheaded carp and Common Carp to show core home range where the fish spend most of their time, and the total range showing possible expansion. Home range sizes were created using the *adehabitatHR* (Calenge 2011) package within the R environment version 3.5.3 (https://www.r-project.org/) using the *kernelUD* function. Fish detections were taken using the acoustic receivers located within the Illinois River. Kernel density polygons were only created for fish that were detected at 5 or more different receivers. Polygons were created for the total range (99%) and "home range" (50%). A one sample t-test was used to compare the mean sizes of the total range and the home range for Common Carp and bigheaded carps. Standard Error (SE) was calculated around the average of home range sizes.

Movement differences between Common Carp and bigheaded carp were analyzed three different ways using passive telemetry receivers; total linear range (rkm), movement probability, and movement rate to compare their potential spread. Total linear range was defined by the distance (rkm) between the most upstream and fartherst downstream receivers on which the fish was detected through the duration of the study. Total linear range was analyzed using a Wilcoxon test once data was determined to be non-normal in order to determine if total linear range differed between species.

Movement probability was defined as the probability each fish would move (0 = did not move, 1 = move) during a week and was determined based on whether movement rate (rkm/day) was calculated for each individual fish for every week of the study (i.e. 4/22/2019: week 1, 4/29/2019: week 2, etc.). If a fish was not detected in a given week, no value was assigned for total linear range. Four abiotic environmental variables were used in this analysis; average

weekly temperature (°C;USGS gage station # 5543010 in Seneca, Illinois), change in average weekly temperature (°C, calculated from USGS gage station #5543010), average weekly discharge (ft^3/s; USGS gage station # 05543500 in Marseilles, Illinois) and change in weekly average discharge (m^3/s; calculated from USGS gage #05543500. Pearson's correlations were used to determine if variables were uncorrelated and all $r < 0.5$ so all four environmental variables could be included in full models. A logistic mixed-effects models was used to relate movement (0 vs 1) as a response variable for each species to the environmental variables (average weekly water temperature °C, change in average weekly water temperature °C, average weekly discharge ft^3/s, and change in average weekly discharge ft^3/s, all environmental variables were scaled and centered prior to analysis) which were fixed effects, while week number and transmitter number were random effects. Model selection was done using a full model average of model $\Delta AIC<2$ to evaluate environmental drivers of non-zero distances moved (using weekly total linear distance) for each species. Both models were evaluated using Akaike's Information Criterion with small sample size correction (AIC_c). Weeks where only one fish had movement were removed from the dataset before analysis. A linear mixed-effects model for both Common Carp and bigheaded carp was also created using the movement rate (rkm/week) as the response variable. Abiotic factors (average weekly water temperature °C, change in average weekly water temperature °C, average weekly discharge ft^3/s, and change in average weekly discharge ft^3/s) were fixed effects, and week and individual fish were accounted for using random effects. Model selection was done using a full model average of $\Delta AIC<2$ to evaluate environmental drivers of movement rate for each species.

The timing of dam passages was determined using passive receiver data. Dam passage is important to evaluate due to the Illinois River being heavily impounded and dams can serve as a

barrier to movement. Receivers located within the locks, directly upstream and downstream allowed for passages to be detected through the lock but also through the passage gates. Passages were determined at SRLD from April 2019- May 2020 due to receiver downloads. In order to determine if passage numbers by species was independent, Fisher's exact test of independence was used for upstream passages and downstream passages. Passages could occur through two different routes; the lock chamber (lock passage) or through the dam gates (dam passage).

HABITAT USE AND SELECTION

Habitat selection was analyzed seasonally using only active tracking detections of fish. Seasons were categorized into three-month periods: winter was December through February, spring was March through May, summer was June through August, and fall was September through November. Active tracking only occurred in summer and fall of 2019 and 2020; winter and spring were omitted due to COVID-19.

Common Carp and bigheaded carp detections were classified into 5 macrohabitats (main channel, channel border, side channel, backwaters, and tributary) similar to DeGrandchamp et al. (2008) and binned based on season in order to determine habitat use similarities. Each active tracking detection was grouped with the physically closest 60 sec YSI reading and represented the environmental readings that were being used by each Silver Carp or Common Carp (Prechtel et al. 2018). The Manly et al. (2007) estimation method, $\hat{W}_i = u_{i+}/\pi_j u_{++}$, was used which is the ratio of the proportion of habitat used (environmental measurements matched with active tracking detections) to the proportion available ($\hat{W}_i > 1$ indicates selection; $\hat{W}_i < 1$ indicates avoidance; and $\hat{W}_i = 1$ indicates neutrality). $\hat{W}_i$ was calculated for all non-zero bins and Bonferroni 95% CI's around each $\hat{W}_i$ were estimated. Water quality data (variables used) grouped by habitat type were used to create a principle component analysis (PCA) in order to

visualize differences among the five habitat classes. Principle component analysis was done for summer and fall 2019, and summer 2020. For each season the two principle components (PC) that accounted for greater than 70% variance were selected. Pearson's correlations were then run with the site averaged environmental data (data were centered and scaled) for each habitat to check for any correlations between environmental data.

Substrate type at each fish's location during active tracking was also determined using side scan sonar and classified as silt, sand or rock (citation for definitions of these). Confirmation of substrate types occurred using a ponar grab (Wildco® Petite Ponar Sampler 6"x6"). A multinomial model using *mclogit* package (Elff et al. 2021) using the *mblogit* function was used to compare substrate type among species (seasons and year excluded). Only the dominant substrate types (most selected) used by each individual fish were included in analysis due to low sample size.

CHAPTER 3

RESULTS

OBJECTIVE 1

Home Range and Movement

Fifty percent and 99% home ranges were initially calculated for 12 Common Carp and eight bigheaded carp that met minimum criteria (detected on 5 or more stationary receivers). However, one Common Carp (Tag ID 8741) was removed from the analysis as an outlier (unusually large 50% range of 4,322,259 m^2 and a 99% range of 7,561,746 m^2). Areas created by the 50% and 99% ranges were determined to be normally distributed for Common Carp: ($W=0.87732$ $p=0.09618$ & $W=0.91286$, $p=0.2636$ respectively) after removal of the outlier fish and bigheaded carp: ($W=0.89988$, $p=0.2882$ & $W=0.90306$, $p=0.2792$) respectively. The average 50% home range for Common Carp was 1,519,195m^2 ± 219,553m^2 SE was significantly larger than the 50% home range for bigheaded carp (1,097,774 m^2 ±201,475m^2 SE) (Table 1) ($t=8.5624$, $p<0.0001$). Bigheaded carp had significantly larger 99% range (7,090,325m^2 ± 1,024,713m^2 SE [Figure 4]) compared to Common Carp's range of 6,376,517m^2 ±694,694m^2 SE (Figure 4) ($t=12.515$, $p<0.0001$). Both Common Carp and bigheaded carp exhibited 3 different size groups of home ranges: small (Figure 5), intermediate (Figure 6), and large (Figure 7).

Total linear range was determined to be statistically different ($V=1830$, $p<0.0001$) between Common Carp and bigheaded carp. The Levene's test for homogeneity of variance was also significant ($F_{77}=16.047$, $p<0.0001$). The largest Common Carp movement was 171.07 rkm while bigheaded carp was 356.95 rkm (Figure 8). Common Carp on average had 9.1% individuals making upstream movements every week, 6.8% making downstream movements, and 84% not making any movements weekly (Figure 9). Bigheaded carp had a weekly average of 9.1% individuals making upstream movements, 8.1% making downstream movements, and

82.8% of individuals making no movements (Figure 10). Common Carp remained more stationary, making movements of less than 15rkm on average (Figure 11), while bigheaded carp made larger distance movements on average (Figure 12).

Common Carp movement probability had four models with ΔAIC < 2 (Table 2). Weekly average discharge was highly significant for Common Carp (coefficient= 0.36, p<0.0001, Table 4), whereby fish were more likely to move with increasing discharge. Bigheaded carp movement probability had 4 models with ΔAIC < 2 (Table 2). Increasing weekly average discharge was also highly, positively significant (coefficient =0.34, p<0.001, Table 4). Both Common Carp and bigheaded carp movement probability model had no significance for weekly average temperature, change in temperature, or change is discharge (Table 4). Common Carp movement rate had 6 models with ΔAIC < 2 used to create the averaged model. Bigheaded carp only had one model with ΔAIC < 2 (Table 3) thus so model averaging was not used. Increasing temperature was significant for Common Carp (coefficient= 1.90, P=0.006) while bigheaded carp increased movement as weekly average discharge declined (coefficient =-9.38, p=0.0016, Table 3). Common Carp movement rate was non-significant for weekly average temperature, weekly average discharge, and change in discharge, whereas bigheaded carp was non-significant for weekly average temperature, change in temperature and weekly average discharge (Table 4).

Both upstream and downstream passage through SRLD of Common Carp and bigheaded carp were not similar (Fisher's exact test; upstream p= 0.9636, downstream p=0.09061) in timing of passages; however, sample size was extremely limited. Both downstream (Figure 13) and upstream passages (Figure 14) occurred mainly during May-June during 2019 and 2020. Upstream and downstream passage occurred on rising water temperatures (Figure 15 & 16). For Common Carp, 90.9% of downstream passages occurred through Starved Rock Dam while only

9.1% occurred through Starved Rock Lock; upstream passage showed the opposite with 75% of passages occurring through the lock with only 25% passing through the dam. Bigheaded carp passage had 71% moving downstream through the dam and 100% of upstream passages occurring through the dam.

OBJECTIVE 2

Habitat Selection

To compare habitat selection, a total of 31 Common Carp were found 89 times, and 17 bigheaded carp were found 43 times over the course of seven tracking events. During summer 2019, both Common Carp and bigheaded carp avoided the main channel ($\hat{W}_i$=0.59 [0.44, 0.74 CI] and $\hat{W}_i$=0.62 [0.43, 0.81 CI]), and channel border habitats ([$\hat{W}_i$=0.64 [0.49, 0.79 CI] and $\hat{W}_i$=0.26 [0.14, 0.38 CI]), while showing selection for side channel habitats ($\hat{W}_i$=1.95 [1.76, 2.14 CI] and $\hat{W}_i$= 1.45 [1.21, 1.67 CI]). Common Carp exhibited additional avoidance for backwater habitats ($\hat{W}_i$=0.70 [0.52, 0.88 CI]) whereas bigheaded carp selected heavily for backwaters ($\hat{W}_i$=6.94 [6.38, 7.50 CI]). Similar results were seen during fall 2019, in which bigheaded carp selected for backwaters ($\hat{W}_i$=6.06 [5.48,6.65 CI]) and side channel habitats ($\hat{W}_i$=1.14 [1.16, 1.66 CI] while Common Carp selected for side channels ($\hat{W}_i$=1.18 [1.01, 1.35 CI]) and main channel habitats ($\hat{W}_i$=1.43 [1.21, 1.63 CI]). Both Common Carp and bigheaded carps selected against channel borders ($\hat{W}_i$=0.81 [0.65, 0.96 CI] and $\hat{W}_i$= 0.78 [0.57, 0.99 CI]), additionally Common Carp selected against backwater habitats ($\hat{W}_i$=0.62 [0.47, 0.78 CI]. No bigheaded carp were found in main channel habitats during fall 2019. During the summer of 2020 Common Carp and bigheaded carp selected for backwater habitats ($\hat{W}_i$=1.49 [1.28, 1.70 CI] and $\hat{W}_i$=3.49 [3.08, 3.90 CI]) and had no selection for channel border ($\hat{W}_i$= 1.03 [0.88, 1.18 CI] and $\hat{W}_i$=1.12 [0.93, 1.33 CI]), additionally bighead carp selected for side channel habitats ($\hat{W}_i$= 1.40 [1.19, 1.61

CI]). No bighead carp were found in main channel habitats while Common Carp showed no selection for main channel habitats ($\hat{W}_i$=1.04 [0.88, 1.20 CI]). Overall bigheaded carps selected heavily for backwater habitats ($\hat{W}_i > 3$) and side channel habitats ($\hat{W}_i > 1$) while showing generally no selection or selecting against channel border habitat (Figure 17). Common Carp showed more generalized habitat use with mostly no selection. During active tracking no bigheaded carp or Common Carp were found in tributaries during the entirety of this study. However fish were found on the passive receivers using tributaries during select times of the year during spring and summer months.

Substrate Model

Bigheaded carp were found in both sand (n=7) and silt (n=54) habitats, while Common Carp were found in sand (n=13), silt (n=39), and rock (n=1) substrate habitats. There was no significant difference among substrates selected by Common Carp and bigheaded carp (z=1.838, p=0.066).

CHAPTER 4

DISCUSSION

Surrogacy use is still a highly debated topic in conservation (Andelman and Fagan 2000, Favreau et al. 2006, Murphy et al. 2011) because of the differences between the surrogate and target species and whether they respond in the same manner to environmental conditions (Murphy et al. 2011). Despite this debate, the use of surrogate species has proven useful in the management of rare, elusive, or cryptic species (Caro and O'doherty 1999a, Murphy et al. 2011). This research shows that surrogacy may also be a useful way to understand how nonindigenous and invasive species behave in novel environments where they do not yet occur. Native and invasive plants have been used as surrogates in order to evaluate the potential ranges of future invasive plants (Molofsky and Collins 2014) and the same approach is applicable to invasive carps. Comparison of behaviors, including movement and habitat use, of the surrogate species and invasive species could result in more effective management via improved understanding of future spread and habitat use.

In the Illinois River, bigheaded carp ranges (total linear range, 99% home ranges) were larger than Common Carp ranges, indicating that the broad-scale movements of Common Carp are an inadequate surrogate for bigheaded carp. Many studies have documented movements > 100 kms by bigheaded carps (Peters et al. 2006, DeGrandchamp et al. 2008, Coulter et al. 2016, Prechtel et al. 2018) that are attributed to spawning migrations (DeGrandchamp et al. 2008, Coulter et al. 2016). Similarly, Common Carp made movements greater than 100 kms during the spawning period in the Murray River, Australia (Jones and Stuart 2009), although this pattern did not occur in this research. Core home ranges (50% home ranges), which are less influenced by short-term movements (e.g., spawning migrations) and are instead driven by daily patterns of

movement (e.g., foraging), were larger for Common Carp. Benthic feeding Common Carp have been shown to move to new areas outside of core habitat areas in order to search for food (Bajer et al. 2010), whereas bigheaded carp being planktivorous may not have to travel for food as it floats by. Therefore, differences in diet and the distributions of diet items may preclude use of Common Carp as a surrogate in this aspect of bigheaded carp behavior.

In contrast to home range, the movement probability and rate of movement of Common Carp and bigheaded carps were similarly influenced by environmental conditions with average weekly discharge linked with increased movement likelihood. This may allow the timing of bigheaded carp movements to be inferred from Common Carp behavior. Bigheaded carp movements are known to be influenced by discharge (Coulter et al. 2020); however Common Carp longitudinal movements were previously shown to be more associated with temperature than discharge (Jones and Stuart 2009). Similar factors affecting movement probabilities in the Illinois River would inform managers that, during high discharge events, both Common Carp and bigheaded carp can be making movements to either get out of the current and move into backwaters or to access spawning areas. Common Carp and bigheaded carp did exhibit different environmental cues related to their movement rate. Similar to Jones and Stuart (2009), this study found that Common Carp movement rate was impacted by change in temperature. An increase in water temperature could push Common Carp out of deep wintering habitats and cause them to move more rapidly to prepare to spawn or move into feeding habitats. Movement rates of bigheaded carp increase as the change in discharge gets larger which could indicate bigheaded carp are moving out of high discharge areas during non-spawning time periods (MacNamara et al. 2018) or, moving to spawning sites (Deters et al. 2013). Bigheaded carp's primary spawning cue is a rising hydrograph once the water temperatures are ≥ 18 °C (Abdusamadov 1987,

Kocovsky et al. 2012), while Common Carp spawn at temperatures of 18-23 °C (Swee and McCrimmon 1966, Auer 1982) following discharge events in the spring (Resseguie and Kelsch 2008) showing overlap of spawning timeframes. Larvae of Common Carp and bigheaded carp have also been documented in the same ichthyoplankton drift nets (Samuel Schaick, personal communication 5/3/2021) further indicating potential overlap in when these fishes may migrate to spawn Additionally, both bigheaded carp and Common Carp had similar percentages of fish moving upstream, downstream, and no movement during a one week period on average, although when the bigheaded carp did move, the movement distance and rate was usually larger. Managers can use this information to aid in removal or to aid in sampling to quantity bigheaded carp in areas of low density. If managers can identify the times at which both species are spawning in overlapping areas then removal could be more focused to remove cohorts of fish at larval stages.

Dams may function to partially inhibit the spread of bigheaded carps in major rivers (Tripp et al. 2014, Lubejko et al. 2017) and, despite limited numbers of observed dam passages, it appears that Common Carp may pass through dams at similar times to bigheaded carp indicating possible surrogacy in this behavior. Bigheaded carp dam passages have previously been linked to a rising or near peak hydrograph and rising temperatures (Lubejko et al. 2017, Fritts et al. 2021)) while Common Carp passages were similar to studies conducted on the Mississippi River (Finger et al. 2020) with a majority of passages on rising or near peak hydrograph. The routes taken do appear to be different. Similar to previous studies, bigheaded carp mainly passed through dams (Lubejko et al. 2017) while Common Carp passed mainly through lock structures similar to Finger et al. (2020). If Common Carp dam passage observations could be used to understand the potential route or timing of passage, this information can be used in the deployment barriers

(e.g., CO_2, electricity) to inhibit bigheaded carp passage or to predict when passage may occur so that early detection or removal efforts could target specific time periods. At this time, it does appear that Common Carp are a surrogate for estimating when bigheaded carp dam passages may occur although additional observations, including observations from other types of dams, are still needed.

Both bigheaded carp and Common Carp showed preferences for side channel habitats and similar types of substrates, allowing managers to target areas that can contain both groups of fish for harvest. Habitat use was especially similar in the summer in that Common Carp and bigheaded carp both use backwater and side channel habitats with reduced water velocities (this study, Butler, Wahl 2010; Abeln 2018). However, other seasons showed less potential for surrogacy in habitat use. For example, bigheaded carp continue to select side channel and backwater habitats in the fall (this study, Abeln 2018) while Common Carp appear to shift their habitat use, showing increased use of higher flow areas such as main channel habitats (this study; Butler, Wahl 2010). While overwinter habitat use could not be examined in this study due to sampling limitations, potential surrogacy in habitat use may occur during this time. Common Carp are known to overwinter in deeper water or backwater habitats creating thermal refuges (Garvey et al. 2007a) while bigheaded carp also may overwinter in lateral habitats such as backwaters (Abeln 2018). Many of the home ranges of Common Carp and bigheaded carp in this study showed high use of specific locations again indicating the potential for surrogacy in habitat use. Overlap or differences in habitat use could be partially driven by differences in the feeding ecology of the two species. Common Carp feed benthically on detritus, algae, and invertebrates (Michel 1995, Batzer et al. 2000, García-Berthou 2001), while bigheaded carp feed pelagically on plankton (Kolar et al. 2007, Zhang et al. 2016). These food vary in abundance at

different times or year in different types of habitats (Wahl et al. 2008) and have been linked to rapid shifts in habitat use (e.g., bigheaded carp follow plankton bloom, Abeln 2018). Similar use of substrates and season specific overlap in habitat use further support the viability of Common Carp as a surrogate for bigheaded carps to allow for estimation of habitats bigheaded carp may use in currently uninvaded habitats.

This study will assist managers in the future when it comes to collection of bigheaded carp and identifying potential upriver locations where bigheaded carp could be found. Overall, Common Carp are the best surrogate we have available in the Illinois River and CAWs in any numbers. Although the home range sizes are different, there is much overlap between the habitat used which was collected either using active tracking or the passive receivers. Common Carp and bigheaded carp both exhibited passage events at the same time, sometime within the same week. There was difference in the distance traveled of these fish, although this could be attributed to different biological requirements. Movement cues were similar although the rate at which each species moved was different. All of the presented data show that Common Carp serve as a viable surrogate for bigheaded carp in dam passage, habitat selection during summer, and movement probability. However, surrogacy may not be an option when predicting range size and movement rates. Common Carp can serve as an early detection for locations to search for bigheaded carps in uninvaded areas, such as the CAWS or the upper Ohio River to give managers an idea of locations to start sampling for bigheaded carp. Locations with high abundance of Common Carp during summer months could indicate locations of bigheaded carp as well. More active tracking is required during the winter and spring months to identify whether additional overlap of habitat occurs, which could aid in removal efforts. Additional tracking

could also further enhance home range estimates if a sufficiently large sample of detections are found for each fish.

For some invasive species where an ecological equivalent or evolutionarily similar species is not available, which is the case for bigheaded carp (i.e., no other fish in genus *Hypophthalmichthys*), multiple surrogate species (surrogate for habitat, surrogate for movement, and surrogate for feeding) may be necessary to fully estimate how an invasive species may behave. Because Common Carp are not an ideal surrogate for distance and rate of spread, a more migratory surrogate with a similar potential for dispersal could be explored such as Paddlefish or Blue Sucker due to known migratory tendencies.

EXHIBITS

Table 1. Sizes of 50% and 99% home ranges in m^2 for Common Carp and bigheaded carp created by Kernel Density using receiver detections on the Illinois River, USA.

Common Carp			Bigheaded Carp		
Tag ID	50%	99%	Tag ID	50%	99%
8729	1,375,139	5,295,462	13280	1,463,988	7,497,889
8730	1,783,891	8,897,867	13289	1,060,883	4,665,816
8737	1,366,107	5,489,381	13290	912,842	5,615,674
8740	1,327,456	5,541,221	51784	2,163,583	10,210,572
8743	3,328,080	8,719,209	51786	1,072,248	12,617,283
8756	1,222,342	4,194,017	51794	1,047,473	10,049,581
8762	2,037,212	7,483,620	51776	931,182	6,041,638
8769	954,879	5,805,574	51797	129,993	5,131,664
8770	1,102,632	3,599,626			
8774	1,694,300	9,852,161			
13283	519,102	9,572,805			
Mean	1,519,195	6,768,268		1,097,774	7,728,765
Standard Error	219,553	694,694		201,475	1,024,713
Minimum	519,102	3,599,626		129,993	4,665,816
Maximum	3,328,080	9,852,161		2,163,583	12,617,283

Table 2. Results of model selection procedure to predict movement probability (0 = did not move; 1= did move) for bigheaded carp and Common Carp using logistic mixed effects model. The full model included: average weekly temperature (°C;USGS station # 5543010 in Seneca, Illinois), change in average weekly temperature (°C, calculated from gage #5543010), average weekly discharge (ft^3/s; USGS station # 05543500 in Marseilles, Illinois) and change in weekly average discharge (m^3/s; calculated from gage #05543500

Bigheaded Carp	AICc	ΔAIC
Weekly Average Discharge	586.65	0
Weekly Average Discharge+ Weekly Average Temp	587.71	1.06
Change in Temp + Weekly Average Discharge	588.08	1.42
Change in Discharge + Weekly Average Discharge	588.64	1.99

Common Carp		
Weekly Average Discharge	1062.81	0
Weekly Average Discharge + Weekly Average Temp	1063.37	0.56
Change in Temp + Weekly Average Discharge	1063.55	0.74
Change in Temp + Weekly Average Discharge + Weekly Average Temp	1064.31	1.5
Change in Discharge + Weekly Average Discharge	1064.40	1.59

Table 3. Results of model selection procedure to predict movement rate (rkm $week^{-1}$) for bigheaded carp and Common Carp using linear mixed effect model. The full model included: average weekly temperature (°C;USGS station # 5543010 in Seneca, Illinois), change in average weekly temperature (°C, calculated from gage #5543010), average weekly discharge (ft^3/s; USGS station # 05543500 in Marseilles, Illinois) and change in weekly average discharge (m^3/s; calculated from gage #05543500

Bigheaded Carp	AICc	ΔAIC
Change in Discharge + Change in Temp + Weekly Average Discharge + Weekly Average Temp	1121.13	0
Common Carp		
Change in Discharge + Change in Temp	1619.04	0
Change in Discharge + Change in Temp + Weekly Average Temp	1619.14	0.10
Change in Discharge + Change in Temp + Weekly Average Discharge	1620.14	1.10
Change in Discharge + Change in Temp + Weekly Average Discharge + Weekly Average Temp	1620.19	1.16
Change in Temp + Weekly Average Discharge + Weekly Average Temp	1620.87	1.83
Change in Temp + Weekly Average Discharge	1621.01	1.97

Table 4. Results of model averaging of all models with ΔAIC <2 for Common Carp (CC) and bigheaded carp (BH) for weekly movement probability and rate Average model coefficients are listed with associated p values below in italics. Models for movement probability (move = 1, stationary =0) were logistic mixed effects models while movement rate (rkm week^{-1}) uses linear mixed effects models. Variables included in the model were weekly average water temperature (°C), change in weekly average temperature (°C), weekly average discharge ft^3/s, and change in average weekly discharge ft^3/s. Individual fish and week were included as random effects.

	Movement Probability		Movement Rate	
	CC	BH	CC	BH
Weekly Average Temperature	0.04	0.04	-0.32	-4.78
	0.45	*0.71*	*0.64*	*0.53*
Change in Temperature	0.03	0.02	1.90	5.66
	0.47	*0.78*	*0.006*	*0.33*
Weekly Average Discharge	0.36	0.34	-0.16	-9.38
	<0.0001	*0.001*	*0.76*	*0.05*
Change in Discharge	-0.01	0.00	-0.73	16.94
	0.69	*0.94*	*0.21*	*0.0016*

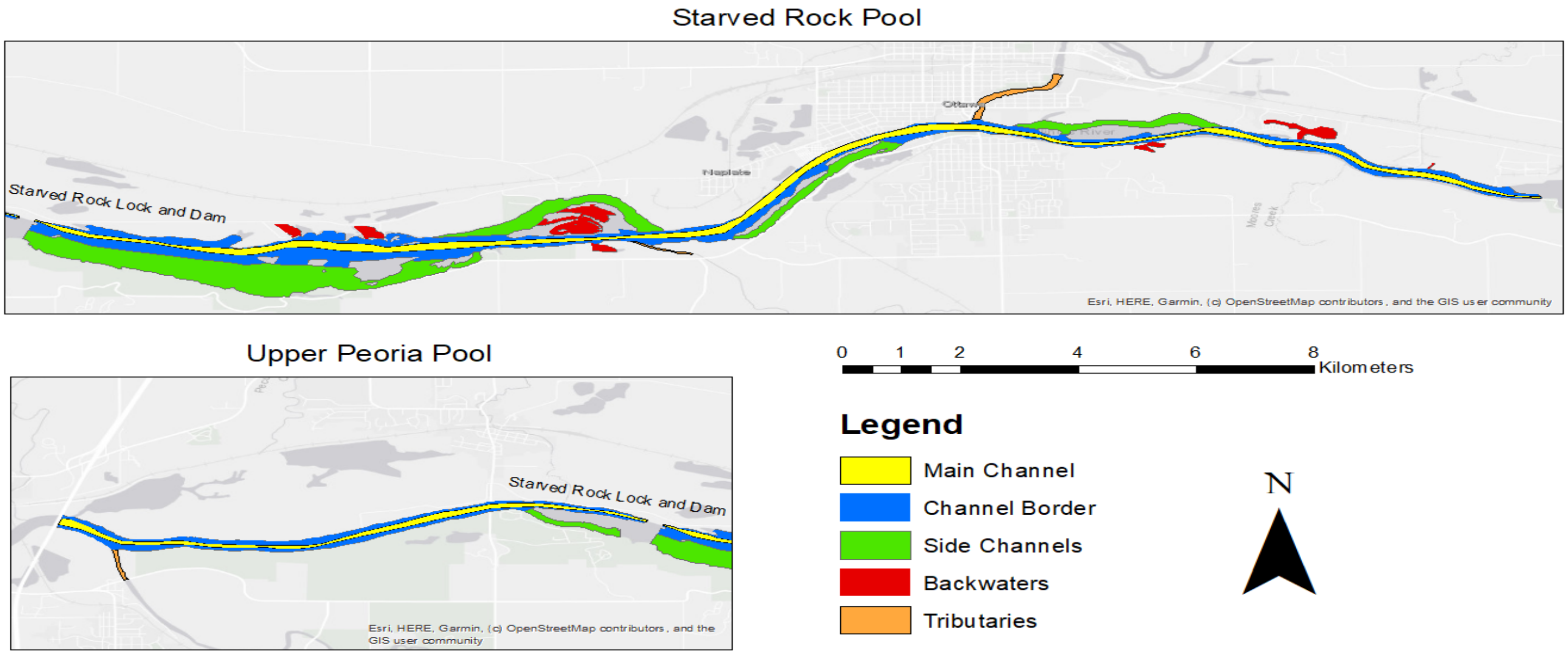

Figure 1. Map of Starved Rock Pool and the Upper Peoria pool on the Illinois River, USA. The five different macrohabitats classified in this study are listed.

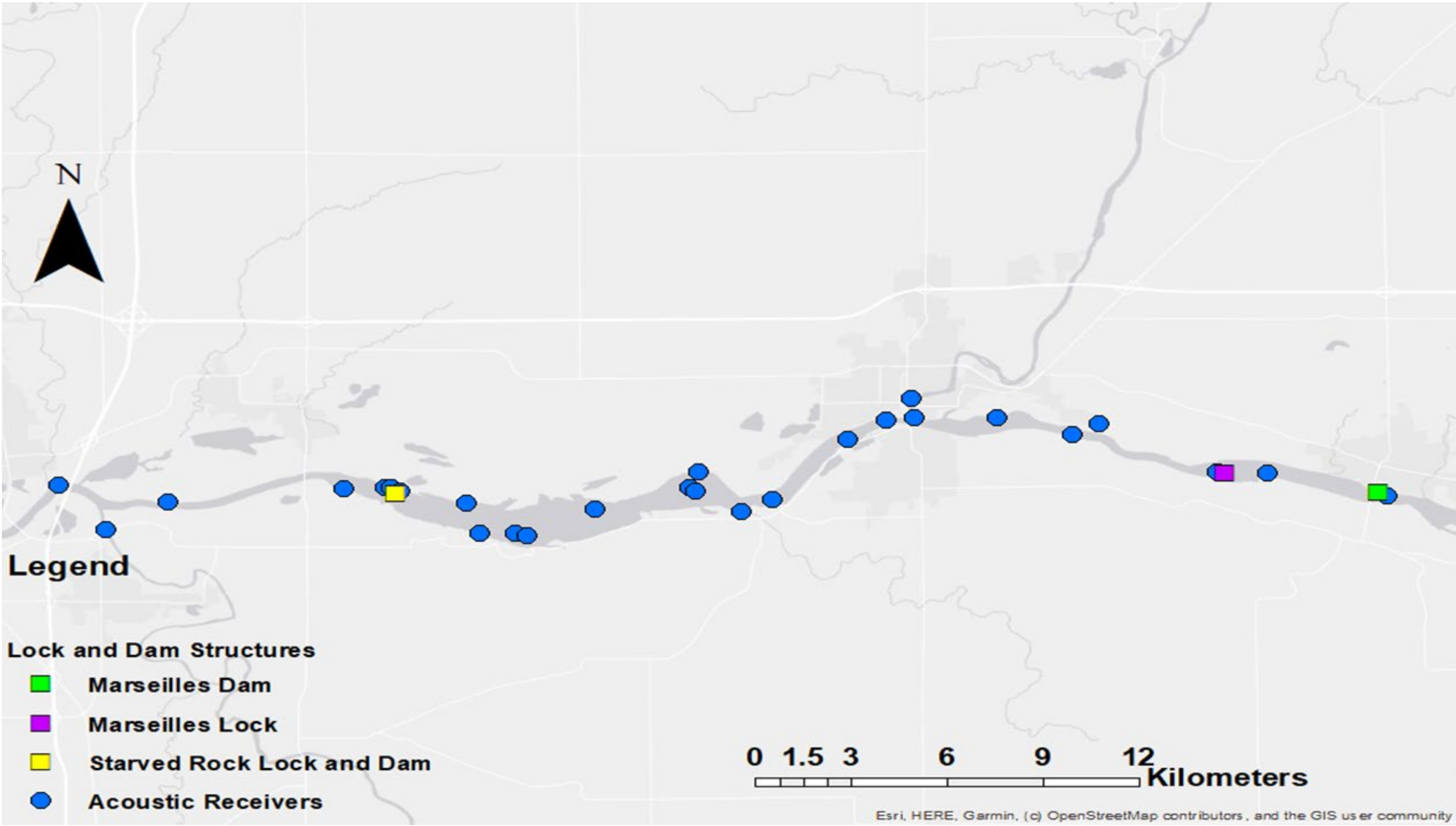

Figure 2. Map of Starved Rock Pool and the upper Peoria Pool on the Illinois River, USA. Acoustic receivers are denoted in blue. Lock and Dam structures are denoted by squares.

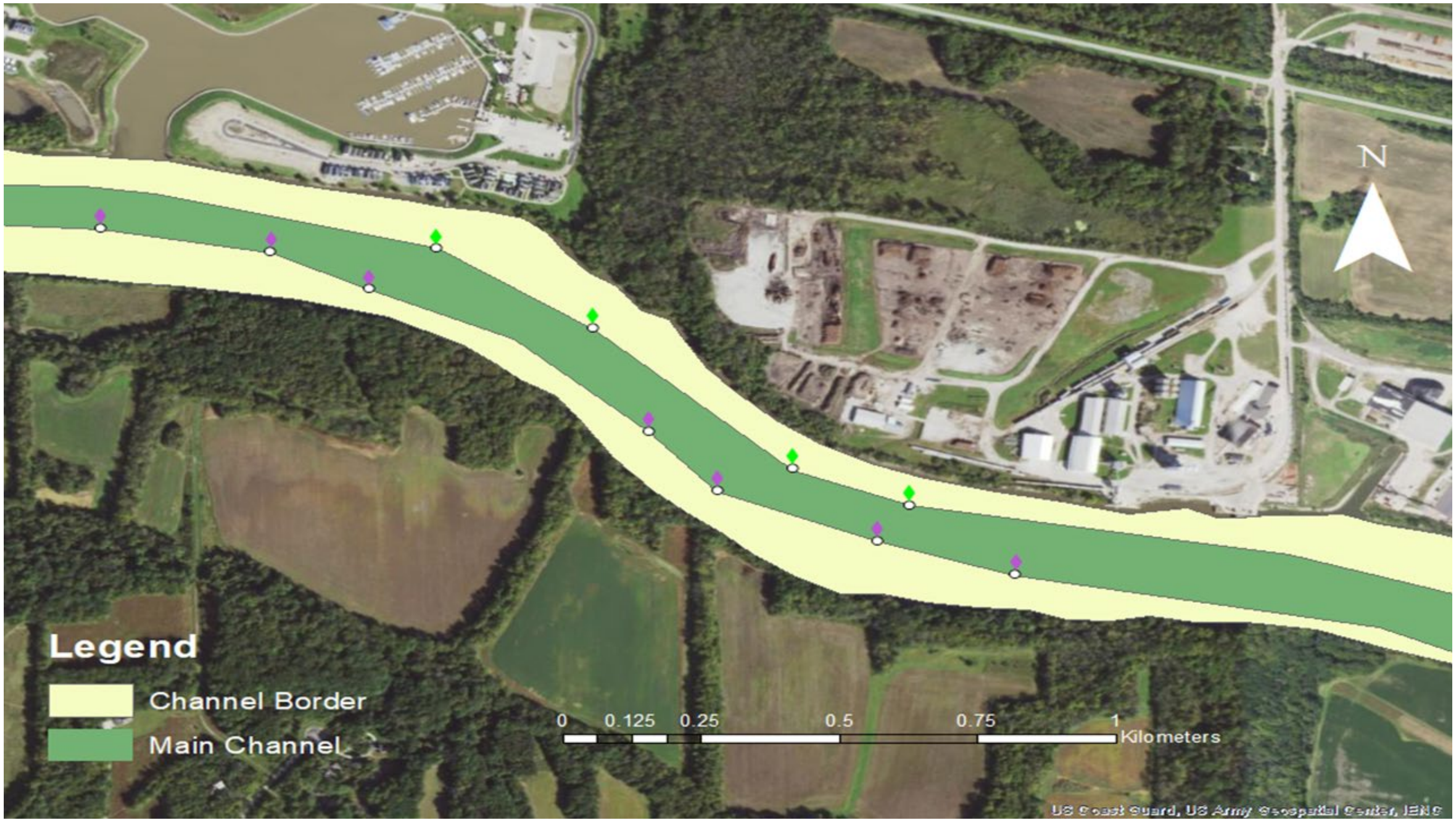

Figure 3. A section on the Starved Rock Pool, Illinois River, USA, showing the main channel, as distinguished by the navigational channel, and the channel border.

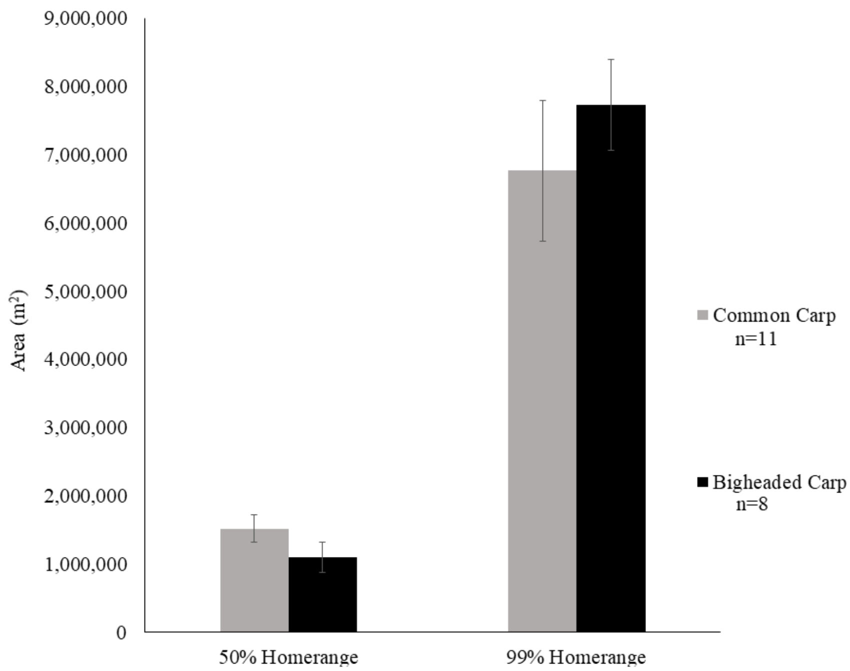

Figure 4. Comparison of the average 50% home range (core home range) and the average 99% home range (total range) calculate using Kernel Density of Common Carp and bigheaded carp on the Illinois River, USA. Standard error is shown with error bars.

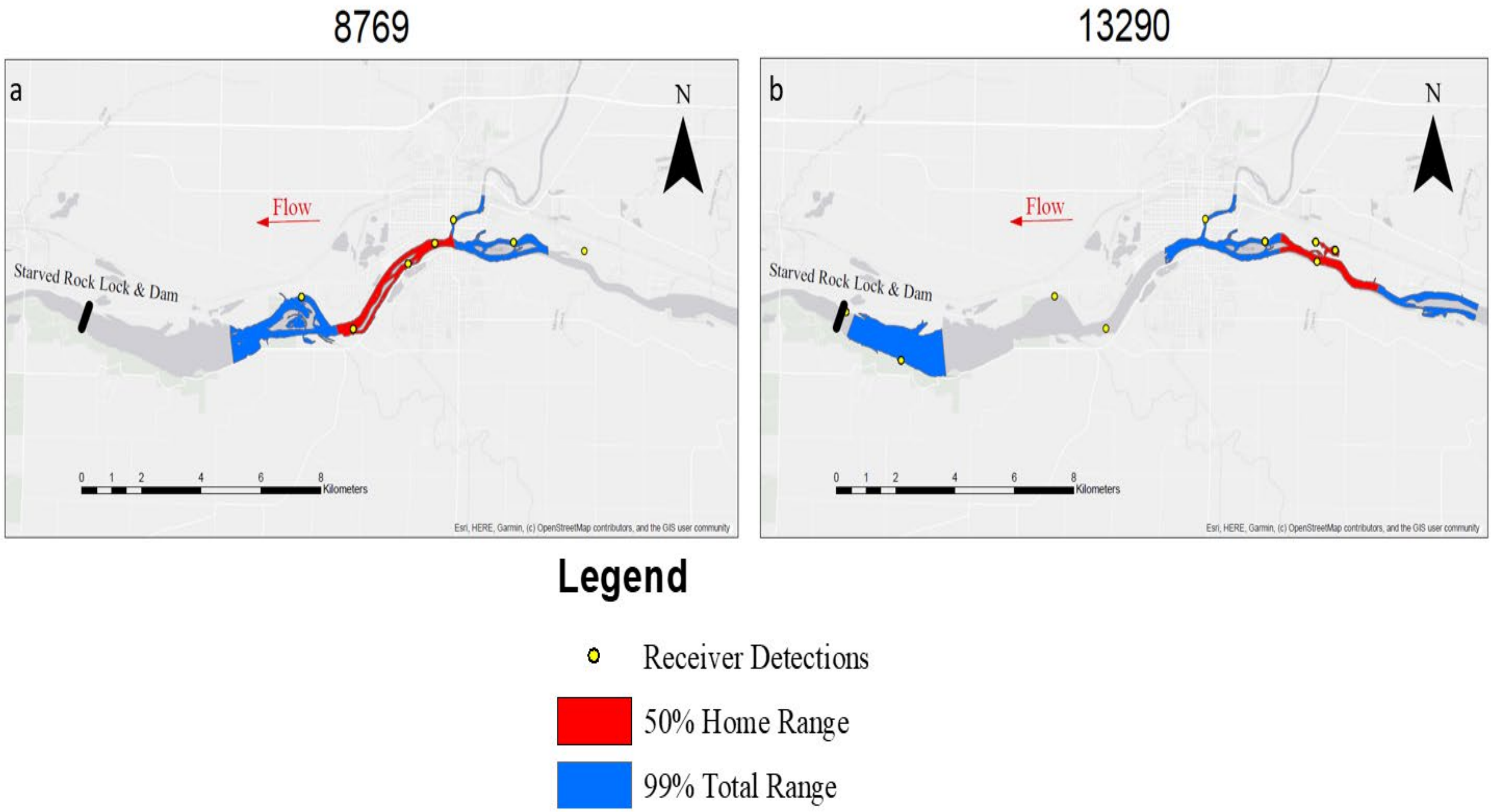

Figure 5. Maps of home range size using Kernel Density of Common Carp (a) and bigheaded carp (b) that represent fish with a small range size.

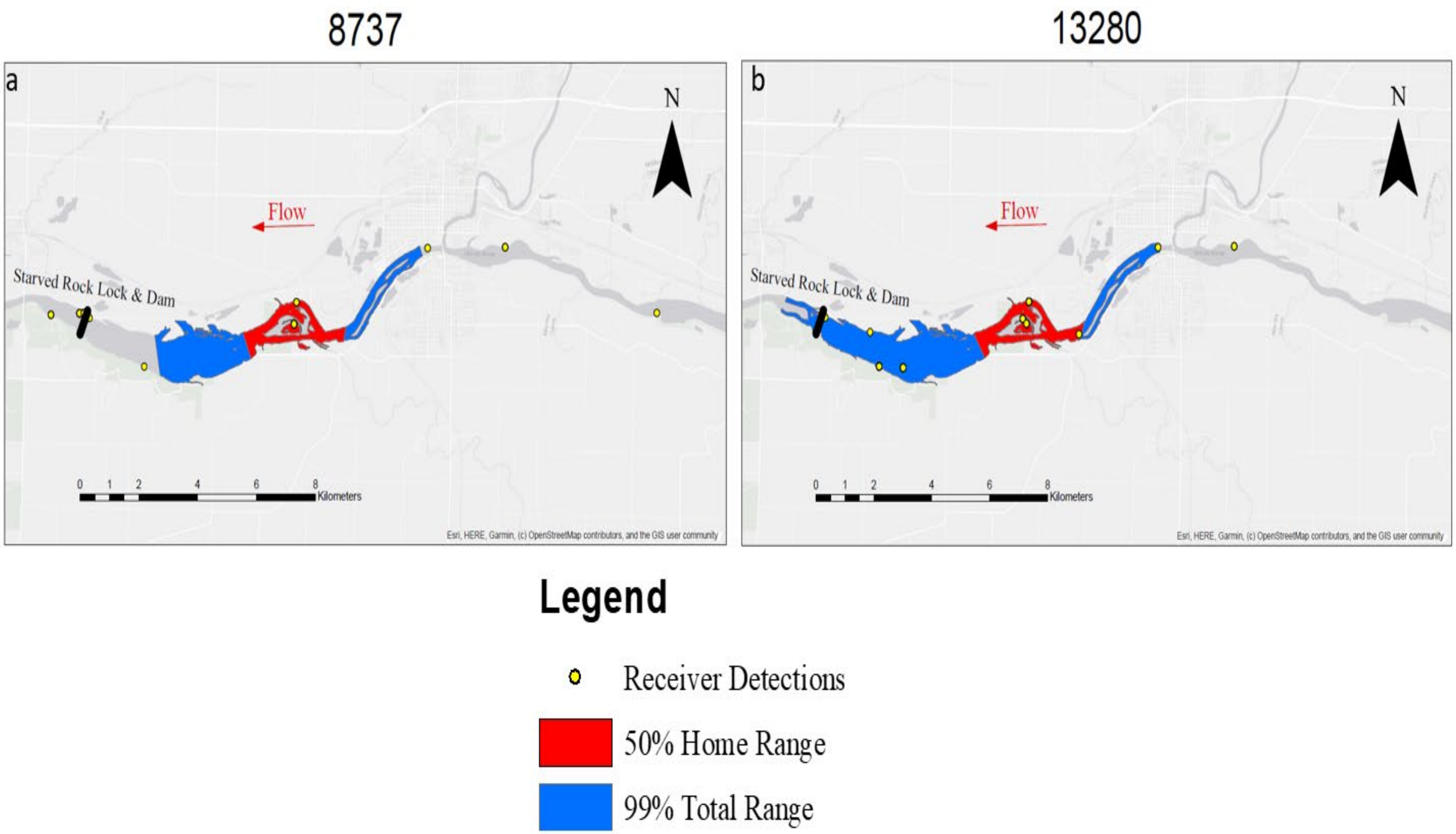

Figure 6. Maps of home range size using Kernel Density of Common Carp (a) and bigheaded carp (b) that represent fish with a medium range size.

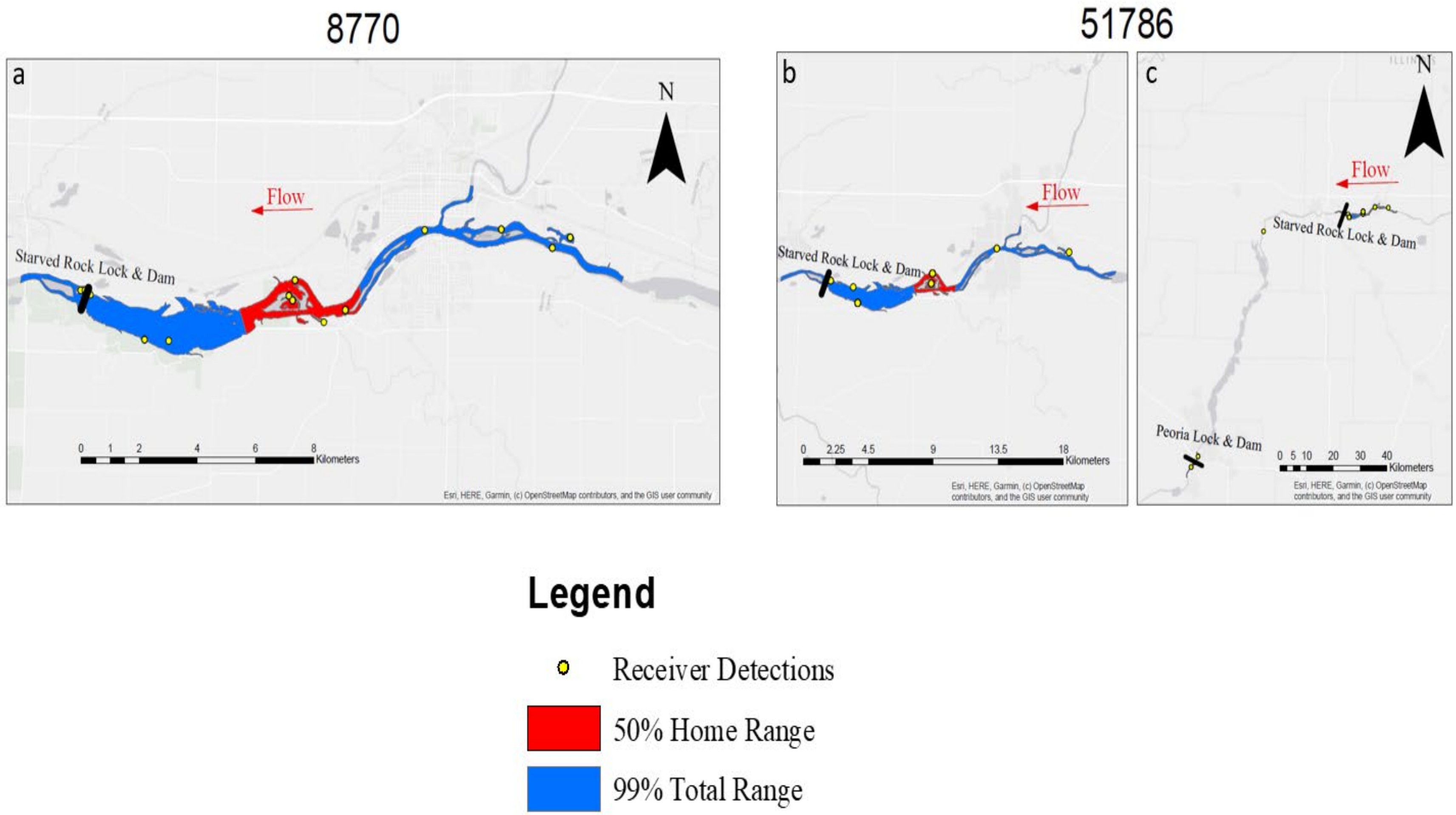

Figure 7. Maps of home range size using Kernel Density of Common Carp (a) and bigheaded carp (b & c) that represent fish with a large range size. Figure c represents the entire range for 51786 while b is a close up of the home range.

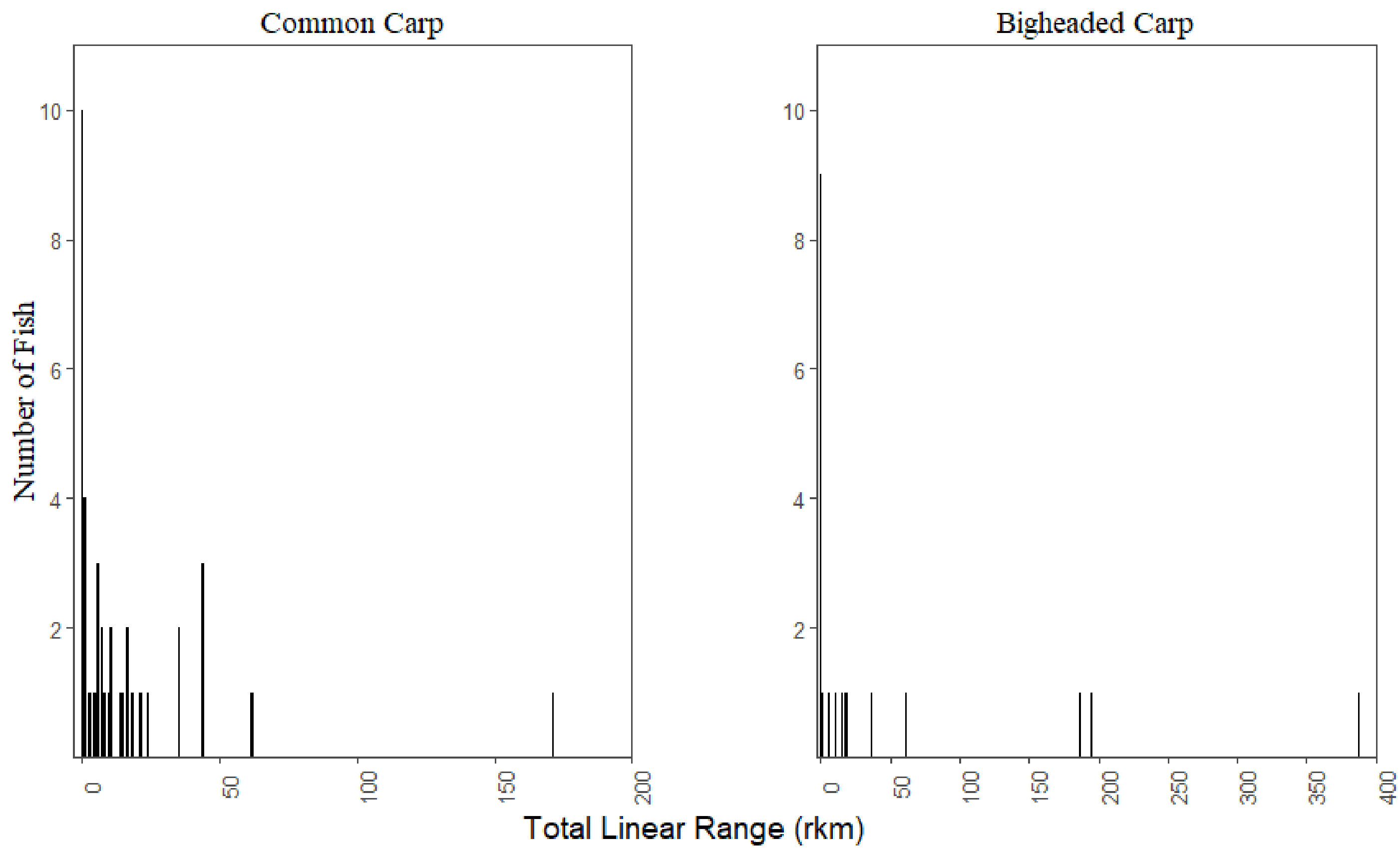

Figure 8. Total linear distance traveled by acoustically tagged Common Carp and bigheaded carp in the Illinois River. Total linear distance is calculated from the farthest upstream rive kilometer detection-farthest downstream rive kilometer detection.

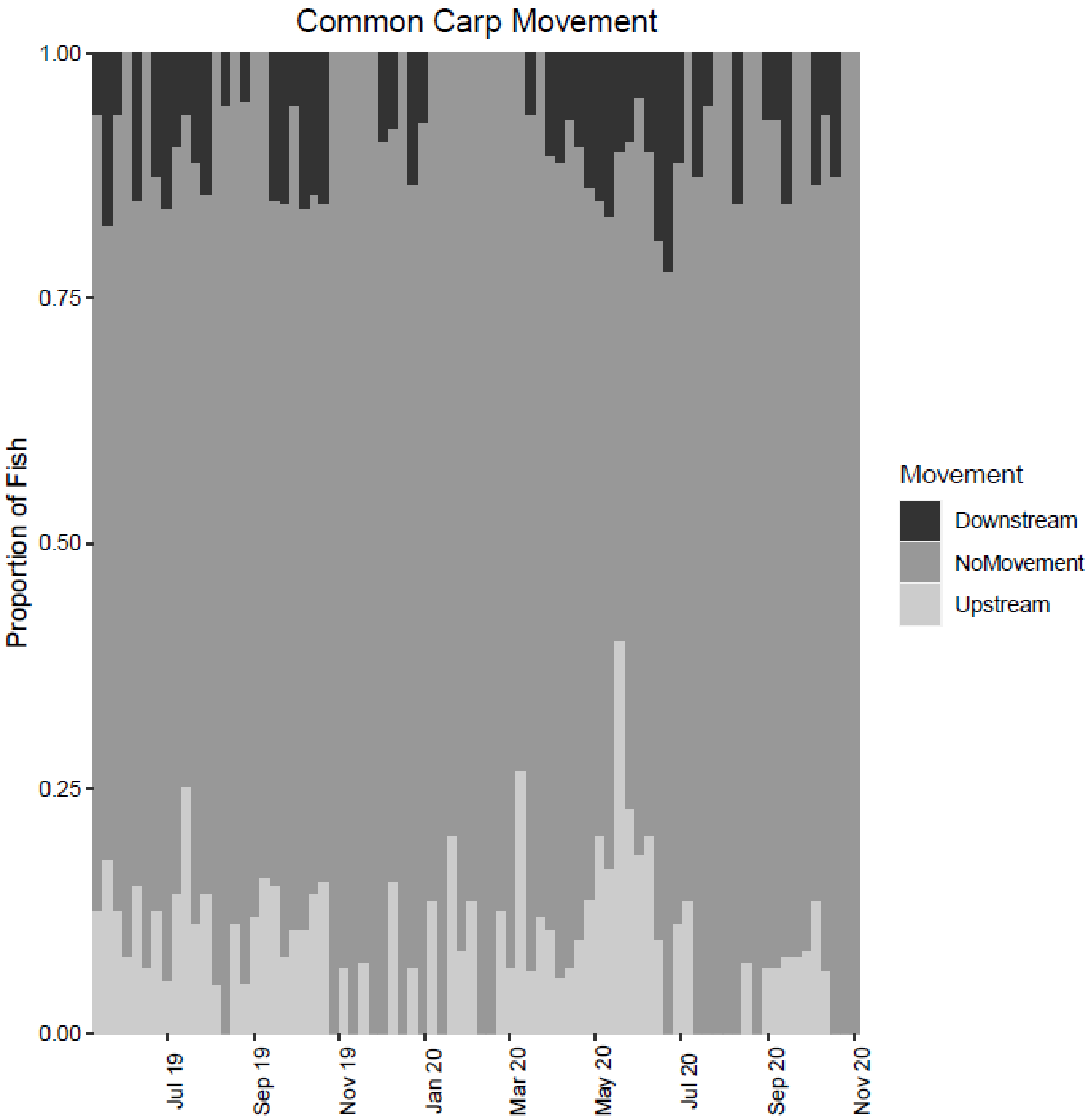

Figure 9. Weekly proportion of Common Carp moving in the Illinois River.

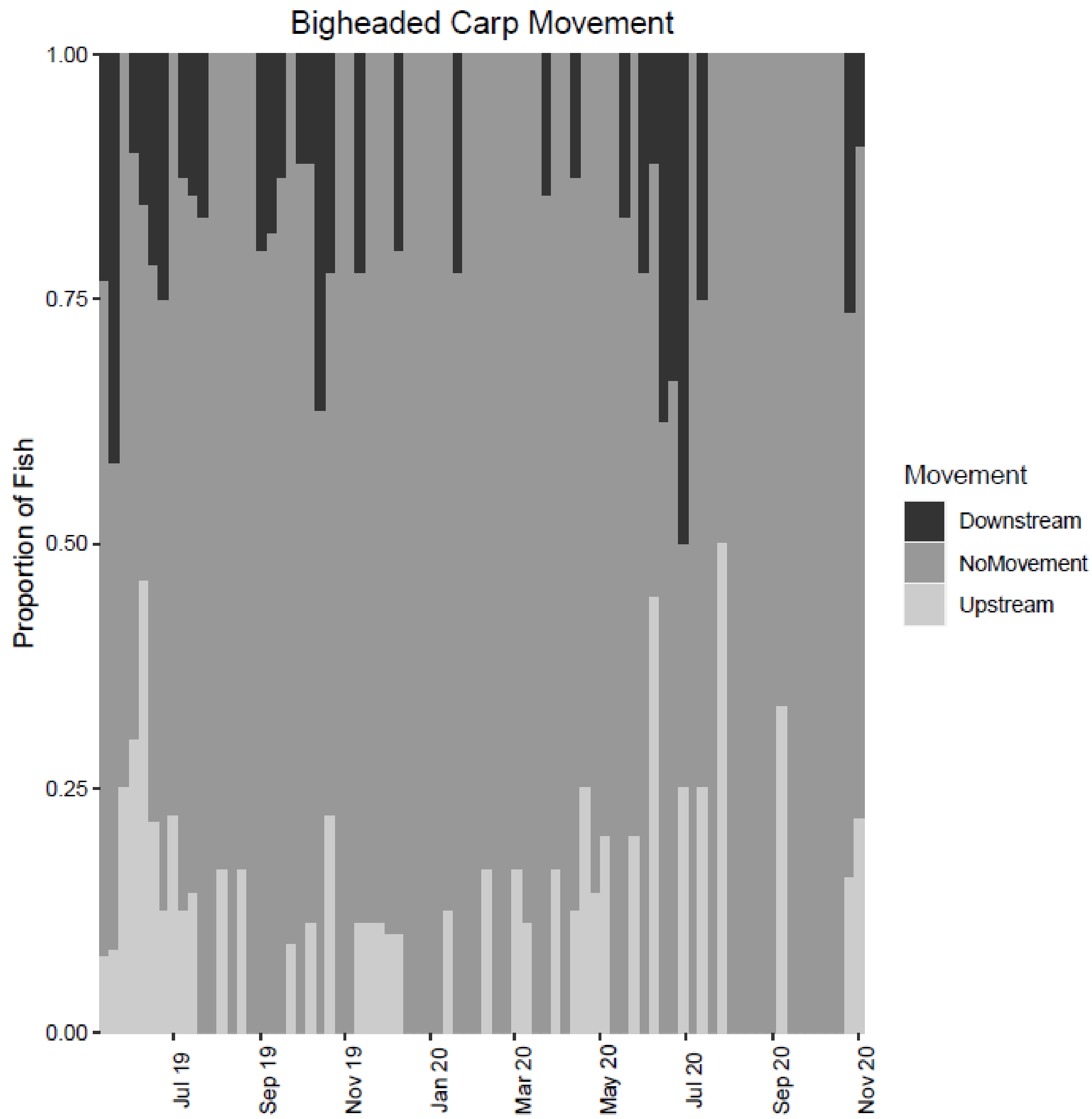

Figure 10. Weekly movement proportions bigheaded carp in the Illinois River.

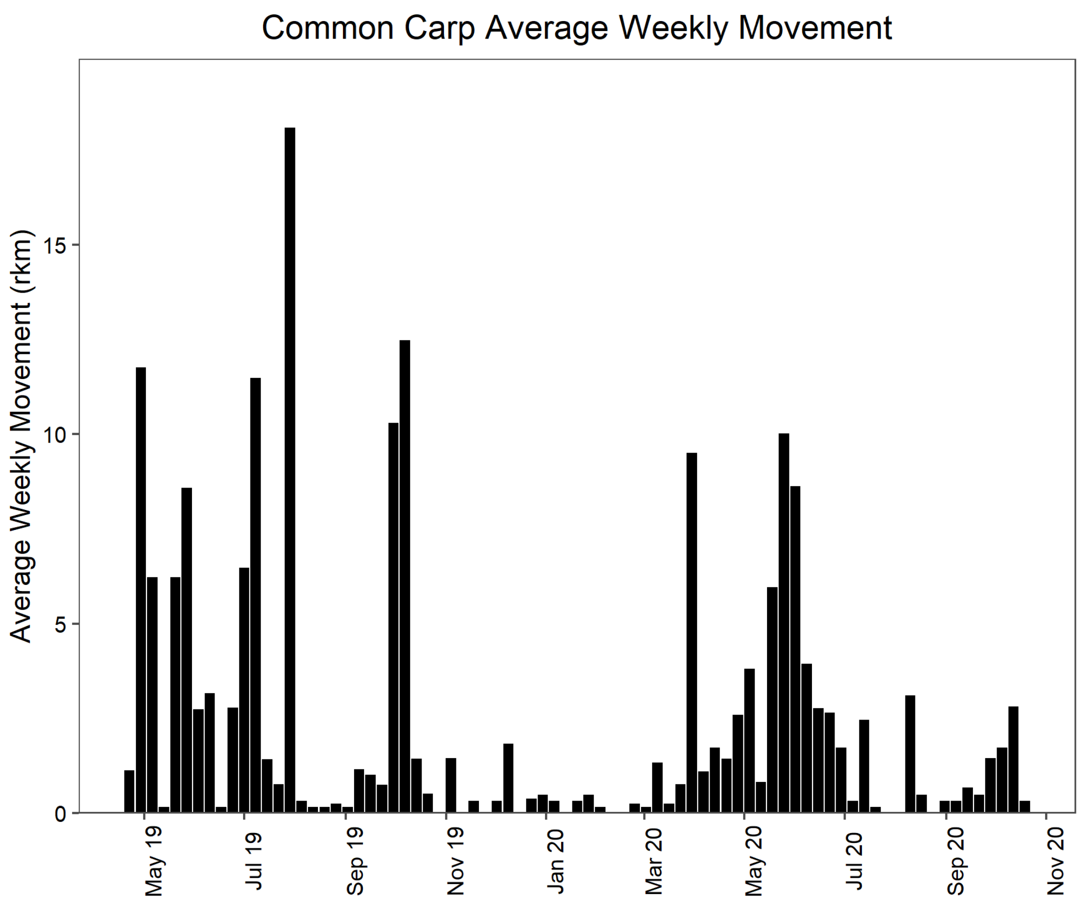

Figure 11. Average movement distance of all tagged Common Carp by week in river kilometers in the Illinois River.

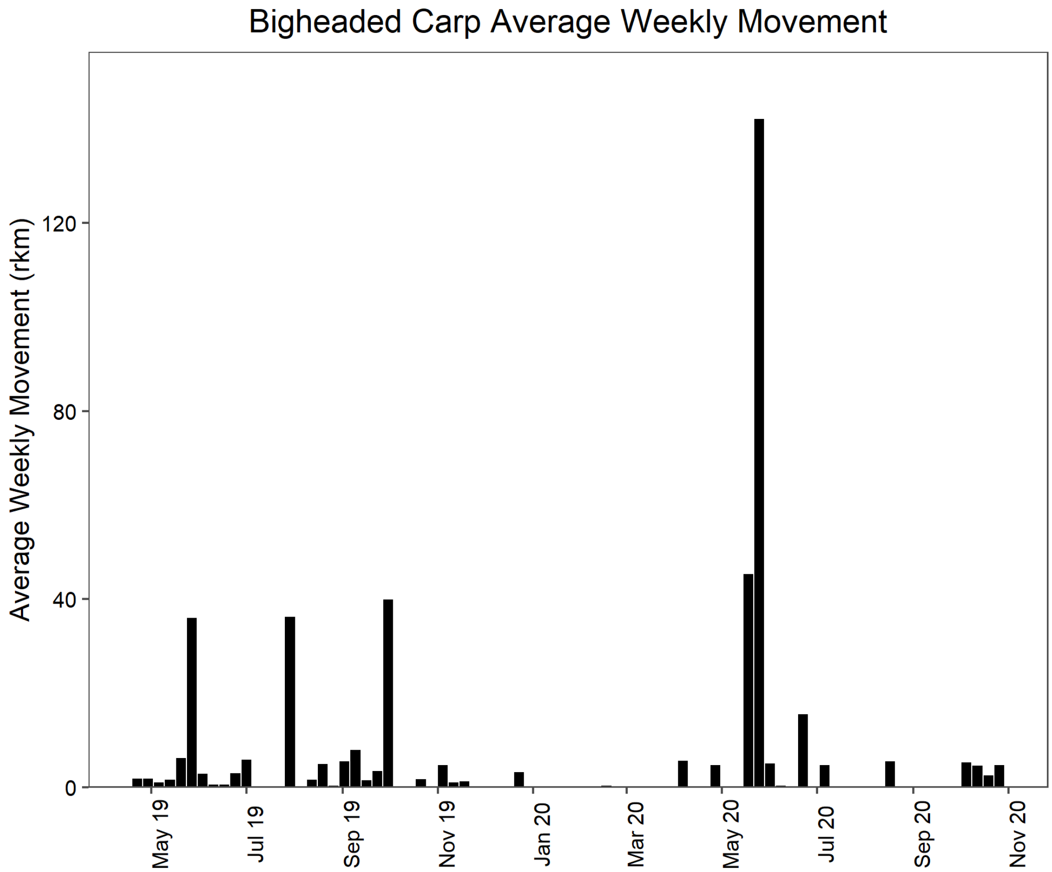

Figure 12. Average movement distance of all tagged bigheaded carp by week in river kilometers in the Illinois River. Note difference in y-axis scale from Figure 11.

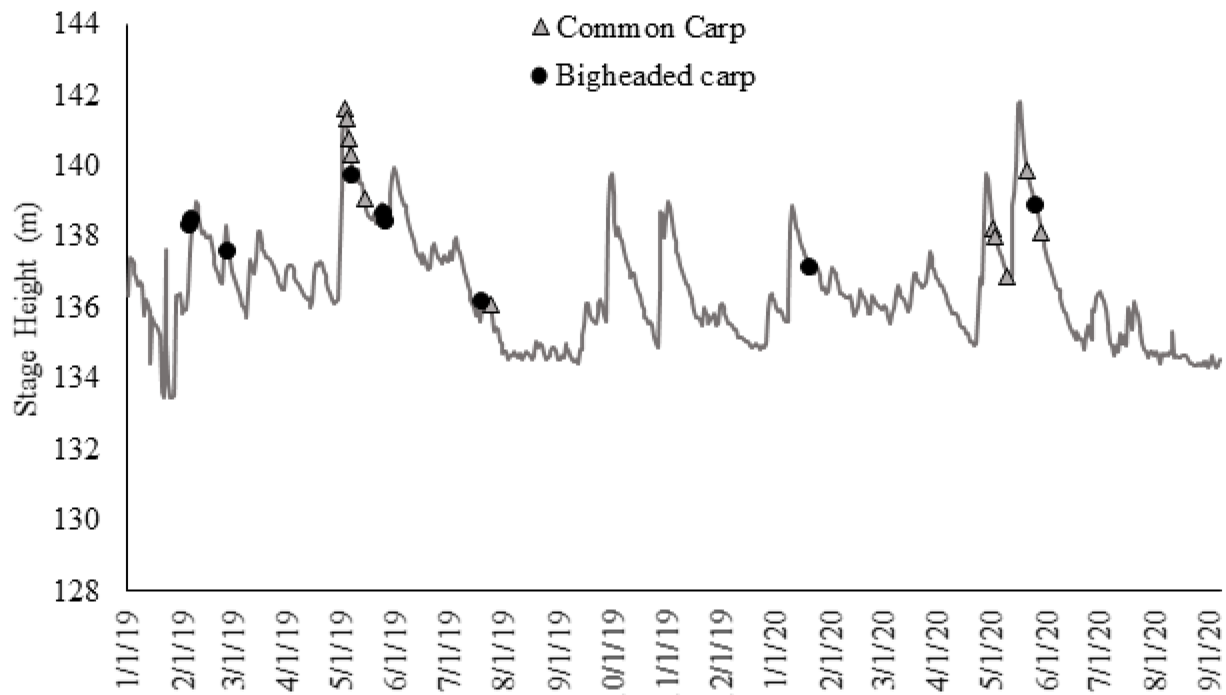

Figure 13. Downstream passage of bigheaded carp and Common Carp through Starved Rock Lock and Dam, Illinois. Daily average stage heigh (m) is represented by the grey line. Additional bigheaded carp passage occurred on 5/27/2019.

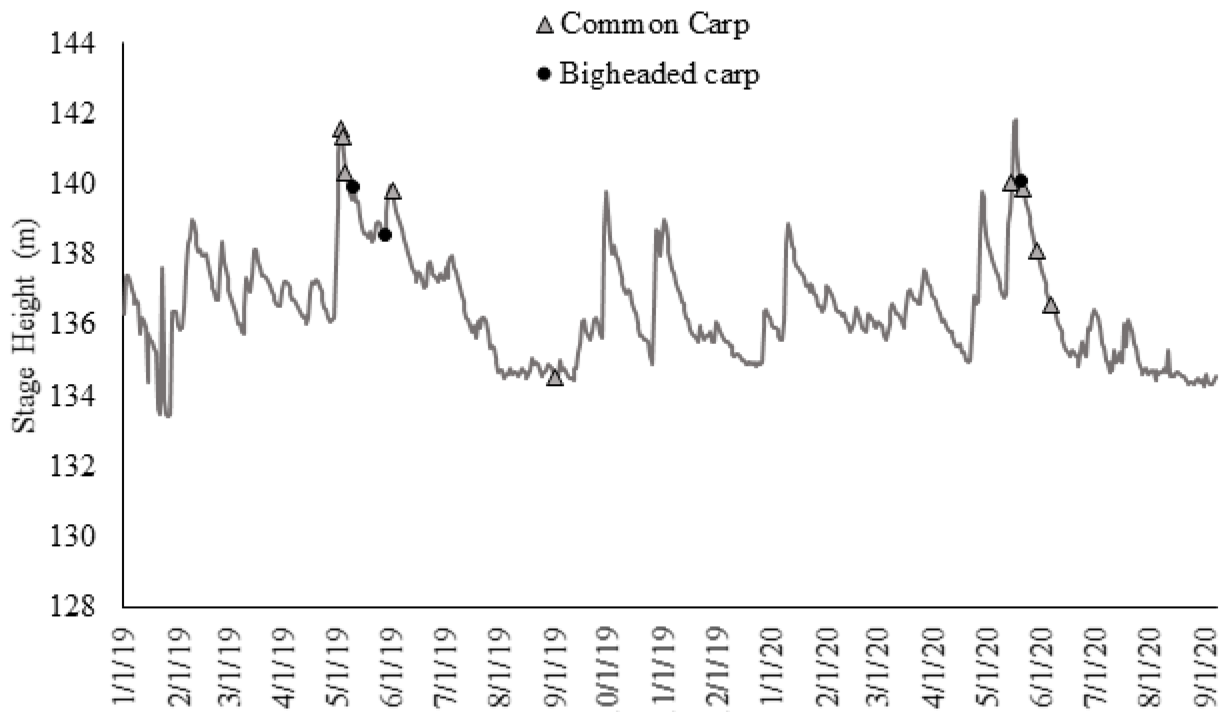

Figure 14. Upstream dam passage of bigheaded carp and Common Carp through Starved Rock Lock and Dam, Illinois River. Daily average stage heigh (m) is represented by the grey line.

Figure 15. Downstream passage of bigheaded carp and Common Carp through Starved Rock Lock and Dam, Illinois River. Additional bigheaded carp passage occurred on 5/27/2019. Daily average water temperature (℃) is represented by the grey line.

Figure 16. Upstream dam passage of bigheaded carp and Common Carp through Starved Rock Lock and Dam, Illinois River. Daily average water temperature (°C) is represented by the grey line.

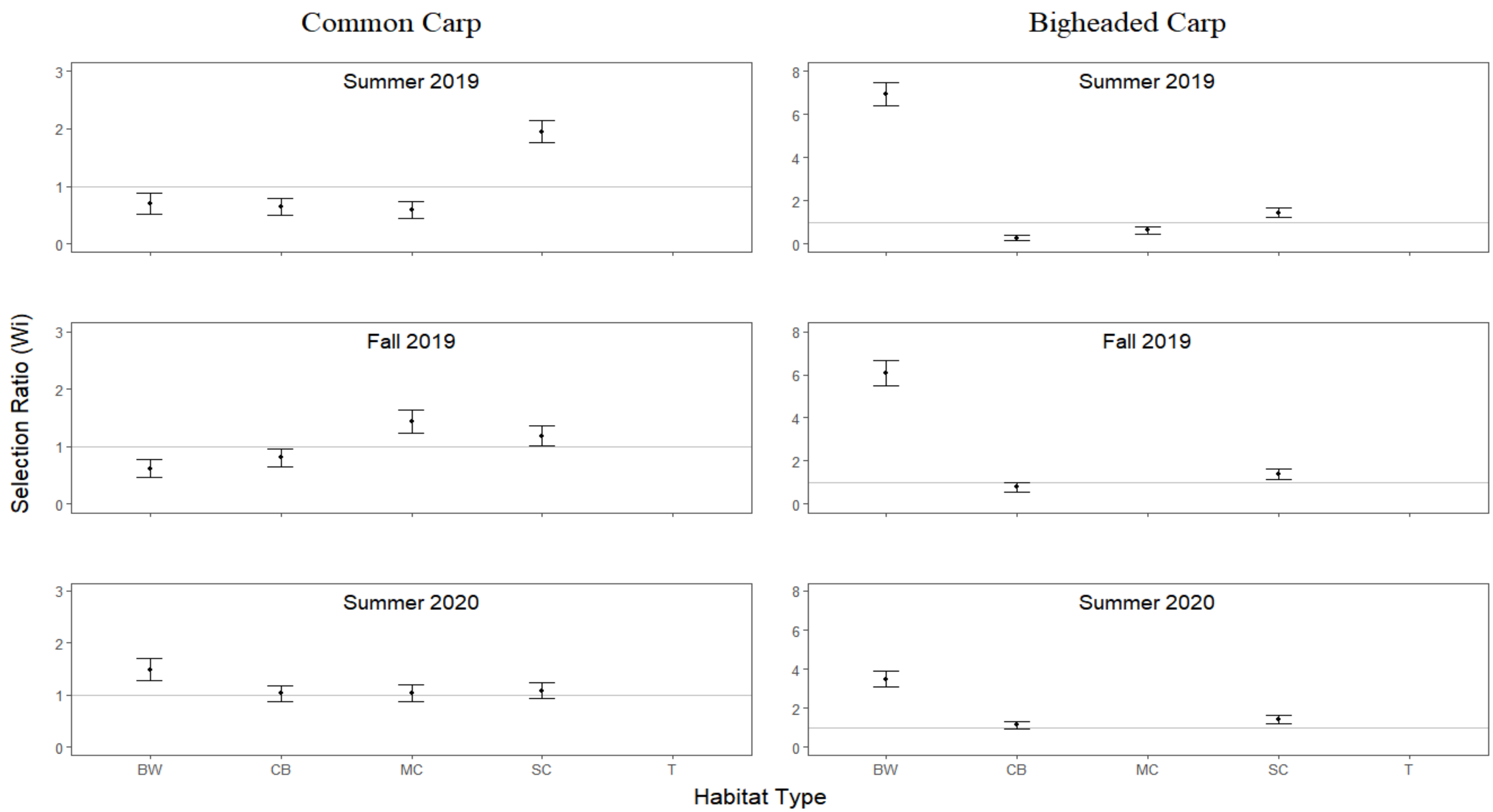

Figure 17. Resource selection index values (Wi) and Bonferroni 95% confidence intervals for acoustically tagged Common Carp and bigheaded carp on the Illinois River. $W \pm$ 95% Bonferroni CI values that overlap with 1 indicate neutral selection for that habitat bin while W values <1 indicate avoidance, and W values >1 indicate selection. If no data point and CI are present, then no fish were detected in that habitat.

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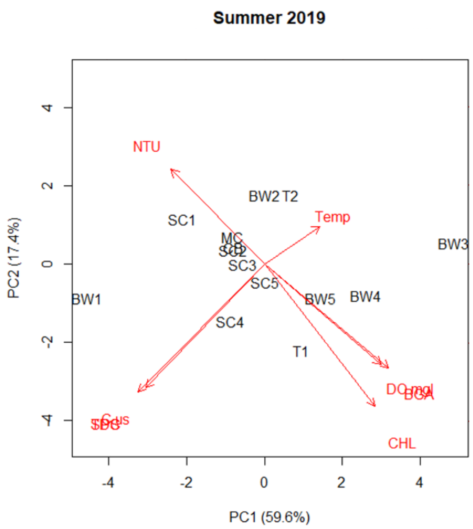
APPENDIX

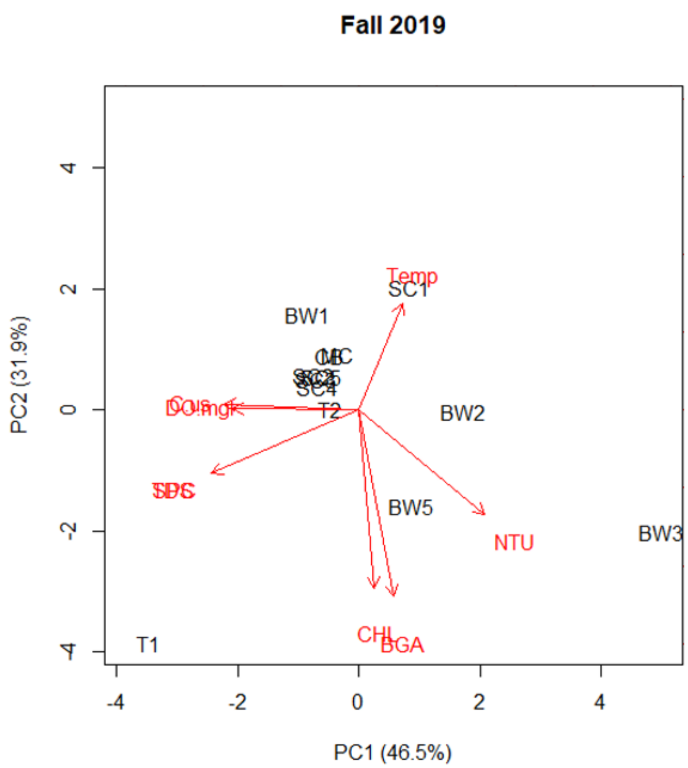
Table A-1 (Right): Correlation values from running correlation tests with abiotic factors with the two leading principle components for Summer 2019 sampling. Positive (+) values indicate positive correlation while negative (-) values indicated negative correlation.



Summer 2019	PC1	PC2
Temp	0.383482	0.141257
BGA	0.86089	-0.38784
CHL	0.764667	-0.53212
DO	0.808606	-0.37519
SPC	-0.8775	-0.47843
NTU	-0.64853	-0.35474
TDS	-0.87747	-0.47844
C.us	-0.82355	-0.46183

Figure A-1 (Left): Principle components (PCs) from principle component analysis (PCA) of Sumer 2019. Percentages represent the variability explained by each PC. Abiotic data include water temperature (temp), Dissolved oxygen (DO mgl), blue green algae (BGA), chlorophyll (CHL), total dissolved solids (TDS), specific conductance (SPC), C-us/cm (Conductivity), and turbidity (NTU). Habitats are Bulls Island side channel (SC1), channel border (CB), Covel Creek (T2), Delbridge side channel (SC4), Fox River (T1), Heritage Harbor Marina (BW2), Mayo Island side channel (SC2), main channel (MC), main channel barge backwater (BW1), Plum Island side channel (SC5), Sheehan Island side channel (SC3), Sheehan Island backwater (BW3), backwater across main channel from Sheehan Island (BW4), Starved Rock Marina and Starved Rock Yacht Club (BW5).

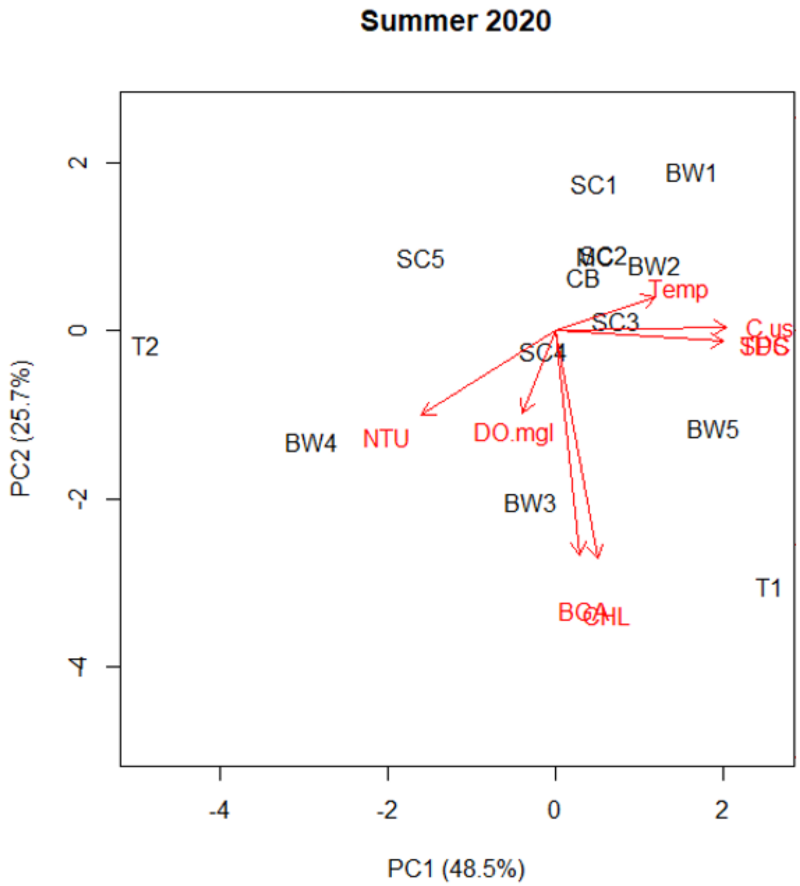
Table A-2 (Right): Correlation values from running correlation tests with abiotic factors with the two leading principle components for Fall 2019 sampling. Positive (+) values indicate positive correlation while negative (-) values indicated negative correlation.



Fall 2019	PC1	PC2
Temp	0.266345	0.548476
BGA	0.215019	-0.95623
CHL	0.096547	-0.91681
DO	-0.78186	0.006534
SPC	-0.91636	-0.32519
NTU	0.775658	-0.53639
TDS	-0.53639	-0.32533
C.us	-0.83471	0.032358

Figure A-2 (Left): Principle components (PCs) from principle component analysis (PCA) from Fall 2019. Percentages represent the variability explained by each PC. Abiotic data include water temperature (temp), Dissolved oxygen (DO mgl), blue green algae (BGA), chlorophyll (CHL), total dissolved solids (TDS), specific conductance (SPC), C-us/cm (Conductivity), and turbidity (NTU). Habitats are Bulls Island side channel (SC1), channel border (CB), Covel Creek (T2), Delbridge side channel (SC4), Fox River (T1), Heritage Harbor Marina (BW2), Mayo Island side channel (SC2), main channel (MC), main channel barge backwater (BW1), Plum Island side channel (SC5), Sheehan Island side channel (SC3), Sheehan Island backwater (BW3), backwater across main channel from Sheehan Island (BW4), Starved Rock Marina and Starved Rock Yacht Club (BW5).

Table A-3 (Right): Correlation values from running correlation tests with abiotic factors with the two leading principle components for Summer 2020 sampling. Positive (+) values indicate positive correlation while negative (-) values indicated negative correlation.



Summer 2020	PC1	PC2
Temp	0.571659	0.141257
BGA	0.134423	-0.93906
CHL	0.237852	-0.95392
DO	-0.19233	-0.34481
SPC	0.968566	-0.04343
NTU	-0.77283	-0.35525
TDS	0.968518	-0.04348
C.us	0.986318	0.015891

Figure A-3 (Left): Principle components (PCs) from principle component analysis (PCA) from Summer 2020. Percentages represent the variability explained by each PC. Abiotic data include water temperature (temp), Dissolved oxygen (DO mgl), blue green algae (BGA), chlorophyll (CHL), total dissolved solids (TDS), specific conductance (SPC), C-us/cm (Conductivity), and turbidity (NTU). Habitats are Bulls Island side channel (SC1), channel border (CB), Covel Creek (T2), Delbridge side channel (SC4), Fox River (T1), Heritage Harbor Marina (BW2), Mayo Island side channel (SC2), main channel (MC), main channel barge backwater (BW1), Plum Island side channel (SC5), Sheehan Island side channel (SC3), Sheehan Island backwater (BW3), backwater across main channel from Sheehan Island (BW4), Starved Rock Marina and Starved Rock Yacht Club (BW5).

VITA

Graduate School
Southern Illinois University

Alexander V Catalano

alexcatalano28@gmail.com

University Of Wisconsin- Stevens Point
Bachelor of Science, Fisheries and Aquatic Sciences, May 2018

Thesis Paper Title:
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Major Professor: Dr. James E. Garvey