Passage and Fine Scale Movements of Paddlefish and Smallmouth Buffalo near Claiborne Lock and Dam

by

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Abstract

Dams often impede spawning migrations of fishes, concentrating adults in their tailwaters. Little is known about behavior of migrating fishes as they approach dams, including where fish are located in the tailrace, their vectors of approach, and their residence time in the tailrace. During two spring migration periods (2018 & 2019) I quantified approach paths and locations of two migratory fishes (Paddlefish *Polyodon spathula*, Smallmouth Buffalo *Ictiobus bubalus*) at the lowermost lock-and-dam on the Alabama River to determine fish approach patterns, staging locations, and residence times. I implanted acoustic/radio transmitters in 330 fish (165 of each species) of which 181 (89 Paddlefish; 92 Smallmouth Buffalo) also received a coded electromyogram (CEMG) transmitter to measure muscle activity, and used an array of 17 passive receivers to generate two dimensional locations, movement patterns (including dam passage), residence times, and mean coded electromyogram scores. Of the tagged individuals, 39 paddlefish and 23 Smallmouth Buffalo were triangulated in the array. Sixty-three Paddlefish and 53 Smallmouth Buffalo passed upstream over the spillway (none moved upstream through the navigational locks). Fish locations combined with a U.S. Army Corps of Engineers Engineer Research and Development Center flow model showed that fish used low flow velocity microhabitats within the tailrace while staging. Individuals that passed the dam via the crested spillway when it was inundated had significantly longer residence times than those that did not pass, suggesting that residence time may influence passage success.

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List of Abbreviations

ARkm	Alabama River Kilometer
CART	Combined Acoustic/Radio Transmitter
CEMG	Coded Electromyogram
EFL	Eye to Fork Length
EMG	Electromyogram
ERDC	Engineer Research and Development Center
GLM	Generalized Linear Model
GPP	Generator Powered Pulsator
L&D	Lock and Dam
MS-222	Tricane Methanesulfonate
SAR	Submersible Acoustic Receiver
SCUBA	Self-Contained Underwater Breathing Apparatus

Introduction

Rivers are often highly modified to provide for agriculture/crop irrigation, hydroelectric power generation, industrial and drinking water sources, improved navigational channels, flood protection, and increased recreational opportunities (Graf 1999). Unfortunately, these modifications often can have unanticipated and sometimes negative effects on ecosystems (Schilt 2007).

According to the United States Army Corps of Engineers (USACE) Inventory of Dams, as of October 2016 there were 90,580 regulated dams in the United States with Atlantic and Gulf of Mexico coastal states having the highest density (Graf 1999; Downing et al. 2006). Most of these are low head dams (less than 7.62 m high) of earthen construction. In the United States, 28% of dams create recreational waterways, i.e. reservoirs, by impounding upstream waters, causing the fluvial system to be lost and lacustrine habitats to be created (Graf 1992, 1999; USACE 2016). Dams have negatively affected fish populations in many rivers around the world in part because they can impede migrations for spawning, feeding, and refuge, and can concentrate migrating adults in their tailwaters (Southall and Hubert 1984; Northcote 1998; Stancill et al. 2002; Zigler et al. 2004; Firehammer and Scarnecchia 2006). Dams can also unfavorably affect river ecosystems by changing flow dynamics, disturbing thermal routines, altering sediment transport, disconnecting river corridors from previously continuous stretches, and modifying aquatic and terrestrial habitats (Ward and Stanford 1983; Ligon et al. 1995; Poff et al. 1997; Bednarek and Hart 2005).

Altered downstream temperature, discharge, and turbidity due to the presence of a dam can have substantial effects on fish reproductive success, disrupting important cues that trigger fish to migrate and spawn (Pankhurst and Munday 2011). This disruption could cause fish to miss required river discharges for their upstream migration and water levels needed to reach their ideal spawning locations such as flooded timber or flood plain fields and allow their eggs and larvae time to develop and survive.

Dam construction and resulting habitat alterations have contributed significantly to the increase of imperiled fish species worldwide (Penczak et al. 1998; Warren et al. 2000; Vörösmarty et al. 2010; Liermann et al. 2012). Migration is a critical part of the life history of many riverine fishes to reach spawning areas and feeding areas (Firehammer and Scarnecchia 2006) and dams can block or delay these migratory pathways. Delays in passing dams have been associated with unsuccessful migrations (Caudill et al. 2007). Efforts to mitigate the effects of this blockage and enhance the ability of fish to move past dams have been implemented in a number of areas (Barry and Kynard 1986; Cada 1996; Tripp et al. 2009). Mitigation of passage disruption caused by dams has been studied in threatened or endangered populations, as well as recreationally, and commercially important species, such as Coho Salmon *Oncorhynchus kisutch*, Chum Salmon *Oncorhynchus keta*, Chinook Salmon *Oncorhynchus tshawytscha*, European Eel *Anguilla anguilla,* American Shad *Alosa sapidissima*, Blueback Herring *Alosa aestivalis*, Striped Bass *Morone saxatilis*, White Sturgeon *Acipenser transmontanus,* and Paddlefish *Polyodon spathula* (Larinier and Dartiguelongue 1989; Francfort et al. 1994; Cada 1996; Gowans et al. 1999; Jansen et al. 2007; Mallen-Cooper and Brand 2007; Enders et al. 2009; Williams et al. 2012a). Efforts to modify existing structures to allow upstream fish passage include fish ladders, fish lifts, weirs, capture and haul, non-navigation lockage (i.e., cycling navigation locks to move fish past a dam), and implementation of attraction flows (Francfort et al. 1994; Cada 1996). The Southeastern United States in particular faces many challenges due to effects caused by dams, given the large number of hydroelectric dams where fish lifts and fish ladders may not represent viable options due to behavioral traits of some Southeastern fish (e.g. metal avoidance [Gurgens et al. 2000]). As an alternative, non-navigation lockages may work to pass fish upstream successfully.

The costs of migration to an individual fish can include physiological changes, changes in energy allocation for swimming, and an increased probability of mortality (Gross and Coleman 1988). Mortality of fish can be increased when passing dams, particularly when headed downstream after spawning. Injuries can be caused by dam structures, debris, and by fish passing through dam gates or turbines. Fish entrained in turbine intake flows can sustain turbine related injuries and often death (Cada 1996). Not all migration injuries or deaths are caused by direct impacts, for example, gas bubble disease is caused when fish draw in water supersaturated with gases (which can occur downstream of a dam) and excess gas comes out of solution into tissues similar to the "bends" in SCUBA divers (D'Aoust and Smith 1974), leading to injury or death (Rucker 1972; Harvey 1975; Stroud et al. 1975; Nebeker 1976). Migrating fish are susceptible to gas bubble disease while staging in downstream pools before passing dams and while migrating downstream past dams after spawning. Dam structures can also cause hydraulic trauma, disorienting fish and leaving juveniles more susceptible to predation (Cada et al. 1997). Soft tissues have been shown to sustain significant damage when a fish goes downstream over a spillway and drops to the lower pool at a velocity exceeding 16 m/s (as would result from a 13 m drop) (Jackson and Marmulla 2001).

Benefits of migration have been widely studied in migratory species and have been shown to include higher fecundity, larger body size, and increased growth rates for both adults and juveniles (Gross 1987; Gross and Coleman 1988; Roff 1988, 1991; Snyder and Dingle 1989;

Snyder 1991; Jonsson and Jonsson 1993, 2006; Frier 1994; Crossin et al. 2004). Individuals who migrate tend to grow larger and have higher fecundity than non-migrating individuals of the same population (Gross 1987; Jonsson and Jonsson 1993; Klemetsen et al. 2003). In several salmonid species, Gross (1987) found an average three-fold increase in egg production by migrating individuals when compared to non-migrating individuals.

While passage mitigation has been mostly focused on cold water systems, primarily in support of salmonid migrations, rivers in the Southeastern US such as the Alabama River also face challenges. The Alabama River with its locks, hydroelectric dams, and one crested spillway dam is similar in construction to many other of the 226 U.S. Army Corps of Engineers lock-and-dam structures in the United States (USACE NID 2019). The dam furthest downstream on the Alabama River (Claiborne Lock and Dam) is a unique structure on this system in that it has a non-gated crested spillway. This spillway allows fish to pass over the dam, upstream and downstream, when water levels are high enough. While passage by Paddlefish has been documented over the crested spillway at Claiborne Lock and Dam (Simcox et al. 2015) the full effects of the crested spillway on Paddlefish or the migrations of other fish species is not fully understood. No estimates are available for the amount of energy required, nor how various species navigate the complex flow fields approaching the dam. To fully understand the impacts of a dam structure on migratory species in the system, it is important to investigate different species given that they are likely to have different energy expenditures for approaching and potentially passing dam structures. In addition, varying seasons and/or spawning conditions can also affect these expenditures, and seasonal variations in precipitation and temperature can further influence fish movement. Paddlefish are strong swimmers and can pass the crested spillway, but much less information is available for other lotic migratory species such as the Smallmouth Buffalo *Ictiobus bubalus*.

Here I quantify residence time in the dam tailrace by two lotic species, including activity levels while present there and while crossing the crested spillway, as well as fish use of eddies and vortices when approaching the dam structure.

Study Species

In this study, individuals of two fish species with known potamodromous migratory life histories were tagged with an acoustic and/or radio transmitter to monitor their movements and activity levels near dam structures and within tailrace flow regimes. The focal migratory species for this study were Paddlefish, a pelagic mid-water strong swimming fish, and Smallmouth Buffalo, a benthivorous riverine fish (Shormann and Cotner 1997; Boschung and Mayden 2004).

These species overwinter in slow-moving areas of main rivers (e.g., oxbows or backwater channels (Edwards and Twomey 1982; Hoxmeier and DeVries 1997); however, as spring temperatures rise and freshets occur, their extended distance, abiotically cued migration begins with sexually mature fish moving from these overwintering habitats to main river channels and fast flowing reaches, eventually moving upstream (Hoxmeier and DeVries 1997; Firehammer and Scarnecchia 2006).

Smallmouth Buffalo exhibit significantly higher mean critical swimming speeds during spring versus fall and winter (Adams and Parsons 1998). This increased performance and swimming efficiency is believed to be associated with requirements for migration (Adams and Parsons 1998). Smallmouth Buffalo have been documented migrating up to 725 km over a 577-day period (Martin et al. 1964b) and may migrate away from their preferred bottom substrate, characterized by mud and silt, and into flooded fields and shallow weedy areas for spawning

(Martin et al. 1964a; Wrenn and Shoals 1968; Adams and Parsons 1998). Smallmouth Buffalo use broadcast spawning to distribute their adhesive eggs that then stick to the substrate (Wrenn and Shoals 1968).

Paddlefish is a mid-water pelagic species (Meyer 1960; Hoxmeier and DeVries 1997) that uses a variety of habitats throughout the year, which can vary both annually and seasonally (Simcox et al. 2015). One individual in the Missouri River moved over 2000 km from its original tagging location (Rosen et al. 1982; Jennings and Zigler 2009). This movement, as with Smallmouth Buffalo, is believed to be associated with a spawning migration to preferred spawning habitat or substrate. Paddlefish prefer gravel substrates in swift water to deposit their eggs (Purkett 1963). Paddlefish in the Alabama River represent a genetically distinct population versus the Mississippi River strain (Epifanio et al. 1996), and has been shown to exhibit spawning site fidelity (Unkenholz 1986; Lein and DeVries 1998; Jennings and Zigler 2000).

Study Area

The Coosa and Tallapoosa rivers join to form the Alabama River (Figure 1), and the Alabama, Coosa, and Tallapoosa Basin drains roughly 37,000 square kilometers of eastern Alabama, northwestern Georgia, and a segment of southeastern Tennessee (Mettee et al. 2005; USACE 2015). The average grade of the Alabama River is 0.064 m/km, descending a total of 32.31 m over its 505 km river path (USACE 2013). The three USACE lock-and-dam (L&D) structures in this section of the river are Robert F. Henry L&D at Alabama River kilometer (ARkm) 395 (construction began in 1966, opened for commercial and recreational navigation in 1972), Millers Ferry L&D at ARkm 214 (construction began in 1964, completed in 1970), and Claiborne L&D at ARkm 118 (construction began in 1964, completed in 1970) (USACE 2015). My study area (Figure 2) extended from 1 km upstream of Millers Ferry Lock and Dam (ARkm

215) downstream to the confluence of the Alabama River and lower Tombigbee River (ARkm 0). Among these structures, Claiborne L&D is unique due to its having a crested spillway and gate layout (i.e., gates that do not span the entire width of the river), as well as because it is not a power-generating dam. The crested spillway at Claiborne L&D measures 154 m wide by 10.1 m high, and is next to six gated spillways (18.5 m wide gates), and a 25.9 m wide by 184.6 m long lock chamber (Mettee et al. 2015). Millers Ferry L&D is a hydroelectric power-producing dam with its powerhouse positioned on the east bank about 0.5 km downstream of the dam. The dam comprises seventeen 15.4 m wide gated spillways and a lock chamber that is 25.9 m wide by 184.6 m long (Mettee et al. 2015). In 2008 the USACE restricted dredging to the lower 118 km of the Alabama River. Non-navigational locking has occurred during February - June migratory periods at Claiborne L&D and Millers Ferry L&D to aid fish upstream spawning migrations and downstream post spawning migrations. Non-navigational locking at Claiborne L&D is only performed if the downstream pool is below 4.6 m, or at Millers Ferry when the downstream pool is below 17 m. Fish can only pass Millers Ferry L&D via lock operations, given that it is a hydroelectric producing dam that only diverts water through its seventeen gates and away from the powerhouse in flood situations.

Methods

Collection and Anesthesia

From January 2017 through February 2019 I collected fish using floating large-mesh (150-200 mm) mono-filament gill nets (Simcox et al. 2015) and pulsed-DC electrofishing using a Smith-Root 7.5 Generator Powered Pulsator (GPP) (Lein and DeVries 1997). I collected Paddlefish over 500 mm eye to fork length (EFL) and Smallmouth Buffalo over 444 mm total length (TL), to assure that I was tagging fish that were sexually mature and thus likely to migrate

(Wrenn and Shoals 1968; Hoxmeier and DeVries 1997; Mettee et al. 2009). Sampling was conducted both above and below Claiborne L&D. Although fish were caught both above and below Claiborne L&D, 96.4% of all tagged fish were caught and tagged below Claiborne L&D. Once collected, I sedated fish with MS-222 or CO_2 in preparation for tagging (CO_2 was used for Paddlefish within 21 days of the commercial season, Bernier and Randall 1998, given that they could be consumed within the 21-day hold time required for MS-222; Trushenski et al. 2013).

Tagging and surgical methods

Once fish were sedated, I disinfected the surgical area and all tools (scalpel blades and handles, hemostats, forceps, and transmitters) with 2% chlorhexidine gluconate solution and rinsed with distilled water (Summerfelt and Smith 1990; Hasler et al. 2012). I then made a small incision (2-3 cm) on the left ventral side where I implanted a coded electromyogram radio transmitter (CEMG, Lotek Wireless Inc.) and/or a combined acoustic/ radio transmitter (CART, Lotek Wireless Inc.). The total weight of all implanted transmitters was kept below the recommended 2% of the total fish wet weight (Table 1) (Winter 1983; Summerfelt and Smith 1990; Cooke et al. 2012) and transmitters were tested for function prior to and during the procedure. A CEMG transmitter emits a radio signal and is used to measure electrical currents produced in muscles; these tags were implanted as described for CART tags, but with electrodes that were embedded approximately 1cm apart in red muscle at 70% of standard body length below the lateral line (Beddow and McKinley 1999; Taylor et al. 2012). All radio transmitters had a radio antenna that was threaded through the body wall using a 14-gauge needle. The incision was closed with simple interrupted PDS II sutures (Miller et al. 2013; Robillard et al. 2015) appropriate to the size of the fish (suture sizes 2-0 to 1) (Mulcahy 2003). In addition to the sutures, a liquid adhesive (3M Vetbond) was applied to the incision site after suturing to ensure a protective barrier. Tagged fish also received a sequentially numbered waterproof Floy anchor tag (FM-95W) that was placed internally on the right side of the abdomen behind the pelvic girdle (Simcox et al. 2015). Once I placed the transmitter in the fish and closed the incision, I placed it into a recovery tank until it reached stage III of recovery and regained its equilibrium (Bernier and Randall 1998). I then released the fish and recorded the GPS coordinates.

Acoustic Tracking and telemetry

Fish were located using WHS 3250L Submersible Acoustic Receivers (SAR, Lotek Wireless Inc.). The acoustic receivers operated continuously, logging any tags present within range, providing a data point with date, time, signal strength, and whether the accelerometer (CART tags only) had recorded motion in the last 24 hours (failure to move is an indication of mortality). The motion sensor provided accurate indications of survival for Paddlefish that swim almost continuously within the main river. The motion sensors, however, did provide false mortality indications for Paddlefish (2-3 fish) found within the lock chamber given that they were cruising instead of fast or burst swimming, and for Smallmouth Buffalo (6-8 fish) that can periods of very little movement. SARs were deployed in 2 configurations: 1) an array of 17 SARs was established in the dam tailrace used for triangulating fish positions (Figure 2), and 2) 21 SARs were deployed along the Alabama River in the study area centering around Claiborne L&D to determine presence/ absence of tagged fish (Figure 3).

Acoustic Array Claiborne L&D Tailrace

The array in the tailrace of Claiborne L&D was deployed in December 2018 (Figure 2). When 3 or more of these SARs simultaneously received a signal from an individual CART tag, this detection then provided a 2-dimensional (2D) position using the Universal Transverse Mercator (UTM) coordinate system.

Run-of-the-River Receivers

To quantify migrations, 21 SARs were deployed along the Alabama River (Figure 3). In February 2017, nine SARs were installed along the river starting downstream at the confluence of the Alabama and Tombigbee rivers and continuing upstream to 1 km above Claiborne Dam. These receivers were placed at approximately 25-km intervals along the river. In December 2017 an additional eight SARs were deployed, three being placed across the first 10 km upstream of Claiborne L&D, four across the first 10 km downstream of Claiborne L&D, one 1 km downstream of Millers Ferry L&D and one 1 km upstream of Millers Ferry L&D. In October 2018, four additional SARs were placed between 10-32 km upstream of Claiborne L&D, centered around the inlets of backwater channels. Claiborne L&D is the central point of the distribution of these receivers but the run-of-the-river array provided coverage of both dams, allowing me to see a broader picture of when tagged fish moved past either dam or upstream/downstream past a receiver.

During the initial installation of the run-of-the-river array in February 2017, one SUR was placed inside the ladder well of the lock chambers at both Claiborne and Millers Ferry L&D. The ladder well is located at the most downstream section of the lock so fish could be detected entering the lock. Fish within the lock can be detected throughout the majority of the lock, providing data on when fish entered or exited the lock and whether fish in the lock were alive.

Radio Telemetry

I also installed radio receivers (Lotek Wireless Inc. SRX800) with an antenna array at a stationary site on the Claiborne L&D structure. This antenna array recorded both CEMG and CART signals using five antennas covering nearly 360 degrees around the dam (Figure 4). The CART receiver switched antennas every 20.5 seconds. With five antennas it took the receiver

102.5 seconds to make a complete cycle on one frequency. Given that there were three frequencies of CART tags, one complete cycle through all CART tag frequencies took 307.5 seconds. The CEMG receiver switched antennas every 3.5 seconds. With 5 antennas it took the receiver 17.5 seconds to complete the entire cycle. Although the detection range varies among antennas, most have a range in normal conditions of 250-300 m.

Analysis

Residence time of all fish observed within the tailrace was quantified and a nonparametric permutation test was used to determine whether residence time for fish that successfully passed the dam differed from that of fish that did not pass the dam. A nonparametric permutation test was selected because of non-normal data and unequal variance.

Fish passage was analyzed using SAR data to determine when fish were detected on upstream receivers after having been tagged or/and located downstream. Fish tagged upstream of Claiborne L&D were not used in determining passage numbers. Fish tagged downstream of Claiborne L&D and then subsequently detected at a later date on an upstream receiver were considered to have passed Claiborne L&D. Passage data were analyzed by species and broken into two seasons (2017/2018 and 2019). This was done to due to the lack of current data on the 2019 season which skewed some results. A generalized linear model (GLM) was used to analyze the passage data by fish length. For the GLM, fish were divided into groups by both species and whether they had passed Claiborne L&D.

In addition to quantifying residence time in the tailrace, I identified areas of high use using spatial point pattern analysis. I analyzed this in several ways: First, I overlaid a grid on a Claiborne tailrace shape file to analyze only the points that occurred within the bounds of the tailrace. I then did a quadrat count analysis by running a chi-squared test that compared the observations within each grid square against a theoretical distribution. Second, a G- function was generated which, is the cumulative distribution of the nearest neighbor distance for a randomly-selected data point. This function describes characteristics of a point pattern at multiple distance scales by using a Monte Carlo simulation of 99 randomly-selected point generations with a number of points that is equal to that in the dataset. This is used to generate a confidence interval with which to compare the cumulative distribution of the nearest neighbor distances of my data. Finally, I produced a kernel density plot which provides a visualization of the clustering of the points using a heat map.

Residence location was then quantified by generating a centroid using a 3D contour map where the z-axis was the elevation based on the number of detections in an area. The peak of the highest elevation was designated as the centroid for that individual fish as it had the highest amounts of detections at that area within the tailrace.

EMG data were evaluated using the mean EMG score of individual fish. Mean EMG scores were broken into two categories, those for fish that had passed Claiborne Dam and those that had not, and were compared using a t-test.

Results

Detections

Of the 240 fish tagged between March 2017 and March 2018, 236 (98%) were detected at least once after release. Four of the 240 fish were believed to be dead, as indicated by the mortality sensor and a consistent location on three separate trips separated by a minimum of seven days. These fish (3 Smallmouth Buffalo and 1 Paddlefish) died shortly after tagging and likely never fully recovered from sedation. An additional 90 fish were tagged during January and February of 2019 for a total of 330 fish. Of the 330-tagged fish, 318 (96.4%) were tagged below

Claiborne L&D and 12 (3.6%) fish were tagged between Claiborne L&D and Millers Ferry L&D. Between December 2018 and March 2019, 50 (56%) of the 90-additional fish tagged in 2019 were detected after release. The detection rate of the 90-additional fish was reduced due to dead batteries in the SARs during February and March 2019, when excessive water levels prohibited battery replacement (until late March).

Three fish were physically recaptured. A Paddlefish tagged near Eureka Landing (ARkm 85) that was caught 11 months later with gillnets in the same general area of initial tagging. The suture site was completely healed. Moderate irritation of the antenna and Floy tag insertion sites was present, likely due to constant movement of the tag and antenna. The second recaptured fish was a Smallmouth Buffalo initially tagged at Isaac Creek (ARkm 131) that was killed by a bow fisherman in Isaac Creek 6 months later. And the third was a Paddlefish caught by gillnet in the lower pool of Claiborne L&D one month after initial tagging 1 km upstream from its release location. The condition of this fish's surgery site was irritated and not fully healed, but the sutures were still present and holding the incision site closed. The irritation is again likely due to constant movement of water over the site. The longest span between recaptures for those 3 fish was 11 months.

There were 7,158,476 detections logged by SARs between March 2017 and February 2019. Detections were made on all receivers except the receiver upstream of Millers Ferry L&D and the receiver within the Millers Ferry lock chamber. The receiver with the most detections (1,096,100) was located within the Claiborne tailrace array.

Passage

Passage across either Claiborne L&D or Millers Ferry L&D was determined by detections from SARs above the dam, if a fish was detected upstream of either dam after having been tagged downstream of Claiborne L&D, a passage event had occurred. Data were analyzed for fish tagged in 2017 and 2018 using a cutoff date of 11/30/18 at midnight; all data after that were considered part of the 2019 migratory season data and analyzed separately.

Of the 240-fish tagged in 2017 and 2018, 204 (86%) were observed by one or more receiver in the array at Claiborne L&D. A total of 85 (42%) of the 204 fish detected in the Claiborne tailrace passed Claiborne L&D. Of the 85 fish that passed Claiborne L&D, 33 (39%) of those were Smallmouth Buffalo and 52 (61%) were Paddlefish. There were 141 fish believed to be alive that were tagged downstream of Claiborne L&D that did not pass the dam, and 22 of those 141 fish never approached within 2 km of the dam, while 119 fish that did not pass the dam were observed within the tailrace of the dam on the SAR array. Of the 85 fish that passed Claiborne L&D 13 (15%) were subsequently recorded in the tailrace of Millers Ferry L&D. No tagged fish were detected by SARs upstream of Millers Ferry L&D.

For the 2019 migratory season (starting December 1, 2018) 90 additional fish were tagged, yielding a total of 330 fish. Of the 330 total tagged fish 87 (26%) were detected in the tailrace at Claiborne L&D. Of the 87 detected at the dam, 53 (61%) passed the dam of which 37 (70%) were Paddlefish and 18 (33%) were Smallmouth Buffalo. Of the 53 fish that passed Claiborne L&D in 2019, 26 (49%) of those fish were tagged in 2019 and 27 (51%) were tagged in the 2017 or 2018 seasons. Twenty-two (42%) of these fish were returning fish previously seen passing Claiborne L&D in 2017 or 2018.

Size Dependent Passage

I used a generalized linear model to determine if fish length was related to passage success. This GLM was conducted separately for each species using a logistic regression where passage was used as a binary factor and fish length was a continuous predictor. Length was determined not to be a significant factor related to passage for either species (Paddlefish P=0.31; Smallmouth Buffalo P=0.37).

Residence Time

Residence time was calculated for all fish that were tagged below Claiborne L&D (318 fish). Residence time was calculated by summing the time individual fish spent within the tailrace array. These sums were calculated for fish in two groups: 1) fish that passed the Claiborne L&D, and 2) fish that did not pass the dam. Individual fish that passed the dam spent an average of 264 hr (1SE= 47.55) within the tailrace array. Individual non-passing fish spent an average of 138 hr (1SE= 19.74) within the tailrace array. The difference in means between groups was not normally distributed and the variance in these observations was unequal between those that passed and those fish that did not, so I used a randomization permutation test to compare the average residence time difference between these groups. The permutation test was run 100,000 times to provide a normal distribution of expected mean differences. The mean difference between the two groups was 125.66 hr (P< 0.006) indicating that residence time of fish that passed the dam differed significantly from zero (Figure 5). I then considered the residence time data for the two species individually. Paddlefish that passed the dam spent an average of 365.01 hr (1SE=72.90), whereas individual fish that did not pass spent an average of 198.74 hr (1SE= 33.51). The permutation test indicated that the mean difference in time spent in the tailrace between those Paddlefish that eventually passed upstream and those that did not was 166.26 hr which differed significantly from zero (P<0.023) (Figure 6). Smallmouth Buffalo that passed the dam spent an average of 139.78 (1SE= 59.66) hr in the tailrace whereas the fish that did not pass spent an average of 88.32 (1SE= 17.46) hr. Permutation analysis suggested the mean difference in the residence time was 51.45 hr, which did not differ significantly from zero ($P < 0.30$) (Figure 7).

A GLM was also performed on the residence time data. This GLM was conducted using a logistic regression where passage was used as a binary factor and fish length, species and residence time was a predictor variable. I determined fish length was not a significant factor related to passage probability ($P=0.12$), combined species residence was a significant factor to passage probability ($P=0.017$), Paddlefish residence time was also a significant variable for passage probability ($P=0.027$), but residence time for Smallmouth Buffalo was not a significant factor in passage probability ($P=0.26$).

Residence Locations

Locations were plotted using 2D triangulation within the SAR array in the tailrace of Claiborne L&D. This was completed for 48 individual fish (19 Smallmouth Buffalo and 29 Paddlefish) for which there were enough points to provide a detailed location for analysis. I determined that 30 triangulated locations on an individual fish was the minimum necessary to get an accurate representation of a fish's pattern of movement within Claiborne's tailrace. Grid count analysis determined that for all 48 individual fish there was significant clustering of the data points within the tailrace using chi-squared test of significant difference from a random pattern (χ^2 test, $P<0.001$). However, for all 48 fish the grid used had cells with no observations which violates one of the assumption of a chi-squared test. In order to provide support for the significance of the chi-squared test, a G-function plot (Brunsdon and Comber 2015) was produced for each fish (Figure 8). As with the chi-squared test, the G- function plot showed significance for all 48-fish tested. I then combined the locations of all 48-fish with points located within the boundaries of the Claiborne L&D tailrace in order to determine if all fish locations within the tailrace were still significantly clustered. With all data points combined, both the chi-squared (P<0.001) and the G-function showed significant clustering (Figure 9). I then used the centroids of the 3D kernel density plot to generate a plot showing the locations of the previously used 48 fish locations. These locations showed clustering as described above, after which I considered separate species. These species primarily used different areas from one another, but when using the same habitat, they tended to congregated in the same areas (Figure 10), which were known lower flow areas with eddies or structure such as rock piles or sandbars.

Lock Data

A total of 23 tagged fish were detected within the Claiborne lock chamber. Of these fish, 8 eventually passed the dam. Only 5 individuals spent an extended period of time (a total of 60 minutes or longer) within the lock chamber, and 8 fish were present within the lock chamber during non-navigational lockages. Although fish were present within the lock chamber during both non-navigational and navigational lockages, none of those fish were subsequently seen on the SAR immediately upstream of the dam within 2 hr of gate closure; therefore, I concluded that no tagged fish passed Claiborne L&D through the lock chamber. No tagged fish were ever detected within the Millers Ferry lock.

Electromyogram (EMG) Data

The mean EMG score for 181 fish was determined and the mean for fish that passed Claiborne Dam (12.11, [1SE=0.23]) did not differ from that of fish that did not pass (12.52, [1SE=0.16]) (GLM; P=0.81; Figure 11).

Discussion

Fish passage of potamodromous species has been an issue since even before The Rivers and Harbor Act of 1890 began regulating dams in the United States (Williams et al. 2012). While many fish passage structures have been created across the US, few have been constructed in the Southeastern US and therefore fish in those systems rely entirely on aspects of the construction of the dam (e.g., a crested spillway), the operation of the dam (Southall and Hubert 1984), and/or lock operations in order to make successful passage attempts (Bailey et al. 2004).

Lock Operations

The current approach used by the USACE to allow the potential for fish passage on the Alabama River is non-navigational locking during February through June, which, as in other systems has resulted in extremely limited success (Cooke et al. 2002; Bailey et al. 2004; Simcox et al. 2015). These non-navigational lockages at Claiborne L&D are restricted to times when the lower pool is below 4.6 m in elevation (USACE, Claiborne L&D personal communication), limiting the number of such lockage events. Non-navigational lockages consisted of roughly 4 hours open on the downstream lock doors alternated with 4 hours open on the upstream doors, with all doors closed overnight and on weekends. Navigational lockages were rare; Claiborne averaged 3 per month during January – June 2018 (based on lock operation logs provided by USACE), and non-navigational lockages rarely occurred (13 days of 86 possible days in 2018). in the spring due to water levels regularly exceeding the 4.6 m maximum allowable height. Millers Ferry L&D performed non-navigational lockages any time the lower pool was below 17 m and consisted of roughly 3 hours open on the downstream doors alternated with 2 hours open on the upstream doors with all doors closed overnights and on weekends. With results comparable to Moen et al. (1992) on the Mississippi River, fish were detected being at or near the face of Millers Ferry L&D but, were never detected within the lock chamber or upstream of the dam structure. Similarly, I found that tagged Paddlefish and Smallmouth Buffalo only occasionally entered or used the Claiborne lock chamber. This limited use of the lock chambers is likely due to the lack of attraction flow, given that fish have been shown to be attracted to higher flows within the surrounding river and lock structures lack the flow necessary to motivate the fish to enter the lock or move upstream out of the lock (Gowans et al. 1999; Pratt et al. 2006; Naughton et al. 2007; Bunt et al. 2012). This left the primary routes of passage to rely on the hydrology of the river to create a passable environment either through the gates, or at Claiborne L&D, over an inundated crested spillway. In fact, at Claiborne L&D, all fish that passed did so over the crested spillway; none used the lock chamber.

Passage and Residence Time

My results support that fish are not passing through the gated structures, given that I found no passage upstream of Millers Ferry L&D. The increased velocity of water through the gates along with behavioral avoidance of turbulent environments are thought to limit fish passage through the gates (Zigler et al. 2004). I did find results similar to Simcox et. al. (2015), and Southall and Hubert (1984) in that dams impeded movement but may not fully block passage depending on dam construction. I documented both Paddlefish and Smallmouth Buffalo were able to pass Claiborne L&D over the crested spillway during periods of inundation, which, in the case of Claiborne L&D occurred often during the spring when the upper and lower pools of Claiborne L&D reached roughly 10 m. And this inundation was highly variable from year to year. According to Simcox et. al. (2015) spillway inundation occurred for 33 days during the spring 2010 and for 13 days during spring 2011. I found that during 2018 the crested spillway was inundated for 18 days, but that value was 75 days during 2019. In fact, 2019 was an extremely wet spring and the duration of inundation was more than double the 5-year average of 33 days of inundation per spring migration period (Dec. 1- May 31). While inundation likely opens a passage route over the crested spillway for days or even weeks during periods when fish are likely migrating, these time windows are variable across years, as well as within a year and periods of inundation may not be long enough for fish located further downstream to reach and pass the dam. As such, residence time in the tailrace area is an important factor for Paddlefish passage of Claiborne L&D because abiotic cues (i.e., changing water level and velocity) can take days to reach fish staging locations that are further downstream. Fish in general, and Paddlefish in particular, that actively stage near the dam when water levels reach inundation have higher chances of passage likely due to shorter response times. Interestingly, Smallmouth Buffalo did not have higher chances of passing Claiborne L&D based on the amount of time spent within the tailrace.

Residence Locations

While residing near the dam, both Paddlefish and Smallmouth Buffalo tended to congregate in areas of lower velocity flow within the tailrace out of the main flow coming through gates or over the crested spillway often behind man made or natural structure (Rosen et al. 1982; Southall and Hubert 1984; Bailey et al. 2004). The primary locations used by both study species were along or within current refuge areas as has been documented previously for American shad (Barry and Kynard 1986). In my study, I found that Smallmouth Buffalo and Paddlefish used habitats (flow fields) within the tailrace differently. While a few Smallmouth Buffalo primarily spent their time within the large eddy of the crested spillway near the center of the tailrace, most Smallmouth Buffalo preferred the shallower slower moving sandy substrate at the river's edge. Paddlefish spent most of their time within the same eddy at the center of the tailrace and occasionally within the eddies immediately adjacent to the lock chamber wall. While the two species tended to use separate areas, the areas being used are similar in flow structure suggesting their general use of eddies as flow microhabitats within the tailrace. These eddies can be used to reduce energy expenditures in high flow environments (Facey and Grossman 1992), and for protection from currents behind the lock and dam or natural structures such as a sandbars (Rosen et al. 1982; Southall and Hubert 1984; Moen et al. 1992) and fish in my study area may have been using these area to reduce their energy expenditures.

Electromyogram (EMG) Data

EMG data proved to be difficult to work with, given that tags function best when calibrated to each individual fish (Brown et al. 2007) and they require precise placement of electrodes during implantation (Beddow and McKinley 1999). The reason for the calibration of each fish was shown by Brown (2007) where they used the same tag in multiple fish and observed different EMG results across fish. Calibration required a riverside swim tunnel or transportation of fish to a lab and then back to the river which was not feasible in my study; as such, I was unable to get a true energy expenditure by the fish and instead used it as an indicator as to the degree to which individual fish were putting effort into their movements. In my data there were no differences between the mean amount of effort exerted between fish that passed versus those that did not pass Claiborne L&D. This is not to say effort was not elevated during a passage event, but only that the mean efforts of the two groups did not differ significantly.

Implications

My results have shown there is some movement of fish between the lower Alabama River (downstream of Claiborne L&D) and Claiborne Lake (downstream of Millers Ferry), but that it relies on flow and a crested spillway which cannot be guaranteed for any particular number of days during any particular year. This suggests that fish in these two sections of the Alabama River should be managed as one population, at least for large and mobile species such as Paddlefish and Smallmouth Buffalo. There was no movement of tagged fish past Millers Ferry and therefore fish upstream of Millers Ferry should be managed as a distinct and separate population from the fish of the lower Alabama River. And given that this was the case for these large and mobile species, it is likely that movement of smaller and/or less mobile species will similarly be restricted, suggesting that they should also be managed as separate populations. Conservation lockages do not appear to be a broadly successful conservation strategy for Claiborne L&D or Millers Ferry L&D particularly with the low water level threshold above which conservation lock operations cease and without any sort of attraction flow to encourage fish to enter the open lock chamber, nor to encourage fish to exit the lock chamber and to enter the upstream pool and continue its upstream migration. At Claiborne L&D, raising the maximum gage height for non-navigational lockages to 9 m (if safely feasible) would mean that conservation lockages would be conducted until a point where the crested spillway was inundated thus providing routes past the dam (either via the lock or crested spillway). Having both options available during spawning migration seasons is important to enhance movement of fish beyond the dam. The situation at Millers Ferry L&D is more complicated given that there is no crested spillway; however, the gage height at which they open the dam gates should at least equal the height at which they cease non-navigational lockages in order to provide at least one possible migration path beyond the dam as often as possible.

In addition to enhancing potential passage opportunities, habitat in the river could be modified to enhance fish residence times in the tailrace, given that the importance of this to fish passage. My study in particular highlights a need for structures such as rock weirs, wing dams or jetties in or around the Claiborne L&D tailrace area to provide areas of lower velocity water for refuse during staging and migrations of Smallmouth Buffalo, Paddlefish, and other migratory species. While areas with low velocity water are important for staging, they are also prone to deposition and filling with mud and sand. As such, maintenance of these areas may be required, although such structures clearly exist in other lotic systems, and could likely be adapted to work in the Alabama River as well.

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Tables

Table 1: Transmitter life expectancy and fish weight requirements

Transmitter	Battery Life (Days)	Transmitter Description	Transmitter Total Weight (g)	Required Fish Weight (g)
CART MM-MC-11-45	479	CART Small	16	800
CART MM-MC-16-50	1409	CART Large	37	1,850
CEMG2-R11-35	143	CEMG Small	15	800
CEMG2-R16-50	490	CEMG Large	33	1,850
		CART Small + CEMG Small	31	1,550
		CART Small + CEMG Large	49	2,450
		CART Large + CEMG Small	52	2600
		CART Large + CEMG Large	70	3,500

Figures

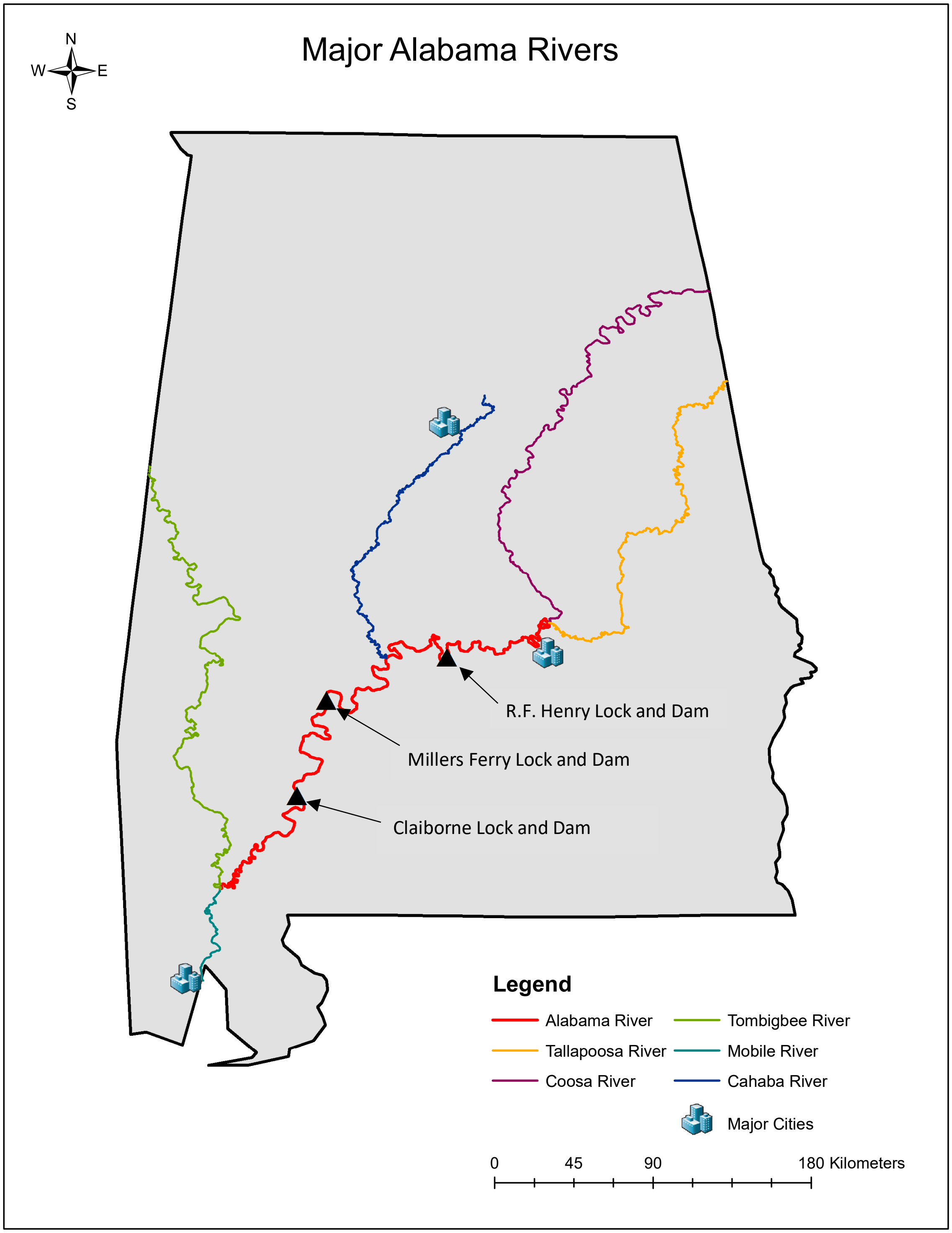

Figure 1: Major rivers in Alabama with three USACE dams on the Alabama River.

Figure 2: SAR Array locations within the tailrace of Claiborne L&D.

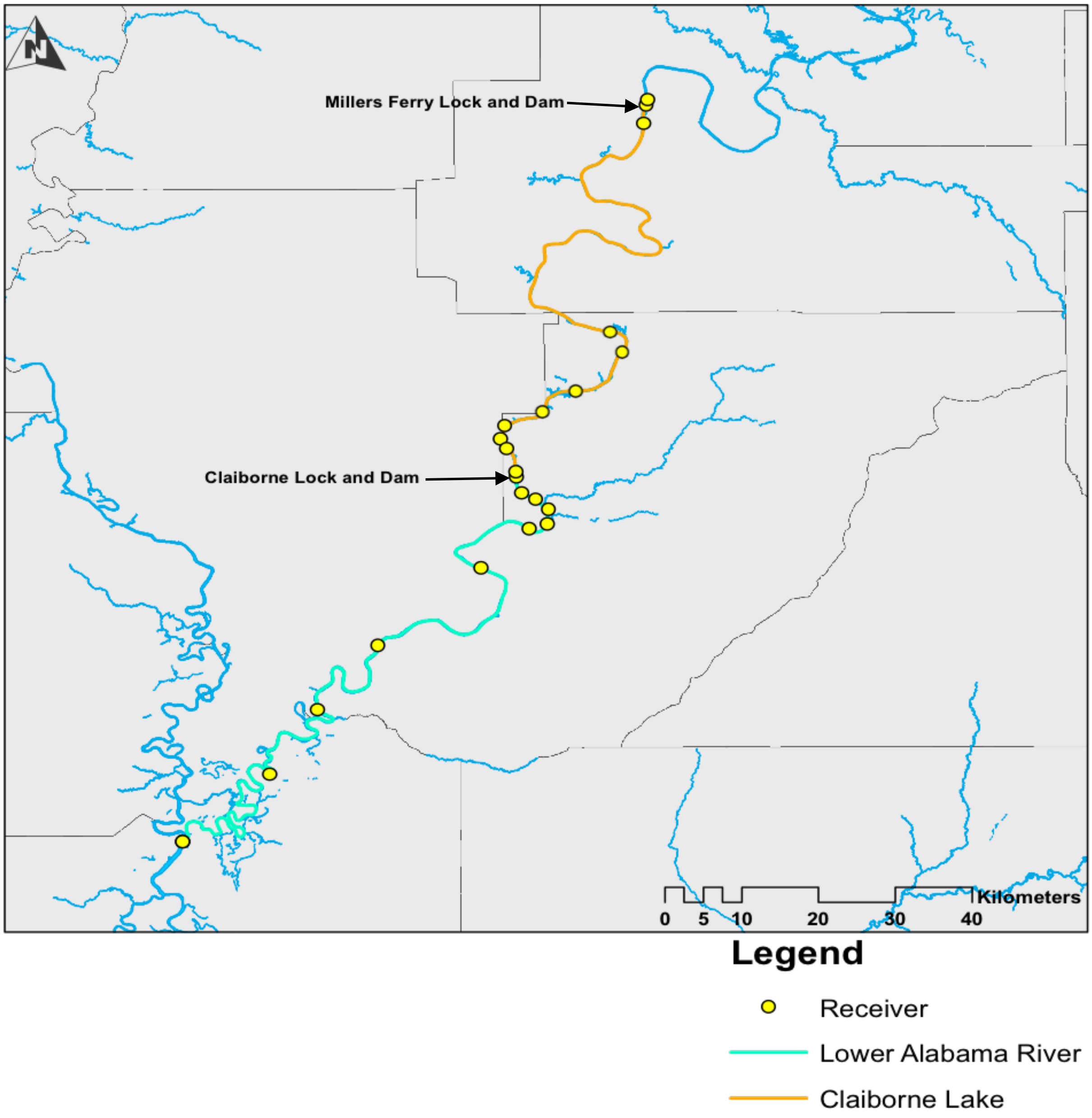

Figure 3: Upper and lower Alabama River with SAR receiver locations.

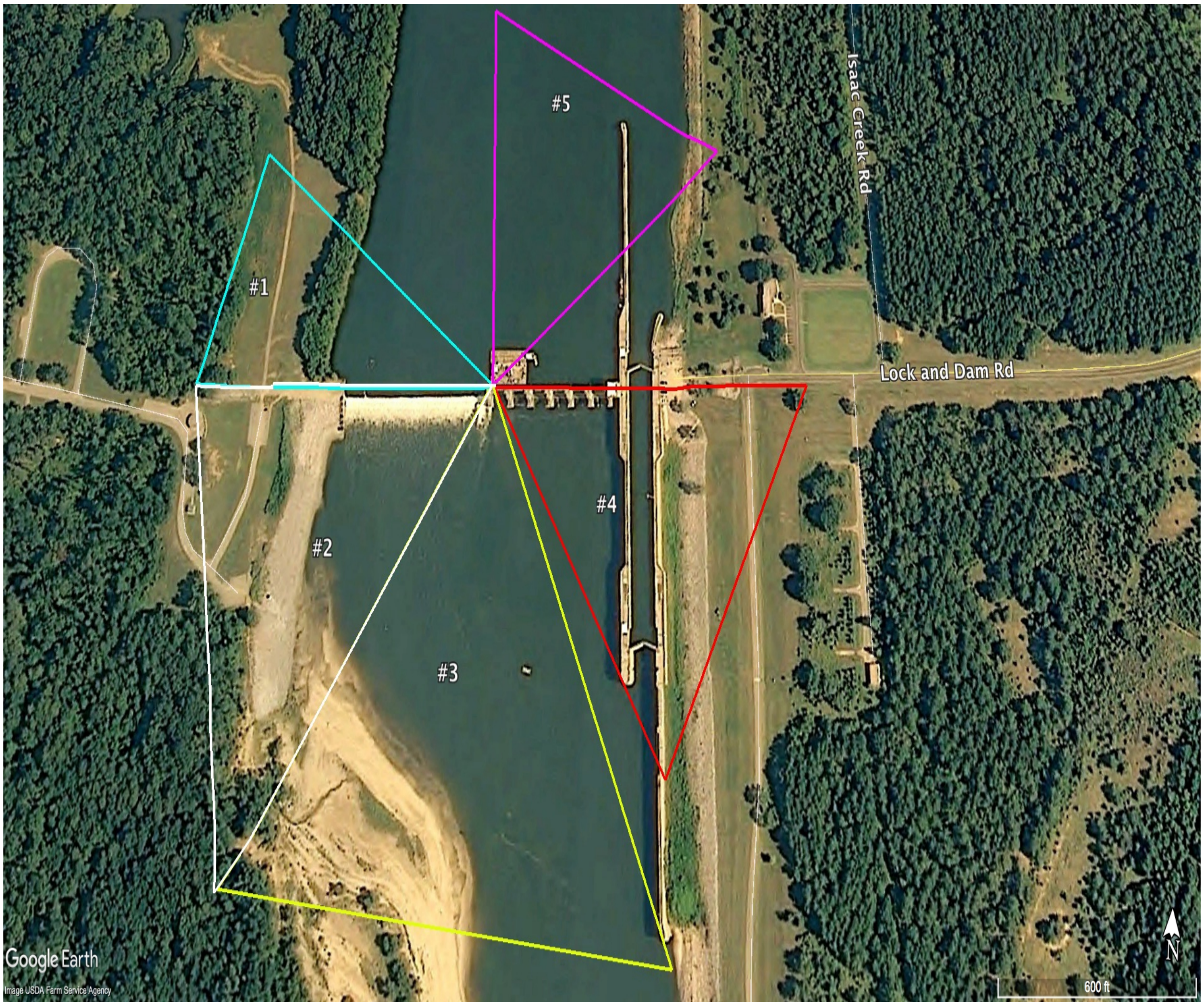

Figure 4: Radio antenna arrangement and expected coverage area at Claiborne L&D

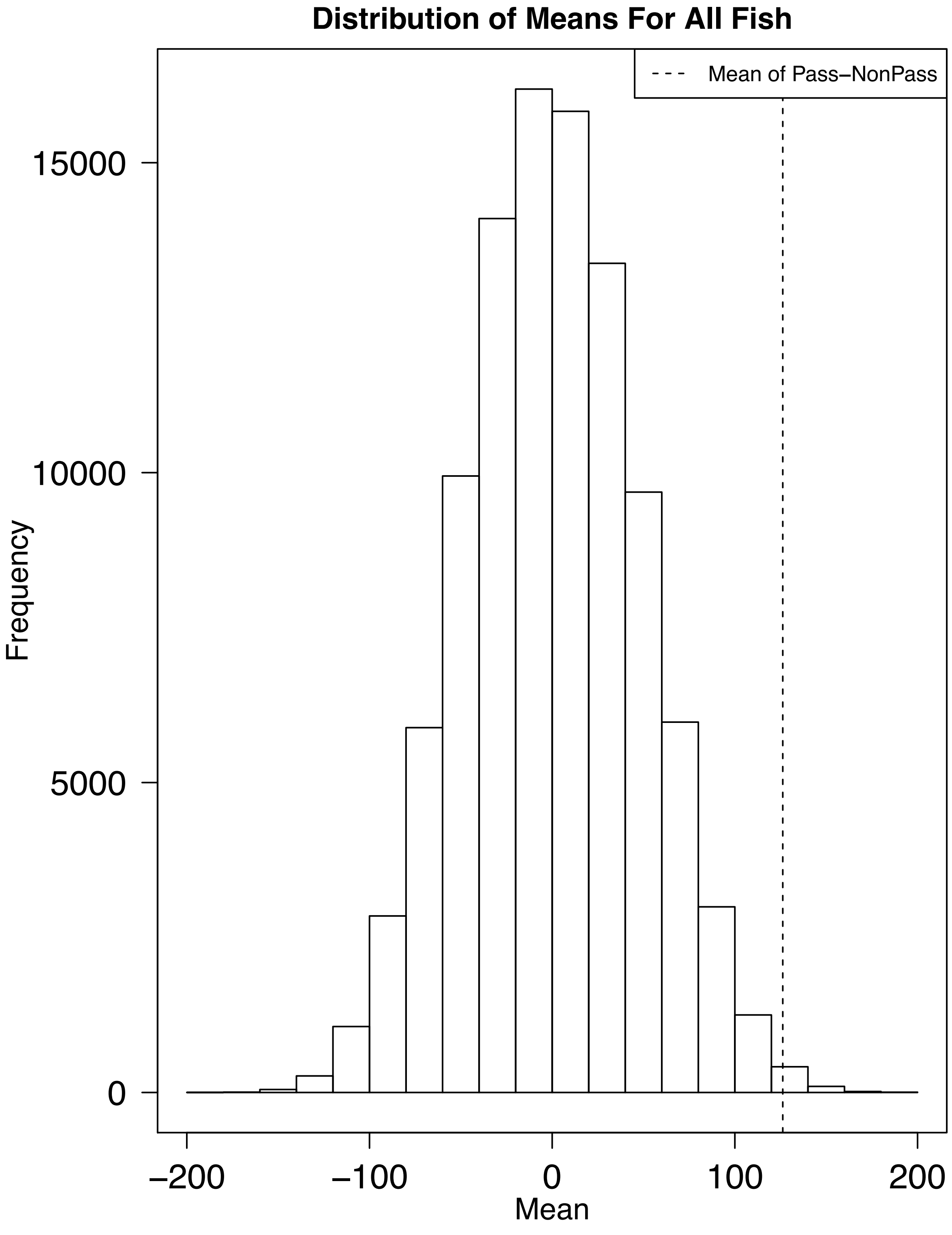

Figure 5: Permutation distribution of the mean of the difference in residence time between fish that did pass Claiborne L&D and fish that did not.

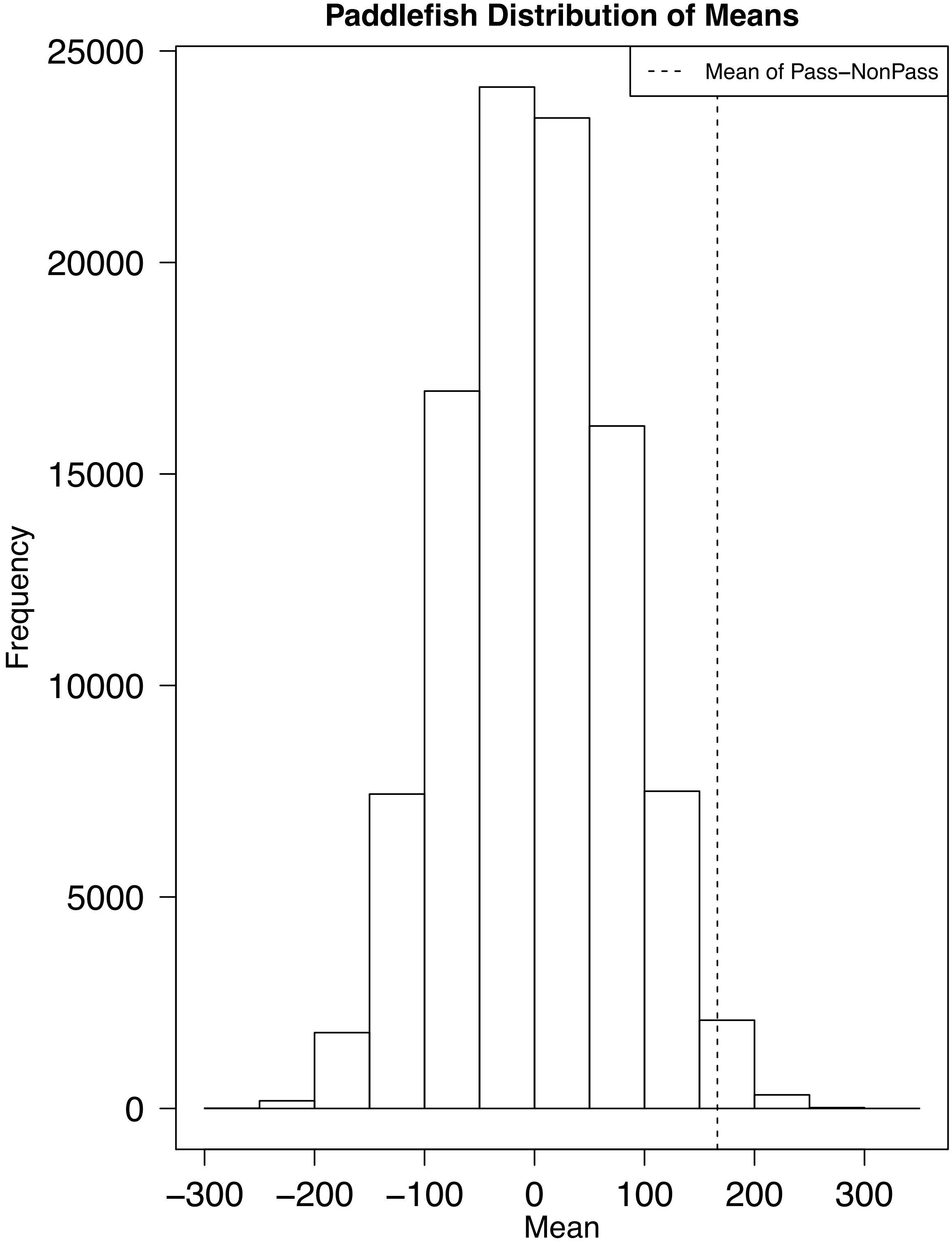

Figure 6: Permutation distribution of means comparing paddlefish that passed Claiborne L&D and those that did not.

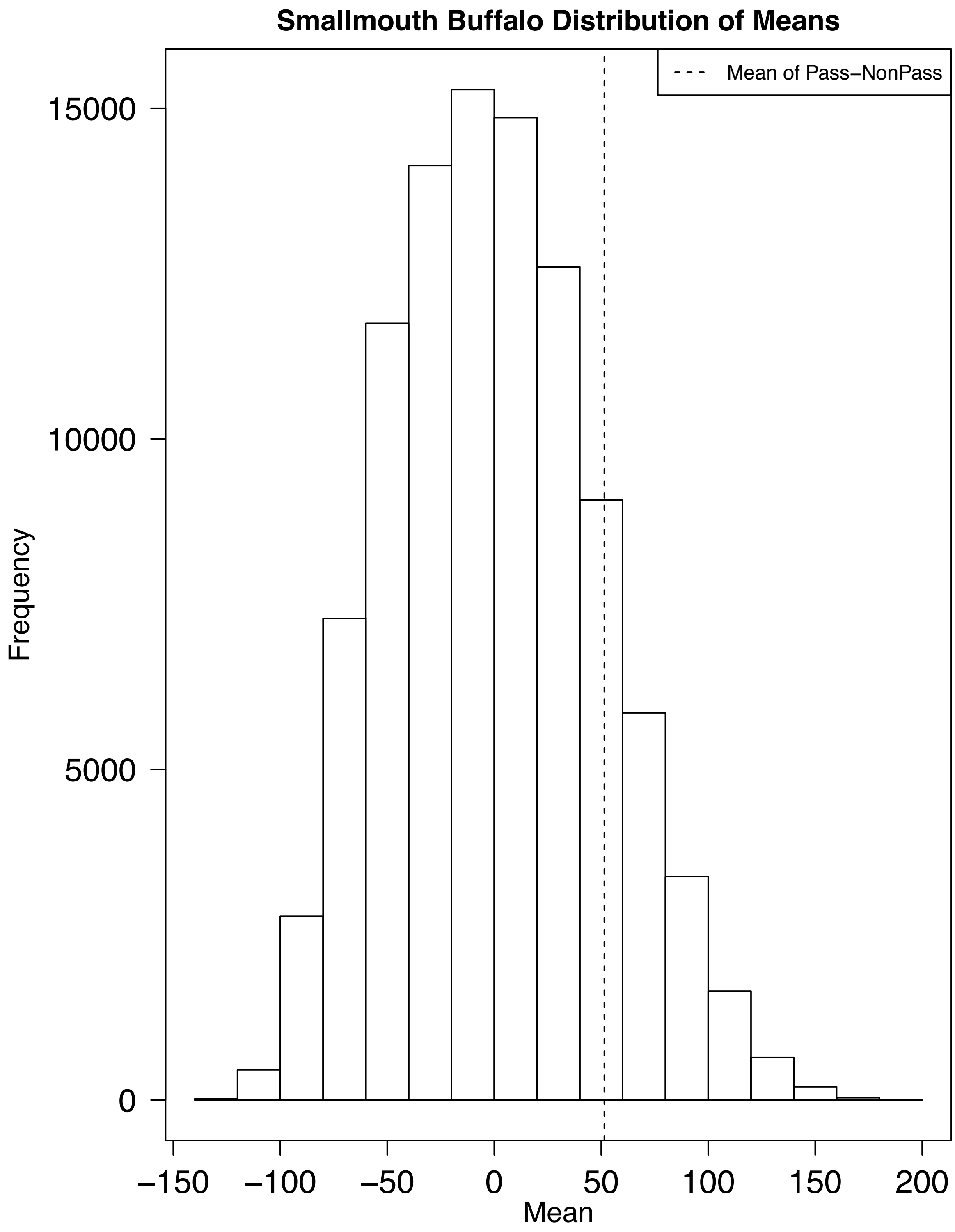

Figure 7: Permutation distribution of means comparing smallmouth buffalo that passed Claiborne L&D and those that did not.

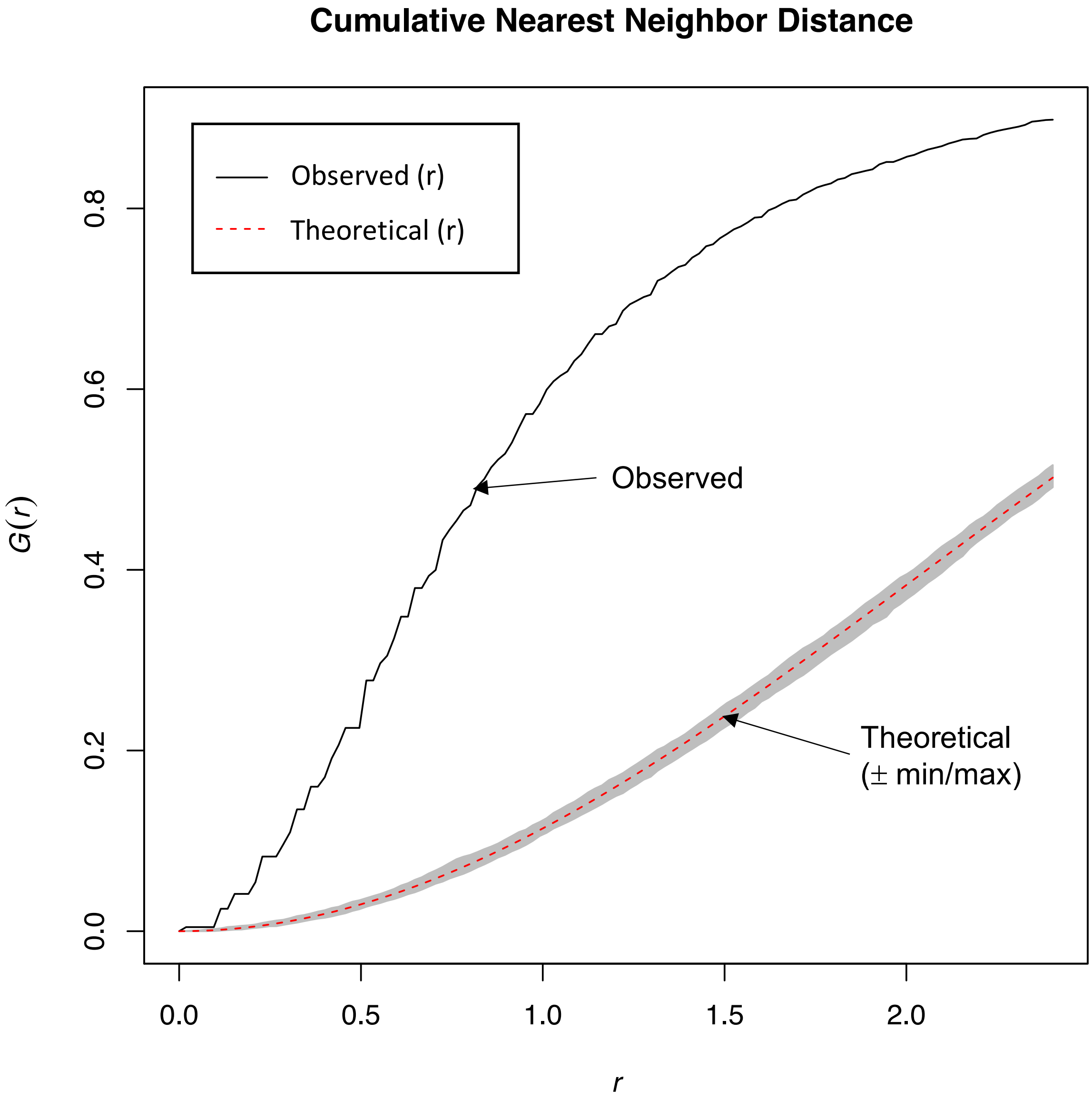

Figure 8: An example G-function plot for one of the 48-individual fish tested. The G-function plot includes the observed line (solid black line) showing the proportional cumulative nearest neighbor distance of the positional data. The theoretical high and low lines (grey shaded area) indicate the 95% confidence interval around the theoretical cumulative nearest neighbor distance (red dashed line).

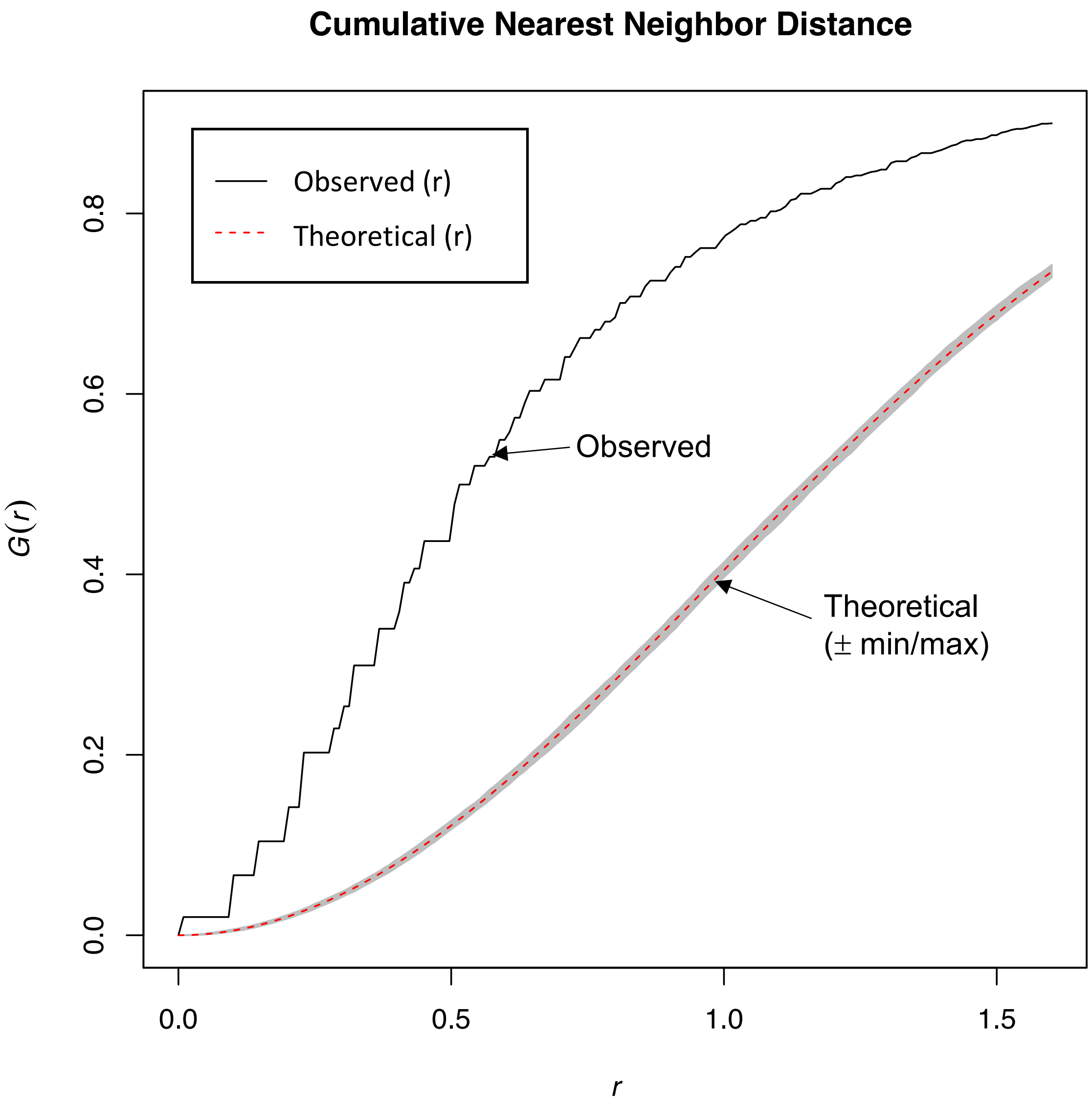

Figure 9: A G-function plot using all 48 combined fish positions. This G-Function uses the combined positions of all 48 fish to indicate that fish detections clustering still occurs when all fish are combined meaning that detections centralize in relatively the same areas. The G-function plot includes the observed line (solid black line) showing the proportional cumulative nearest neighbor distance of the positional data. The theoretical high and low lines (grey shaded area) indicate the 95% confidence interval around the theoretical cumulative nearest neighbor distance (red dashed line).

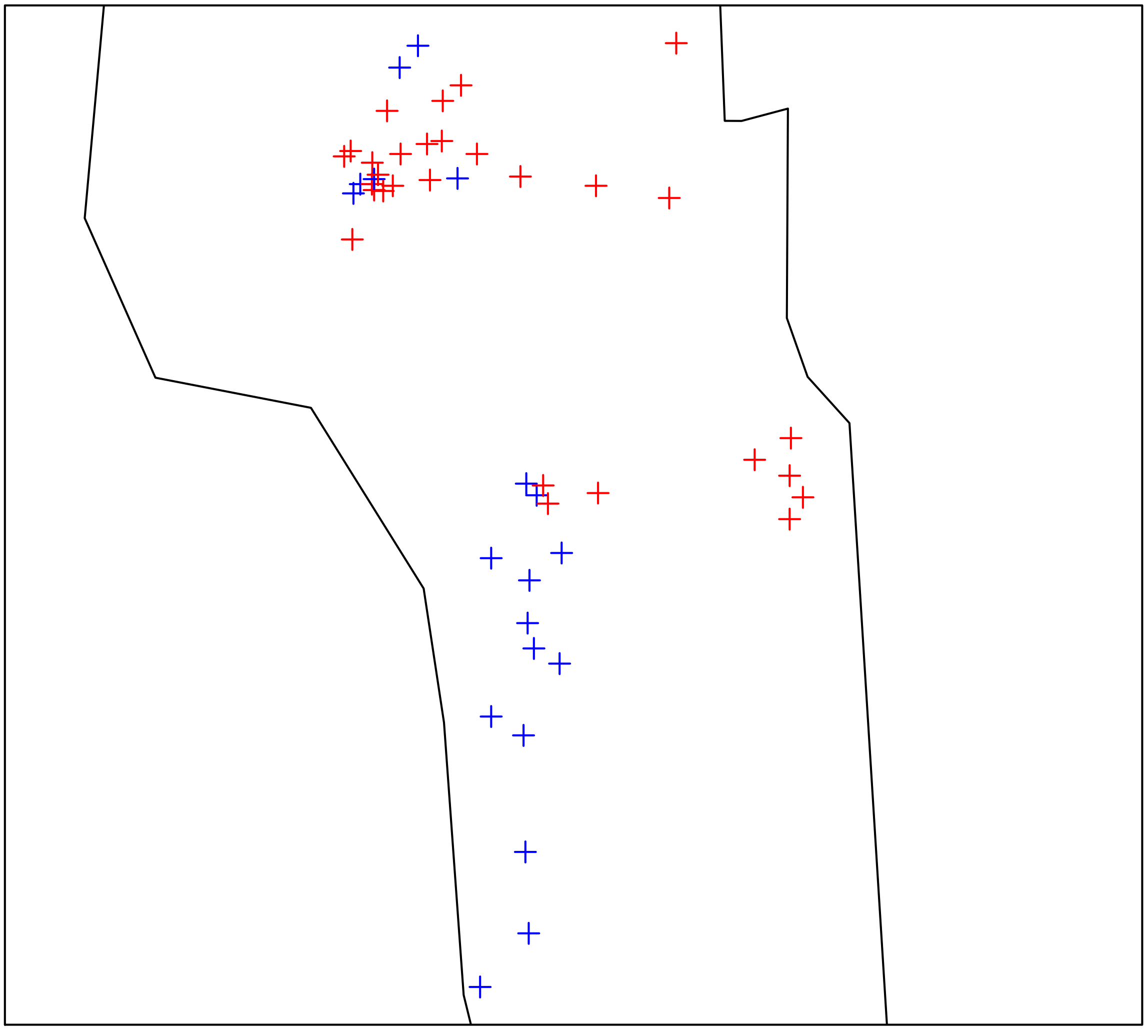

Figure 10: Centroid of highest activity areas for individual Paddlefish (red) and Smallmouth Buffalo (blue) with ≥30 observations within the tailrace of Claiborne L&D.

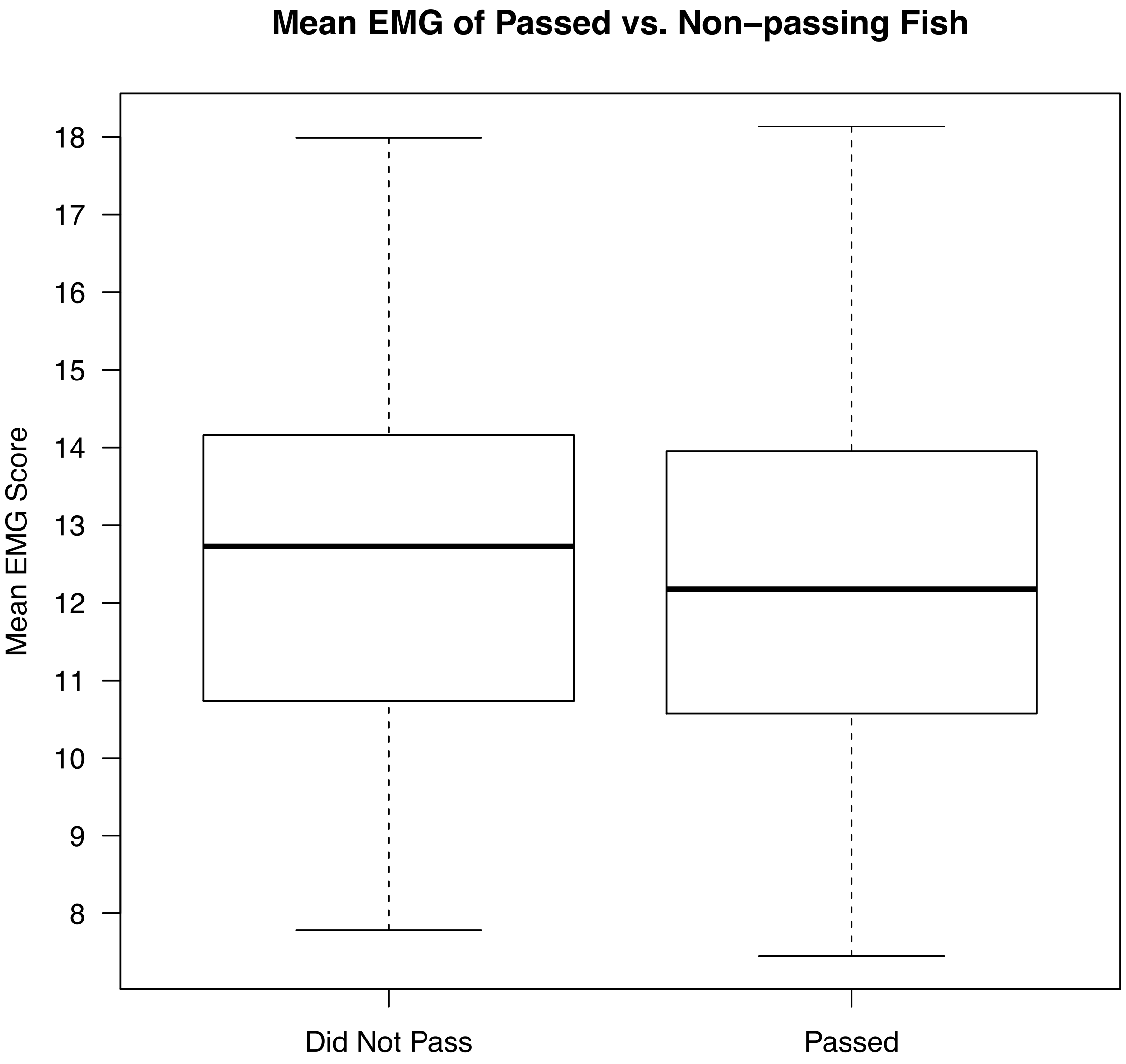

Figure 11: Box and whisker plot with the box containing 50% of the individual fish mean EMG scores, the lines incorporating the remaining 50%. The dark bar in the center of the box is the mean EMG scores of comparison for fish (Paddlefish and Smallmouth Buffalo combined) that passed versus did not pass Claiborne L&D.

Appendix 1.

Installation of Tailrace Array Below Claiborne Lock and Dam

Materials

The Claiborne L&D tailrace array was constructed using primarily concrete and ¼” galvanized steel cable. Each receiver unit consisted of a parking stop anchor, 3 eyebolts, 1 quick link, 2 jaw eye swivels, 100-foot section of cable, a 6-foot section of cable, a 50-pound anchor, 5 thimbles and 2 buoys. I determined parking stops would provide the highest weight to surface area exposed to the flow and therefore should be able to provide solid holding ability. Concrete products were purchased from Hovey Precast in Opelika, AL. A Lotek Wireless WHS3250L Submersible Acoustic Receiver (SAR) (Figure A-1) and a Sonardyne Lightweight Release Transponder (LRT) with rope canister (Figure A-2) were used.

Construction

Two eyebolts were placed in the parking stop holes (Figure A-3). These eyebolts were used to hold the parking stops to the boat during deployment and to be an attachment point for the cable at the 50- pound anchor. At all cable attachment points a thimble was placed inside the loop of the cable to keep the loop from elongating and creating a break point. A 100-foot section of 7x19 hot dipped galvanized steel cable was used in the original deployment and was a poor choice. The only suitable cable for long term deployment within a river is 316 stainless which was used for all subsequent work after the initial deployment. This 100-foot section of cable was connected to the parking stop and to a 50-pound anchor (Figure A-4). The 50-pound anchor was constructed by Hovey Precast. It was 4 inches tall and 18 inches diameter with a rebar reinforcement and an eyebolt welded to a t-bar with the t-bar inside the concrete pour. Attached to the 50-pound anchor was a jaw eye swivel that was attached to a 6-foot section of cable. The

6-foot section is where the SAR was attached (Figure A-4). LRT units were also placed between the end of the 6-foot cable section and the buoys. The buoys were two 15-pound buoyancy crab pot bullet shaped buoys attached to the LRT units with a thimble and jaw eyed swivels. The swivel is a very important component because the water current will cause the buoys to rotate and eventually break the cable without it.

LRT units were used to allow recovery of the 50-pound anchor and receiver unit. They were attached to the 6-foot cable by a clevis and worked by unscrewing a Teflon nut between the clevis and the rope canister. Once the nut unscrewed, the buoy floated the LRT and the rope stays attached to the 6-foot cable, allowing capture of the LRT and SAR units.

Deployment

Before deployment I assured that all cable and attachment points allowed for quick deployment. In order to deploy the parking stops we had the cable preattached to the eyebolt, hung the parking stop from the cleats of a boat with quick release shackles. I used a depth finder and GPS to determine proper areas for the parking stops to be released. Areas deeper than 10 feet in depth were chosen in an effort to keep the entire structure below striking distance of a boat’s lower unit. Once a suitable location was found, the parking stops were dropped into the water long ways with the smallest surface area pointing into the expected current and the cable on the downstream end. The cable was then unspooled and attached to the 50-pound anchor along with the swivels, buoys, LRT and 6-foot cable. Once everything was attached and ready to deploy I attached an activated and logging SAR. Once prepped, I dropped the 50-pound anchor with receiver and release attached. I allowed the river’s current to position the boat as long as the location met the above location criteria. This allowed for the least movement possible of the 50-pound anchor due to current during the time the receivers are left in the tailrace. While deploying, the precise GPS location of the 50-pound anchor was recorded by handheld GPS as well as the boat’s GPS unit (a Lowrance HDS 12).

Recovery

In order to recover a receiver, a Sonardyne Command Deck Unit (CDU) was used in conjunction with a 50-foot transducer cable to produce a coded acoustic tone. This tone was programed into individual LRT units and releases the LRT units and their attached rope canisters one at a time. Once released, the buoys pulled the LRT and rope canister to the surface. I was then able to recover the LRT and pull the rope and 50-pound anchor into the boat, allowing for data download and maintenance of the SAR.

In the event of a failure on the LRT unit, a grapple hook or mooring anchor was used to drag the bottom of the river in an effort to snag the 100 ft. cable leading to the 50-pound anchor, after which it was pulled into the boat as described above.

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Figure A-1: The Lotek Wireless 3250L used in the array

Figure A-2: Lightweight Release Transponder with rope canister used in the tailrace array to release the buoys.

Figure A-3: Concrete parking stops with eyebolts and 100 feet of cable attached.

Figure A-4: The 50-pound anchor is attached to the Lotek 3250L and Sonardyne LRT with rope canister via a 6 to 10ft cable.