Effects of Tagging and Translocation on Paddlefish in the Alabama River

by

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Abstract

Dams directly impede fish movement. Different passage structures have been incorporated into the design of dams in attempt to restore connectivity, however, passage is limited to particular fish species. Lock-and-dam structures offer two paths of bi-directional movement: spillway gates and navigational locks. However, studies show they provide little opportunity for fish passage. An alternative method, translocation, can be used in assisting fish beyond these barriers. I quantified movements of tagged and translocated Paddlefish above Claiborne Lock and Dam (CLD) using telemetry to evaluate movements to quantify ultimate effectiveness of translocation. I found that spawning condition did not influence initial movement, or the likelihood of fish reaching Millers Ferry Lock and Dam, the next upstream from CLD within the first 30-days of observation. Average net movement results show translocated fish exhibited up river movements once translocated. Fish released below CLD did have a higher probability of being found below their release sites beyond release date compared to the other two release sites.

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CLD	Claiborne Lock and Dam
MFLD	Millers Ferry Lock and Dam
SP	Spawning Period
PS	Prespawn Period
EPS	Early Prespawn Period
CHL	Main Channel
SC	Silver Creek
BLD	Below Claiborne Lock and Dam
RKM	River Kilometers
hr	Hours
kph	Kilometers Per Hour
wk	Week

Introduction

Historically, there was 5,200,000 km of free-flowing river in the 48 continental United States, but only 42 free flowing rivers longer than 200 km still exist due to the construction of more than 75,000 dam structures that have segmented rivers and drastically altered river channels and downstream portions of their tributaries (Benke 1990; Lydeard and Mayden 1995; Graf 1999). Dams modify flow and impede fish movement, with more than 85% of the navigable waterways in the continental United States now under artificial control (NRC 1992). This affects 1 million km of rivers (Echeverria et al. 1989), and 50% of freshwater eco-regions world-wide have a large or medium sized dam affecting them (Liermann et al. 2012).

Such changes to rivers result in habitat loss, over-allocation by humans, failure of some organisms to complete their life cycles (e.g., blockage of spawning migration pathways), and loss of the natural flow regime that can act as a cue or signal for migration (Lydeard and Mayden 1995; Larinier and Travade 2002; Bunn and Arthington 2002). As dams release stored water, the discharge creates an artificially increased water level and flow (Taylor and Cooke 2012) which can have negative effects on fish and their habitat (Haxton and Findlay 2008). On the upstream side, dams retain water (for transportation, water supply, flood control, agriculture, and power generation) which disrupts the movement of water and sediments that would exist naturally (Dunne and Leopold 1978; Taylor and Cooke 2012). Many riverine fishes depend on naturally diverse habitats to complete their life cycle (Sparks 1992; Greenberg et. al 1996; Reeves et al. 1996). Regulated releases can disrupt the timing of annual flow pulses, causing fish to confuse releases with natural peak flows used to cue specific spawning behaviors (Naesje et al. 1995; Poff et al. 1997). This hydrologic disconnect has become a major concern (Poff et al. 1997; Lucas and Baras 2000; Poff and Zimmerman 2010; Koehn and Crook 2013).

River connectivity is important for anadromous or potamodromous fishes (Cote et al. 2009; Beechie et al. 2006; Sheer and Steel 2006; Schick and Lindley 2007). In free flowing systems, both the quantity and variability in flow are important for supporting ecological integrity and species richness (Poff et al. 1997, Matthews and Robison 1998; Hitt and Angermeier 2008). Fish migrations can cover long distances and link diverse populations and ecosystems; for example, salmon provide nutrients to >22 species of mammals and birds that depend on the annual spawning runs (Willson and Halupka 1995; Pringle 2001; Mattock et al. 2017). Migratory fishes may play a role in the juvenile life stage of mussels given that multiple mussel species have host-specific requirements during the glochidial larval stage (Pringle 2001). Declines in mussel population due to reduced connectivity can be dramatic (Middleton and Liitschwager 1994).

In an effort to improve longitudinal connectivity (Ward and Stanford 1989) flow regulations and fish passage structures have been installed world-wide to mitigate the impacts of dams (Pringle 2001; Finger et al. 2019). In the early 20th century, Denil-type fishway structures were developed with narrow slopes and various vanes; variations of these structures were studied and tested into the 1980s (McCleod and Nemenyi 1939; Williams et al. 2012). More recently fish ladders have been incorporated into the design of dams in attempts to restore connection between habitats above and below the dam (Crook et al. 2015). However, they are not without problems in that they can limit passage to particular fish species and are ineffective at moving fish downstream (Baumgartner et al. 2006; Agostinho et al. 2007; Schilt 2007). Lock-and-dam structures typically found on large shallow rivers can offer two paths of bi-directional movement: via spillway gates and navigational locks (Poff et al. 2007; Argent and Kimmel 2011; Liermann et al. 2012; Finger et al. 2019). However, recent studies have shown they provide little opportunity for fish passage and because of this, they can continue to endanger species found in rivers and their associated tributaries (Ramsey 1986; O'Neil 2004; Mirarchi et al. 2004; Mettee et al. 2005; Simcox et al. 2015).

Translocation has been used in association with fish passage structures to help improve connectivity and decrease the time it would take fish to get above barriers (WDFW 2004; Ward et al. 2012; Sprugeon et al. 2015; Lusardi and Moyle 2017). Translocation is defined as the movement of a species captured in the wild from one place directly to another (Minckley 1995; Shively et al. 2007; Hayes and Banish 2017). In fisheries it can include stocking as a conservation measure (Minkley 1995), but can also involve moving fish beyond physical barriers. Capture can be done at various stages: egg, fry, juveniles, sub-adults, and adults. This approach has been used for high value migratory species, and is particularly useful when species have to deal with various challenges (e.g., high flows, weirs, locks, etc.) due to barriers (Harris and Hightower 2011; Ward et al. 2012; Hayes and Banish 2017; Lusardi and Moyle 2017; Rahel and McLaughlin 2018). Fish ladder structures are commonly associated with dams and can lead to a holding area where fish can easily be collected and loaded into tanks that are moved further up river where fish are released and allowed to reorient for their continued upstream migration (Larinier 2000). When done correctly, translocation can be beneficial to fish populations that are fragmented by barriers and unable to be restored naturally (George et al. 2009). Success depends heavily on when transport occurs, the distance moved, species targeted, fish density, stress, and even delayed effects (Congleton et al 2000; Lusardi and Moyle 2017). Telemetry studies have been used to monitor post-translocation movements although the tagging process itself may lead to stress and failure to complete migration (Cougleton et al. 2000; Schmetterling 2003; Frank et al. 2009; Naughton et al. 2018).

Fallback is defined as the downstream movement of an upstream migrating anadromous fish following tagging (Frank et al. 2009). Most studies that report fallback have been focused on *Alosa* spp. or multiple salmonid species, although similar fallback-like behaviors have also been documented in several other species (Jackson and Hightower 2001; Moser et al. 2008; Hatry et al. 2016; Gagne 2017). Fallback may be an important element of any tagging study and more recently has begun to be included in evaluation of tagging effects. For example three species of *Moxostoma* were implanted with a pit tag, or with both a pit tag and an external coded radio tag (Hatry et al. 2016). Fish tagged with both types of tags displayed a behavioral difference such that once released, only one double-tagged fish was recorded in the downstream array versus nearly all pit-tagged-only individuals that were successfully relocated (Hatry et al. 2016). Bunt and Cooke (2001) found immediate downstream movement of tagged greater redhorse *Moxostoma valenciennesi* that were released downstream of a barrier, although these movements were considered part of their normal post-spawn behavior (Hatrey et al. 2016). Gardner et al. (2015) and Clough and Beaumont (1998) found that both Common Bream *Abramis brama* and Common Dace *Leuciscus leuciscus* initially moved upstream within the first five days after being tagged, showing no indication of fallback. Such variation across studies suggest that there may be interspecific variation in effects of handling and tagging.

Paddlefish *Polyodon spathula* is an important commercial and recreational species in its native waters, despite declining harvest (Carlson and Bonislawsky 1981; Gengerke 1986). They have been found to display site fidelity, and move long distances upstream and downstream to reach summer and winter habitats and these movements can be impacted by dams (Stancill et al. 2002; Roush et al. 2003; Zigler et al. 2003; Mettee et al. 2005; Simcox et al. 2015). I quantified movements of tagged and translocated paddlefish after translocating them upstream of a lock-and-dam structure using telemetry to evaluate reorientation by tagged fish post release, as well as to monitor movements to quantify ultimate effectiveness of translocation. These data are important for informing management strategies to increase connectivity to potential upstream spawning habitat and therefor reduce population fragmentation.

Methods

Study Area and Sampling Site

The Alabama River is approximately 500 km long, formed by the confluence of the Coosa and Tallapoosa rivers from which it continues to flow southwest (U.S. Army Corps of Engineering 2013). It eventually converges with the Tombigbee River to form the Mobile River that flows into the Mobile-Tensaw Delta, which drains into the Gulf of Mexico (Figure 1). My study area contains two of the three United States Army Corp of Engineers (USACE) navigation lock-and-dam structures on the Alabama River: Claiborne Lock and Dam (CLD) at RKM 116.6 and Millers Ferry Lock and Dam (MFLD) at RKM 214. Both were built in the late 1960s for commercial navigation, and MFLD also includes a hydroelectric dam. MFLD has seventeen flood gates and a lock chamber; the flood gates generally remain closed to retain water upriver for power production (U.S. Army Corps of Engineering 2013). Claiborne Lock and Dam, the furthest downstream structure on the Alabama River, has a crested spillway that becomes inundated when gauge height is approximately 10.06 m, six flood gates, and a lock chamber (U.S. Army Corps of Engineering 2013). My study was focused between RKM 72.4 and 214, which includes the tailwater below CLD upstream to just above MFLD. Paddlefish, along with numerous other species, are found in increasing numbers below CLD during their spawning migrations triggered by high flows (Mettee et al. 2005). During winter and spring, water levels can inundate the crested spillway, allowing the potential for fish to pass over it. Despite incorporating seasonal fish conservation locking efforts and mandated flow levels that have been determined by Federal and state regulations to improve passage opportunities and make the river more suitable to native riverine aquatic fauna, fish passage rarely occurs through the lock chamber (Mettee et al. 2004; Zigler et al. 2004; Simcox et al. 2015; Mckee 2019) making the time the spillway is inundated important to the long-term sustainability of these migratory fish.

Fish Collection and Translocation

I collected prespawn Paddlefish at three separate times (February, November, and December 2019), and spawning fish in March 2019. Paddlefish were collected in the tailrace of CLD using 203-254 mm stretch mesh gillnets. Net set times ranged from 3 minutes to 1 hour depending on flow conditions. I attempted to determine sex during surgery if no external tubercles were present (Alexander and Peterson 1985; Mettee et al. 2004; Mettee et al. 2015). Only Paddlefish that did not have any visible sores, freshly broken rostra, or other recent body damage were tagged. This selection minimized use of fish potentially subjected to prior stress. In February 2019, 15 Paddlefish were tagged and translocated during prespawn conditions (water temperatures 10-12°C). During spawning conditions (March 2019) 12 Paddlefish were tagged and translocated (at surface temperatures of 14-15°C). All 27 Paddlefish translocated in February and March were hauled 6.5 km upstream of CLD and released in Silver Creek tributary (Figure 2; fish were released 0.16 km upstream within Silver Creek). In November and December 2019 a total of 30 paddlefish were tagged and translocated above CLD, and 15 others were tagged and released below CLD to track fish during an earlier prespawning time period. Those Paddlefish tagged and translocated above CLD in November and December 2019 had two separate drop locations. Half of the 30 Paddlefish translocated above CLD were tagged and released at the same upstream location in Silver Creek as those from February and March 2019, while the other

15 fish were released in the main channel adjacent to the mouth of Silver Creek. The upstream Silver Creek release location had a backwater area to provide fish with an opportunity to recover from tagging and translocation. Water temperatures during this early prespawn time declined from 15-12°C.

To minimize stress, fish were placed in a 609 L tank filled with river water for translocation to the Silver Creek release site. Tanks had two pumps-one for circulation and the other to agitate the water to help increase dissolved oxygen levels prior to and during addition of fish, while also reducing buildup of CO_2 . No more than 9 individuals were held in the hauling tank at one time to avoid DO depletion. Fish were held in the tanks for a minimum of 30 minutes to a maximum of 5 hours prior to release upriver. In order to move the fish to the translocation site I either locked through Claiborne Lock or used the boat ramps located at Claiborne and Isaac Creek (just downstream and upstream of CLD, respectively). The translocation process, including travel, took 10-13 min when moving through the lock, and approximately 30-45 minutes when using the boat ramps.

Surgery Methods

All fish were weighed (nearest 0.1 kg) and measured (nearest mm eye-fork length for Paddlefish) to determine appropriate tag size. Tags were either model MM-MC-16-50 or MM-MC-11-45 Lotek CART tag, depending on the weight of the fish so as to not exceed 2% of body weight (Winter 1996). Tags emitted both a radio and acoustic signal, which was received on stationary acoustic (once every 20 sec) and manual tracking receivers. An anchor tag was inserted on the ventral side of the fish (opposite of tag incision) for external identification purposes if the fish was recaptured. Fish were then placed on a V-shaped board that was covered in a wet foam to fish moist throughout the surgery process as water was pumped over the gills

(Harms and Lewbart 2000). Water from the tank was run through the mouth of the fish using a pump and hose to both supply oxygen and keep the fish wet. Scalpel blades (#11) and PDS 2-0 tapered needle sutures were brought to the field in individual sterile prepackages. Prior to surgery all supplies and tags were soaked in chlorhexidine for sterilization before surgery. Incision locations were anterior to the pectoral fins and were closed using 1-2 interrupted sutures and a surgeon's knot. Veterinary grade cyanoacrylate glue was applied to the knots to prevent slipping.

Manual Tracking

Manual tracking occurred using a three-bar Yagi antenna and a Lotek radio receiver SRX 800 at four specific post-release intervals --24 hrs, 48 hrs, 1 week, and 1 month. Fish tagged in November 2019 were tracked at 2 weeks post translocation instead of 1 week due to high water levels that made boat ramps inaccessible. Boat speed was kept between 16-22.5 kph with the radio receiver gain set to 70 to reduce interference while not sacrificing signal detection capability. The yagi antenna was held level towards the river and alternated between sides of the boat bow every 30 seconds to improve signal detection. For the 24 hr post-release manual tracking upstream of CLD I began tracking approximately 1 RKM upstream from CLD and proceeded down river towards CLD to a safe distance, ~0.5 RKM upstream of the dam. I listened between the boat and dam to check for any fish that had moved downstream from the release site, and then continued tracking upriver listening throughout the 6.5 RKM to Silver Creek, entering the tributary and tracking in the backwater area to listen for any fish that may have swam up the tributary from the surgery location. Once I made a full circle in the backwater area, I returned to the river channel and listened across 32.2 RKM up river to identify any upstream movement. For the 48 hr post-surgery manual tracking I began tracking from Cobbs Landing at

RKM 207.6 (just downstream of MFLD) travelling 8 RKM up river to MLF and the hydroelectric dam, getting as close to the structures as safely possible. I first checked the hydroelectric release tailrace by scanning the area in a clockwise pattern listening for 5 min before moving up to the dam along the river right ascending bank. I tracked up as close as safely possible to the face of the dam and then returned down river along the river right descending bank. I manually tracked ~96.6 RKM down river towards CLD. When I reached Silver Creek I tracked upstream into the backwater area, after which I continued downstream to the upriver face of CLD staying ~0.5 RKM from the gates. I completed manual tracking for tagged fish upon reaching the Isaac Creek boat ramp (just upstream from CLD). I used this same procedure for the remaining two manual tracking events at 1 wk and 1 month post-translocation. Tracking of fish released below CLD in November and December of 2019 began in the tailrace and continued down river ~48 km to Eureka Landing. While in the tailrace of CLD I made 4 complete laps that covered the region below the spillway and the gates.

When a signal was detected, the boat speed slowed to 3.2-6.4 kph. Once the receiver was able to pick up and read the radio signal to identify the individual fish, I searched until I was able to get a signal strength of 70-115 (depending on water depth) and collect multiple detections. This was accomplished by pointing the antenna in multiple directions while listening to signal volume and detection strength so I could determine directionality of fish. Once direction was confirmed I proceeded until I reached the highest signal strength. Each successful detection logged longitude and latitude locations for the detected fish. All detections were downloaded after every manual tracking event and filtered by signal strength for the most accurate in-river position of the detected fish. I recorded a minimum of 3 detections at this strength while also using a Lowrance HDS-12 GEN 3 to capture images of the Paddlefish at the location with the highest signal strength.

Acoustic Tracking

Additional movement data were collected passively using Lotek acoustic receivers (model WHS 3250L). Receivers were individually stationed from the confluence of the Alabama and Tombigbee rivers up river to just above MFLD (Figure 2). In addition, multiple receivers were anchored to the river bottom both immediately above and below CLD which created two arrays that provided triangulations for detailed two-dimensional positions above and below CLD (Figure 3). The triangulation array in the tailrace of CLD consist of 15 acoustic receivers; while the array above CLD consist of 8 receivers. All receivers were placed to optimize the ability to detect tagged fish. During my study 15-19 acoustic receivers were located between the confluence and MFLD.

Data Collection, Processing, Analysis

Detections from both receiver types provided ID code, date, and time and were combined with files containing RKM for each individual receiver and then filtered using Rstudio. Filtering removed false singular (ghost) detections, duplicate, triplicate, and quadruplet detections that occurred on receivers within 1 km of each other. Data were then subset by extracting the first 30 days after fish were released for different analyses using various packages in R studio.

To compare directional movement of Paddlefish spawning periods and release sites, I used methods similar to Grabowski and Jennings (2009). I used net movement (*NM)* which can be calculated as $NM = P_{t+1} - P_t$, where P_t is the position of a fish at time t and P_{t+1} is the location of that same fish at t+1. A positive *NM* value indicates that the fish moved upriver, while a negative *NM* value means that the fish downriver; a *NM* = 0 means that the location at P_{t+1} was the same as P_t. Net movement was then summed for individual fish within each spawning condition. Directional movement was tested using a one sample t-test with the null hypothesis that net movement was equal to zero.

I used the program UMAP to triangulate fish positions within the arrays above and below Claiborne Lock and Dam using the raw data files and receiver locations in UTM format to calculate location files for fish that were triangulated. I used ARCGIS along with the triangulated position files to visualize areas used by Paddlefish both above and below CLD. A bathymetric map was used to indicate water depth at fish location sites. I then combined the position files with the bathymetry data to estimate the average depths used by triangulated fish around the dam. I also estimated water depth for fish located with manual radio telemetry. To determine where fish were crossing over CLD during a passage evet, I used ARCGIS to determine the location of the last detection in the upper array and the first location in the lower array, and vice versa (as long as positioning was within a 30-60 min time window).

A chi square analysis was used to determine whether release location and/or spawning condition affected initial movement, located 6 km upriver or downriver at weeks 2, 3, and 4, or whether fish made it to MFLD. The first directional movement of tagged fish from their release location within the first week after translocation was recorded. Movement types documented were either “up” or “down”. Up and down river movements had to be a difference greater than 3.2 km from the release site for initial movement. Fish tagged and translocated in March and February 2019 were separated by spawning period. Fish tagged and translocated in November and December 2019 were separated by release site.

Results

A total of 72 Paddlefish were tagged during my study and of those 72 Paddlefish no mortalities were observed. I tagged and translocated 27 Paddlefish during February through March 2019 during prespawning (PS; 15) or spawning (SP; 12) periods and all were released 6.5 RKM upriver from CLD in Silver Creek (SC) (Figure 2). In November and December 2019, 45 Paddlefish were tagged during the early prespawn period (EPS) and released at one of three locations: below Claiborne Lock and Dam (BLD; n=15), in Silver Creek (n=15), and in the main channel of the river just outside Silver Creek (CHL; n=15). Spawning fish had the highest percentage of females (5/12=42%), followed by prespawn fish (4/15=27%), and early prespawn fish (5/45=11%). During the 30-day post tagging/translocation observational period the average number of days fish were detected ranged from 5.5-18.5 days across the three spawning periods and release sites (PS=5.5; SP= 11.4; EPS: BLD=17.2; CHL=18.5; SC=15.4). Of the 72 Paddlefish that I tagged, no mortalities were believed to have occurred. Only one fish was never detected by either acoustic or radio receivers after tagging, which could have been due to tag failure.

Acoustic Tag Detections

Acoustic receivers, including both those stationed along the bank and those in the arrays directly above and below CLD, detected 12 of the 15 (80%) prespawn fish and all of the 12 (100%) spawning fish after data were filtered. Of the 45 early prespawn fish, 44 (98%) were detected at least once by acoustic receivers. A total of 1,671 acoustic detections occurred during the 30-day period after fish were tagged and translocated during prespawn (February 2019), while spawning fish (March 2019) were detected 68,022 times during the subsequent 30-day period. A total of 445,227 detections occurred during the 30-day observational period after early prespawn fish were tagged and translocated (November and December 2019). Early prespawn fish released at BLD were detected 122,206 times, while CHL fish were detected 175,938, and SC fish were detected 147,083 times during the 30-day period. The relatively lower number of detections for prespawn and spawning fish versus early prespawn fish may have resulted not only from having tagged fewer fish (15 and 12 vs. 45 fish), but also from high water conditions that prevented retrieval and maintenance of receivers, producing some temporal gaps in the data.

Manual Radio Telemetry

All 27 fish that were tagged and translocated during the prespawn and spawning periods were detected during manual tracking. Only 24 of the 45 (53%) fish tagged and released during the early prespawn period were detected during manual tracking. On average, each prespawn Paddlefish were detected 7.4 times during the 30-day manual tracking period, while spawning fish were detected an average of 37.4 times. Total detections for prespawn fish were 111 and for spawning fish were 449. Total detections for early prespawning fish were 809; on average each early prespawn fish were detected 33.7 times. Fish released at BLD were detected 277 times, CHL were detected 190 times, and SC were detected 342 times during the 30-day manual tracking period. Using combined bathymetry and telemetry data, average (±SE) depth used by prespawn fish was 6.2 (±1.61) m, while for spawning fish average depth was 3.83 (±1.11) m, and average depth used across all early prespawn fish was 5.91 (±0.60) m; fish released at BLD used an average depth of 4.34 (±0.41) m, those released at CHL used 7.28 (±0.8) m, and those released at SC used 6.03 (±1.16) m. Depth differed among spawning periods, except for prespawning versus early prespawning periods (ANOVA df= 2, *F*=5.404, p=0.0068; Tukey PS-EPS p=0.929; SP-EPS p=0.0079; SP-PS p=0.019) (Figure 4), and depth at the BLD release site differed from both CHL and SC release sites (df=2, *F*=14.1, p<0.00001; CHL-BLD p=0.0000142, SC-BLD p=0.015, SC-CHL p=0.080) (Figure 4).

Three fish that were tagged and translocated during prespawn (n=2) and spawning (n=1) periods initially moved upriver to MFLD during March and April 2019 post translocation, returned to below CLD during summer 2019, and were detected again in subsequent tracking below CLD during November 2019 through January 2020. All three fish successfully passed back upstream of CLD in 2020 and once again moved upriver to MFLD. These three fish were detected a total of 28 times during November through December 2019.

Passage and Lock use at Claiborne and Millers Ferry Lock and Dams

All BLD fish tagged during 2019 (n=15) were able to pass CLD; 13 of these fish were detected above CLD by the upstream array while the other two were first detected further upriver. All passages occurred at a gage height of 10.73 m or greater. On average it took 38.5 days for BLD fish to pass and be detected above CLD (range: 11-111 days) from their initial release date. Between the initial release date and the date of first detection above CLD fish spent 13.5 days (range: 2-28 days) in the tailrace of CLD before passing and being detected upriver. Once upstream of CLD, fish moved upriver reaching as far as 130.4-215.7 RKM.

A larger proportion of fish tagged during prespawn (n=6) and spawning (n=2) periods (versus early prespawn periods) were detected in the MFLD tailrace area (8/27= 30%) during the initial 30-day manual tracking period. Six of the 45 (13%) fish that were tagged during the early prespawn period moved upstream to the MFLD area within the 30-day observational period; however, over the entire length of the study (i.e., beyond the initial 30-day tracking period) 33 of 45 early prespawn fish (73%) were eventually detected in the MFLD tailrace area (BLD=30.3%;

CHL=36.4%; SC=33.3%). During the entirety of the study, 44 fish (PS=7; SP=4: EPS: BLD=10; CHL=12; SC=11) were detected at least 4.83 km below the MFLD tailrace during the study, with 14 of those detected inside the MFLD lock chamber (PS=6; SP=2; EPS: BLD=1; SC=1; CHL=4). On average, prespawn and spawning fish spent approximately 12.2 hours inside of the Millers Ferry lock chamber, while early prespawn fish spent on average 1.3 hours there (PS=5.0; SP=34.0; EPS: BLD=1.2; SC=1.0; CHL=1.3). Two fish successfully made it upstream of MFLD (SP=ID29268; EPS: BLD=ID29344) during the study. The effect of release site on time spent within the Millers Ferry lock chamber was not compared statistically due to low sample size from BLD and SC. However, lock usage did differ between spawning and early prespawning fish, and the difference between spawning and prespawning fish was marginally significant (ANOVA: d=2, *F*=4.331, p=0.041; SP-PS: p=0.064; PS-EPS: p=0.887; SP-EPS: p=0.0365) (Figure 5). The average time spent in the MFLD tailrace was 1.5-1.6 days for prespawn and spawning fish, but was 5.6 days for early prespawn fish (BLD=3.8; SC=4.1; CHL=8.4). The time spent below MFLD did not differ across release locations (ANOVA: d=2, *F*=2.72, p= 0.083), or across spawning periods (ANOVA: d=2, *F*=2.5547, p= 0.091) although both comparisons were marginally significant (Figure 6).

Once Paddlefish reached their furthest extent of upriver movement they began heading downriver. Fish spent between 0.5– 14.9 hours immediately above CLD before passing the dam and being detected by receivers in the tailrace or further downriver. On average, fish spent 3.2 hours immediately above CLD before continuing downriver (PS=2.8; SP=3.9; EPS: CHL= 4.5; SC=2.1). Time spent above CLD did not differ across spawning periods (ANOVA: d=2, *F*=0.18, p= 0.83) (Figure 7). No statistical comparison across release sites was performed due to small sample sizes (BLD= 0; CHL=2; SC=3).

Array Triangulations

Over the course of my study (02/2019-05/2019) the array below CLD triangulated locations for 19 of the 27 (70%) fish tagged during prespawn (n=12 of 15) and spawning (n=7 of 12) periods, while a total of 6 of 45 (13%) early prespawn fish were triangulated (all BLD releases) after translocation. The upper array triangulated positons for 5 of the 27 (19%) fish tagged during the prespawn (n=2) and spawning (n=3) periods, and 5 of the 45 (11%) fish tagged during the early prespawn period (CHL=3; SC=2) after translocation. Between the two arrays a total of 31 fish were triangulated having a total of 24,231 positions (range per fish: 4-4,885). Three fish were triangulated in both the upper and lower arrays. However, fish that were triangulated in both arrays did not have an upstream and downstream position located within a 30-minute timeframe so specific passage locations could be estimated. Fish in spawning period that were triangulated in the lower array were located in water with an average depth of 4.16 (±0.3) m, early prespawn fish averaged 4.1 (±0.15) m deep, and prespawn fish had an average depth of 3.64 (±0.52) m. In the upper array, prespawn fish had an average depth of 7.6±2.52 m followed by spawning (6.9±0.72 m), and early prespawn fish (6.6±0.45 m). Average depth of fish did not differ across spawning periods in either array (lower array ANOVA: df=2, *F*=0.195, p=0.195; upper array ANOVA: df=2, *F*=1.72, p=0.247) (Figure 8). No comparison was done on release locations in the lower array as only fish released at BLD were triangulated there; however, depth of use did not differ between SC and CHL fish triangulated in the upper array (df=1, *F*=2.194, p=0.14) (Figure 9).

Analysis of Movement Post Tagging and Translocation

Initial movement

Spawning period did not significantly influence the probability that a translocated fish made an initial upriver or downriver movement from the release site (X^2 =1.6692, df=2, p=0.43). Initial net movement across all spawning periods was positive (PS= +12.74±7.32; SP=+12.33±13.50; EPS=+11.36±6.10). In addition, prespawn and early prespawn periods fish net movement was significantly different from zero while spawning period fish net movement was marginally different from zero (PS: t=3.656, df=14, p=0.0026; SP: t=2.0116, df=11, p=0.069; EPS: t=3.7769, df=43, p=0.00048). Spawning period, however, marginally influenced whether a fish would make it upstream to MFLD (X^2=5.1783, df=2, p=0.08) with early prespawn fish most likely to make it to MFLD. In contrast, fish release location influenced whether a fish made an initial upriver or downriver movement from the release site, with no BLD fish making an upriver movement due to CLD (X^2 =24.592, df=2, p<0.0001), although release site did not influence whether a fish made it to MFLD (X^2=1.1538, df=2, p=0.56). Initial movement was positive and significantly different from zero for fish released at the Silver Creek and main channel sites (BLD= -1.98±8.92, t=-0.47613, df=14, p=0.6413; CHL=+23.24±10.87, t=4.5834, df=14, p=0.0004257; SC=+12.93±9.16, t=3.0506, df=13, p=0.009289).

For weeks 2, 3, and 4 also showed that release site influenced whether a fish moved 6.44 km above where it was released (week 2: X^2=13.037, df=2, p=0.0015; week 3: X^2=12.683, df=2, p=0.0018; week 4 X^2=11.943, df=2, p=0.0026). Spawning period, again, did not influence whether a fish moved 6.44 km above where it was released (week 2: X^2=0.12379, df=2, p=0.94; week 3: X^2=1.3376, df=2, p=0.51; week 4 X^2=0.76149, df=2, p=0.68).

Net Movement

Paddlefish that were tagged and translocated during the early prespawn period and released at three different sites all had significantly positive average net movements (BLD: t=2.2867, df=14, p=0.038; CHL: t=4.7667, df=14, p=0.0003; SC: t=5.0535, df=14, p=0.0002). Net movement did not differ across release sites (*F*=0.97, p=0.388) (Figure 10).

Paddlefish that were tagged and translocated during prespawn and early prespawn periods had positive average net movement (PS= +42.84 ±21.08 RKM; EPS=+37 ±11.45 RKM) that differed significantly from zero (PS: t=4.36, df=14, p=0.00065; EPS: t=6.57, df=44, p <0.0001). In addition average net movement did not differ between these periods (p=0.623). Paddlefish that were tagged and translocated during the spawning period had an average net movement of +20.24 (±23.5 RKM), which was marginally significantly different zero (t=1.8962, df=11, p=0.084). There were no significant differences in net movement among spawning periods (*F*=1.327, p=0.27) (Figure 10).

The daily average river kilometer location of fish within each release site indicated similar upriver and downriver movement patterns for fish release at the two upriver sites (CHL and SC) during November-December 2019. In contrast, fish released at BLD remained below CLD. The spill way became inundated during December and January and fish released at both CHL and SC moved up to MFLD, while BLD fish passed CLD. During periods of inundation in February and March 2020 fish from all release sites were found in the tailrace of MFLD; they began moving back downriver during March-May 2020 (Figure 11). The daily average river kilometer location of fish from prespawn and spawning periods indicate that prespawn fish moved upriver to MFLD during high water in February and March 2020, and both groups were similarly found throughout the river between MFLD and CLD during March thru June 2020. No receivers were deployed to provide coverage in the tailrace early in my study which reduced my ability to determine how many fish were in the tailrace during those months. Both prespawn and spawning period fish displayed similar downriver movement in May through July (Figure 12). Average number of acoustic detections per month of tagged fish detected at all receivers stationed at and above RKM 130 coincided with months that typically receive high amounts of rainfall and high flows (January-March). Numbers of detections per month peaked in January and began to decline into June (when rainfall declined) (Figure 13).

Discussion

Effects of Tagging and Translocation

Negative effects (e.g., fallback or even death) due to stress from tagging and translocation have been widely studied on diadromous fish such as Sockeye Salmon (*Oncorhynchus* nerka) and *Alosa* species during spawning conditions (Naughton et al. 2006; Frank 2009; Harris and Hightower 2011). This has encouraged research to examine this stress response on potamodromous fish species as well (Hatry et al. 2016; Heironimus et al. 2015; Van Leeuwen et al. 2014). Paddlefish is an economically important species (Carlson and Bonislawsky 1981) and while several telemetry studies have reported on Paddlefish movements (Stancill et al. 2002; Roush et al. 2003; Barry et al. 2007) none have addressed whether these movements could represent fallback induced by the tagging and release process.

In this study, I found that initial Paddlefish movements across all spawning conditions and at 2 of 3 release sites were significantly positive (upriver) from their release site suggesting little or no fallback behavior; the one exception was the below Claiborne Lock and Dam site, where the presence of the dam clearly hindered upriver movements. In addition, longer-term movement (i.e., at 2, 3, and 4 weeks post tagging and translocation) similarly showed that spawning condition did not affect upriver movement, while upriver movement was affected by release site (again, fish released at the below Claiborne Lock and Dam site were significantly less likely to be found upriver).

Paddlefish did make downstream movements after translocation throughout the study, but these should not be considered a form of fallback, given that several upstream and downstream movements were also reported by Moen et al. (1992) and Zigler et al. (2003). Acolas et al. (2012) observe similar movement patterns in European sturgeon *Acipenser sturio* who described them as exploratory behaviors. Average net movement results show translocated fish exhibited upriver movements after translocation, further suggesting little evidence for permanent fallback. While spawning condition did not affect whether fish ultimately made it upstream to Millers Ferry, early prespawn fish not only spent more time in the tailrace of MFLD but also had more fish successfully make it above RKM 201, suggesting that the timing of translocation played some role in the success and extent of upriver movements.

Fish released below CLD did have a higher probability of being found below their release site relative to the other two release sites. However, this is expected for a release below a barrier where passage success depends on the occurrence and duration of spillway inundation. That being said, 2019 and 2020 were both relatively wet years, so fish tagged and released below Claiborne Lock and Dam were able to make it upriver during my study, albeit with the added hurdle of passing the dam spillway. Fish released in the main channel had a higher rate of success relative to moving upstream to MFLD versus fish released at Silver Creek and below Claiborne Lock and Dam. Being released into the flow instead of in a feeding tributary likely helped orient these fish upriver. Both Firehammer and Scarneccia (2007) and Miller and Scarneccia (2008) found that Paddlefish entered either the Yellowstone or Missouri rivers based on consistent high flows in each system, making several repeated directional changes in each river. Fish that were released in Silver Creek across all spawning conditions were detected in the backwater area within the first week before making their way out into the main river channel. While this could be a result of fish recovering from surgery and translocation, given that this behavior was not exhibited by fish released in the main channel, it is more likely due to the lack of strong flow in the tributary from the backwater to provide needed rheotactic cues (Taylor and Cooke 2012). While this did not prevent fish from eventually moving upstream, it could cause them to spend more time navigating out of the backwater area before eventually orienting in the main river

Tracking Paddlefish Movement

The combination of active and passive tracking, and USACE bathymetry data was invaluable relative to being able to draw conclusions about Paddlefish movement. Zigler et al. (2003) defined “excellent” habitat for Paddlefish in the Mississippi River to be areas >6 m deep, and they commonly found Paddlefish in depths ranging from 4 to >8 m; similarly I found Paddlefish used sites with average depths ranging from 3.6-7.7 m across spawning conditions; in addition, both tagged and untagged fish were observed via sidescan sonar image to be occupying deeper areas during manual tracking. Manual tracking data also showed that my tagged fish moved up into the same deep areas as other previously tagged fish I tagged did as they progressed upstream to Millers Ferry, this was particularly common for early prespawn fish. Use of these deeper waters during prespawn conditions suggests they might represent staging areas where fish wait for migration cues (e.g., increased temperature and flow) to trigger upstream movements (Lein and DeVries 1998; Paukert and Fisher 2001). Triangulated positions of Paddlefish below CLD showed they were primarily found in the interface area where flow from the gated spillways intersected the flow from the crested spillway. Manual tracking and sampling confirmed that those areas were used by both tagged Paddlefish as well as other species (Quilback *Carpiodes cyprinus*, Smallmouth Buffalo *Ictiobus bubalus,* Highfin Carp *Carpiodes velifer*, Spotted Gar *Lepisosteus oculatus,* Striped Bass *Morone saxatilis,* Blue Catfish *Ictalurus furcatus*, Freshwater Drum *Aplodinotus grunniens*). Other high use areas were the main channel downriver from the gated spillway and an eddy that formed below the crested spillway (also observed by McKee 2019).

Fish Passage

Previous work on how fishes interact with dams that impede migratory movements has led to innovative approaches such as conservation lock operations, fish ladders, and safe transportation methods (Agostinho et al. 2007; DeHaan and Bernall 2013). Most of those approaches have been used in the Western and Northeastern US in an effort to assist salmonids or shads to pass barriers as they migrate inland from the sea. However, the Southeastern US has implemented very few structures or techniques to the point where endemic species that once made historic runs (e.g., Alabama Sturgeon *Scaphirhynchus suttkusi*, Gulf Sturgeon *Acipenser oxyrinchus* desotoi, Alabama Shad *Alosa alabamae*, Lake Sturgeon *Acipenser fulvescens,* Striped Bass) are becoming rare or dependent on hatchery restocking (Jackson and Hightower 2001; Kuhadja and Rider 2016). Many Southeastern US dams were built for navigation, hydropower, or flood control, but were not designed to assist fish during migrations; as such, they may contain crested spillways, gated spillways, or lock structures. Conservation lockages are used in many systems (e.g., Yangtze, Mississippi, Cape Fear, Columbia rivers) in an attempt to assist fish upstream (Moser et al. 2000,2002; Lin et al. 2014; Tripp et al. 2014). Currently the USACE performs scheduled non-navigational lockages during February-June to provide passage opportunities at two lock-and-dam structures on the Alabama River (Simcox et al. 2015; McKee 2019). Studies performed in the Mobile and Mississippi river drainages have addressed how migratory fishes in these systems use the locks or gates as viable paths through the barriers, and, as with my findings, with little upstream passage success via locks (Cooke 2002; Zigler et al. 2004; Simcox et al. 2015; McKee 2019). Alternatively, work with other migratory species studied has shown passage success via gates or locks to be variable (Young et al. 2012; Finger et al. 2019; Tripp et al. 2014).

Upriver Passage

The crested spillway at CLD becomes completely submerged when water levels reach 10.67 m, directly connecting Claiborne Lake with the lower portion of the Alabama River. Claiborne Lock and Dam was inundated approximately 94 days out of 452 between the first day fish were tagged and translocated (14 February 2019) until the date of the last receiver download (11 May 2020). In contrast, while high water conditions inundated the crested spillway and allowed for passage of fish across CLD, it did not affect passage success of fish at MFLD.

Fish released below CLD passed at gage heights of 10.73, high enough to allow passage over the spillway; in fact, Hershey (2019) found Paddlefish to be more active in the CLD tailrace at gage heights of 10.7 m. Suggesting that Paddlefish actively search for ways to pass CLD in the main river channel, decreasing the likelihood of using the locks for passage (in addition, locks cannot be operated when the lower pool is 4.6 m in elevation). Manual tracking data showed that fish released below CLD remained in the tailrace within 24 hrs after release. In addition, acoustic data showed fish moved in and out of the tailrace to areas within 8.05 RKM downstream CLD until gage heights inundated the crested spillway. The Claiborne lock chamber receiver only recorded one fish from the BLD release site inside the lock chamber; unfortunately, the entry time was unknown given that the receiver malfunctioned several times after initialization.

Lack of success using locks to pass fish at these structures further supports a need for alternative passage methods, given that fish spent between 0.2-64.0 hours in the Millers Ferry lock chamber, ultimately resulting in only 2 out of 72 fish ever successfully passing MFLD via the lock, spillway gates, or power house. Outside of these 2 fish, there are only 4 other published accounts of tagged Paddlefish passing MFLD reported out of the hundreds of tagged Paddlefish across studies (Mettee et al. 2005; Simcox et al. 2015).

Downriver Passage

Passage is a bi-directional problem for migratory species, particularly at structures lacking the means to assist fish past barriers although fish may be able to use a spillway or lock chamber to move downriver after spawning to return to summer or winter home ranges similar to upriver movements. Positional data from the array upstream of CLD showed fish were primarily detected near the upriver guidewall where water depths exceed 10 m, in deep waters in the main channel, and by the ascending left river bank. This suggests that as fish reached the upper pool above CLD they did not use the lock chamber (on the right ascending river bank) to pass downstream, but rather used the spillways when water levels or gates were sufficiently high to allow passage downstream (Wilcox et al. 2004). On average fish spent less time above CLD before successful downstream passage into the tailrace versus those attempting to make an upriver passage from below CLD, similar to findings of Southall and Hubert (1984) who showed that high flows increased the difficulty of fish moving upstream through the gates such that fish used the spillway more readily going downstream. The lack of fish with recorded locations in the upstream array is likely due in part to the initial lower numbers of receivers in that array, combined with logistic issues relative to receiver retrieval. Few triangulations of fish tagged in early prespawn condition occurred due to consistently high water levels and receiver anchors being buried by deposited sediment during flooding events, preventing retrieval of all receivers and their data, reducing triangulation ability.

Timing of Translocation

The earliest time when a prespawn stage fish was detected within 4.83 km below MFLD was 20 March 2019, while the earliest spawning stage fish was detected was 8 April 2019. Early prespawn fish released at SC and CHL reached MFLD within a day of each other (SC= 12/04/2019; CHL= 12/03/2019), while the first BLD fish was detected at MFLD approximately two weeks later (12/31/2019). The abundance of fish collected and seen below CLD during November 2019 through January 2020 suggest that fish began to stage below CLD as water temperatures decreased and waited on appropriate water levels before they passed and continued upstream as has been observed in other systems (Pasch et al. 1980; Zigler et al. 2004). Early prespawn fish released above CLD were able to reach MFLD earlier than those that were released below CLD, moved upstream during pulses of high flow towards MFLD (as did BLD fish), and displayed similar “attempts” to pass MFLD as did fish released below CLD prior to passing. This suggests that Paddlefish would continue upriver beyond MFLD with potential to reach the Cahaba River, R.F. Henry Lock and Dam, or perhaps even further, if there were no barriers and appropriate flow cues. Timing these manual movements to coincide with natural pulses that can occur between November and February could improve connectivity between the fragmented populations and potentially Paddlefish spawning success (Purkett 1961; O’Keefe 2006).

Future Use of Translocation as a Management Tool

My results suggest that implementing an alternative strategy assisting Paddlefish, and potentially other migratory species, above dams on the Alabama River would serve to improve population connectivity. While the population appears to be sustaining itself currently, providing Paddlefish with opportunities to reach higher quality spawning habitat when flow conditions are appropriate could improve egg survival, potentially resulting in increased recruitment (O'Keefe 2006; Lallaman 2012). Genetic research with Alabama River Paddlefish has shown the fragmented populations do not yet appear to be genetically diverging (Kratina 2019). The lack of genetic divergence is potentially a result of Paddlefish being a long-lived species. Translocation appears to be a viable method with no apparent negative impacts on fish behavior that could be done to mitigate the impact of low water years at CLD and annually at MFLD. If translocation were implemented, I recommend that fish be released in the main channel of the river, given that Paddlefish are attracted to flow and more likely to continue upriver reaching habitat suitable for staging and spawning while in prespawn condition (Mettee et al. 2005; Miller and Scarneccia 2008; Taylor and Cooke 2012). In addition, I also recommend releasing fish near mouths of tributaries, but not within the tributary. Fish could also be moved upriver by land-based haul tanks if translocation sites were far enough upriver to make travel by boat inefficient. Barton et al. (1998) found that plasma cortisol and plasma lactate both increased significantly after an hour of confinement, so minimizing tank residence time should be considered in transportation. Future work should include translocating and tracking fish upstream of MFLD, as well as looking at downriver passage to inquire if translocation downriver is needed. Learning more about how far Paddlefish travel upstream, how often they return to specific stretches of river, and locating spawning habitat would provide managers with needed information for managing this migratory species.

Assisting fish movement back downstream of dams so they can access summer or winter habitats is also an important aspect to improving connectivity, especially at MFLD. Paddlefish did pass back downstream below CLD using either the crested or gated spillways. However, at dams with hydroelectric facilities where the gated spillways are closed to store water, passing through the hydropower turbines could result in mortality and could be the cause of many Paddlefish with damaged or missing rostrums (personal observations; Schilt 2007; Pracheil et al. 2015). Additional wok on such post-spawning movements, as well as the potential need for a natural type of spillway is needed before such questions can be answered.

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Figures

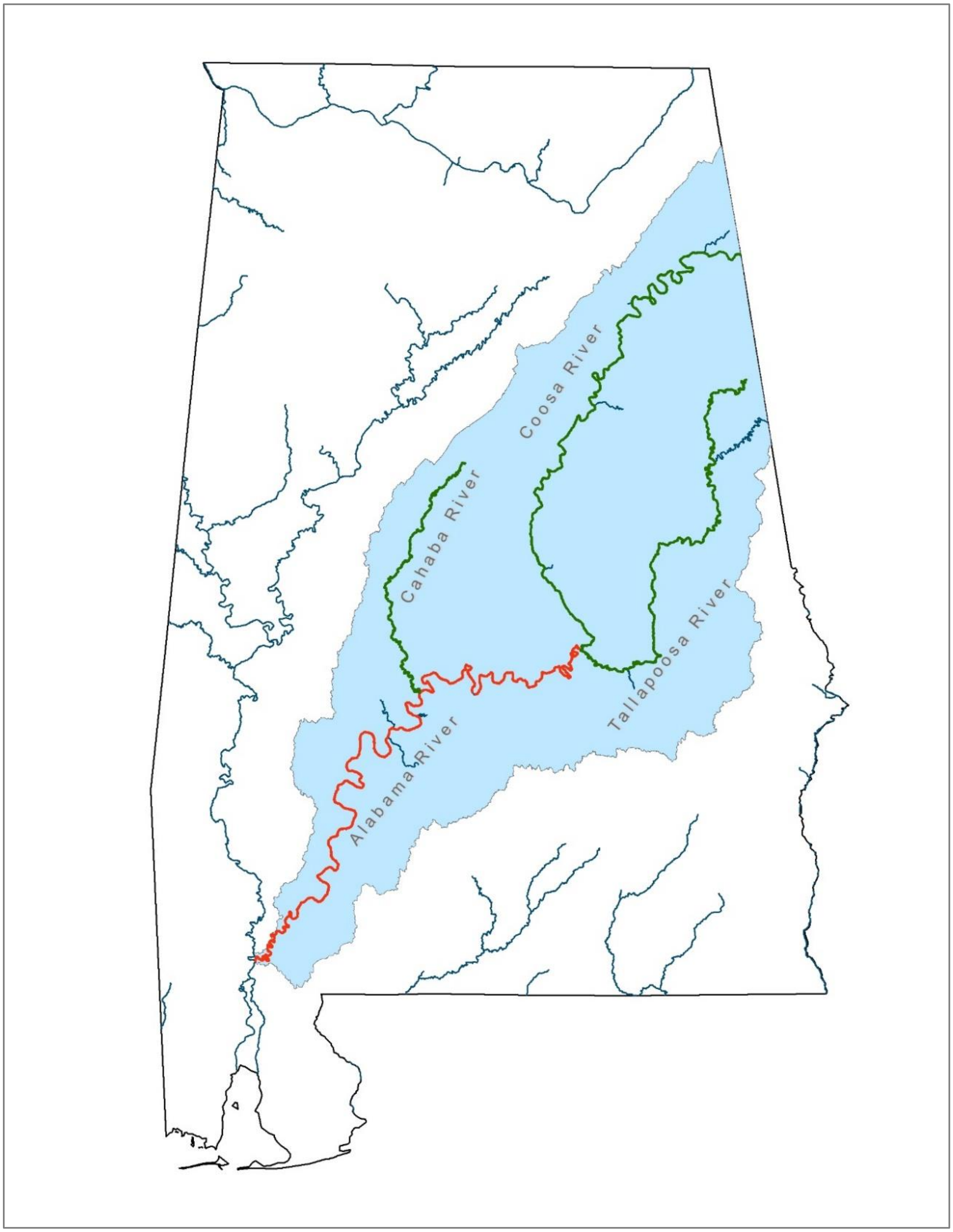

Figure 1: The above map depicts the major rivers and some larger creeks of Alabama. The drainage basin for the Alabama, Cahaba, Coosa, and Tallapoosa rivers is indicated by the light blue area. The Coosa, Tallapoosa, and Cahaba rivers are green, the Alabama River is red, and all other bodies of water are dark blue.

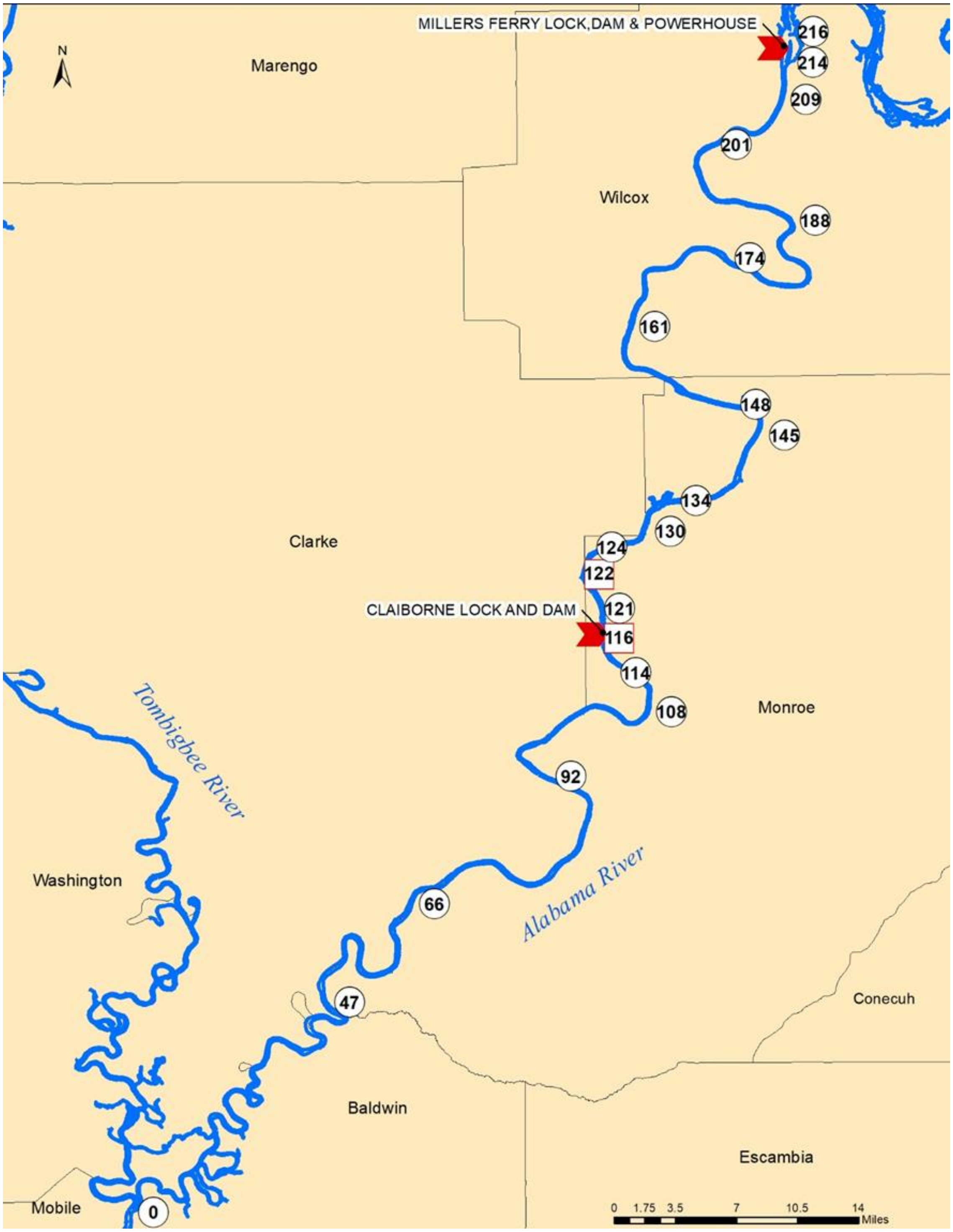

Figure 2: Locations of stationary acoustic receivers that were placed along the Alabama River to passively detect tagged fish as they passed. The numbers encompassed by circles indicate the river kilometers at which the receivers were stationed, while numbers with outlined red squares represent release sites, and the red arrows indicate the locations of the lock-and-dam structures.

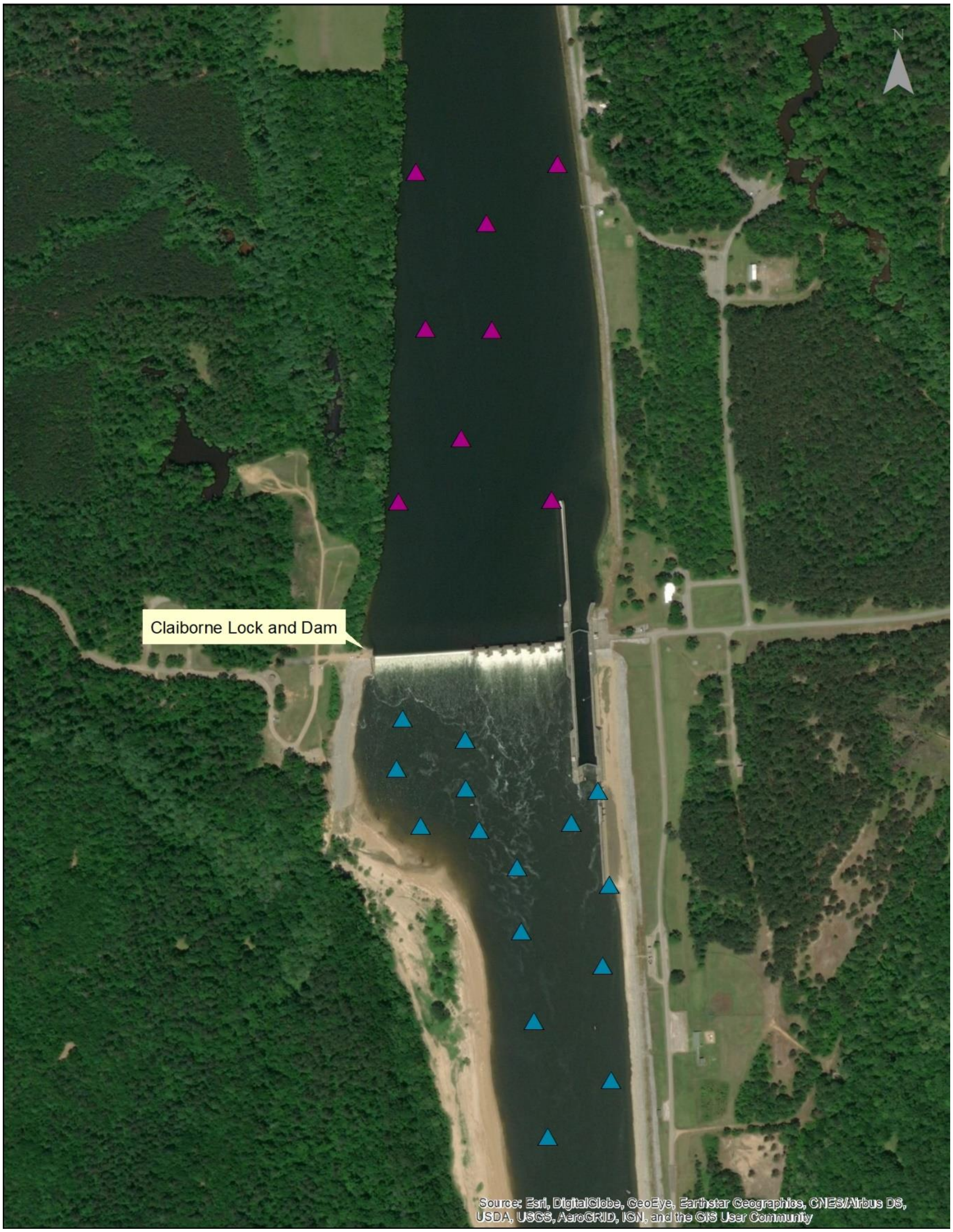

Figure 3: Triangles indicate individual receivers in the arrays setup above and below Claiborne Lock and Dam. The purple triangles form the upper array that consist of 8 acoustic receivers while the blue triangles form the lower array that consisted of 15 acoustic receivers.

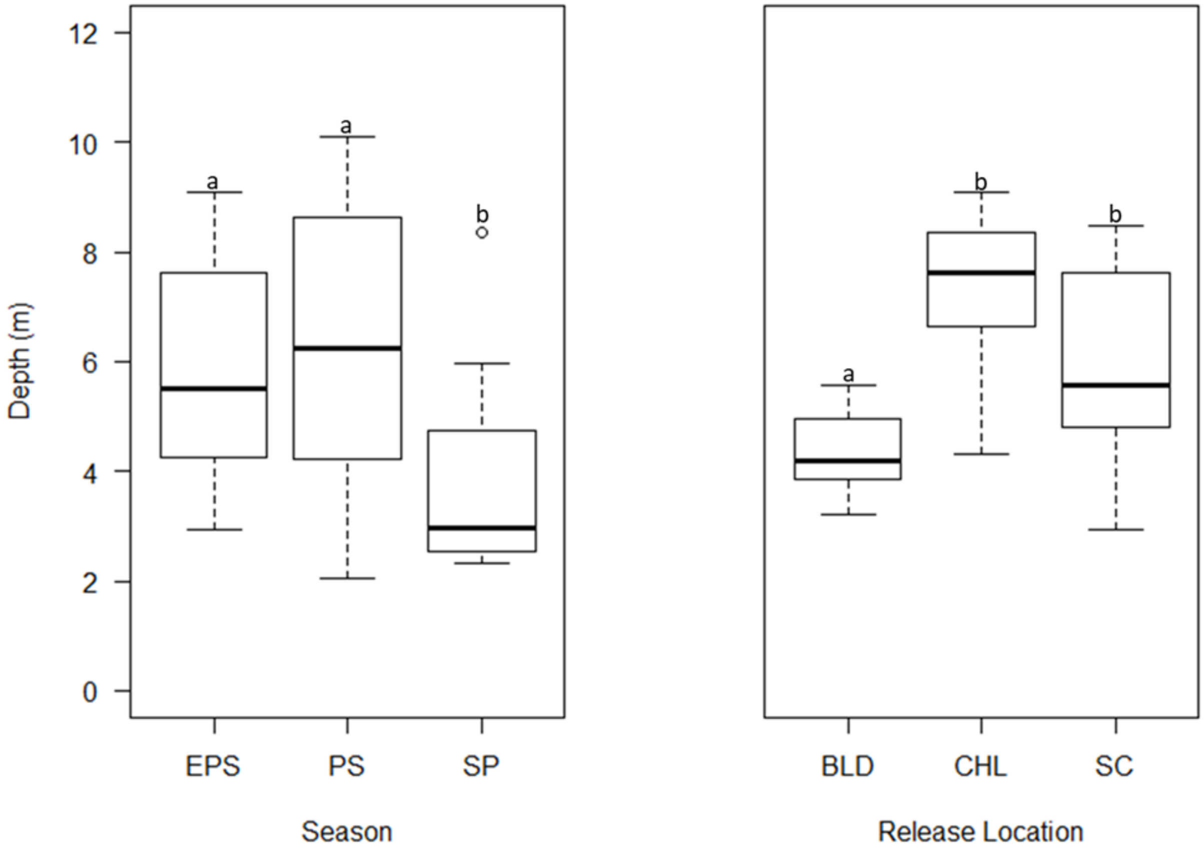

Figure 4: Average depth used by fish in the three spawning periods (left) and at the three release sites (right) based on combined radio telemetry and bathymetry data. Box represents the ±25% upper and lower quartiles, solid line is the median, whiskers are the data range, and dots represent outliers in the data. Boxes with different letters above them within a panel indicate statistically significant differences.

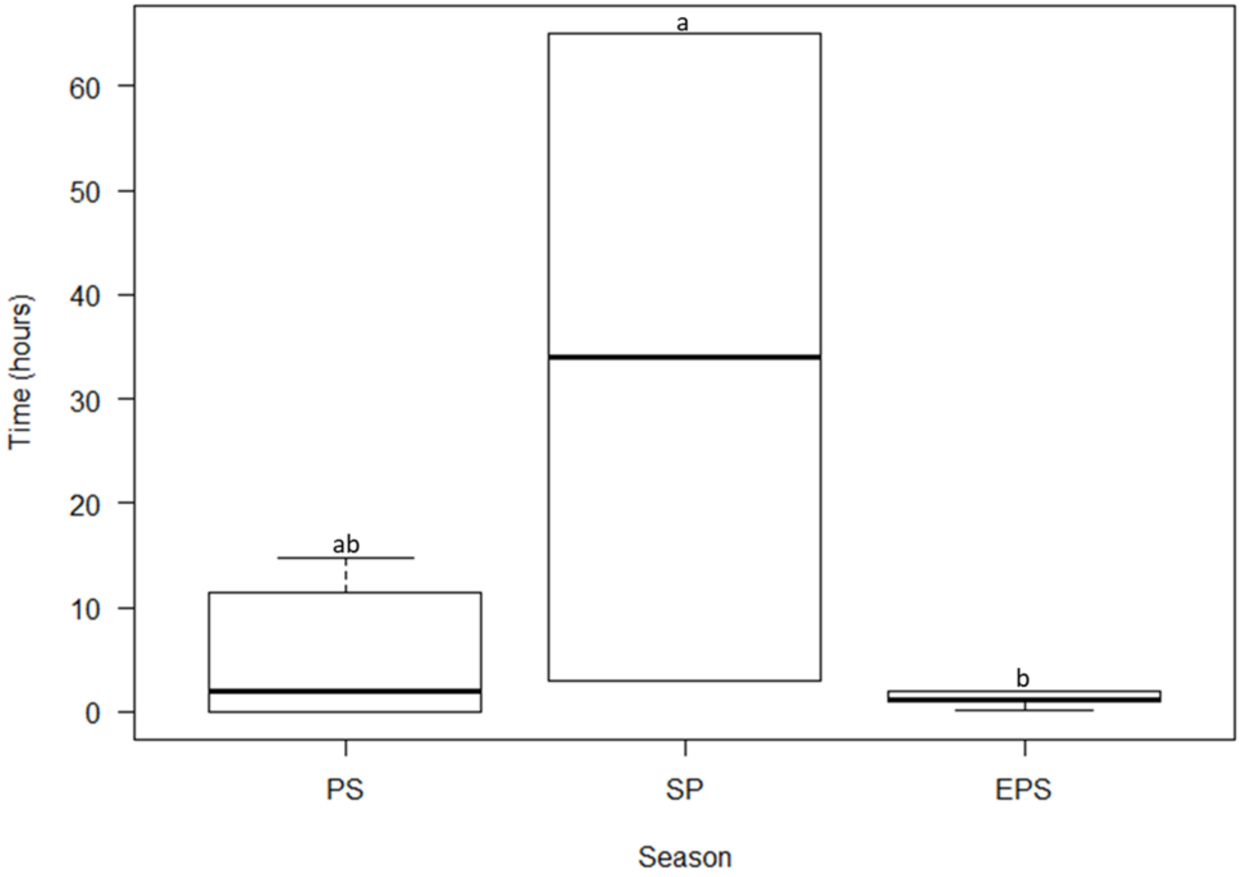

Figure 5: Time spent in the lock chamber at MFLD across spawning periods. Data are as represented in Figure 4.

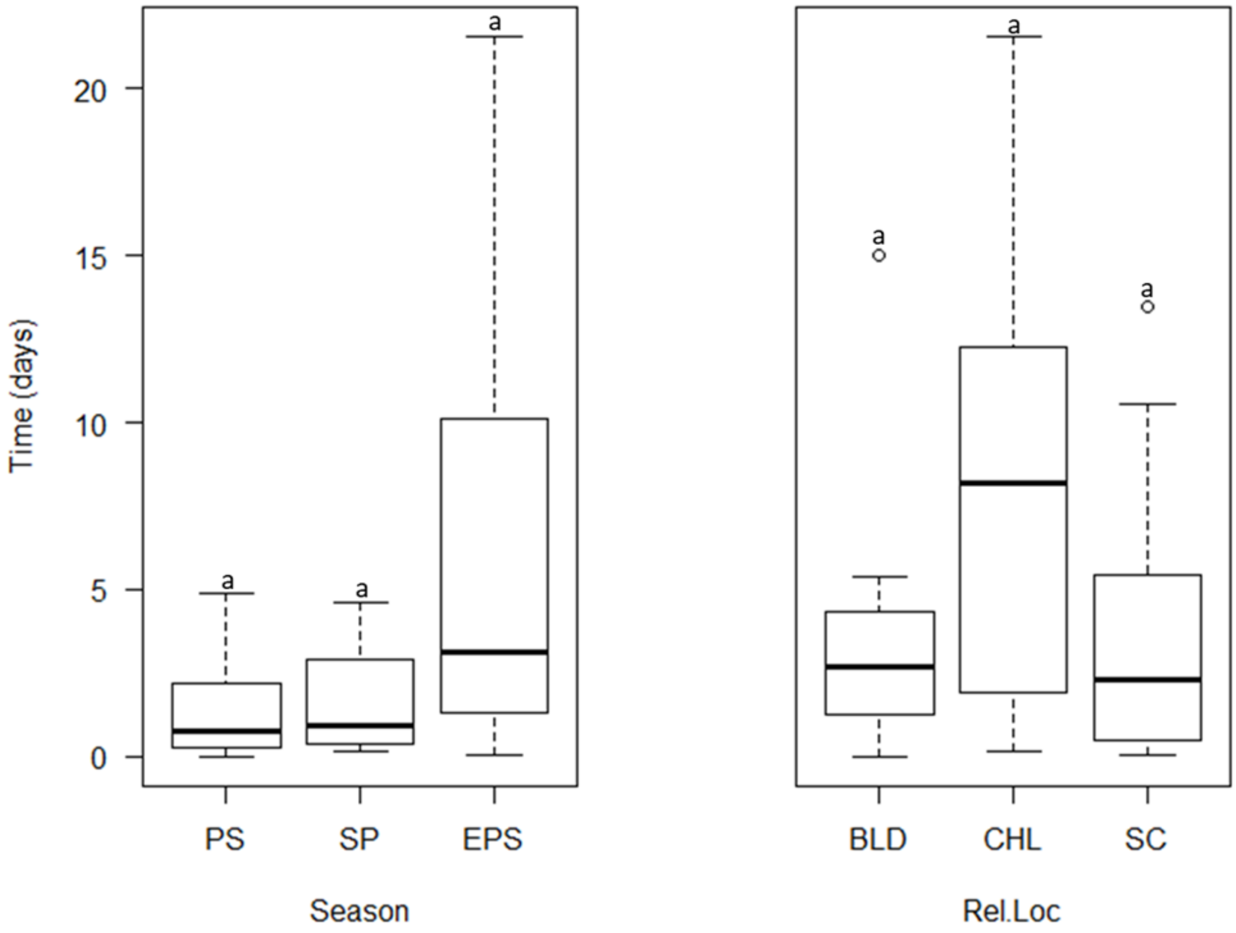

Figure 6: Time spent below MFLD across spawning periods (left) and the three release sites (right). Data are as represented in Figure 4.

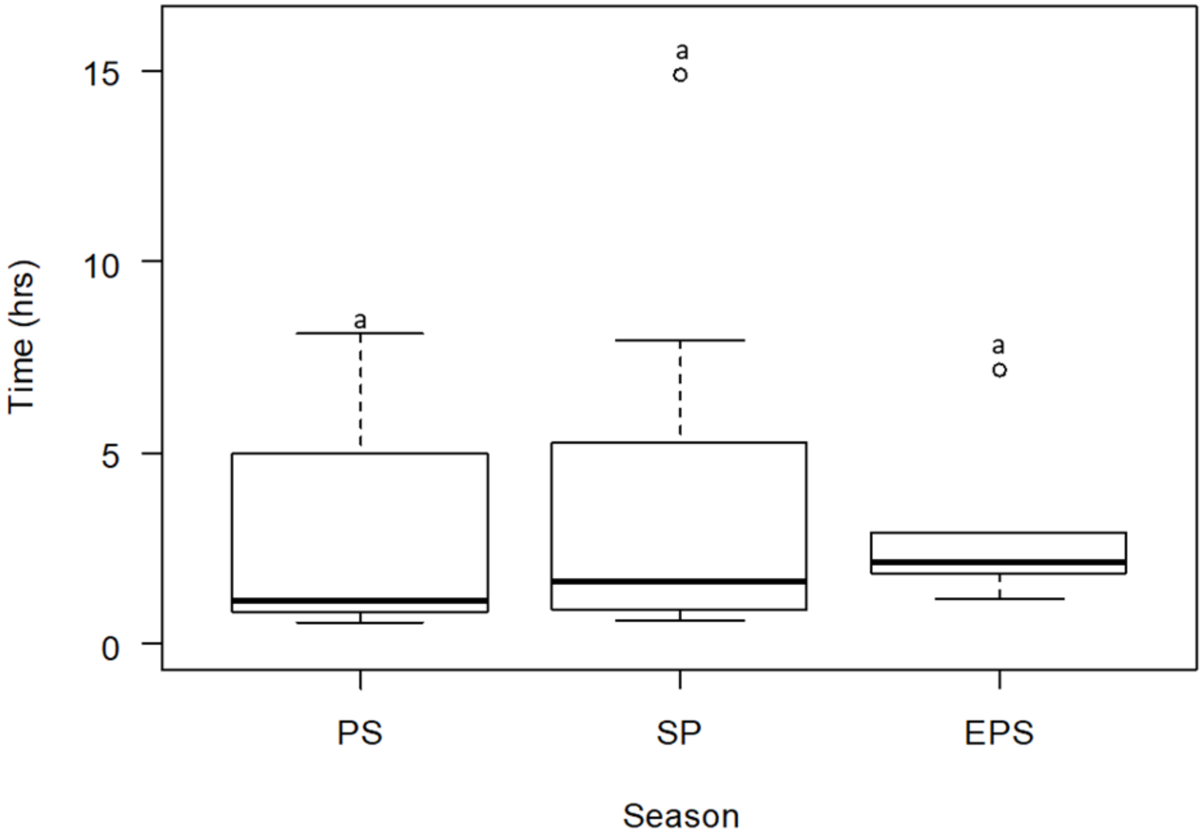

Figure 7: Time spent immediately above CLD before passing downstream for each spawning period. Data are as represented in Figure 4.

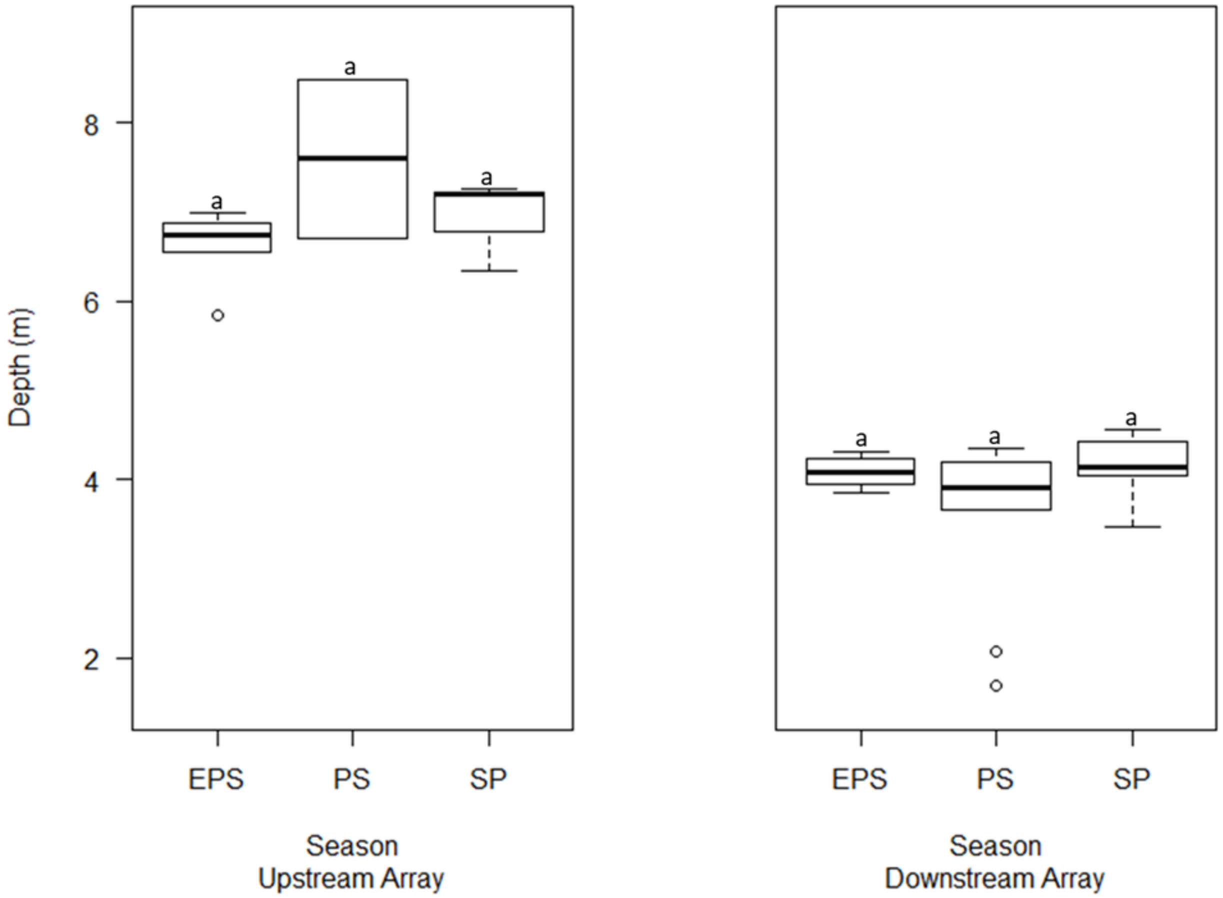

Figure 8: Average depths used by fish of each spawning period based on triangulated fish locations in each array. Data are as represented in Figure 4.

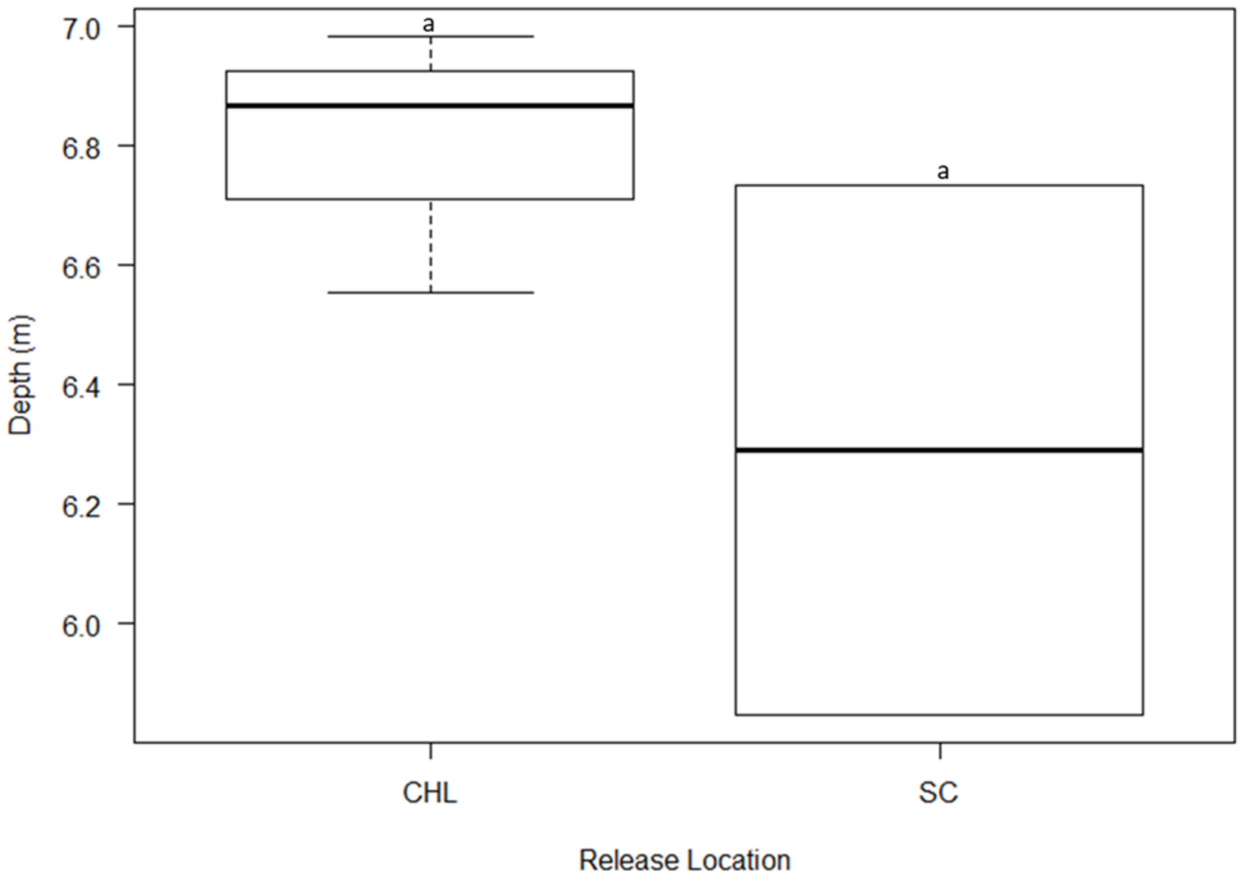

Figure 9: Average depth used by fish from two release sites within the EPS release group that were triangulated in the upper array. Data are as represented in Figure 4.

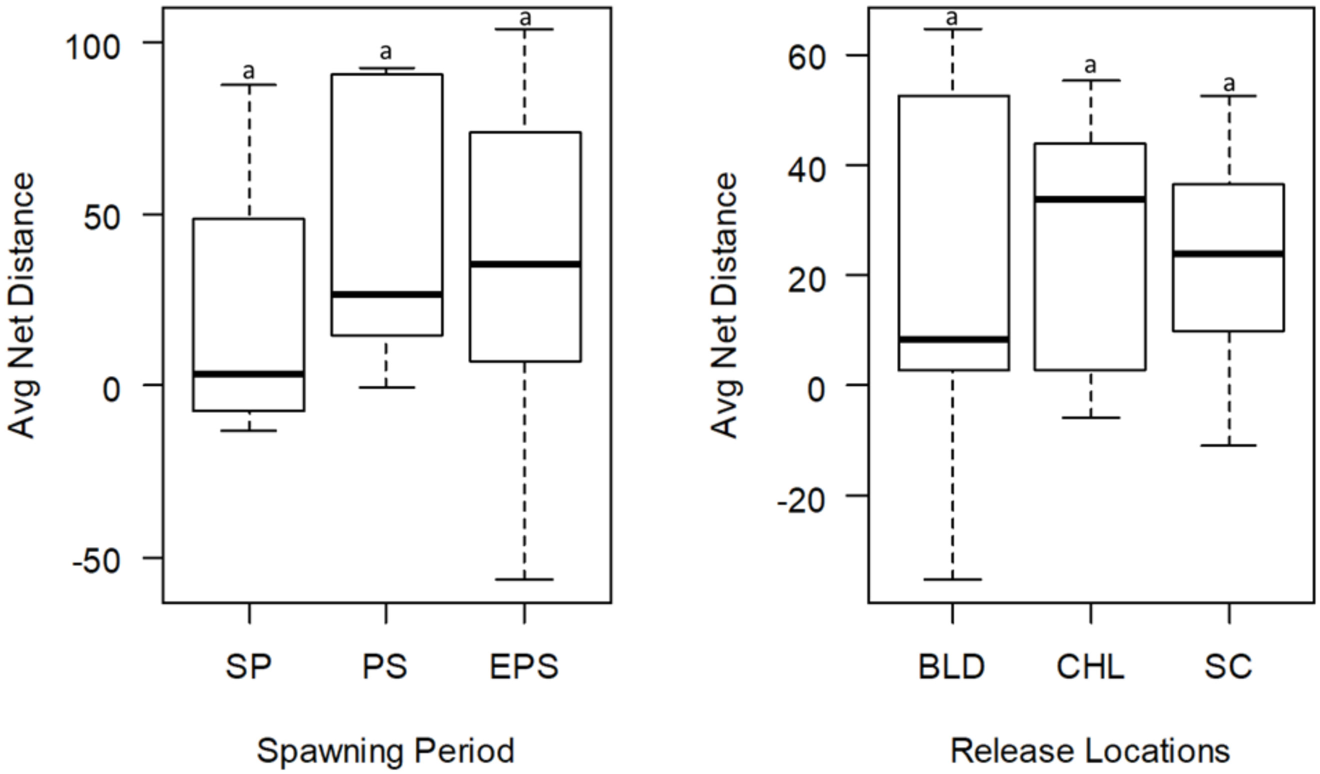

Figure 10: Distribution of average net distance that fish moved across spawning periods (left) and the three release sites during the EPS period (right). Data are as represented in Figure 4.

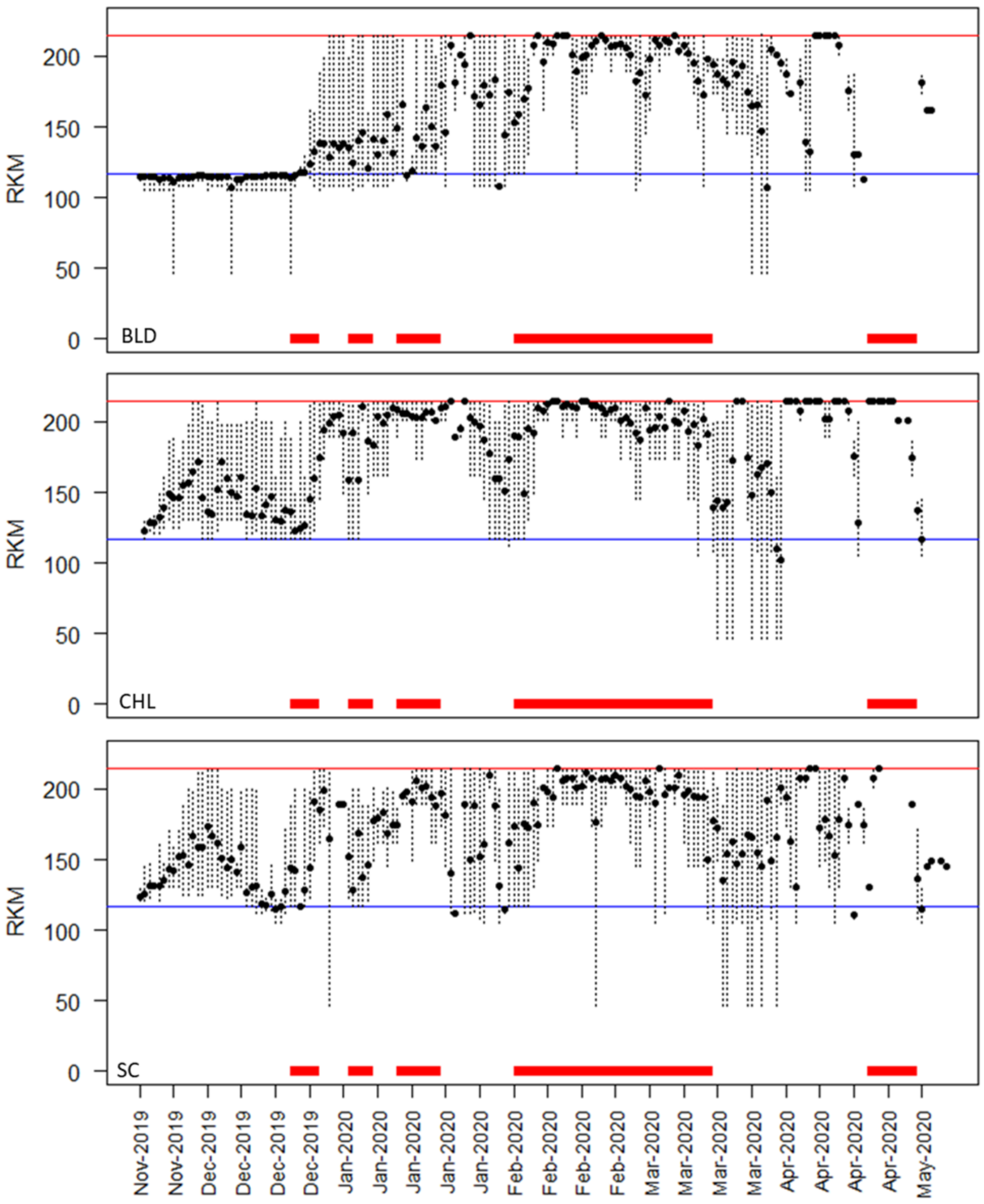

Figure 41: Black dots represent the average RKM of BLD (top panel), CHL (middle panel), SC (bottom panel) fish each day. Vertical dotted lines represent the range of fish from each release site that were detected each day. Bars at the bottom of the figure indicate dates the crested spillway was inundated. The blue horizontal line indicates CLD and the red horizontal line indicates MFLD.

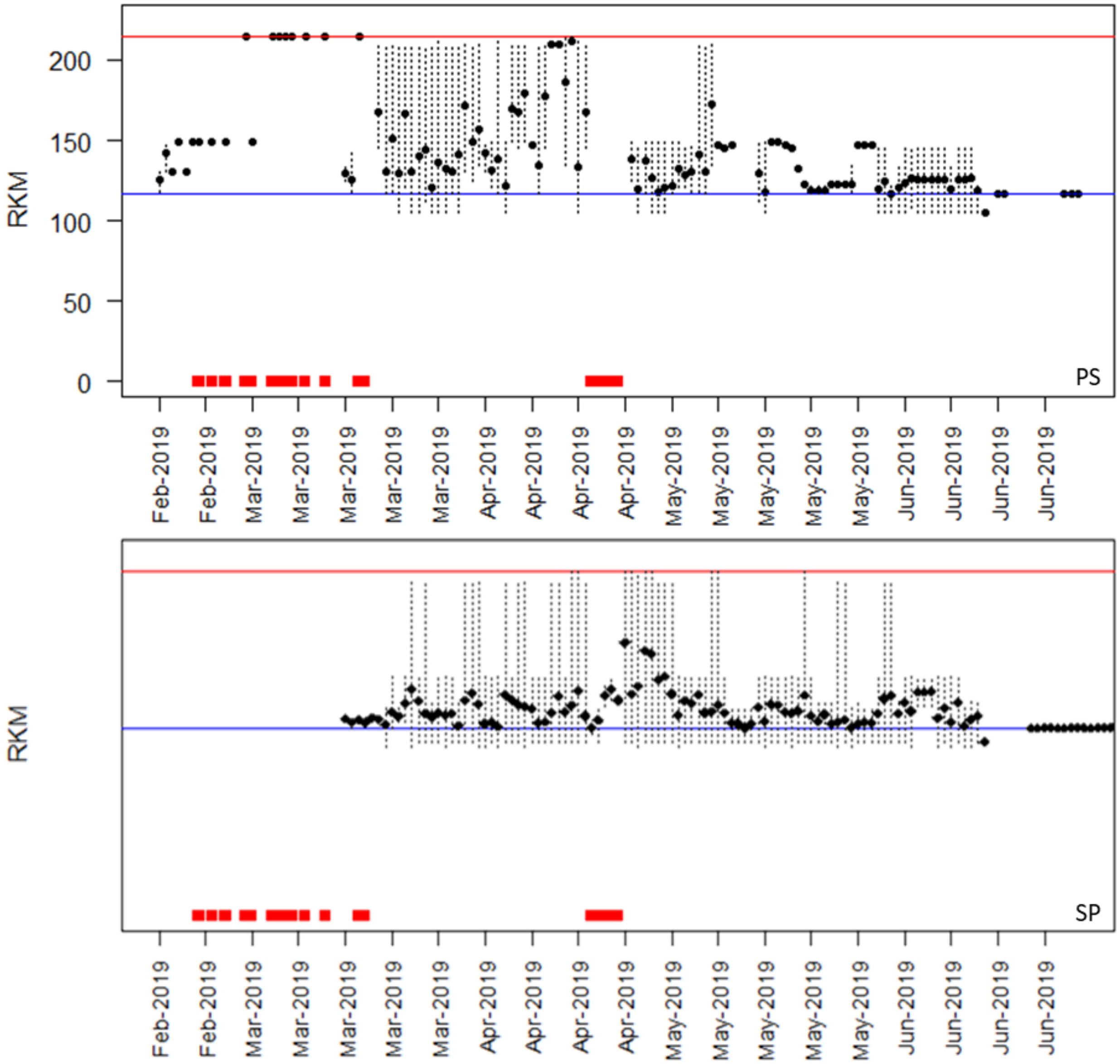

Figure 12: Black dots represent the average RKM each day of PS fish (top panel) and SP fish (bottom panel). Vertical dotted lines represent the RKM range of locations of fish from each prespawn and spawning periods. Bars at the bottom of the figure indicate dates that the crested spillway at CLD was inundated. The blue horizontal line indicates CLD and the red horizontal line indicates MFLD.

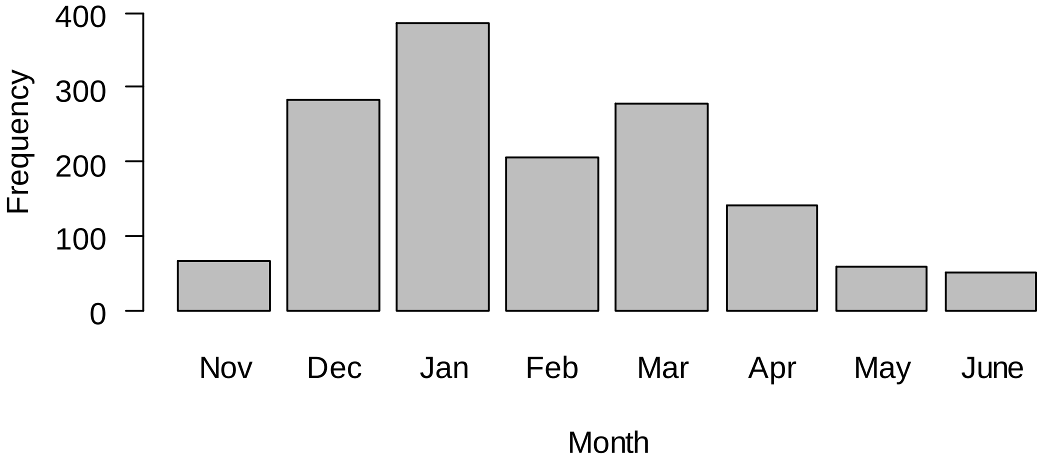

Figure 13: Average number of acoustic detections per month on stationary receivers at and above RKM 130.