MOVEMENT PATTERNS AND HABITAT USE BY JUVENILE AND ADULT SICKLEFIN REDHORSE (*MOXOSTOMA SP*.) IN THE TUCKASEGEE RIVER BASIN

A thesis presented to the faculty of the Graduate School of Western Carolina University in partial fulfillment of the requirements for the degree of Masters of Science in Biology

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

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The purpose of this study was to determine the seasonal movements and microhabitat use of juvenile and adult sicklefin redhorse (SFRH) (*Moxostoma sp.)* in the Tuckasegee and Oconaluftee rivers in western North Carolina. Seven hatchery-reared juveniles and six wild adults were implanted with radio transmitters in order to determine and assess movement patterns and habitat use and preference, along with spawning migration of adults. Fish were monitored daily to weekly over the operating-life of the radio transmitters. Juveniles preferred moderate to deep pools with large boulder crevice cover and slow moving currents. Juveniles displayed major movements occurring in late summer and fall, resulting in downstream movements. Adult sicklefins preferred moderately deep river channels with swift thalwegs and coarse substrate supporting river weed *Podostemum ceratophyllum* during summer, fall and winter. The adult SFRH differed by sex in their movement patterns. Males moved to lower river reaches and reservoirs in winter then to spawning areas in upper river reaches in late winter and early spring. Females resided in the same river stretch for all seasons, moving minimally.

INTRODUCTION

The sicklefin redhorse (SFRH) is a large migratory riverine catostomid from the genus *Moxostoma* (Warren et al. 1997, Cooke et al. 2005). The SFRH is currently undescribed, but efforts by Dr. Robert Jenkins (1999) to fully describe the species are ongoing. SFRHs are adapted to swift currents and most commonly found in riffles, runs, and flowing portions of pools in medium to large rivers (Jenkins 1999). SFHR are similar in shape and color of other redhorse species but are distinct by their deeply falcate (sickle shaped) dorsal fin. The SFRH are benthic omnivores, and forage on benthic macroinvertebrates, small bivalves, and gastropod mollusks (Jenkins 1999). The SFRH's main diet staples are macroinvertebrates. SFRH often forage among tufts of riverweed, *Podostemum,* which provides a rich habitat for macroinvertebrates in streams (Hutchens et al. 2004). SFRH also glean food items from surfaces of clean gravel, rocks, bedrock, sticks, and logs. Only rarely do SFRH forage on substrate with even slight silt overlay (Jenkins 1999), which has become a growing concern in many streams and rivers.

The Tuckasegee River where the SFRH inhabit has seen a large amount of siltation over the years which has been associated with poor land use (Jenkins 1999). Sedimentation from mostly small mines for tourism has led to a large amount of sedimentation and habitat degradation in the Little Tennessee River (Jenkins 1999). Sedimentation can inhibit the growth of aquatic plants (e.g., river weed; Hutchens et al. 2004) which are intolerant of excessive sedimentation (Meijer 1976, Philbrick and Crow 1983), lead to stream bank instability, and can suffocate fertilized fish eggs. The demise of some sicklefin populations may be linked to heavy sedimentation, whereas extant populations likely are benefitting from probable reduction of sedimentation in the last few decades (Jenkins 1999).

Many freshwater fish found in the Southern United States are at risk due to pollution, siltation, destruction, and impoundments of the rivers and streams that they inhabit. Habitat degradation and fragmentation among other causal factors may have contributed to the reduction in SFRH abundance and distribution (Warren et al. 2000). Restoration efforts have been focused in the Tuckasegee River where hypolimnetic discharges from upstream dams and past water pollution may have affected the abundance of SFRH (Moyer et al. 2009). SFRH have been found at very low densities in the Tuckasegee River even though a large portion (19.3 km) of the river appears to be of suitable habitat for the species (Duke Energy Corporation 2003). Due to the limited geographic distribution of SFRH and threats associated with physical alteration of the habitat, restoration and reintroduction efforts are still ongoing for the SFRH (Petty et al. 2010).

Behavior, movement patterns, and habitat selection of many fish species render them cryptic, difficult to observe, capture or study, and ultimately poorly known (Bruton 1995). In our study we used hatchery-reared juveniles and wild adults. The hatchery-reared "sentinel" fish were used to represent wild juveniles, and hopefully guide us to wild populations. The use of hatchery-reared individuals was used with another endangered sucker species, the robust redhorse in the Oconee River in Georgia. Grabowski and Jennings (2009) found that these hatchery-reared individuals led investigators to unknown untagged resident fish. The tagged fish also revealed to investigators new spawning areas for the robust redhorse (gravel bars).

With the restricted area that the SFRH now occupies, only a small amount of spawning habitat still exists. Much of the river habitat that was available has now been converted into reservoirs, such as Hiwassee and Fontana Reservoirs (Jenkins 1999). A combination of these factors may be responsible for the reduced number and abundance of the SFRH and other suckers in highly regulated systems, such as those found in the Tuckasegee Drainage Basin.

Impoundments on rivers and the resulting changes to riverine habitat (e.g., physical barriers to upstream reaches, physical alteration of the habitat, and changes in flow regimes) are known to adversely affect fish communities (Bain et al. 1988, Kinsolving and Bain 1993, Travnichek and Maceina 1994, Freeman et al. 2001). Fluvial specialists, such as redhorses, are more abundant in unregulated river reaches compared to similar sized reaches that are regulated (Travnichek and Maceina 1994). Many of the rivers that the SFRH inhabit are impeded by numerous dams that inhibit their movement patterns and restrict their access to spawning grounds (Erman 1973, Allan and Flecker 1993, Taylor et al. 2001), restrict the transport of all but the finest sediments down river (Ligon et al. 1995, Poff et al. 1997), and alter downstream habitats (Travnichek and Maceina 1994, Freeman et al. 1997, Poff et al. 1997). Populations of SFRH in the Hiawassee and Little Tennessee drainage are confined within reaches enclosed by impoundments such as Fontana Dam downstream and multiple dams upstream (Petty et al. 2010), potentially blocking movement into smaller tributaries.

SFRH reside, and are confined in the rivers of the Hiawassee and the Little Tennessee basins of western North Carolina and northern Georgia. The SFRH is currently a candidate species for federal protection under the Endangered Species Act (USFWS 2010) and is recognized as a priority wildlife species for North Carolina with a state status of “significantly rare” (NCWRC 2005). As a result this species has recently received considerable attention from regulators, resource managers, and conservation-minded individuals. However, recovery of the SFRH has been hindered due the limited knowledge of their movement patterns, habitat use, and overall life history.

SFRH are a long lived species (17-20 years) and do not reach sexual maturity until age 5-8 (males 5-7 years, female 7-8 years: Jenkins 1999). Understanding the critical time period from fry to sexually mature adult is needed to better manage populations. Studying juvenile SFRH biology, habitat use, and movement patterns is important because many animals shift patterns of movement and habitat use as they grow. These changes may reflect changing resource needs, life history strategies, intraspecific competition, or predator avoidance (Van Horne 1982, Hart 1983, Werner and Gilliam 1984, Blouin-Demers et al. 2007).

OBJECTIVES

The purpose of this study was to determine the seasonal movements and microhabitat use of adult and juvenile SFRH in the Tuckasegee and Oconaluftee rivers in western North Carolina. Specific objectives included (1) determining seasonal movement patterns and overall habitat use by juvenile SFRH; (2) potentially locate wild populations of juvenile SFRH; (3) determine seasonal linear movements and habitat use of adult SFRH in the Tuckasegee River.

METHODS

Study Sites

SFHR have been collected in the Tuckasegee River basin, and historically inhabited the Oconaluftee River system (USFWS 2010). To gain a better understanding of these populations our study was conducted in the Oconaluftee and Tuckasegee rivers of western North Carolina (Figure 1). The Oconaluftee River, a tributary of the Tuckasegee River, forms at the most eastern part of the Great Smoky Mountain National Park by the confluence of three streams: Kephart Prong, Kanati Fork, and Smith Branch. The Oconaluftee River is approximately 30 km long, has a maximum headwater elevation of 1,611 m, and drains an area of 477 km^2. In its headwaters, the Oconaluftee is a moderately steep gradient stream with large boulders, cobble, and cool fast moving water. Below the confluence of Bradley Fork, a large tributary, the gradient becomes less steep with smaller substrate creating plenty of riffle and run type habitats. Also, large boulders are present throughout creating deep pools for fish, such as the SFRH.

The Tuckasegee River begins in Jackson County, NC at the confluence of Panthertown and Greenland creeks. It is approximately 97 km long, has a maximum headwater elevation of 1,210 m, and drains an area of 1,696 km^2. It flows in a northwesterly direction into Swain County and through the center of Bryson City, North Carolina. The river passes around the Bryson City Island Park, where it then enters Fontana Lake. The Little Tennessee River is another tributary of Fontana Lake that contains SFRH. The Little Tennessee River originates in the headwaters of Rabun County, GA and flows northwest into North Carolina and into Tennessee until it meets with the Tennessee River. The Little Tennessee River is 217 km long and has a drainage area of 1,129 km^2.

Fontana Lake is a 4,410 ha reservoir impounded by Fontana Dam on the Little Tennessee River located in Graham and Swain counties in North Carolina. Fontana Dam is the tallest hydroelectric dam in the eastern United States (721 m long, and 146 m high). Its construction was begun in 1942 and completed in 1944. The lake forms part of the southern border of Great Smoky Mountains National Park and the northern border of the Nantahala National Forest. The lake is composed of 383 km of shoreline with steep banks and cliffs, and is approximately 27 km long.

Radio Telemetry

On August 8, 2011 USFWS personnel surgically implanted radio transmitters into 20 juvenile SFRH. The juveniles were spawned from roe and milt collected from wild adults sampled from the Little Tennessee River near Franklin, NC. Conservation Fisheries Inc. (CFI) “spawned” and provided early culture for the fish before the fingerlings were transported to Warm Springs National Fish Hatchery, Warm Springs, GA by the US Fish and Wildlife Service (USFWS). Warm Springs hatchery personnel reared and held these individuals until surgery. Experienced USFWS personnel conducted SFRH transmitter implantation surgeries on-site at Warm Springs hatchery. Due to a large number of mortalities, only 7 juveniles were transported to the release site to be used in this study.

Juvenile SFRH were held in tanks at Warm Springs Hatchery until surgery. A surgical station was set up on the day of surgery with an operating table, towels, and a lighted magnifying lens. Surgical instruments, PIT tags, and radio transmitters were disinfected and sterilized (Cidex®, Kalona, Iowa USA). PIT tags and transmitters were placed in petri dishes with 10ml of sterile saline until surgery.

Juveniles chosen for radio-tag implantation were removed from the holding tank with a net and placed in a 10 gallon aquarium with 100 mg/L MS-222 solution (an isomer of benzocaine). Individuals were kept in this solution until a loss of equilibrium and reduced opercular rate was achieved (usually 1-3 minutes). When an anesthetized individual displayed the symptoms of stage 4 anesthesia (Summerfelt and Smith 1990), fish were removed and placed on the operating table between moistened towels while a solution of 75 mg/L MS-222 was continuously rinsed over their gills during surgery.

For the insertion of the transmitters, scales were removed and cleared from the incision area with hemostats and forceps, and a topical antiseptic was applied (Betadine®, Samford, Connecticut USA) to the surgical area before incision. A 0.5 cm incision anterior to the pelvic girdle and offset 2 cm left of the ventral midline was made. This location for the incision and implantation was chosen to reduce damaging vital capillaries and internal organs of the fish. A sterilized Lotek nanotag-series transmitter (Lotek Wireless Inc., Ontario, Canada), along with a 12 mm passive integrated transponder (PIT) tag (Biomark, Inc.) was inserted into the body cavity. The size and model of the Lotek Nano Tag transmitter (transmitter series models NTC-3-2, 1.1g and NTC-4-2L, 2.1g) was based on the size of the juvenile fish and overall body weight (Winter 1996). These Lotek transmitters have a trailing antenna to maximize field range. Antennas were to coiled and inserted into the body cavity. But, after observing a large number of mortalities, we worried that the coiled antenna had caused torsional strain on the internal organs of the juvenile fish. To counter this affect the trailing antenna was shortened and allowed to exit the body wall. After insertion the incision was sutured and a small amount of water resistant adhesive was added to hold sutures closed. Fresh water was run over the gills of the SFRH until the individual began to recover from anesthesia. Fish were then placed into a 50 gallon aerated circular fiberglass tank and monitored until normal equilibrium and operculum rate were regained. Fish remained in these tanks until the start of the study. Surgery time took an average of 7 minutes and 13 seconds (6:20-8:38 min).

The seven surviving implanted juvenile sicklefin were packaged in coolers with an aeration system and were transported by US Fish and Wildlife Service (USFWS) and Cherokee Fisheries and Wildlife Management department (Eastern Band of Cherokee Indians, CFWM) personnel by truck from Warm Springs to the release site. Tagged juvenile fish were released into the Oconaluftee River at Island Park, in Cherokee NC, on September 9, 2011 with the advisement and assistance of personal from the CFWM.

To increase overall sample size and broaden the scope of the study, wild adult sicklefin were also tagged. Adult fish were captured by boat electrofishing. A team consisting of USFWS, NCWRC, and CFWM personnel captured seven adult individuals in the Tuckasegee River upstream of Bryson City, NC. Following capture, wet weight (g), water temperature (°C), location (UTM), and sex were recorded. Individuals from the USFWS personnel determined sex of adults by examining anal fins and caudal peduncle. Male SFRH have long angular anal fins and a narrower caudal peduncle compared to females, which have much shorter rounded anal fins and a thicker caudal peduncle (John Fridell USFWS, personal communication). SFRH transmitter implantation surgeries for adults were conducted on a portable surgical table, provided by USFWS personnel, on the stream bank following capture on October 12, 2011 by USFWS personnel. The same surgical procedure was followed for adults as with the juveniles. Adults were marked with a PIT tag in the muscle tissue near the base of the dorsal fin instead of inserting it into the body cavity as with the juveniles. Following initial recovery the implanted adults were transferred to an instream cage to ensure immediate post-surgery survival prior to release. Adults were monitored for 2 to 3 hours post-surgery. Adults were released back into the Tuckasegee River after they were fully recovered from surgery and anesthesia.

The seven juvenile and six adult SFRH were implanted with Loteck nanotag transmitters with a 12 h/d duty cycle and were tracked throughout seasons (Spawning-March 1 – April 30, Summer-Fall-May 1 – November 30, Winter-December 1-Febuary 28). Four juveniles were implanted with smaller transmitters (model NTC-3-2) that had approximately a 136 d lifecycle. These transmitters stopped transmitting on December 21, 2011. Three other juveniles and all adults were implanted with larger, 275 d life cycle transmitters (model NTC-4-2L). These models stopped transmitting in late July 2012. The transmitters were set at 150.950 MHz and each transmitter was assigned an individual pulsation "signature" code to allow identification of individuals. Fish were tracked on a weekly basis from the time of release, September 9, 2011, until early December 2011. From mid-December to the beginning of March, fish were located twice monthly in order to determine wintering habitat. To detect the initiation of spawning movement fish were tracked weekly from March 1st to mid to late March. At the end of March fish were tracked three to four days a week to follow spawning movements. Tracking continued twice monthly until late July 2012 when transmitters ceased transmitting. Most tracking was done by vehicle, enabled by the numerous roadways that parallel the Oconaluftee and Tuckasegee Rivers. A road antenna and a hand held Yagi antenna was used in tandem to track and locate fish. River sections that could not be monitored from the road were accessed by wading or boat. Once a radio transmitter signal was received the position of the fish was estimated using triangulation, and the geographic coordinates (UTM) were determined using GPS. When possible, visual confirmation of the tagged fish was established to verify the location, and ensure that we had located the tagged individual.

Microhabitat

Microhabitat conditions were recorded following Favrot (2009) to allow direct comparison with his study of adult sicklefin movement and habitat preference. Specific variables included distance to bank (m), depth (m), bottom velocity (m/s), mean column velocity (m/s), dominant substrate, cover type, distance to cover (m), occurrence of river weed, *P. ceratophyllum* (i.e., present or absent), habitat type, dissolved oxygen (mg/L), and temperature (°C).

Microhabitat variables were also measured at paired random locations in order to characterize overall habitat availability. Not all relocated fish points had a paired random point due to hazardous sampling conditions. Habitat use versus availability was determined using the methodology described in Lapointe et al. (2010). Each random location was determined by a simple coin toss to determine direction (upstream-heads or downstream-tails) from a relocated sicklefin location. The investigator traveled 100 m from that location within the river on that bearing, and if a shoreline or obstacle was encountered the direction was adjusted and travel continued until the distance was reached. The distance from the stream bank was randomly chosen beforehand through the use of a random number generator. These distances were selected to balance the avoidance of autocorrelation of microhabitat variables between paired samples with efficiency in the field (i.e., limiting travel time) (Lapointe et al. 2010).

For both microhabitat use and availability, depth was recorded to the nearest centimeter. A Swoffer flow meter (Model 2100, Seattle, Washington USA) was used to measure bottom and mean column velocity (m/s). Mean column velocity was measured in the water column at a depth of 60% from the surface (McMahon et al. 1996). Percent composition of dominant substrates was visually estimated and was classified based on a modified Wentworth particle size classification (Appendix C; Bovee 1986, Favrot 2009). Nearest dominant cover type was visually determined by establishing the presence or absence of cover and then determining the distance to the fish location. Cover types included coarse woody debris, fine woody debris, root wad, emergent aquatic vegetation, submersed aquatic vegetation, leaf litter, undercut bank, and boulder. No fish were observed associated with root wad, emergent aquatic vegetation, submersed aquatic vegetation, and undercut bank for cover, so these variables were excluded in data analysis. Cover types were considered associated with fish when the cover was 2 m or less from the fish location. Presence or absence of riverweed was determined for each fish location and was considered present if it occurred within 2 m of the fish location. Along with these variables habitat was determined by visual conformation as a run, riffle, or pool based on the stream morphology.

To monitor stream conditions throughout the course of the study temperature readings were recorded every 30 minutes in the Oconaluftee River using submersible temperature loggers (iBCod, Alpha Mach, Inc.). Four temperature loggers were attached with 16 gauge wire to 3/8” rebar, which was driven into the river bed. Temperature loggers were set out on September 16, 2011. Locations for temperature loggers were chosen based on recommendations from CFWM personnel. One temperature logger was located just above the release site for the juvenile SFRH, the second upstream of the release site near Raven Fork, the third about 4 river kilometers downstream of the release site, and the fourth about 8 river kilometers downstream of the release site, near the Ela community in Cherokee, NC. Due to heavy rains and high flow events 3 temperature gauges were lost and only one remained through the entirety of the study, which was downstream of the release site (UTM zone 17, 0290002E, 3927886N). Data from the temperature loggers were retrieved on a monthly basis throughout the experimental period except for the month of November due to high water. In the Tuckasegee River temperature loggers (StowAway Tidbit ®, Onset Computer Corp.) were programmed to record temperature at 15-minute intervals. The Tidbits were deployed at two locations in the Tuckasegee River on January 6, 2012. One logger was deployed at Barkers Creek (UTM zone 17, 2918401E, 3918075N) and one near Bryson City (UTM zone 2805001E, 3923671N) as advised by USFWS personnel. The loggers were attached to a loop of 3 mm (⅛”) wire rope cable. The loop was crimped with stainless steel sleeves. The tethered loggers were usually placed in a deep pool. The shore end of the cable was looped around an inconspicuous tree (or other permanent object), and again crimped with stainless steel sleeves. Data were retrieved on a monthly basis.

Data analyses

Linear range was calculated for the experimental period and seasonally for both juveniles and adults. Linear ranges were categorized as either upstream or downstream movement (i.e., directional). Characteristics of random microhabitat sites were compared with those of adult and juvenile SFRH locations to test for non-random use of habitats. Experimental period and seasonal microhabitat use data were compared to corresponding microhabitat availability data. During the fall and summer season a paired t-test comparing microhabitat use by juveniles to available habitat was used for all continuous variables (i.e., distance to bank, depth, bottom velocity, and mean column velocity), and a Fisher's exact test was performed on all categorical variables (cover, dominant substrate, presence of river weed, and habitat type). A paired t-test and a Fisher's exact test were used for the adult SFRH to determine habitat use verses availability for the experimental period. To compare the microhabitat difference between juvenile and adult SFHR during the summer and fall season a two sample t-test was used for all quantitative data and a Fisher's exact test was used for all qualitative data.

Statistical analyses were conducted using software package R 2.12.1 (R Development Core Team 2008) with an error rate (α) of 0.05 for all statistical tests.

RESULTS

Seven juvenile SFRH (mean total length of 164 mm, and mean wet weight of 41.4 g: Table 1) were released into the Oconaluftee River (Cherokee, NC) on 9 September 2011 but we stopped receiving a signal from one individual's transmitter (Fish 10) that day. On 12 October 2011, 7 adult SFRH (4 female, 3 male) collected from the Tuckasegee River above Bryson City, NC were each implanted with a radio transmitter and were returned to the Tuckasegee River the same day. Females had a mean wet weight of 164 g (Table 1), and the males had a mean wet weight of 184 g (Table 1). One male was deemed to be over-stressed and was released without performing a transmitter implant. Due to mortalities and the re-implantation of transmitters from one individual to another, length and weight were not recorded for some juveniles. Also, lengths for adults were not recorded.

The estimated linear range movements of SFRH revealed that there was a difference in movement among seasons. During the summer and fall season, juvenile SFRH stayed around the area near Island Park in the Oconaluftee River (the release site) until the middle of October (mean temperature 13.13 °C, 9.88 - 15.63 °C, Appendix D) when fish 23 and 26 began to move downstream. In late October and early November (mean temperature 9.24 °C, 5.38 - 12.0 °C, Appendix D) fish 27 began to move downstream. Fish 12 and 13 moved very little (mean 0.028 km, 0 - 0.046 km, Table 2) until their transmitters ceased operating. Fish 23 continued to move downstream in the Oconaluftee until it reached the Ela Dam. In early November, fish 23 crossed the Ela Dam and on downstream into the Tuckasegee River. It remained in the Tuckasegee River for the rest of the life of its transmitter between Kituwah fields (UTM zone 17, 0282229E, 3924326N) and Darnell Farms (UTM zone 17, 0282240E, 3924478N) (Appendix E). Fish 26 moved downstream (1.5 km, Table 2) from the release site in the Oconaluftee until the middle of November where it stayed in the Oconaluftee for the rest of the study. Fish 27 moved downstream in the Oconaluftee at the end of October and crossed the Ela Dam into the Tuckasegee River in mid-November, and continued to move downstream until late November (Table 2). It stayed in the Tuckasegee River about 2 kilometers from the mouth of the Tuckasegee over winter (Appendix E). In early to mid-March (mean temperature 9.69 °C, 5.62 - 13.95 °C, Appendix D), fish 27 began moving further downstream into the mouth of the Tuckasegee, where it stayed until its transmitter stopped (Appendix E). In summary: seasonal movements for juvenile SFRH were directed downstream, and began in mid-October and continued until late November. Afterward, juvenile movement rate dropped markedly (mid-December to late February) (mean temperature 5.32 °C min-max -0.625 – 9.75 °C, Appendix D). Movements began again in late winter and early spring (late February – early March) (mean temperature 9.00 °C, 5.18 - 12.7 °C). Only three individuals (Fish 23, 26, and 27) were implanted with longer lasting transmitters that continued to function over the winter and into summer and only juvenile fish 26 and 27 moved significant distances in early spring, so these results are not a good sample and may not be indicative of juvenile SFRH in general.

Adult SFRH were sexually dimorphic in their season migrations. Females remained near the area where they were captured in the Tuckasegee River (area between Kituwah fields and Darnell Farms) for the entirety of the experimental period, and moved little (mean 0.370 km, 0.001 - 3.124 km, Table 2). Males moved downstream during late fall and early winter, and then moved back upstream during very late winter, likely in preparation for spawning season (Appendix E). Males stayed near the tagged females during the summer and fall season, moving only short distances over this time period (<0.750 km, Table 2), but their locations were distinctively separate from the females. Females stayed in close proximity to each other and moved minimally during the summer and fall season (<2.600 km). Males began moving downstream from their release site in mid to late November (mean temperature 7.51 °C, 4.5 - 11.6 °C, Appendix D) and moved more than 14 km into Fontana Lake. Males stayed in Fontana Lake over winter (Appendix E), and began to move upstream into the Tuckasegee River in late February (average temperature 8.73 °C, 5.18 - 11.47 °C, Appendix D) and continued moving upstream during early March (average temperature 9.04 °C, 5.62 - 12.78 °C, Appendix D). Males returned to and remained near the tagged females during the spawning season (>14 km, Table 2). After spawning season males separated themselves from the females and stayed in areas where they were located the previous summer and fall season.

Analysis of microhabitat for juvenile SFRH during the summer and fall season revealed preferred habitat versus available habitat. During the summer and fall season observed microhabitat use (distance to bank, depth, bottom velocity, mean velocity, dominant substrate, cover, the presence of river weed, and habitat) differed significantly from paired random locations (Table 3). Juveniles used areas that were farther from the river bank (mean 10.3 m, 1.6 - 20 m, Figure 2) and at greater depths (mean 1.1 m, 0.5 – 2.0 m) than paired random points. They also used areas with slower bottom velocity (mean 0.03 m/sec, 0 - 0.27 m/sec) and mean column velocity (mean 0.09 m/sec, 0-0.6 m/sec) (Table 3, Figure 2) than paired random points. Dominant substrate occupied by juveniles was mainly boulders (42% of relocations, Figue 3, p=0.0067), and provided cover (47% of relocations, p<0.0001). Riverweed was usually absent (87% of relocations, p=0.049) compared to paired random locations. Juveniles used areas in the river that were either a run (64% of observed relocations) or pool (36% of observed relocations) (Figure 3, p<0.0001). Distance to cover was not analyzed due to so few measurements.

Analysis of microhabitat data revealed preferred habitat for adult SFRH. When compared to paired random locations, microhabitat use (distance to bank, depth, mean velocity, dominant substrate, the presence of river weed, and habitat) differed significantly (Table 4), but bottom velocity and cover type did not. Adults used areas that were farther from the river bank (mean 15.9 m, 7.8 – 20.0 m) with many distances being greater than 15 meters, often near the main river channel. These areas are some of the deepest areas in the river, and were heavily used by adults (mean 1.9 m, 0.7 – 6.4 m). While adults were often observed at bottom velocities that were slower than their paired random location (mean 0.2 m/s, 0.06 – 0.78 m/s), the mean difference was not significantly different. Mean column velocity (mean 0.52 m/s, 0.19 – 0.95 m/s) did differ significantly at these same locations with the adults choosing slower mean column velocity than that available (Table 4, Figure 4). Coarse substrate such as gravel and small cobble, which dominate the main river channel, was seen as the dominant substrate. Also bedrock was heavy utilized (N=21) as a dominant substrate. Adults rarely used cover (N=77, p=0.1047). Adult SFRH favored areas that contained riverweed over available areas (p=0.009), most likely for feeding purposes. Adults heavily use run type habitats, or the main river channel (Figure 5, p<0.0001).

Comparisons of juvenile and adult SFRH relocations for the summer and fall season (when both transmitter types were operating) revealed differences in habitat use (Table 5, Figures 6 and 7). Juveniles used areas that were closer to the bank (mean 10.31 m, 1.56 – 20.0 m) than that of adults (mean 15.8 m, 8.9 – 20.0 m). Depth usage was not significantly different between juveniles and adults. Bottom velocity used by juveniles (mean 0.03 m/sec, 0 - 0.26 m/sec) was much slower than that used by adults (mean 0.14 m/sec, 0 –0.59 m/sec). Mean water velocity used by juveniles was also found to be significantly different than that of adults. Juveniles used slower moving current (mean 0.094 m/sec, 0 - 0.57 m/sec) while adults used swifter moving currents (0.31 m/sec, 0.01 - 0.90 m/sec). Juveniles were observed in pool and run type areas, whereas adults were found primarily in run type habitats (Figure 7, $p<0.001$), neither juveniles nor adults were observed to use riffle habitats. Juveniles used mainly small cobble and large boulders, while adults used bedrock and gravel ($p=0.010$). Adults also heavily used bedrock where riverweed grew. Adults preferred areas with riverweed more than juveniles ($p<0.0001$). Cover was almost always present during the summer and fall season for juveniles (boulders crevice cover) compared to adults who preferred no cover (Figure 7, $p<0.001$).

DISCUSSION

Juvenile and adult SFHR prefer different types of riverine habitat. Juvenile SFRH prefered areas at moderate depths (1.5 - 2 m), slow moving currents, and are in close proximity to cover – usually large boulders. These areas were characteristic of pool type habitats. Adult SFRH preferred stream locations that were near the middle of the river channel and that provided run type habitats. These areas are usually dominated by fine cobble to coarse substrate, are in close proximity to areas with river weed. These areas have a fast moving thalweg, which may provide adequate protection for these large riverine fish.

Juvenile SFRH in this study were seen to move towards lentic waters (Lake Fontana) in fall. Current thought is thought that juveniles may migrate to lower river reaches and reservoirs shortly after emergence (Jenkins 1999, Favrot 2009). Findings suggest juvenile SFRH are rare in streams and have been observed and collected in reservoirs at higher frequencies than adults. Juveniles have been collected near dams, river mouths, and within tributary arms (Jenkins 1999). The juvenile study subjects in this study moved downstream, and one individual migrated all the way to Fontana Lake (>15 km). It seems that deep and slow moving areas may be needed as part of the juvenile SFRHs life cycle. If juvenile SFRH need deep, low-velocity type habitats as part of their life cycle it's not known when juveniles transition and begin to occupy more lotic type habitats, or why juveniles prefer or require such types of habitat. Many stream fish change their habitat preference during their life history stages due to a combination of light, temperature, or flow (Power et al. 1988). By using different stream reaches and different habitats throughout the river system during different life history stages, the vulnerability of the population as a whole to localized disturbances may be reduced (Statzner 1987, Power et al. 1988).

Water velocity was important with regards to habitat choice for both juveniles and adults. Juveniles preferred areas with slow moving currents. Weyers et al. (2003) showed that juvenile robust redhorse grew better and had a higher survival rate in slower laminar flows, than individuals who were exposed to fast moving pulsed current. Freeman et al. (2001) reported similar findings with multiple species of juvenile fish. They found that the greatest abundance of juvenile fish were around microhabitats with reduced water flow that was unregulated. The low survival and reduced growth of these individuals may be related to the increase in the bioenergetic costs needed to maintain their position in a “spatially dynamic rearing habitat” (Ruetz and Jennings 1997). Adults preferred river areas that maintained a swift thalweg, near the middle of the river. These areas with swift current and coarse substrate were usually associated with the presence of riverweed. During heavy flow and high water events, such as after a rain or generation events, adult SFRH moved to downstream areas with less water velocity, which were closer to the river bank, shallower in depth, and near cover. This may be to reduce energetic cost attributed in maintaining their position in swifter currents. Also, they may move to avoid finer particulates in the main river channel that are stirred up during high flow events. In addition, they may move to these once inaccessible areas for foraging on newly available habitat that may support macroinvertebrate communities.

Logan (2003) showed that both water quality and food availability are closely related to habitat selection for a riverine fish. Large substrate with riverweed (*P. ceratophyllum)* seems to be the main foraging habitat for SFRH. Riverweed can be found in the rivers of the eastern U.S., (Philbrick and Novelo 1995, Hutchens et al. 2004), and thrives in open canopy rapids (Everitt and Burkholder 1991, Hutchens et al. 2004), of many of the streams and rivers found in the Little Tennessee basin. Nearly 55 percent of all adult relocations were associated with riverweed (*Podostemum ceratophyllum).* During summer and into early fall, adults were located foraging near bedrock with the presence of riverweed in the majority of cases. SFRH may be a specialist in the riverine system and may exclusively feed over riverweed beds. Macroinvertebrates are the main food source for SFRH and riverweed significantly enhances the abundance of benthic macroinvertebrate communities (Grubaugh et al. 1997, Hutchens et al. 2004). The high densities of stream invertebrates in *P. ceratophyllum* mats serve as a valuable prey resource for benthos-feeding fish, such as the SFRH. Grubaugh et al. (1997) showed that riverweed was more abundant in the lower reaches of the tributaries in the Little Tennessee Basin than in upper reaches, and Hutchens et al. (2004) observed many redhorse suckers foraging in *P. ceratophyllum* beds while they were sampling for riverweed in Little Tennessee River basin. Without the presence of *P. ceratophyllum* in stream reaches SFRH may not occupy these areas due to the lack of available resources. They will move to areas that provide these resources. Efforts to maintain *P. ceratophyllum* mats will greatly benefit the SFRH and other aquatic species.

I found a sexual dimorphism in movement patterns between male and female adult SFRH. Males in this study made long seasonal migrations to spawning areas in late winter and from spawning areas during late fall, while females remained stationary in the same river stretch near spawning areas throughout the year and did not make any large-scale movements. Evidence is accumulating that some individual redhorses or populations of redhorse are largely sedentary. They may spawn in home-range runs or move locally to join breeding fish congregations from within short reaches that have been inhabited all year (Funk 1957, Jenkins 2005). This population of female SFRH may not make spawning migration, or may skip migration from year to year. Skipped spawning migration or spawning omission has been widely seen for migratory fish (Rideout et al. 2005, Secor 2008, Favrot 2009). This may be to increase future reproductive output, or decrease the chance of mortality during certain unfavorable years (Jorgensen et al. 2005).

Water temperature may trigger seasonal migrations for SFRH. Water temperature has been linked with the initiation of upstream spawning migration for many sucker species, such as, the robust redhorse (*Moxostoma robustum*) (Grabowski and Isely 2006), northern hog sucker (*Hypentelium nigricans*) (Matheney and Rabeni 1995), razorback sucker (*Xyrauchen texanus*) (Modde and Irving 1998), and the shorthead redhorse (*Moxostoma macrolepidotum*) (Sule and Skelly1985). Male SFRH in this study began upstream spawning movement at water temperatures of approximately 8.7 °C. Our study population seemed to migrate to spawning areas earlier than seen by Favrot (2009) in the Hiwassee River drainage. A study by Huber and Bengston (1999) showed that a uniform stimulus, such as photoperiod, may invoke physiological changes that prepare fish for spawning. An analysis by Favrot (2009) looked at the maturation rate in spawning SFRH in 2006 and 2007, and found that the percent tubercle development was similar in both years despite considerably different water temperatures between years. This may show that water temperature may not be the most vital component contributing to physiological changes that prepare fish for spawning, and other constant physical factors may influence spawning migration of fish and redhorses.

SFRH, along with other redhorse species (robust redhorse, Grabowski and Isely 2006, and greater redhorse, Bunt and Cooke 2006), seem to have a high degree of fidelity and specificity to both spawning sites and home ranges. Juveniles may imprint on the stretch of river where they were hatched and resided during fingering stages until they make downstream migrations. With the river systems that support SFRH having numerous dams along their waterways, juveniles may cross these impediments as they move downstream, but are unable to cross back over these obstacles when and if they move back upstream. This became a concern in our study because juveniles crossed the Ela Dam and migrated downstream into the Tuckasegee River and Fontana Lake. These individuals will be unable to make the return visit over the dam to spawn in the Oconaluftee. Barrier removal to increase river connectivity has become a popular strategy to assist in protecting and maintaining aquatic species in North America in recent years (Cowx and Welcomme 1998, Stanley and Doyle 2003). Dams are frequently implicated as causes of population decline and extirpation of some freshwater fish (Allan and Flecker 1993). Dams along the Tuckasegee River and it's tributaries inhibit the sicklefin's movement. The ability to move about stream environments is important to the survival and reproduction of fishes, particularly catostomids which are regarded as migratory for reproductive purposes (Meyer 1962, Curry and Spacie 1984, Jenkins 1999). The level of fidelity that redhorses show to a home river stretch is not yet known, but in this study and others (Grabowski and Isely 2006, Bunt and Cooke 2006, Favrot 2009), redhorse species returned to specific river sections for spawning.

Like all recovery and restoration efforts of any species, diligence and consistency are a necessity. Knowing habitat requirements and facilitating the ability of individuals to access these areas for all life stages is critical for implementing sound management practices. A combination of these approaches, applied in an adaptive management framework will do much to safeguard catostomid diversity, including SFRH in the southeastern United States.

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Table 1. Characteristics of radio tagged SFRH studied in the Tuckasegee River Basin, North Carolina.

Code	Age	Sex	Total Length (mm)	Weight (g)	Tagging Date	Number of relocations
10	Juvenile	NA	NA	NA	8/7/2011	1
12	Juvenile	NA	152	38.0	8/7/2011	16
13	Juvenile	NA	NA	NA	8/7/2011	5
16	Juvenile	NA	NA	NA	8/7/2011	1
23	Juvenile	NA	175	52.6	8/7/2011	32
26	Juvenile	NA	160	35.6	8/7/2011	30
27	Juvenile	NA	168	39.3	8/7/2011	29
20	Adult	Female	NA	125.0	10/12/2011	24
21	Adult	Female	NA	202.0	10/12/2011	3
24	Adult	Female	NA	211.0	10/12/2011	23
25	Adult	Female	NA	119.0	10/12/2011	23
28	Adult	Male	NA	163.0	10/12/2011	14
29	Adult	Male	NA	204.0	10/12/2011	17

Table 2. Distances moved for radio tagged SFRH for experimental period and seasonally. Experimental period refers to the time span from release until the transmitter could no longer be detected.

Fish Number	Experimental Period (km)	Spawning Season (km)	Summer-Fall (km)	Winter (km)
12				
Mean	0.02	NA	NA	NA
Min-Max	0-0.046	NA	NA	NA
13				
Mean	0.023	NA	NA	NA
Min-Max	0.005-0.046	NA	NA	NA
23				
Mean	0.11	NA	NA	NA
Min-Max	0.046-0.48	NA	NA	NA
26				
Mean	0.13	0.017	0.15	0.19
Min-Max	0-1.51	0-0.04	0-1.51	0.007-0.75
27				
Mean	1.13	0.08	1.05	1.44
Min-Max	0-15.56	0.08-0.08	0-15.56	0.001-6.39
20				
Mean	0.18	0.078	0.242	0.218
Min-Max	0.002-0.71	0.002-0.29	0.003-0.71	0.009-0.67
21				
Mean	2.44	NA	NA	NA
Min-Max	1.67-3.21	NA	NA	NA
24				
Mean	0.26	0.04	0.34	0.35
Min-Max	0.004-0.55	0.004-0.13	0.09-0.46	0.06-0.55
25				
Mean	0.48	0.88	0.48	0.07
Min-Max	0-2.97	0-2.97	0.004-2.6	0.01-0.19
28				
Mean	2.63	3.2	0.27	3.83
Min-Max	0.008-12.17	0.008-12.77	0.14-0.4	0.05-12.22
29				
Mean	2.43	2.36	0.33	5.36
Min-Max	0.005-14.88	0.01-14.04	0.005-0.74	0.43-14.88

Table 3. Comparison of quantitative habitat measures for observed juvenile fish and paired random locations within 100 m for the summer and fall period (paired t-test).

	Mean Difference	SE	t	df	P
Distance to nearest bank (m)	2.64	0.81	3.24	34	0.0026
Depth (m)	0.61	0.07	8.20	34	<0.0001
Bottom Velocity (m/s)	-0.58	0.06	-10.42	34	<0.0001
Mean Column Velocity (m/s)	-0.96	0.10	-10.12	34	<0.0001

Table 4. Comparison of quantitative habitat measures for observed adult fish and paired random locations within 100 m for the experimental period (paired t-test).

	Mean Difference	SE	t	df	P
Distance to nearest bank (m)	3.42	1.03	3.32	34	0.0021
Depth (m)	0.51	0.08	6.63	32	<0.0001
Bottom Velocity (m/s)	-0.21	0.11	-1.99	33	0.0548
Mean Column Velocity (m/s)	-0.47	0.17	-2.81	33	0.0082

Table 5. Comparison of quantitative habitat measures for observed juvenile and adult fish for the fall and summer period (two-sample t-test).

	Mean Difference	SE	t	df	P
Distance to nearest bank (m)	-5.59	1.05	-7.24	96	<0.0001
Depth (m)	-0.08	1.83	-1.04	96	0.1511
Bottom Velocity (m/s)	-0.11	0.13	-5.27	96	<0.0001
Mean Column Velocity (m/s)	-0.21	0.38	-5.68	96	<0.0001

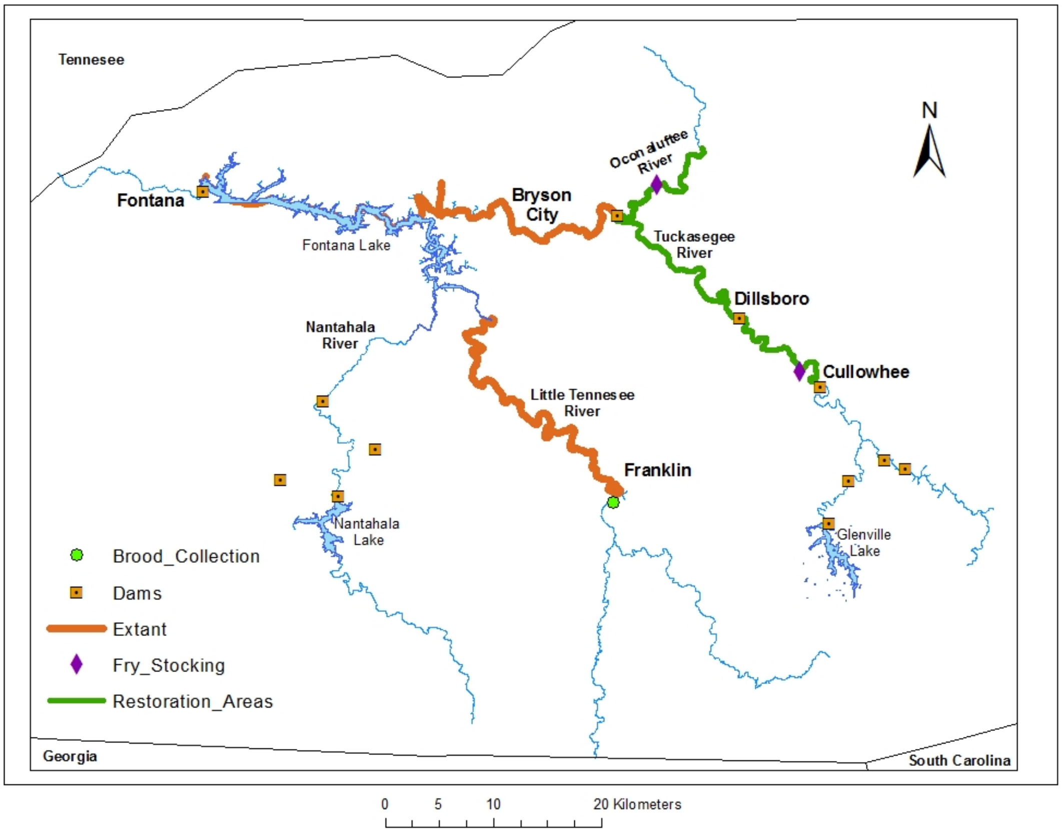


Figure 1. Map showing extant populations and restoration areas for the sicklefin redhorse in the Tuckasegee River Basin in western North Carolina.

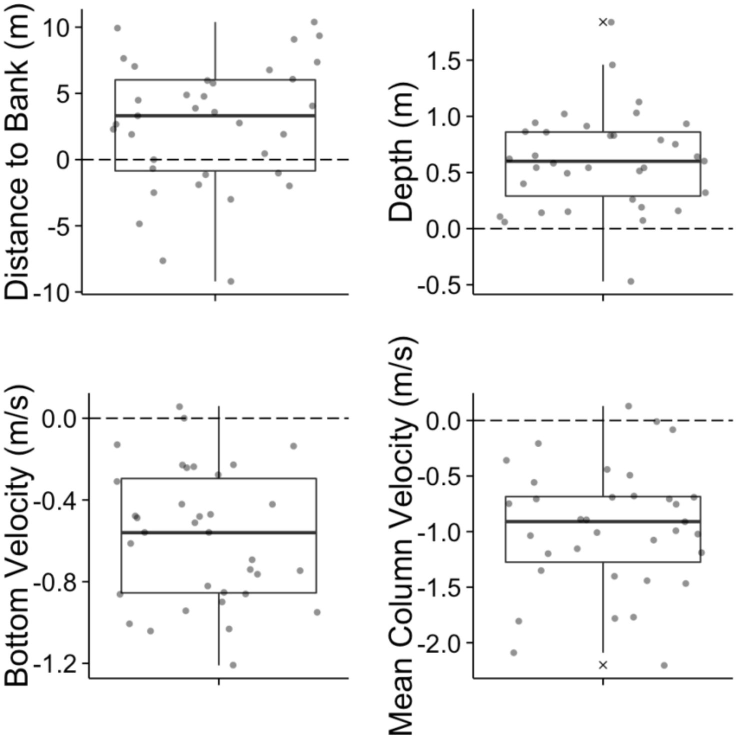


Figure 2. Boxplots of differences between quantitative habitat measures for observed juvenile fish and paired random locations within 100 m. The dashed horizontal line represents the null hypothesis of no difference and dots (dithered to enhance visibility) represent each observed difference.

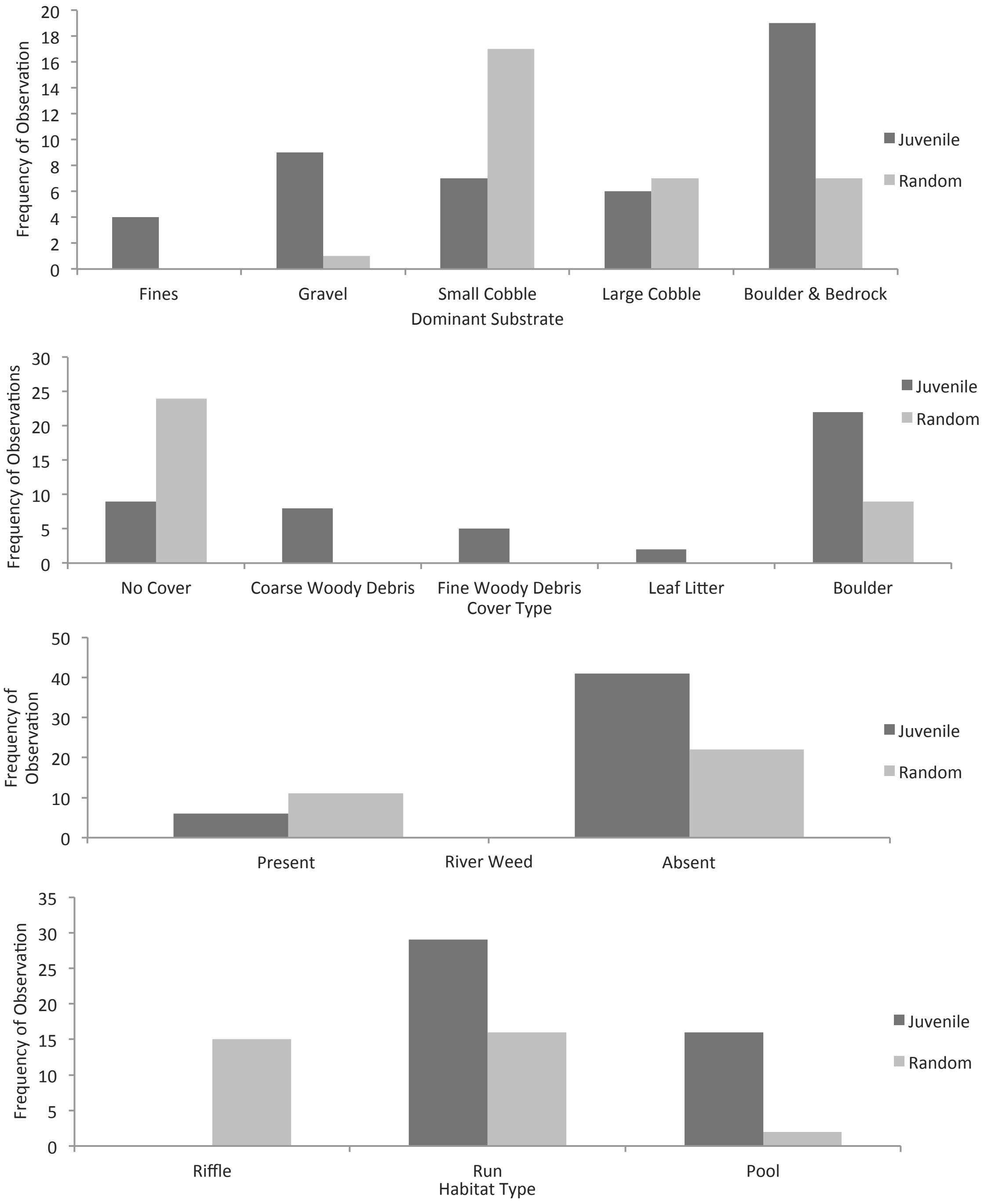


Figure 3. Bar graphs of differences between qualitative habitat measures for observed juvenile fish and paired random locations within 100m during the summer to fall period.

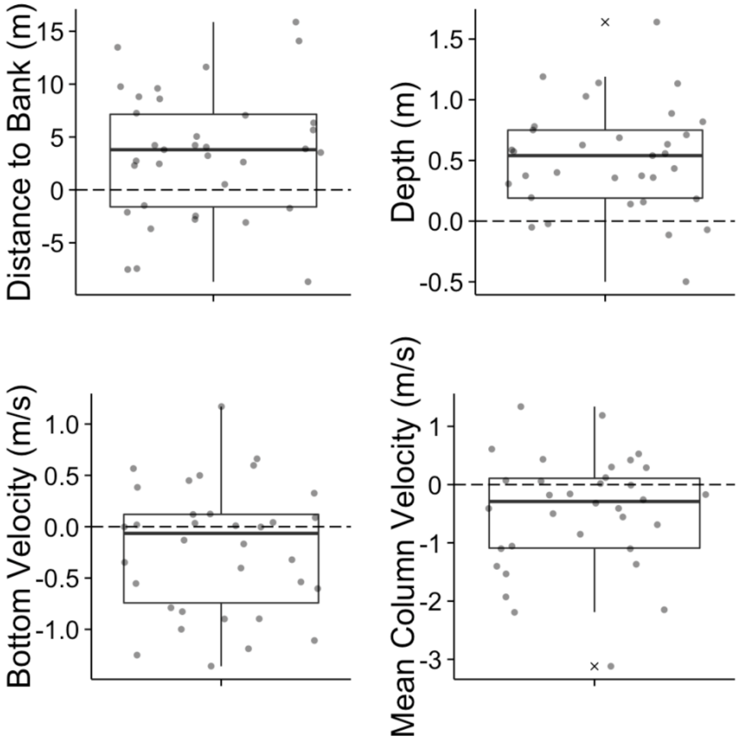


Figure 4. Boxplots of differences between quantitative habitat measures for observed adult fish and paired random locations within 100 m over the entire experimental period. The dashed horizontal line represents the null hypothesis of no difference and dots (dithered to enhance visibility) represent each observed difference.

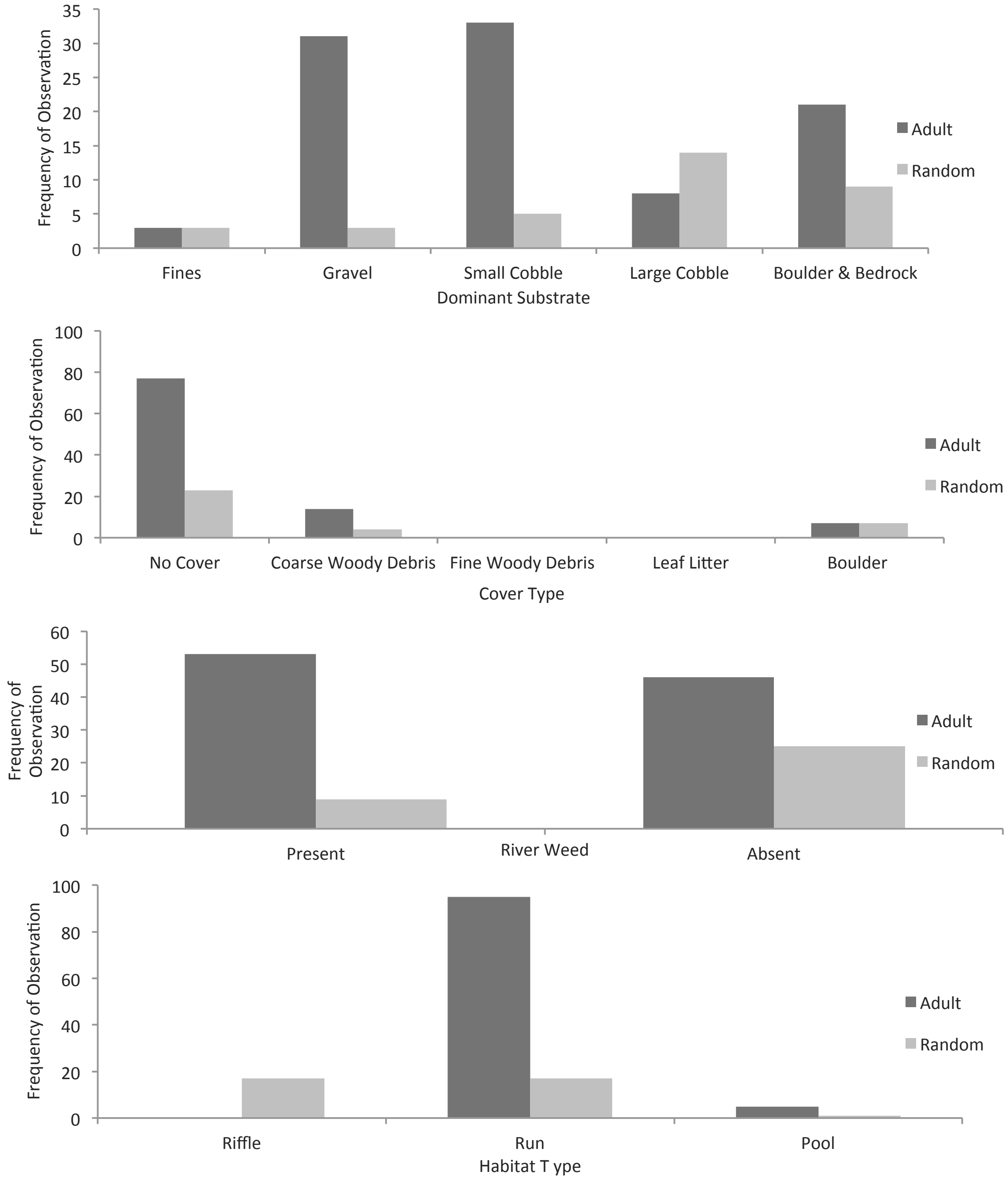


Figure 5. Bar graphs of differences between qualitative habitat measures for observed adult fish and paired random locations within 100 m over the entire experimental period.

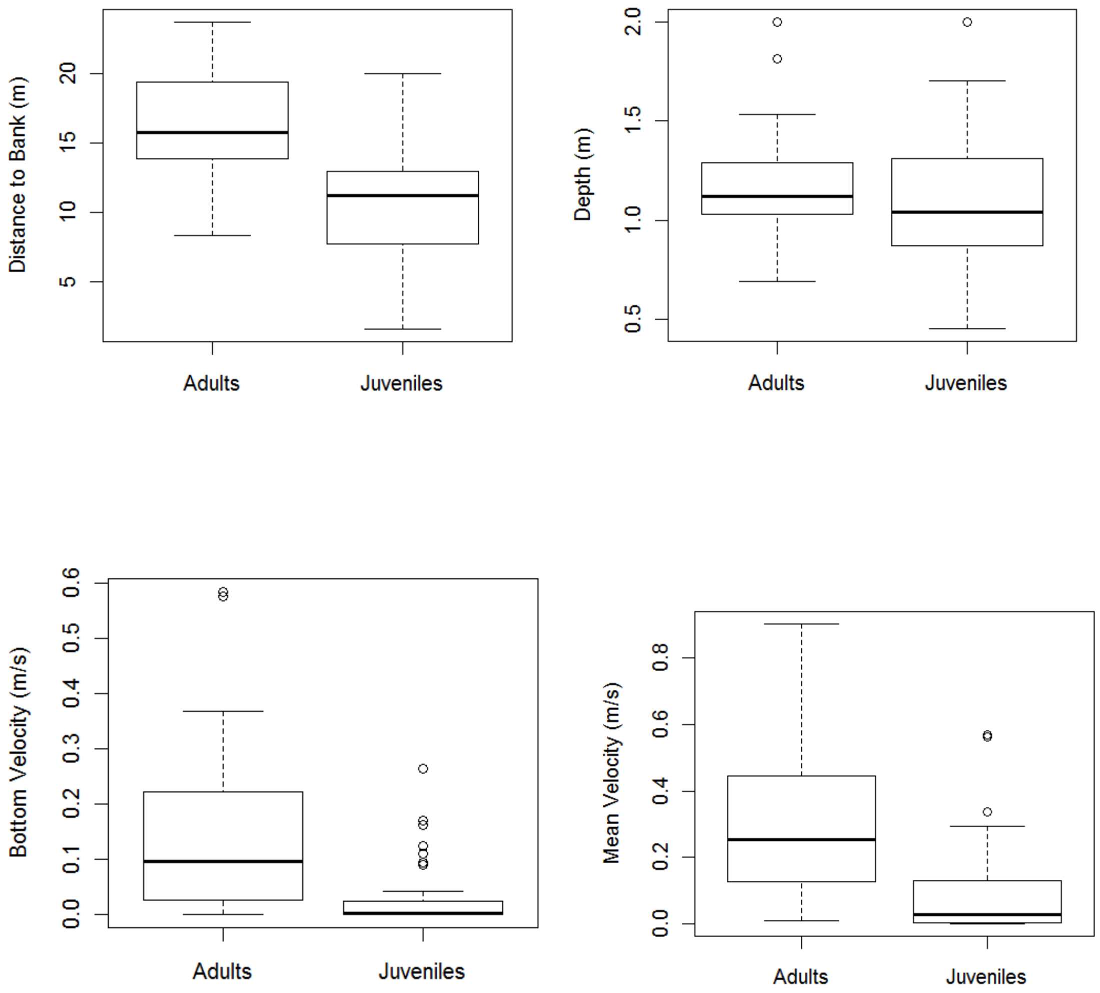


Figure 6. Boxplots of differences between quantitative habitat measures for observed adult and juvenile fish for the summer to fall period.

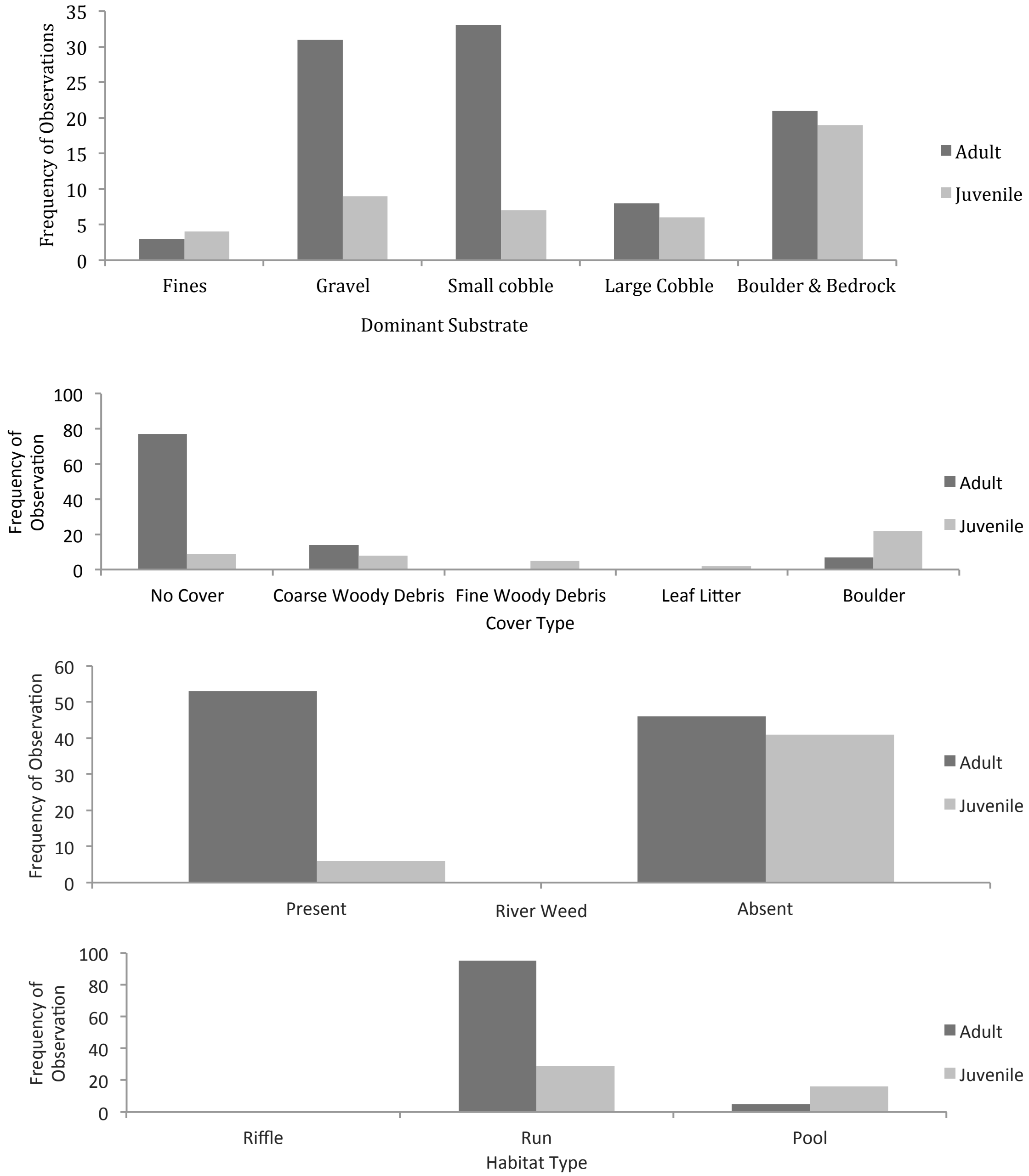


Figure 7. Bar graphs of differences between qualitative habitat measures for observed adult and juvenile fish over the summer and fall period.

Appendix A. Summarized microhabitat use and availability for the Oconaluftee River.

Variable and statistic	Experimental period	Spawning	Summer-Fall	Winter	Available
Temperature (C^{o})					
N	59	8	40	13	34
Mean	12.6	13.64	14.5	6.8	15.1
SE	0.53	1.18	0.53	0.5	0.52
Min-max	-0.5 – 20.7	7.9 – 16.9	7 – 20.7	-0.5 – 11.6	-0.5 – 20.7
Dissolved oxygen (mg/L)					
N	59	8	40	13	34
Mean	10.08	9.72	9.67	11.45	9.99
SE	0.1	0.29	0.19	0.39	0.17
Min-max	7.52 – 13.89	8.42 – 11.02	7.52 – 13.89	8.71 – 12.8	8.42 – 12.62
Distance to bank (m)					
N	60	8	40	11	34
Mean	10.04	12.42	9.81	8.91	6.77
SE	0.47	0.58	0.57	1.35	0.72
Min-max	1.56 – 20	9.36 – 14.55	1.56 – 17.12	5.12 – 20	0.15 – 16.4
Depth (m)					
N	60	8	40	11	34
Mean	1.17	1.11	1.11	1.49	0.46
SE	0.06	0.13	0.06	0.18	0.05
Min-max	0.45 – 2	0.84 – 2	0.45 – 2	0.68 – 2	0.14 – 1.45
Bottom velocity (m/s)					
N	59	8	40	11	34
Mean	0.03	0.11	0.01	0.05	0.2
SE	0.007	0.03	0.005	0.015	0.02
Min-max	0 – 0.23	0.03 – 0.23	0 – 0.15	0 – 0.14	0 – 0.39
Mean velocity (m/s)					
N	59	8	40	11	34
Mean	0.13	0.28	0.07	0.28	0.38
SE	0.02	0.06	0.014	0.08	0.04
Min-max	0 – 0.67	0.04 – 0.56	0 – 0.31	0 – 0.67	0 – 1.2
Dominant substrate					
N	60	9	40	11	34
Mode	LB	VCG & LC	LB	LB	SC
SE	0.47	0.73	0.53	1.37	0.28
Min-max	Clay – Bedrock	FG – LB	Clay – Bedrock	Sand – LB	CG – Bedrock
Cover					
N	113	36	78	20	34
Mode	Boulder	No cover	Woody	Boulder	No cover
Distance to cover (m)					
N	43	1	37	2	30
Mean	2.58	1.81	2.87	0	0.39
SE	0.44	NA	0.49	0	0.27
Min-max	0 – 9.86	1.81 – 1.81	0 – 9.86	0 – 0	0 – 7.81
River weed					
N	85	10	65	11	34
Percent (%)	10.59	0	9.23	27.27	29.4

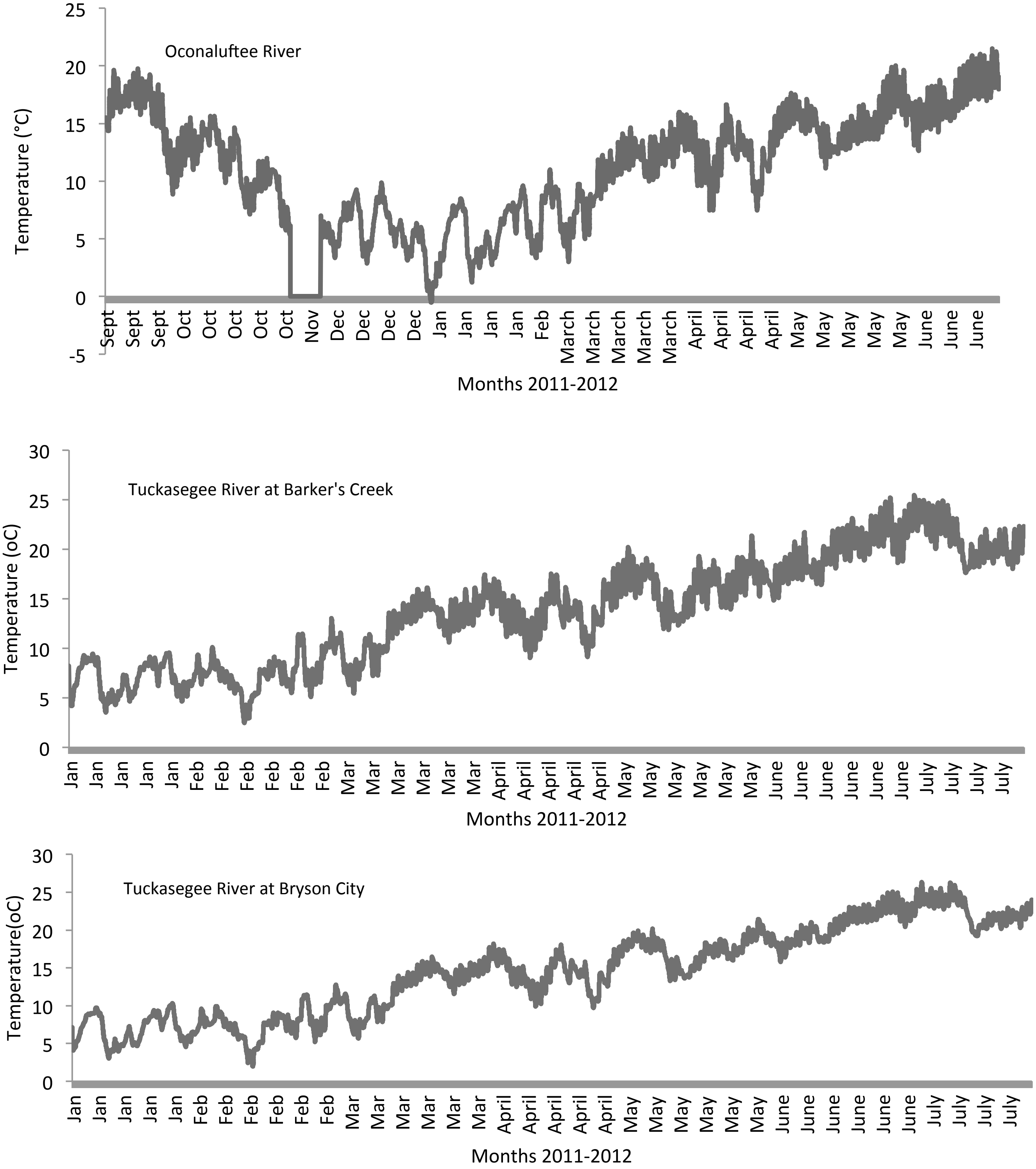
Appendix B. Summarized microhabitat use and availability for the Tuckasegee River.

Variable and statistic	Experimental period	Spawning	Summer-Fall	Winter	Available
Temperature (C^o)					
N	103	33	33	36	36
Mean	11.63	14.43	14.63	6.46	12.84
SE	0.49	0.57	0.73	0.31	0.78
Min-max	2.4 – 20.5	10.8 – 19.2	8.5 – 20.5	2.4 – 11.6	5.3 – 19.2
Dissolved oxygen (mg/L)					
N	101	33	33	34	36
Mean	10.32	9.86	9.59	11.53	10.22
SE	0.16	0.16	0.28	0.25	0.24
Min-max	7.73 – 13.67	8 – 11.49	7.73 – 13.67	8.71– 12.86	7.43 – 12.86
Distance to bank (m)					
N	98	33	32	31	36
Mean	15.76	14.96	17.18	15.87	11.71
SE	0.37	0.64	0.68	0.68	0.73
Min-max	7.81 – 23.7	8.32 – 20	8.94 – 23.7	7.81 – 20	3.93 – 20
Depth (m)					
N	97	32	32	33	35
Mean	1.41	1.17	1.22	1.85	1.40
SE	0.07	0.06	0.04	0.17	0.64
Min-max	0.69 – 6.4	0.69 – 2	0.79 – 2	0.97 – 6.4	0.08 – 2.3
Bottom velocity (m/s)					
N	88	28	32	28	35
Mean	0.18	0.26	0.10	0.19	0.24
SE	0.01	0.03	0.02	0.01	0.03
Min-max	0 – 0.59	0.06 – 0.59	0 – 0.78	0.06 – 0.35	0 – 0.64
Mean velocity (m/s)					
N	88	28	32	28	35
Mean	0.41	0.52	0.27	0.46	0.55
SE	0.02	0.04	0.04	0.03	0.05
Min-max	0 – 0.95	0.19 – 0.95	0 – 0.78	0.21 – 0.69	0 – 1.43
Dominant substrate					
N	98	33	32	33	35
Mode	VCG	SC	SC	VCG	LC
SE	0.22	0.36	0.35	0.34	0.44
Min-max	Sand – Bedrock	CG – Bedrock	CG – Bedrock	Sand – MB	Silt – Bedrock
Distance to cover (m)					
N	48	9	3	3	5
Mean	0.87	1.26	4.22	5.84	3.7
SE	0.27	0.14	2.15	0.58	1.59
Min-max	0 – 8.51	0.67 – 1.76	1.79 – 8.51	4.77 – 6.79	0.82 – 9.68
River weed					
N	99	33	32	33	37
Percent (%)	54.54	42.42	62.5	54.54	24.32

Appendix C. Categories used to estimate dominant substrate size for all radio-tagged fish relocations and habitat availability survey points. Categories are based on a modified Wentworth scale (Bovee 1986, Favrot 2009).

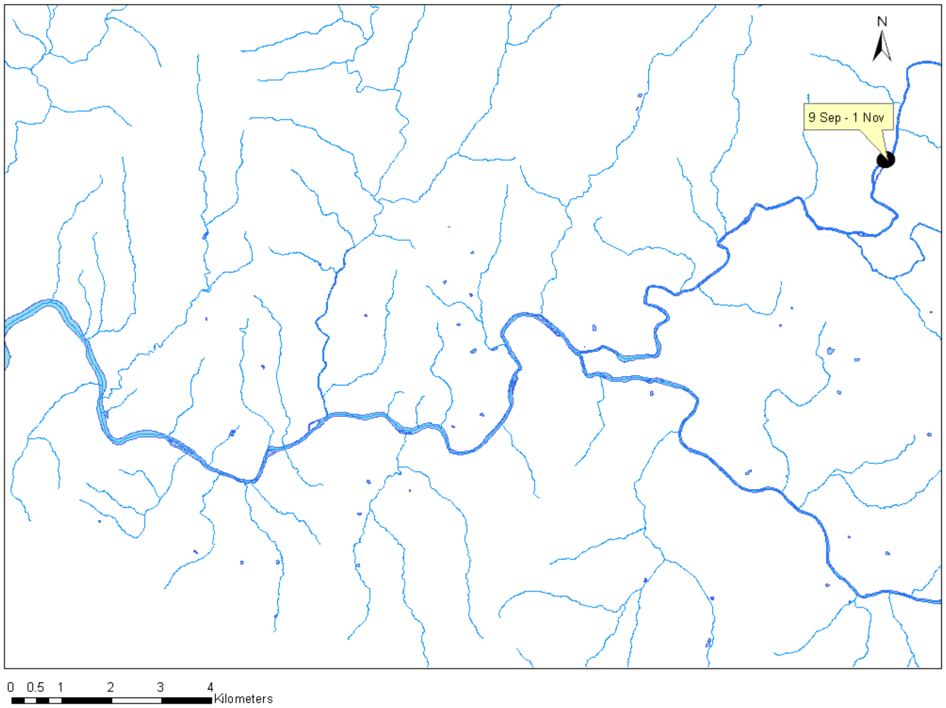
Categories	Particle size (mm)
Fine particulates	<0.004-8
Gravel	8-64
Small cobble	64-128
Large cobble	128-256
Boulders and Bedrock	256>1024

Appendix D. Temperature recordings for Oconaluftee River, Cherokee, NC (UTM zone 17, 0290002E, 3927886N), and the Tuckasegee River at Bryson City, NC (UTM zone 17, 2805001E, 3923671N) and at the confluence of Barkers Creek. (UTM zone 17, 2918401E, 3918075N).

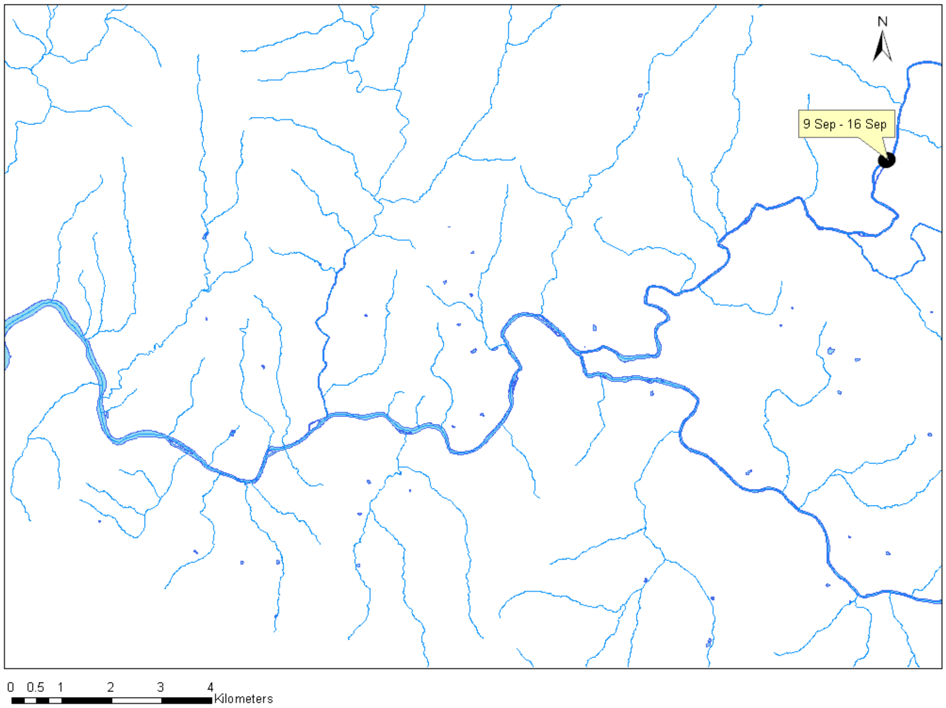


Appendix E. A series of maps showing point relocations and dates for each radio-tagged fish.

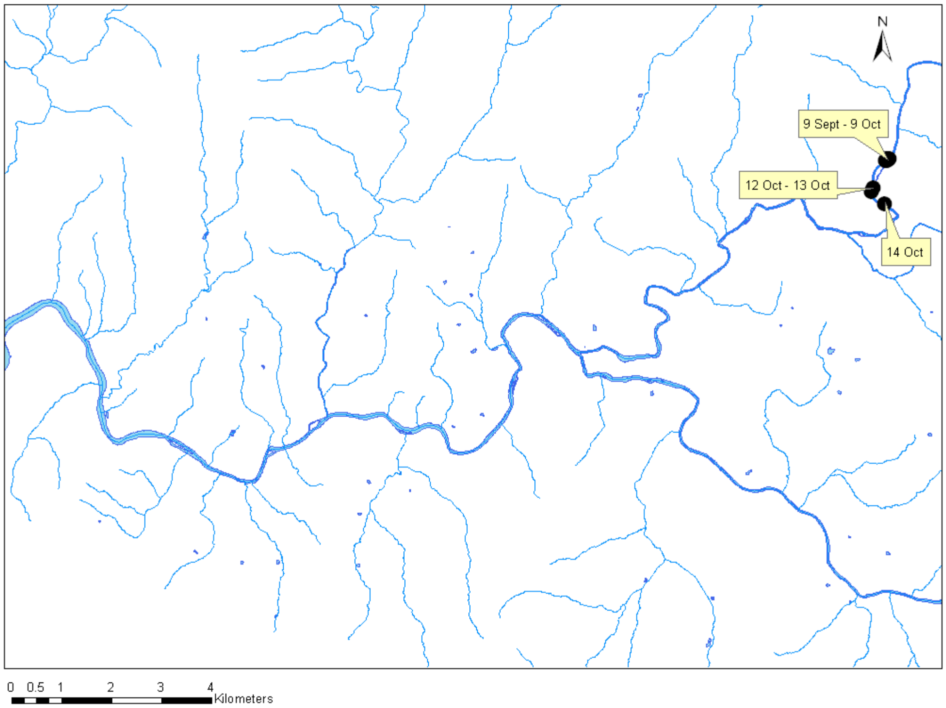
Fish 12



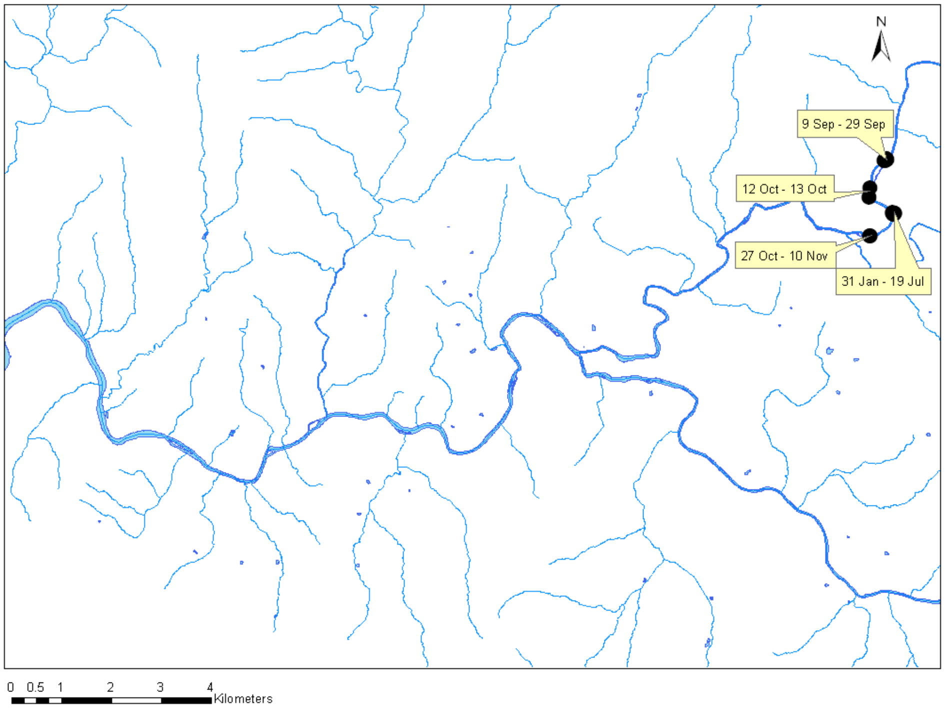
Fish 13



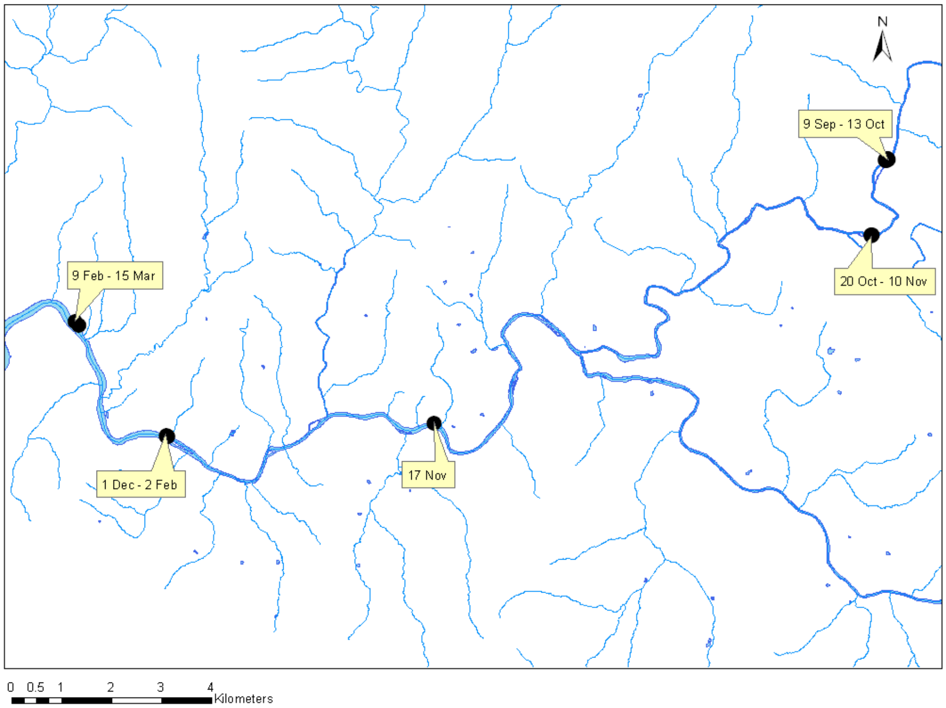
Fish 23



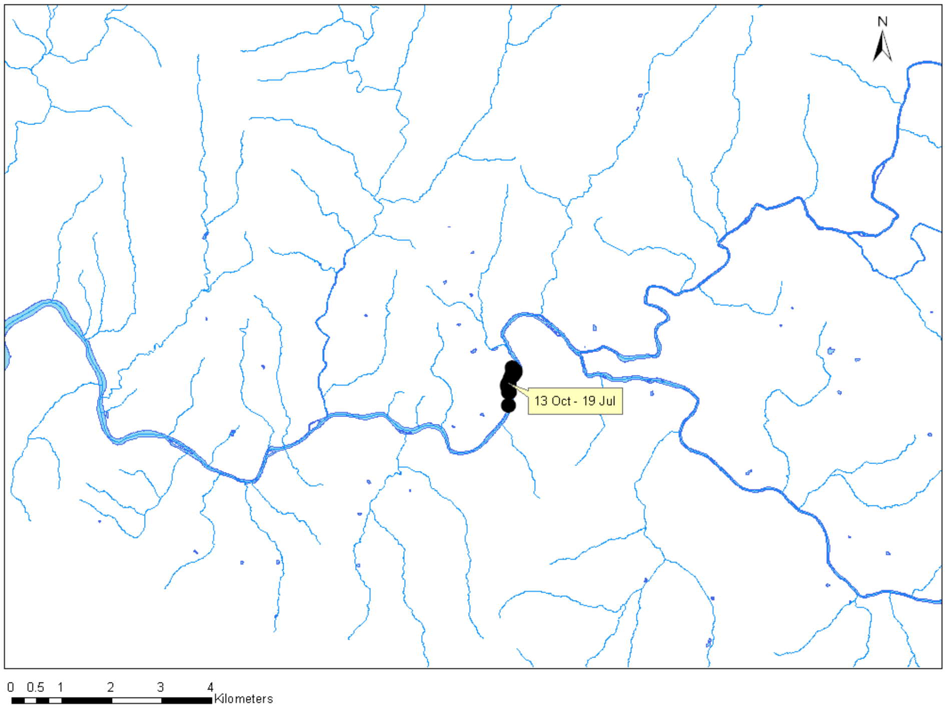
Fish 26



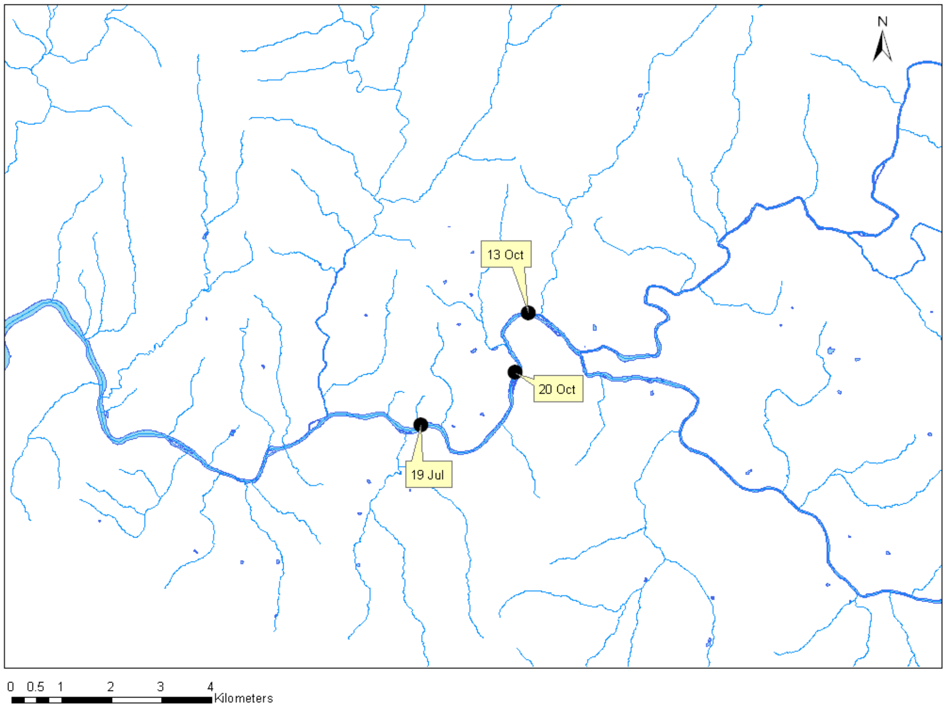
Fish 27



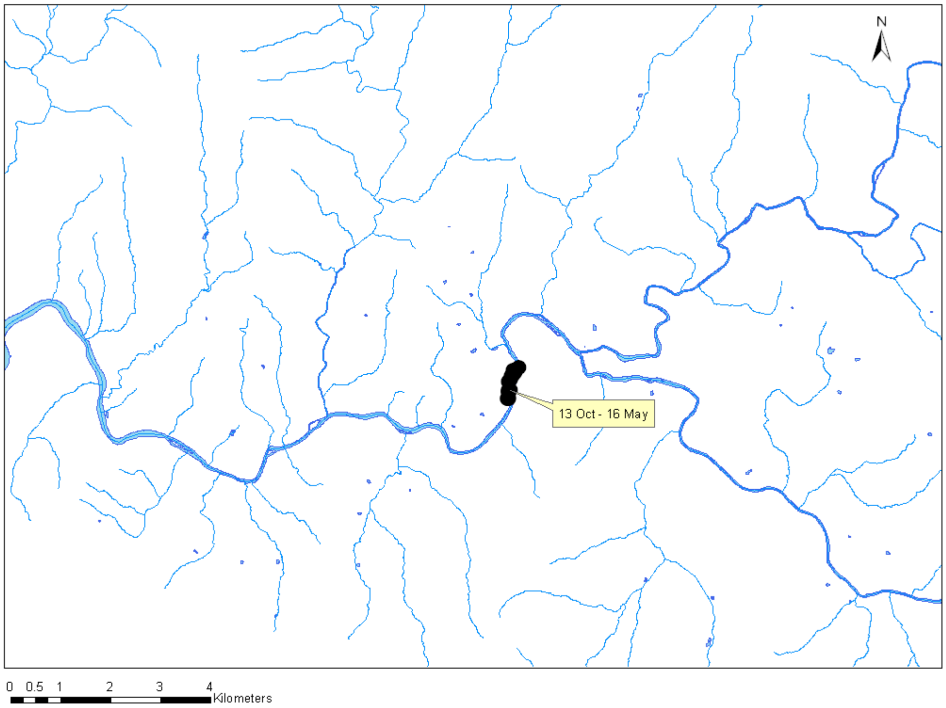
Fish 20



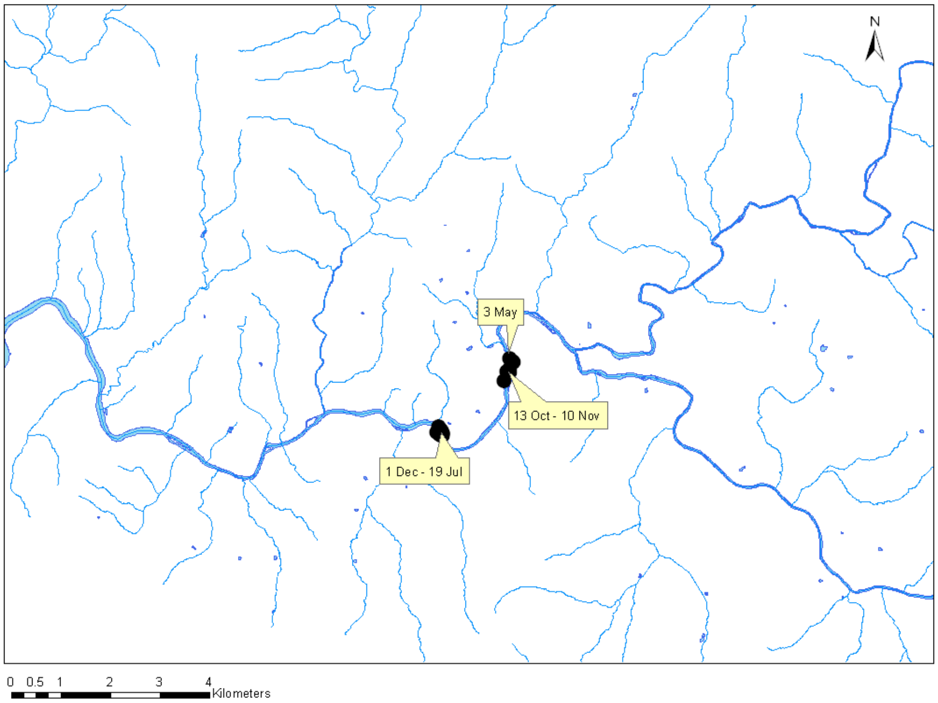
Fish 21



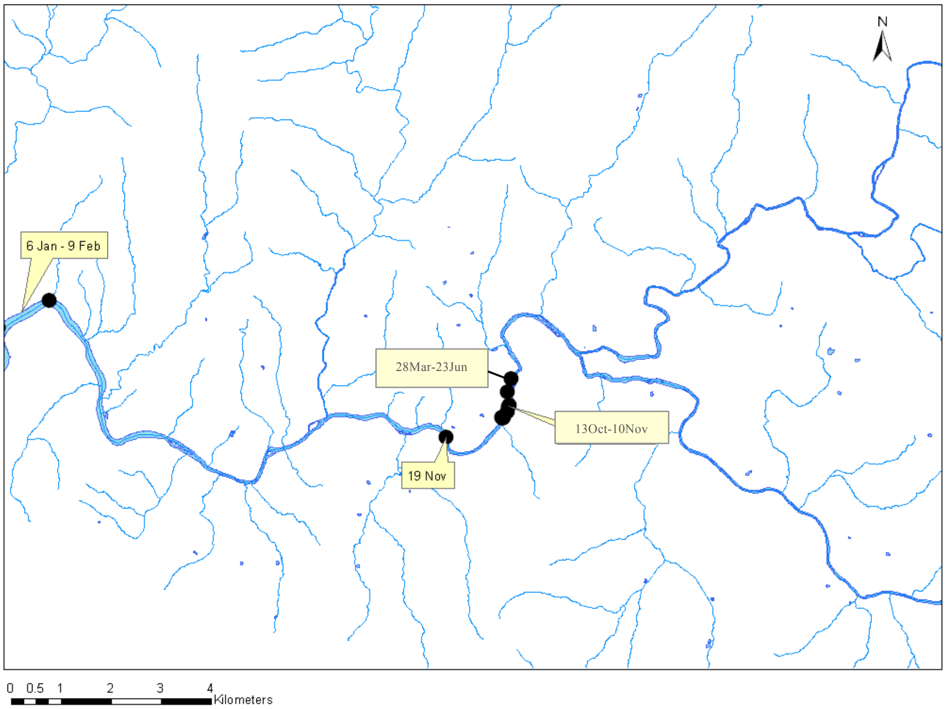
Fish 24



Fish 25



Fish 28



Fish 29