Fate and Habitat Use of Rainbow Trout Stocked in the Canyon Reservoir Tailrace

by
Stephan J. Magnelia and Greg A. Cummings

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INLAND FISHERIES DIVISION
4200 Smith School Road
Austin, Texas 78744

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ABSTRACT

The hypolimnetic release of Canyon Reservoir supports a tailrace trout fishery located on the Guadalupe River in Comal County, Texas. Rainbow Trout *Oncorhynchus mykiss* were first stocked in 1966 and a popular fishery developed over time. Despite documented oversummer survival by the Texas Parks and Wildlife Department in 1968, and anecdotal reports from anglers of trout caught in the late-summer and fall, the fishery was managed exclusively under a put-and-take fisheries management strategy using winter stockings. In the early 1990's there was increased interest in documenting the frequency and downstream extent of oversummer survival. Electrofishing surveys in October 1993 and 1994 documented survival as far as 17.1 km downstream indicating potential for implementing a put-grow-and-take fisheries management strategy in a portion of the fishery. In 1997 457-mm minimum length and one trout daily bag limits were implemented from 6.3 to 22.2 km below the discharge (i.e., special regulation area). Despite protection from harvest and a flow prescription to maintain optimal summer water temperatures in the special regulation area, electrofishing catch rates of trout declined during the summer and reached a low level by fall. Fisheries managers' theorized poor habitat, including a paucity of large woody debris for cover, and associated predation could be one of the factors contributing to the decline. To characterize fate and habitat use, 101 catchable-size Rainbow Trout were stocked and tracked using internally implanted radio transmitters from February to July 2009 and again from December 2009 to August 2010. Individuals were most often located in pools and runs, which appeared to be selected for, while riffles were avoided. Fifty-nine percent of the transmitters were found on the stream bottom and classified as shed, rather than mortality. Of the transmitters that were not shed 48 and 37 percent of all individuals tracked in the respective tracking periods were lost as a result of predation. Clear water, a general lack of cover, and decreasing flows as summer progresses may exacerbate predation. Much of the first 6.3-km of the tailrace has summer water temperatures which consistently remain optimal (< 21.1 °C), even when discharge from Canyon Reservoir is low. In 2014 a protective slot length limit was implemented in 5.6-km of this reach. Habitat improvements which increase pool or run mesohabitat depth and/or provide additional cover during low flows in this reach, where harvest and water temperature related mortality are decreased, might increase oversummer survival.

INTRODUCTION

The hypolimnetic release of Canyon Reservoir supports a 22.2-km tailrace trout fishery located on the Guadalupe River in Comal County, Texas. Rainbow Trout *Oncorhynchus mykiss* were first stocked by the Texas Parks and Wildlife Department (TPWD) in 1966 (White 1968), and annual winter stocking programs by the Department and the Guadalupe River Chapter of Trout Unlimited (GRTU) have continued since that time. It is likely the most fished reach of river in Texas and is considered one of the best trout fisheries in the U.S. (Ross 2013). Although oversummer survival was documented in 1966 (White 1968) water temperatures during the summer were thought to routinely exceed lethal levels (> 25° C), limiting the fishery to a put-and-take fisheries management strategy. Elevated water temperature has limited the scope of other tailrace trout fisheries until reservoir releases were made for maintaining optimal (< 21.1° C) downstream water temperatures (Axon 1974; Harper 1994).

Anecdotal reports from anglers in the 1970's and 1980's indicated oversummer survival was relatively common, sparking interest from GRTU and TPWD in further study of the fishery. In the early-1990's TPWD initiated an extensive water temperature monitoring program, and annual fall electrofishing surveys to document the frequency and downstream extent of oversummer survival (Magnelia 2004). Electrofishing surveys in October 1993 and 1994 documented oversummer survival as far as 17.1 km downstream (Magnelia 2004) sparking interest in developing a portion of the tailrace into a put-grow-and-take fishery using harvest restrictions. A 1993 creel survey indicated most (83-91%) of the trout stocked at high-use public access points were harvested shortly after being stocked (Magnelia 2004). It was thought the use of restrictive length and bag limits in a portion of the fishery would decrease angler exploitation and increase persistence, leading to increased "carryover" from one year to the next. If large numbers of trout could carryover, and the food supply adequate for growth, a catch-and-release fishery for quality size individuals might be developed.

On September 1, 1997 457-mm minimum length and one trout daily bag limits were initiated in the reach of the tailrace from 6.3 to 22.2 km downstream of the discharge (i.e., "special regulation area"; Figure 1). The use of live or prepared bait was also discouraged because of concerns with high hooking mortality (Taylor and White 1992) by specifying harvest could not occur unless the catch was made with an artificial lure. The upper boundary of the special regulation area was set because of public sentiment for maintaining two popular high-use put-and-take access sites in the upper 6.3 km, despite water temperature data indicating the area closer to the discharge had temperatures more conducive for oversummer survival (< 21.1° C; Magnelia 2004). The lower boundary was set at a bridge crossing (i.e., second bridge crossing on River Road) 22.2-km downstream, although we were aware water temperature at this point regularly reached lethal levels by late-spring, and oversummer survival was unlikely.

Although oversummer survival in the special regulation area was documented on multiple occasions, releases from Canyon Reservoir during the summer were not specifically intended to sustain the trout fishery. In dry years discharges were low and water temperatures in the special regulation area regularly exceeded 21.1° C by late-spring (e.g., see 2009, Figure 2) which likely led to temperature related mortality (Magnelia 2004, 2007). In 2001, an agreement was reached between GRTU and the Guadalupe Blanco River Authority (GBRA) specifying a flow prescription from May through September with the goal of maintaining water temperatures which protected the trout fishery. In October 2003, after the first summer of the flow agreement, total boat electrofishing catch per unit effort (CPUE; i.e., abundance) in the special regulation area to 17.1 km was perceived by TPWD fisheries managers as low (total CPUE = 8/hour, effort = 1.75 hours), given 11,724 mainly sub-legal length Rainbow Trout were stocked in this area the preceding winter. Similarly, the electrofishing CPUE in October 2005 in the same reach was only 8/hour, but was more than double this in July (22/hour; Magnelia 2007). The decline in CPUE from summer to early fall was consistent with electrofishing surveys prior to initiation of the harvest restriction and flow agreement (Magnelia 2004).

The decline in CPUE throughout the summer was puzzling. In 2009 and 2010 we tracked catchable size Rainbow Trout stocked in the Canyon Reservoir Tailrace to document fate and habitat use. Results were partially intended to make recommendations for guiding habitat improvement projects which might decrease losses and increase the number of carryover trout available to anglers. We also report results of a separate study conducted after tracking was completed to document transmitter retention, as this helped us differentiate transmitter shedding from mortality.

STUDY AREA

The first 17.1-km of the tailrace was chosen for study as previously collected water temperature data indicated this would likely be the downstream extent in which oversummer survival could occur (Magnelia 2004, 2007). This area covered 51 ha, and had a mean width of 26 m and a mean maximum depth of 1.2 m at a flow rate of 2.8 m^3/s. Mesohabitat was 47% pools, 36% riffles and 16% runs. Substrate was predominantly bedrock (61%), but boulders (14%), large gravel (11%) and cobble (7%) were also present (TPWD unpublished data). There were few pieces of large woody debris (30 pieces/km; 80% was less than 5 m in length and had a diameter less than 55 cm; Table 1), and although we didn't measure the amount of woody debris during the tracking study our observation was it was still extremely sparse.

Canyon Reservoir is classified as an oligo-mesotrophic, hard water, deep storage, bottom draining, reservoir (Hannan et al. 1979). Thermal stratification is normally present from May through November with anoxic conditions existing in the hypolimnion from July through November (Hannan and Young 1974). Water is discharged from a fixed depth of 41 m below the surface, at a conservation pool elevation of 277 m above msl. Interannual variation of water temperature at the discharge is high (Magnelia 2004; Groeger and Bass 2005). Discharge temperature can be as cool as 12° to 13° C in August and September (dry years), but in very wet years cold hypolimnetic waters are lost downstream by early summer as flood waters are released from the reservoir. In wet years August and September discharges can be as warm as 23° to 24° C (Groeger and Bass 2005). A 6-megawatt hydropower plant located below the reservoir operates under a Federal Energy Regulatory Commission hydropower permit which requires minimum discharge into the tailrace during non-drought periods of 2.5 m^3/sec and a minimum dissolved oxygen level of 6 mg/l. Under drought conditions discharge is reduced to match reservoir inflow. A labyrinth weir located just downstream of the hydropower discharge is used to increase dissolved oxygen levels (Hauser and Morris 1995). The Texas Commission on Environmental Quality minimum flows are a "pass- through" requirement based on water permits for GBRA, ranging from 3.06 m^3/s to 4.64 m^3/s. In 2001 discharges from Canyon Reservoir to protect the trout fishery for the first 16 to 17 km were agreed to by GBRA and GRTU. Minimum daily releases averaged over 24 hours specified in the agreement were: May 1-15 (3.96 m^3/s), May 16-31 (4.81 m^3/s), June 1-14 (5.95 m^3/s), June 15-30 (6.80 m^3/s), July 1-31 (5.66 m^3/s), August 1-31 (5.66 m^3/s), September 1-30 (5.66 m^3/s). For the agreement to be triggered, Canyon Reservoir had to reach conservation pool elevation for any length of time prior to that day during the period between January 1 and September 30 of that year. From 2003 to 2010 this flow prescription was in effect for six summers (2003, 2004, 2005, 2007, 2008, 2010), which included one of the years (2010) when tracking was conducted.

METHODS

Fate and habitat use

To document fate and habitat use of stocked Rainbow Trout, we radio tracked fish during two distinct time periods; February 6 to July 8, 2009 (152 days; period one), and December 15, 2009 to August 31, 2010 (259 days; period two). Tracking was initiated one to eleven days post-stocking and was continued until a fate for each implanted fish was assigned. Possible fates included; non-fish predation (i.e., transmitter recovered on the bank, or in the water under the roost or nest of a fish eating bird), harvested (transmitter returned for reward), missing (i.e., assumed moved out of the study area), unknown mortality (carcass found with transmitter still implanted, but with no explanation for the cause of death), and hooking mortality (carcass found with a fishing hook lodged in the esophagus). An attempt to relocate each fish was made over a two-day period at approximately two-week intervals throughout the entire 17.1-km study area from a kayak using a Lotek model SRX 400 scanning receiver and three-element directional Yagi antenna. Location was first approximated using the Yagi antennae, and then an omnidirectional coaxial cable antennae technique (Niemela et al. 1993) used to get a more accurate location. An attempt was made to relocate each fish using the omnidirectional antennae, but some fish were moving, and under these circumstances the technique wasn't as effective. In these instances, the location at the point of maximum signal strength using the Yagi or omnidirectional antennae was recorded. When fish were determined to be moving microhabitat measurements were not recorded. Relocations were recorded using a Trimble GPS receiver (Trimble Navigation, Sunnyvale, California, model GeoXT) and differentially corrected using Pathfinder Office™ software. Tracking was continued until a fate was assigned for each fish.

Accuracy and precision of relocations, and suitability of the omnidirectional coaxial technique (Niemela et al. 1993) for gathering microhabitat data using our tracking gear, were determined by placing a transmitter on the streambed at an unknown location. It was then located using the technique after the general location was determined with the Yagi antennae. The distance between the known location and the estimated location was measured. This was repeated 30 times and mean distance from the known location to the estimated location calculated so a circle of error could be established for gathering microhabitat measurements.

Radio-transmitters (Model SR-11-18, Lotek Wireless, Newmarket, Ontario, Canada; weight in air = 8.0 g, weight in water = 4.0 g, 45 x 11 mm, typical life = 449 days with 5s burst rate) were coated in beeswax to improve retention (Helm and Tyus 1992) and surgically implanted in 112 hatchery reared Rainbow Trout (mean TL = 375 mm, SD = 30 mm); mean weight = 617 g, SD = 233 mm). Each fish was anaesthetized using MS-222 until equilibrium was lost and the transmitter inserted into the body cavity using surgical methods described in Murchie et al. (2004), except a non-absorbable polypropylene monofilament suture (Surgipro™, U.S. Surgical Corporation) was used to increase the speed of healing (Thoreau and Baras 1997) and decrease inflammation (Wagner et al. 2000). After suturing a cyanoacrylate adhesive (Loctite® Super Glue Control Gel, Henkel Consumer Adhesives, Inc.) was applied directly to the margin of the closed incision and the suture knots (Nemetz and MacMillan 1988; Petering and Johnson 1991) to help close the wound and decrease the potential for shedding. In no instance did the transmitter weight exceed 2% of body weight to minimize influence of the transmitter on movement (Brown et al. 1999; Winter 1996). Surgeries were conducted in January (n = 35), March (n = 9), and November (n = 33) of 2009, and in January (n = 9), February (n = 9), and April (n = 17) of 2010. Transmitter antennae were trimmed to 25 cm, which reduced the chance of entanglement (Murchie et al. 2004). Each tag was tested for functionality before it was implanted and all surgeries were performed when water temperature ranged from 9-13° C. To document individuals which were harvested, transmitters were identified with a TPWD identifier, phone number and the word "REWARD" so they might be returned by anglers. Signage was posted at popular access sites alerting anglers to the study and the US$25 reward.

Twenty-one days after surgery trout were transported to the tailrace in a TPWD fish hauling unit and stocked using standard TPWD stocking procedures at seven locations (Figure 1). The 21-day holding period was used to mediate the influence on movement as a result of surgery (Pickering et al. 1982; Mesing and Wicker 1986) and adhere to the waiting period mandated for fish exposed to MS-222. Three stocking locations were within the special regulation area and four others upstream (Figure 1). At the time of stocking each transmitter was checked to ensure it was firmly implanted and operational. Water temperature and dissolved oxygen were recorded at each stocking site. The United States Geological Survey gage at Sattler, TX (08167800) was used to document stream flow at the time of stocking. Onset™ brand water temperature loggers were located at four sites located 0.6 km, 6.3 km, 11.9 km and 17.1 km downstream from the discharge (Figure 1) to document temperature during tracking. At the 11.9–km site data from late-July 2009 to early-June 2010 was lost when the logger malfunctioned. Water temperature was recorded once every 15 to 30 minutes at each location.

Mesohabitat (riffle, run, pool) and microhabitat (surface water temperature, dissolved oxygen, Secchi disk depth, distance from nearest bank, associated cover type, depth, dominant substrate, and surface, mid-depth, and bottom current velocity) were collected at each relocation. When feasible, microhabitat measurements were collected at the point of strongest signal trength, and upstream, downstream, left, and right of the signal at the outer edges of the circle of error established during the omnidirectional coaxial technique error estimate trial. However, when water depth and/or high flows hindered this extensive data collection we limited samples to the point of strongest signal strength. This was especially common in tracking period two when flows were higher.

Mesohabitat was categorized using the criteria described by Roghair and Nuckols (2005), except we did not differentiate glides from pools. To calculate mesohabitat preference the Jacobs (1974) electivity index was used. A mesohabitat survey based on the Roghair and Nuchols (2005) criteria was conducted in summer 2006 during a discharge rate of 2.8 m^3/s (TPWD unpublished data). These data were used to calculate the amount of each mesohabitat available. A map using ArcGIS 3.1 was also created using these data to spatially reference mesohabitats within the study area. We plotted each relocation and the mesohabitat recorded against the 2006 map to confirm mesohabitat had not greatly changed in the interim. We defined cover as any physical object which could serve as velocity refugia or provide cover within the estimated circumference of the relocation error circle. Cover included woody debris, boulders, longitudinal bedrock grooves and bridge pilings. Current velocity (m/s) was recorded using a Marsh McBirney™ brand flow meter.

Transmitter retention

During tracking we became concerned about transmitters found on the stream bottom, and if these were the result of mortality or shedding. Shedding became a plausible explanation when we received a photo of a trout caught by an angler in which the sutures were present, but the transmitter absent. Previous movement studies of stocked Rainbow Trout reported internally implanted radio transmitters were often found on the stream bottom (e.g., Bettinger and Bettoli 2002; Cushing 2007; High and Myer 2009); however, these authors classified these differently. Transmitters found on the stream bottom were classified as mortality (Bettinger and Bettoli 2002; High and Myer 2009) or shedding (Cushing 2007). Implanted radio transmitters can be lost through the incision, through an intact part of the body wall, and through the intestine (Jepsen et al. 2002). Expulsion from an enlargement of the area around the site where the antennae exits the body wall was reported for Rainbow Trout (Bunnell and Isely 1999), but rates of expulsion were variable. Bunnell and Isley (1999) reported 12 to 27% expulsion over 50 days, while Chisholm and Hubert (1985) reported 59% expulsion 42-175 days post-implantation. Conversely only 3% of dummy radio-transmitters coated with a beeswax coating and implanted in Rainbow Trout were expelled up to 419 days post-implantation, although in this study the transmitter had no antennae protruding through the body wall (Helm and Tyus 1992).

To help us classify transmitters found on the stream bottom, we documented retention and mortality beyond the 21-day post-surgical holding period. Ten radio-transmitters recovered from the study area during tracking and 20 replica transmitters (Model MCFT2-3BM, Lotek Wireless, Newmarket, Ontario, Canada) of very similar dimensions (43 x 11 mm; i.e., 2 mm shorter than original transmitters) and equal weight (weight in air, 8.0 g; weight in water, 4.0 g) were implanted by the same surgeon (i.e., S. Magnelia) using the previously described surgical procedures. Implanted ($n = 30$) and non-implanted ($n = 31$) Rainbow Trout were held for observation in a portion (2.7 x 2.4 x 0.8 m) of a flow-through raceway at the A.E. Wood State Fish Hatchery for 21 days. On day twenty-two all trout were transferred to a fish hauling unit, driven around hatchery grounds for approximately one hour to simulate the trip to tailrace stocking locations, removed from the hauling unit and placed back into the same raceway for an additional 65 days of observation. Following simulated stocking the raceway was checked each day for mortality and shed transmitters. Fish were fed a floating pelleted fish food each day ad libitum, and water quality (water temperature, dissolved oxygen, pH) measured twice per day.

RESULTS AND DISCUSSION

Transmitter retention

For implanted (mean TL = 389 mm, SD = 33 mm; mean weight = 778 g, SD = 219; n = 30) and non-implanted Rainbow Trout (mean TL = 382 mm, SD = 32 mm; mean weight = 736 g, SD = 210; n = 31) in the hatchery transmitter retention study there was no significant difference in length (*t*-test, T = 0.88, df = 59, P = 0.19) or weight (*t*-test, T = 0.77, df = 59, P = 0.22). However, the 30 implanted fish were significantly larger in total length (mean = 375 mm for field tracking versus 389 mm for the retention study; *t*-test, df = 140, T = -2.3, P = 0.01) and weight (mean = 617 g for field tracking versus 778 g for the retention study; *t*-test, df = 140, T = -3.4, P = 0.0004) than those used for tracking. Two of the thirty implanted fish died, and one transmitter was shed during the initial 21 day holding period. No other mortality of implanted or non-implanted individuals was observed during the remaining 65-day observation period. Additional shedding began 15 days after the simulated stocking. Sixty-five days post-stocking, 15 of the 27 implanted transmitters (56%) had been shed (Figure 3).

Shedding appeared to be either through the antennae hole (surgical incision was healed, but the tissue around the antennae hole was eroded; n = 3), or a rip through the body wall from the antennae hole to the posterior end of the surgical incision (n = 8; Figure 4, photos B, C, and C1). The rip was likely caused by the antennae, as it was either pulled on by another fish, or snagged and pulled. Expulsion through the antennae hole was consistent with a photo we received of an angled trout where the transmitter had been shed. The surgical incision appeared healed, the sutures still present, but the body wall around the antennae hole exit wound extremely eroded (Figure 4, photos D and D1). We could not determine the mode of expulsion for the remaining four shed transmitters.

Based on our inability to document mortality in the 65 days post-stocking observation period we assumed transmitters found on the stream bottom during tracking were likely the result of shedding. The lack of mortality we observed, despite the wounds caused by shedding, was similar to results reported by Ivasauskas et al. (2012) for Rainbow Trout implanted with ultrasonic transmitters and held in a raceway for 65 days after surgery. We cannot explain the difference in the rate of expulsion observed between the hatchery and tracking portion of the study (Figure 3). Because the fish were relatively confined in the hatchery raceway it is possible antennae were being nipped and pulled at, which may have increased the rate at which they were shed.

The protruding transmitter antennae, and erosion and/or tearing of the body wall we documented in the hatchery study, appeared to be the primary source of transmitter shedding. We chose radio transmitters with external antennae as they were commonly used by many researchers studying movement of trout. The ability of these transmitters to be detected from an airplane, in areas with high amounts of instream cover and over long distances is certainly advantageous in some situations. The range of transmitter loss over a 65-day study period in a hatchery setting with internally implanted ultrasonic transmitters using a suture material like that used in our study, and having no external antennae, was much less than what we experienced (range of 0 - 25%) (Ivasauskas et al. 2012). These authors still recommended implanted hatchery Rainbow Trout be released almost immediately after surgery (i.e., no more than a few hours or days) to increase the number of relocations observed and reduce the confounding effects of shedding. They suggested that in longer-term field studies (> 25-35 days after surgery) shedding be recognized and corrected for. Although ultrasonic transmitters without external antennae have inherent disadvantages over radio transmitters (i.e., can't be detected over a long distance and by air, signal may be blocked by underwater obstructions or turbulent water) these likely would not have been major disadvantages in our study, as there was little instream cover and the study area was relatively small. In addition, because these transmitters don't have external antennae Rainbow Trout may retain them for a longer period, potentially making them more useful for documenting fate and habitat use of individuals stocked in special regulation areas.

The validity of any biotelemetry study is dependent on transmitter loss being minimal. The high percentage of shed transmitters adds uncertainty to our results on fate, as shedding greatly reduced our sample size. Based on previous transmitter retention studies (e.g., Chisholm and Hubert 1985; Bunnell and Isley 1999) with Rainbow Trout we expected some shedding, but had hoped coating the transmitter in beeswax (Helm and Tyus 1992) and use of a cyanoacrylate adhesive (Nemetz and MacMillan 1988; Petering and Johnson 1991) and monofilament sutures (Deters et al. 2010; i.e., less inflammation of the surgical wound) would help minimize this. In studies where documenting fate over a short period of time is the goal shedding may not be much of an issue. For Rainbow Trout stocked and tracked in special regulation areas, where harvest is unlikely and environmental conditions remain optimal, the potential exists for individuals to subsist for long periods of time. The ability to track individuals over multiple years in these areas would be useful in evaluating the utility of special regulations, but the confounding effects of shedding make telemetry much less useful. While telemetry provides an abundance of information, estimating mortality for stocked Rainbow Trout over long time periods likely necessitates a different, and/or concurrent complimentary methodology (e.g., external tagging and capture-recapture population estimates).

Fate and habitat use

Ten of the 112 Rainbow Trout implanted with radio transmitters died and one shed its transmitter during the 21-day holding period in the hatchery. One hundred-and-one implanted trout (43 in tracking period one, and 58 in tracking period two) were stocked at seven stocking locations (Figure 1). Discharge on stocking days ranged from 1.5 to 22.8 m^3/s. Water temperature varied by stocking location, but was less than 21.1° C.

On average we were able to estimate the position of transmitters we placed on the river bottom using the omnidirectional coaxial antennae technique (Niemela et al. 1993) to 1.54 m (SD = 1.17 m) of the actual location. Based on these results we believed relocations were very close to a fish's actual location, and the technique was adequate for collecting microhabitat data. Most relocations were made using this technique (period one = 82.6%, period two = 86.9%) versus the Yagi antennae alone (period one = 16.4%, period two = 11.4%).

For the entirety of both tracking periods, water temperature 0.6 km below the discharge remained below 21.1° C (Figure 2). In the first tracking period discharge from Canyon

Reservoir was well below the median calculated from 1997 through 2012 (5.4 m^3/s) and had little variability (median discharge = 1.7 m^3/s, SD = 0.5 m^3/s). Due to drought conditions discharges prescribed in the flow agreement were not made. Maximum daily water temperature at the beginning of the special regulation area (6.3-km) regularly exceeded 21.1° C by early May 2009 (Figure 2). Only three implanted fish remained in July and these were located in the first 6.3 km of the tailrace where water temperatures remained optimal. By late July 2009, a fate had been assigned to all fish. In the second tracking period discharges prescribed in the flow agreement were made. In general, discharges were higher and more variable (median discharge = 7.0 m^3/s, SD = 11.3 m^3/s; Figure 2). At the beginning of the special regulation area water temperatures remained optimal (Figure 2). The area of the fishery from the discharge to this point has the most consistent optimal summer water temperatures (Magnelia 2004, 2007) and mortality related to high water temperatures is less likely than areas further downstream. Despite increased flows maximum daily water temperatures regularly exceeded 21.1° C at 11.9 km and the end of the study area starting in mid-June (Figure 2) and did not fall below this threshold until mid-September (David Schroeder, GRTU, personal communication). In this tracking period, four individuals were tracked until late August, with two located within 2 km, and two between 8 and 9 km, downstream of the discharge. By the end of August 2010, a fate had been assigned to all fish.

During the two tracking periods, 522 relocations (Figure 5) were made during 56 tracking days. On average each individual was relocated five times (range of 2 to 16 relocations), before a fate was assigned. During both tracking periods 75% and 73%, respectively, of individuals were relocated in pools. Pools and runs appeared to be selected for, while riffles were avoided (Figure 6). In general, fish were found 9 to 10 m from the bank, toward the middle of the river near the thalweg, and in areas of low current velocity (Table 2). It appeared they were utilizing the deepest water available. Brown *Salmo trutta* and Rainbow Trout in the White River tailwater below Beaver Dam, Arkansas also occupied the deepest habitat available at low flows (1 m^3/s; Quinn and Kwak 2000). Water depth can be a limiting factor for salmonid populations and increasing pool depth has been a goal of many habitat improvement projects (Roni et al. 2006). Pools offer preferred habitat, velocity refuge, and sufficient water depth during low flows (Buffington et al. 2002). Pools can also offer thermal refugia during times of water temperature stress (Matthews and Berg 1997; Ebersole et al. 2001; Baird and Krueger 2003).

For most relocations (74.6% and 86.2% for tracking periods one and two, respectively) we were not able to associate fish with cover (Table 2). The use of deeper water available in pools and runs could be a response to the general lack of instream cover throughout the tailrace. Salmonids have been reported to utilize deeper positions in areas devoid of cover (Bugert et al. 1991). Low flows, like those encountered in tracking period one, could also have reduced the need for trout to seek velocity shelters afforded by cover like large woody debris and boulders. Rainbow and Brown Trout in an Ozark tailwater utilized deep microhabitats distant from the streambank and randomly utilized cover at low flows, while at high flows they moved toward the bank and were strongly associated with velocity refugia (Quinn and Kwak 2000). Longitudinal grooves in the limestone bedrock substrate, which are a common feature in the Guadalupe River (Keen-Zebert and Curran 2009), and woody debris made up the highest percentage of cover used in both tracking periods. Longitudinal grooves appeared to be used more in period one when flows were low. These grooves were often deeper than the surrounding area and may have provided cover at low flows and possibly a velocity refuge at high flows. Quinn and Kwak (2000) reported Rainbow Trout in the White River tailrace below Beaver Dam, Arkansas used crevices in bedrock as a velocity refuge at high flows. Longitudinal grooves may have been used more in period two than what we observed because we could not as easily see them with the higher flows and associated increased depth. There were few pieces of large woody debris available for cover in the study area. In tracking period two, when flows were higher, woody debris appeared to be used more. Woody debris was often located near the bank and depth at these sites was likely greater in period two because of the high flows, possibly affording the fish depth, cover and a velocity refuge.

Excluding transmitters that were shed predation accounted for 48 and 37% of losses in the respective tracking periods (Table 3). We attributed 47% of this to fish eating birds, as transmitters were found directly under a Double-Crested Cormorant *Phalacrocorax auritus* roost or Osprey *Pandion haliaetus* nest. Double-Crested Cormorant, Osprey and Great Blue Heron *Ardea herodias* are common in the tailrace and are known predators of stocked trout (Kennedy and Greek 1988, Hodgens et al. 2004, Harris et al. 2008). For the remainder of transmitters found on the bank we were unsure as to how they arrived there. Losses of stocked Rainbow Trout to fish eating birds have been documented in other Rainbow Trout fisheries (Kennedy and Greek 1988, Hodgens et al. 2004, Cushing 2007, Harris et al. 2008). Cushing (2007) reported 27% of total mortality of stocked Rainbow Trout in catch-and-release areas of the White and Norfolk Rivers, Arkansas was attributed to Great Blue Heron predation. Large numbers of Double-Crested Cormorants migrate to Texas, with peak numbers occurring from October through March, and prey heavily on fish during their stay (Dolbeer 1991; Thompson et al. 1995). Double-crested cormorants have been observed at the stocking location just below the discharge eating trout immediately after leaving the stocking truck (S. Magnelia, personal observation). We also routinely observed osprey capturing fish during tracking. The use of deeper run and pool habitats might be an adaptation to decrease predation by wading/diving birds (Harvey and Stewart 1991; Harvey et al. 2005). Large Striped Bass *Morone saxatilis* are also present in the tailrace in low densities (Terre and Magnelia 1996; Magnelia 2007) and are known predators of stocked trout in tailrace fisheries (Deppert and Mense 1979). In tailrace electrofishing surveys we often collected large Striped Bass in pools where there was almost no cover present. During a 2005 October electrofishing survey, we removed a 457-mm Rainbow Trout from the esophagus of a large Striped Bass collected from a small pool in the special regulation area. Effects of Striped Bass predation on tailrace trout populations have been reported as ranging from inconsequential (Bettoli 2000), to consuming up to 28% of the trout stocked annually and a threat to the existence of the fishery (Hess and Jennings 2000). The clear water observed in both tracking periods (Table 2), the shallow nature of the tailrace and lack of cover, likely made trout easy prey for both fish-eating birds and Striped Bass. Survival of trout stocked in southern tailwater fisheries seems largely unreported; however, in the Beaver Dam tailwater of Arkansas annual survival of stocked Brown and Rainbow Trout was reported to be only 0.32 and 0.08, respectively (Quinn and Kwak 2011).

Cover provided by large woody debris can play an important role in setting trout densities and biomass (Flebbe and Dolloff 1995) in streams. This type of cover is often absent in tailrace fisheries due to high velocities during flood releases and/or large fluctuations in flow. In the Canyon Reservoir Tailrace large downed trees, which could provide cover for trout and other fishes, are routinely removed after flood events to facilitate tubing and rafting which generates the bulk of the economic impact from users (Impact DataSource 2012). Few pieces of large woody debris were noted in our 2006 tailrace habitat survey and during tracking. Undercut banks, a form of overhead cover commonly found in many high-quality trout streams, although not quantified in our habitat survey, also appeared to be largely absent. Overhead bank cover was identified as a key limiting habitat variable for adult Brown Trout in Minnesota streams (Thorn 1992). Discharge into the tailrace generally decreases throughout the summer and by October is at its lowest point (Figure 7). The combination of decreased depth from low flow, a general lack of cover, and some of the clearest water of the year (Figure 7) likely increases potential for predation.

The other major source of losses in both tracking periods was harvest (24 and 21% respectively), and fish that were missing in period two (37%). All transmitters returned for rewards were from trout caught in the area above the upper special regulation boundary. During the study period this area had no minimum length limit and fish stocked here were often harvested shortly after stocking (1-15 days) or persisted for relatively long periods of time (mean = 142 days) only to be finally harvested. Those that persisted often took up residence in a location that was away from the public angler access and stocking sites at 0.14 and 6.09 km (Figure 1), where there was moderate to high levels of fishing activity. Given the harvest we documented above the special regulation boundary, and a previous creel survey that reported high harvest rates at put-and-take stocking sites (Magnelia 2004), carryover in this area was likely to be enhanced with a harvest restriction. In 2014 all this reach except the first 732 m directly below the discharge was put under a slot length limit regulation, which limits harvest to trout under 305 mm and one over 457 mm (five fish daily bag limit).

In period two seven trout were either never relocated or were missing after one or more relocations. Transmitter failure because of a depleted battery was unlikely given all these transmitters had less than 240 days of use and the typical transmitter life reported by Lotek was 449 days. In addition, over the 56 tracking days we failed to account for a transmitter that was present on only six occasions. In all cases the transmitter was relocated on the next trip. This gave us confidence that if these transmitters were present, we would have found them. We believe these fish either moved past the end of the study area or were carried away from the river by fish eating birds or anglers (e.g., illegal harvest from the special regulation area). To better document the fate of fish that are classified as missing future studies should consider a fixed transmitter recording station that documents movement past the lower end of the study area.

MANAGEMENT IMPLICATIONS

Improving habitat for trout in the Canyon Reservoir tailrace by increasing the amount of cover available during periods of low flow might decrease predation and increase carryover from one year to the next. Techniques for improving habitat in small coldwater streams are widely used by fisheries managers to increase abundance of trout (e.g., Hunt 1992), but in general habitat improvements have been implemented much less frequently on large rivers (Gore and Shields 1995) and seems even less common in southern U.S. tailrace trout fisheries. Few studies have been published which document the effects of habitat improvements on tailrace trout fisheries. One example is the White River tailrace trout fishery below Beaver Dam in Arkansas where instream boulder clusters and anchored logs, and riparian habitat rehabilitation structures (cedar and rock revetments with bank stabilizing vegetation) commonly applied to small streams were successfully used to increase the density and biomass of Rainbow Trout relative to reference reaches (Quinn and Kwak 2000). Similar type structures could be added to the Canyon Reservoir Tailrace to improve habitat. Adding these to pools and runs might help decrease predation, especially when flows are low, depth is decreased, and fish are likely more vulnerable to predators. These structures might also be used as velocity refugia at high flows, providing suitable resting areas for recently stocked fish which may be less able to locate and maintain energetically profitable positions relative to resident fish, potentially helping limit post-stocking emigration or mortality (Quinn and Kwak 2000).

Additional examples of tailrace trout fishery habitat improvements, although lacking evaluations on effects to the fishery, include the Lower Mountain Fork River tailrace trout fishery in Oklahoma below Broken Bow Reservoir where narrowing of a section of the stream increased flow and decreased the potential for warming. In addition, root wad-and-boulder structures were added for cover and velocity refuges, and large logs were placed across the stream to increase the depth of pools (Oklahoma Department of Wildlife Conservation, unpublished data). Similarly, seventy-one boulder complexes, composed of three to five large boulders for each structure, were added in 2011 to the upper portion of the Lake Taneycomo tailrace trout fishery below Table Rock Reservoir, Missouri to enhance habitat and increase angling success (Allen et al. 2014). Similar type habitat improvements could be implemented in the Canyon Reservoir Tailrace. In addition to having more consistent optimal water temperatures the reach of the tailrace within 6.3 km of the dam has minimal conflicting (i.e., to angling) recreational tubing and rafting activity relative to more popular downstream reaches. It also contains the tailraces only public lands, with the area downstream from the dam along one bank for about 1.2 km controlled by the United States Army Corps of Engineers. This reach provides an opportunity to conduct pilot projects for improving bank and instream habitat and evaluating the influence of these actions on oversummer survival and abundance.

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Table 1. Summary of woody debris observed in a September, 2006 habitat survey of the first 17.1-km of the Canyon Reservoir Tailrace, Texas using the categorization method of Roghair and Nuchols (2005). Discharge at the time of the survey was 2.8 m^3/s.

Length (m)	Diameter (cm)	Description	Total(s)	No. per Kilometer
1-5	10-55	short, skinny	337	19.7
1-5	>55	short, fat	60	3.5
>5	10-55	long, skinny	60	3.5
>5	>55	long, fat	61	3.6
			518	30.3

Table 2. Microhabitat observed at relocations by tracking period (February 6 to July 8, 2009 period one; December 15, 2009 to August 31, 2010 period two) for stocked Rainbow Trout, Canyon Reservoir Tailrace, Texas. Standard error is below means in parenthesis.

Period	Mean Secchi Disk Depth (cm)	Mean Distance from Nearest Bank (m)	Mean Depth (m)	Mean Depth by Mesohabitat (m)	Mean Current Velocity (m/s)	Substrate (%)	Cover type Associated with Relocations (%)	Relocations Associated with Visible Cover (%)
1	72.88 (1.24)	8.91 (0.37)	1.22 (0.04)	Pool - 1.36 (0.05) Riffle - 0.80 (0.13) Run- 0.91 (0.04)	0.12 (0.01)	Organic matter (0.6), Clay (0.6), Silt (1.8), Sand (1.2), Small Gravel (13.4), Large gravel (9.7), Cobble (17.1), Boulder (2.4), Bedrock (53.0)	Boulder (14.0), Bridge piling (4.7), Longitudinal bedrock grooves (65.1), Woody debris (16.3)	25.4
2	134.90 (3.35)	9.70 (0.36)	1.57 (0.04)	Pool - 1.69 (0.05) Riffle - 1.05 (0.24) Run - 1.27 (0.08)	0.22 (0.01)	Organic matter (0.0), Clay (0.0), Silt (16.7), Sand (4.2), Small Gravel (8.4), Large gravel (0.5), Cobble (3.1), Boulder (2.6), Bedrock (64.4)	Boulder (25.0), Longitudinal bedrock grooves (17.9), Woody debris (53.6)	13.7

Table 3. Fate (%) assigned to stocked Rainbow Trout tracked using radio telemetry from February 6 to July 8, 2009 (period 1), and December 15, 2009 to August 31, 2010 (period 2), Canyon Reservoir Tailrace, Texas. Number in each category is included in parenthesis.

		Category (%)			
Period	Predation	Unknown mortality	Hooking mortality	Missing	Harvested
1	47.6 (n = 10)	14.3 (n = 3)	4.8 (n = 1)	9.5 (n = 2)	23.8 (n = 5)
2	36.8 (n = 7)	5.3 (n = 1)	0.0 (n = 0)	36.8 (n = 7)	21.1 (n = 4)
Mean	42.2	9.8	2.4	23.1	22.4

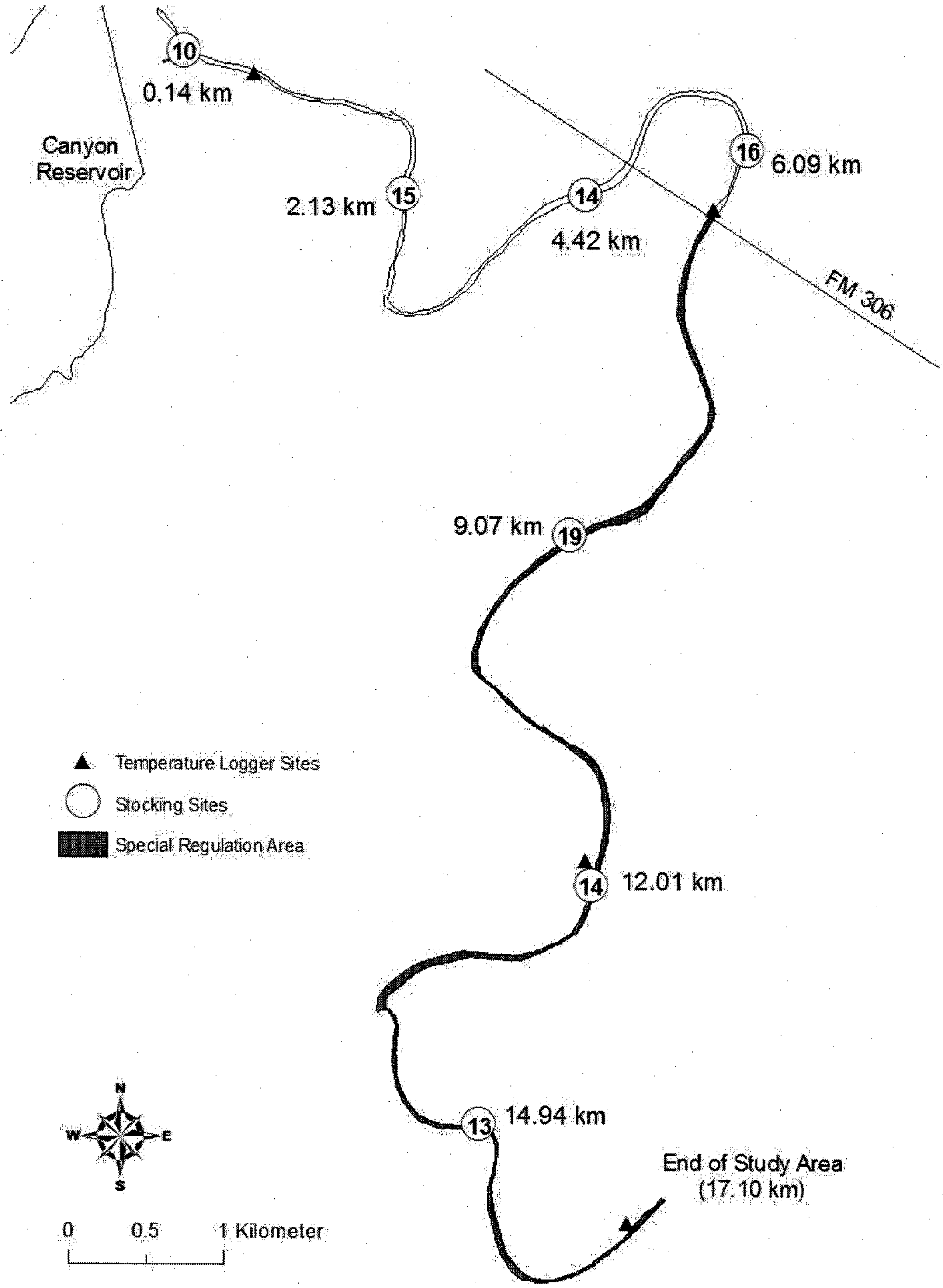


Figure 1. Stocking locations (circles) and number stocked (inside circle) at each location for Rainbow Trout implanted with radio transmitters, Canyon Reservoir Tailrace, Texas, 2009 and 2010. Water temperature monitoring sites are identified with solid triangles. The portion of the study area under a 457-mm minimum length limit and one Rainbow Trout daily bag limit (i.e., special regulation area) is bolded. This regulation was in place during the two tracking periods.

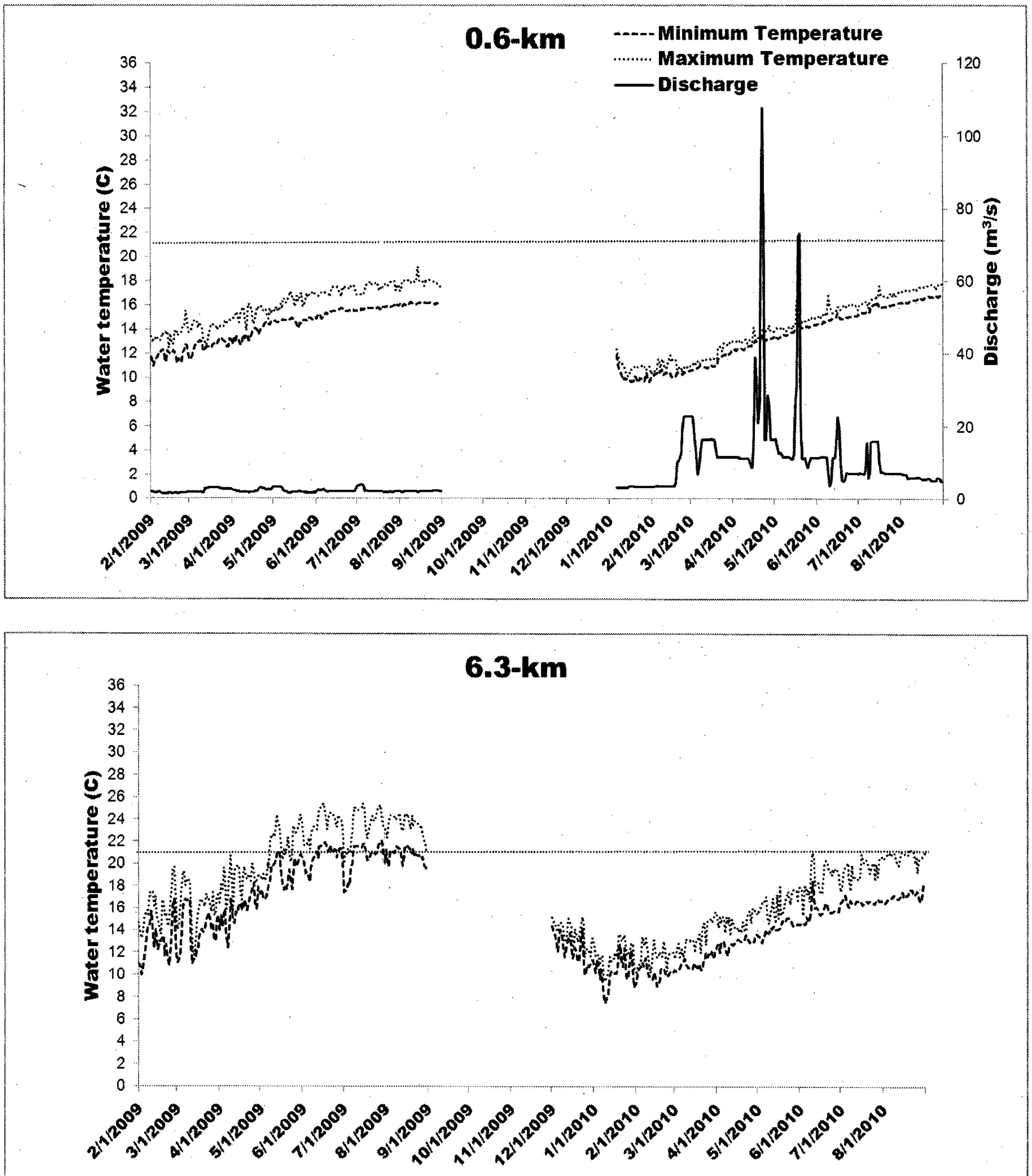
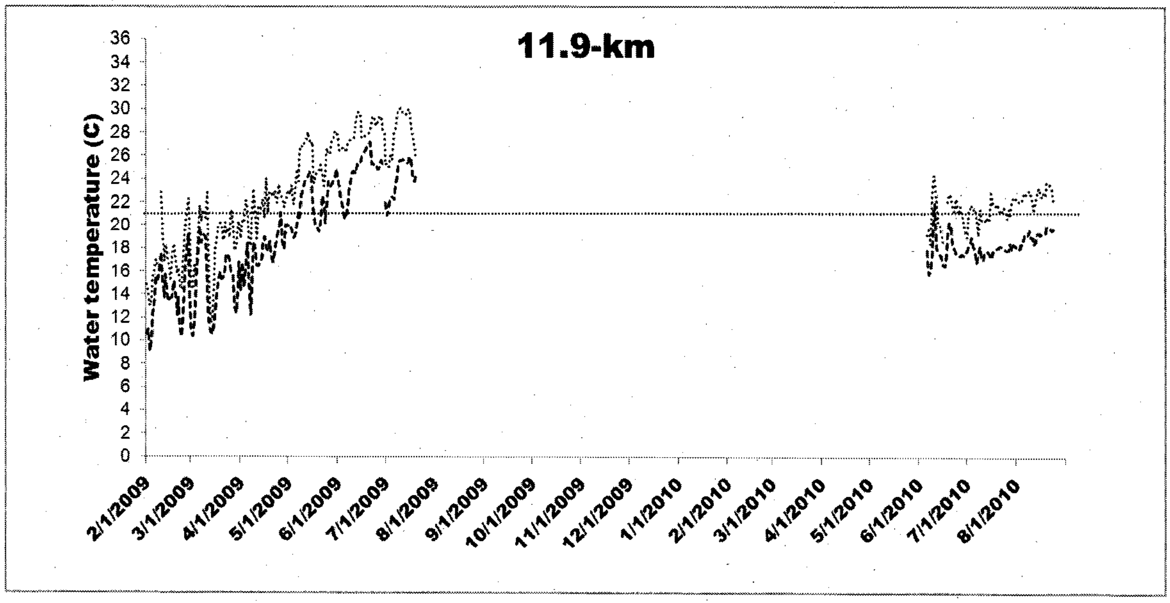
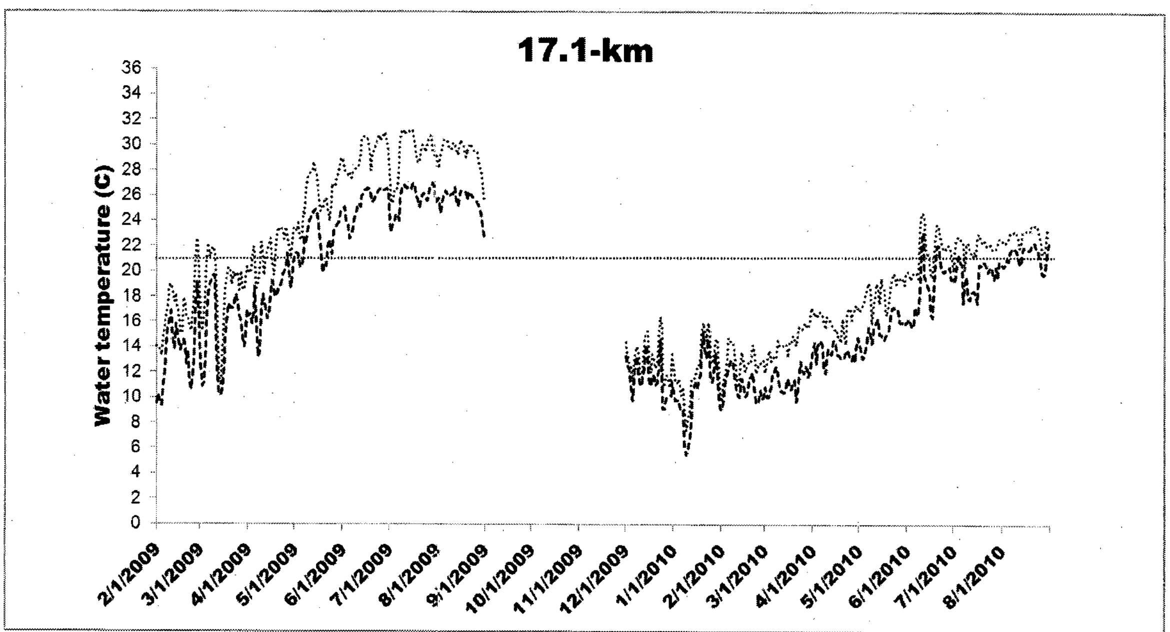


Figure 2. Minimum and maximum daily water temperature (C), 0.6, 6.3, 11.9 and 17.1 km downstream from Canyon Reservoir Dam, and discharge (m^3/s) during the two tracking periods. Horizontal dashed line is set at 21.1° C, the optimal temperature threshold.





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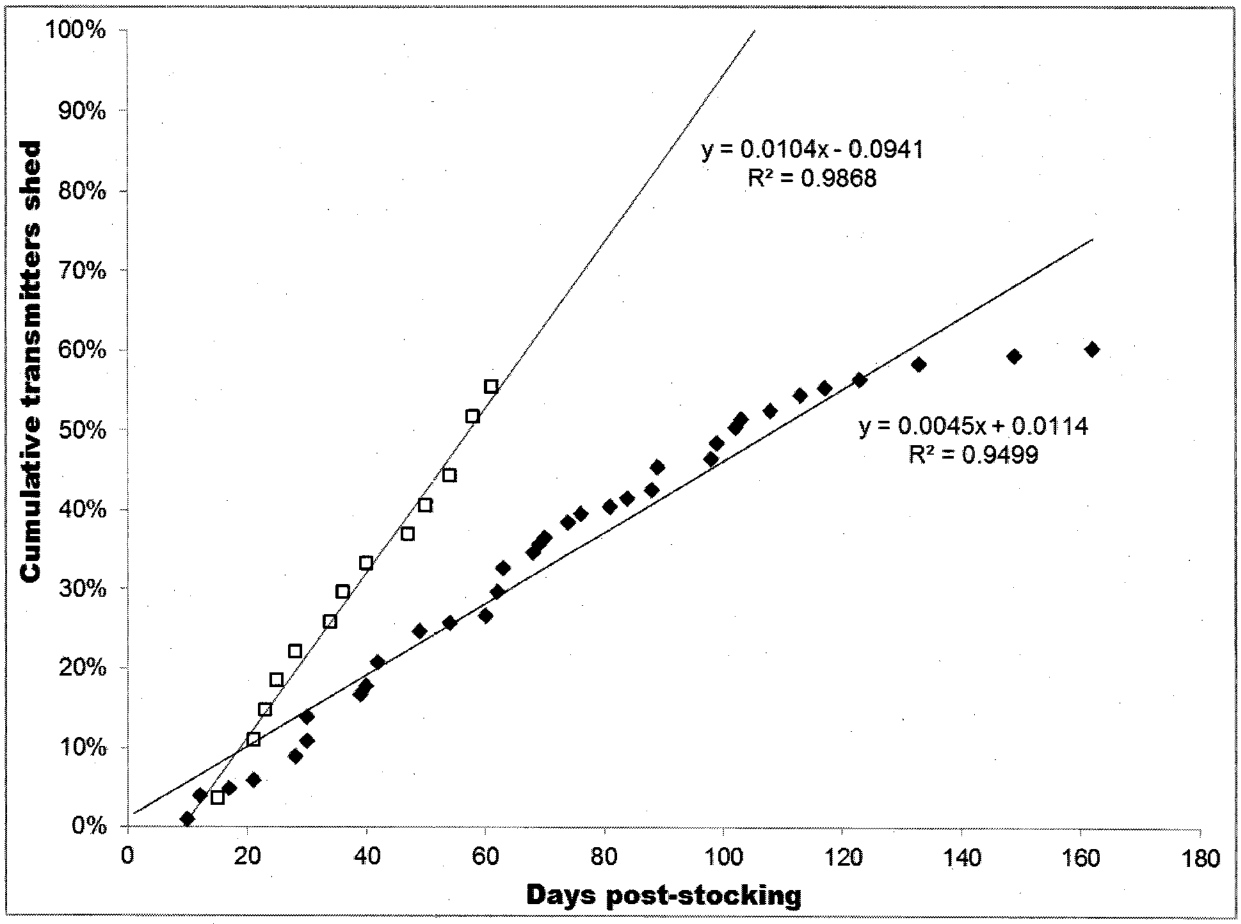


Figure 3. Cumulative transmitters shed (%) days post-stocking for Rainbow Trout held in a raceway at the A.E. Wood State Fish Hatchery, San Marcos TX (open squares) for 65 days following simulated stocking; and, transmitters found on the river bottom in the Canyon Reservoir Tailrace during the two tracking periods (solid diamonds) for 162 days.

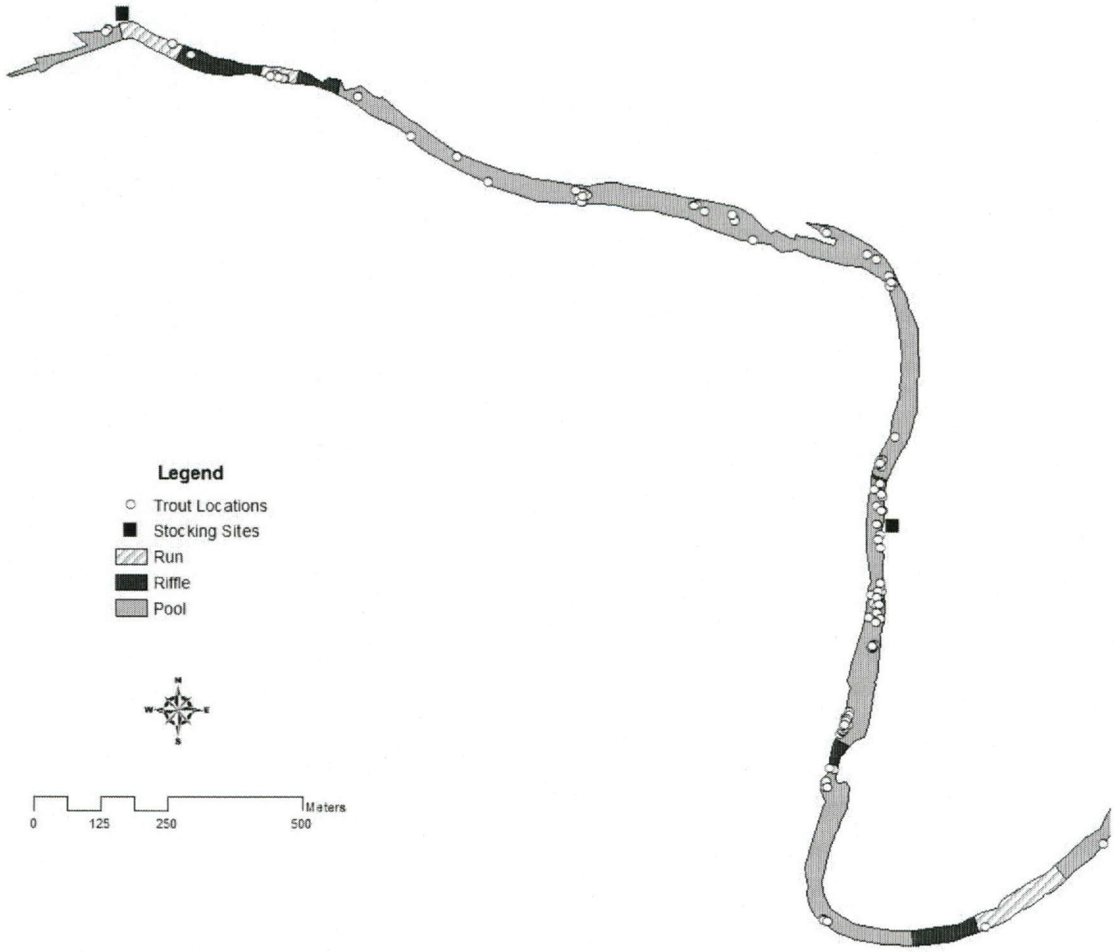


Figure 5. Stocking sites, radio-telemetered relocations, and mesohabitats (riffle, run, pool) for Rainbow Trout stocked in the Canyon Reservoir Tailrace, Texas, February 6 to July 8, 2009, and December 15, 2009 to August 31, 2010. The figure depicts information starting at the discharge from Canyon Reservoir and ending 17.1 km downstream.

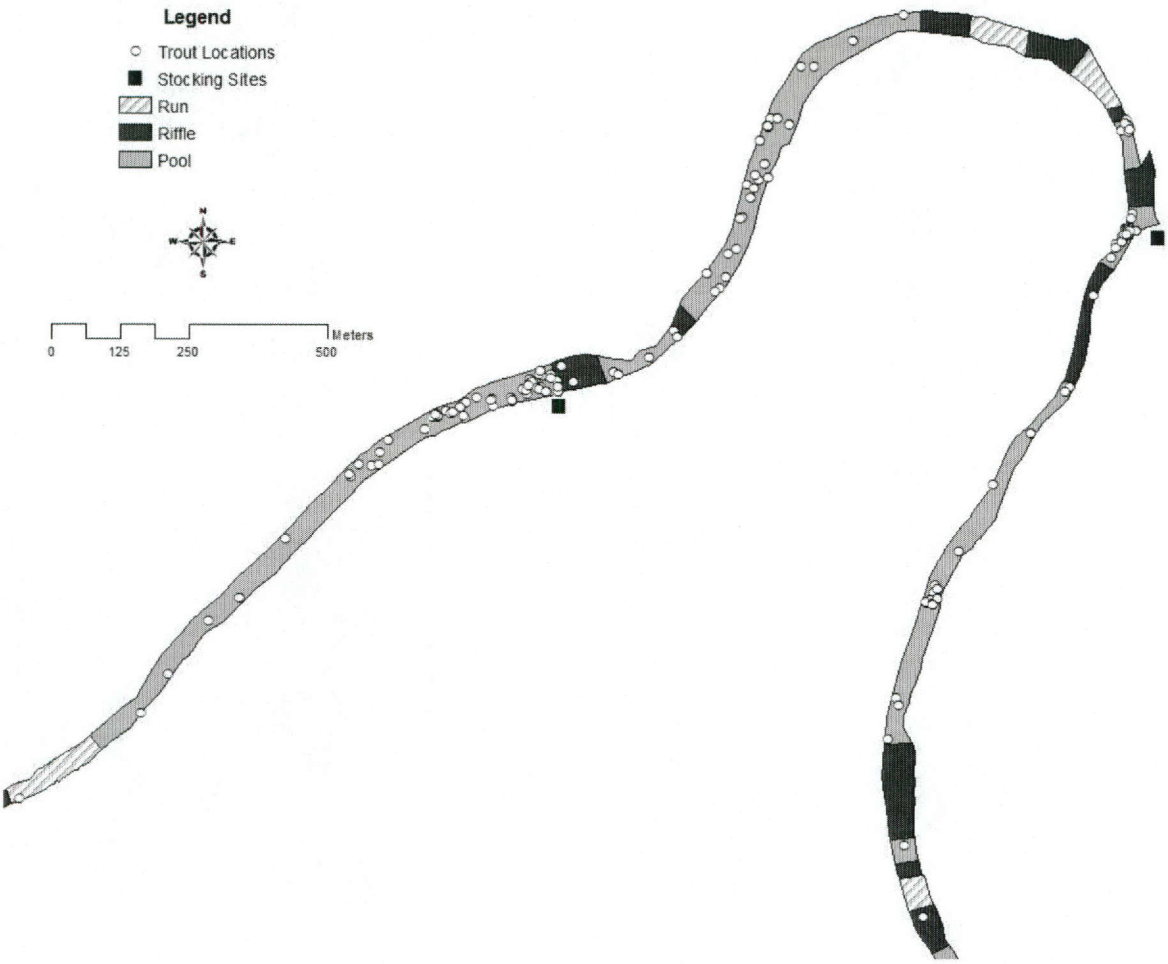
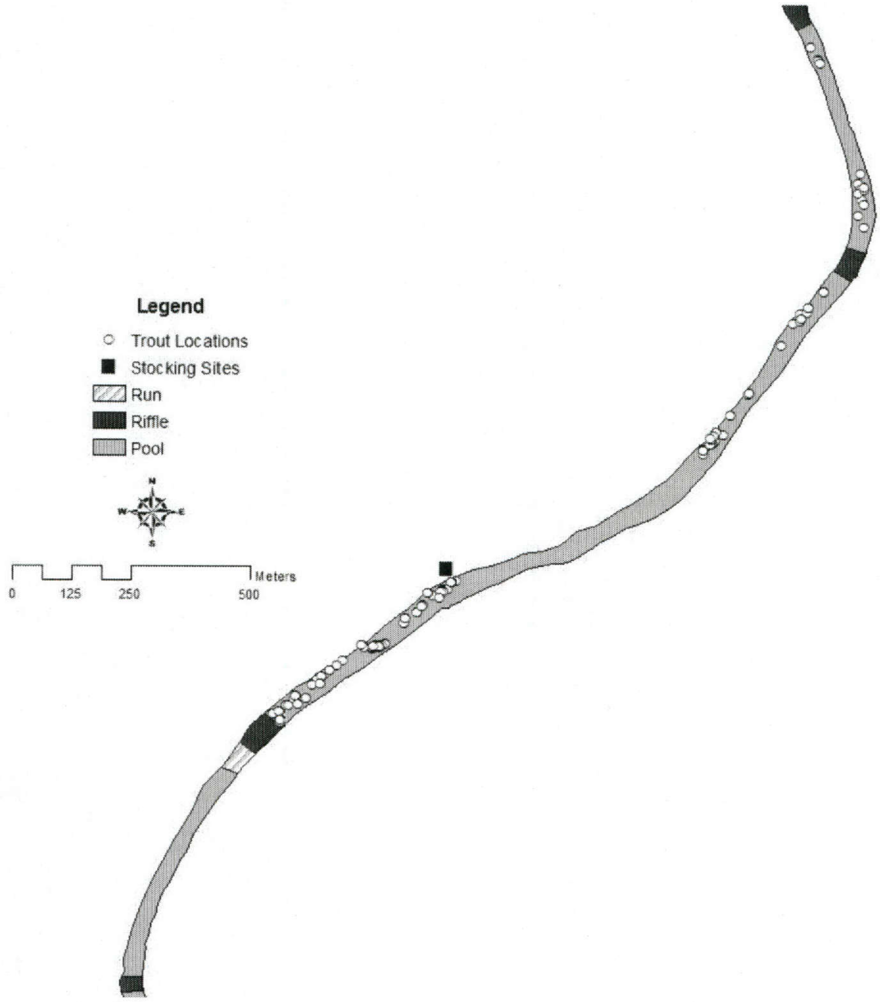


Figure 5. Continued.



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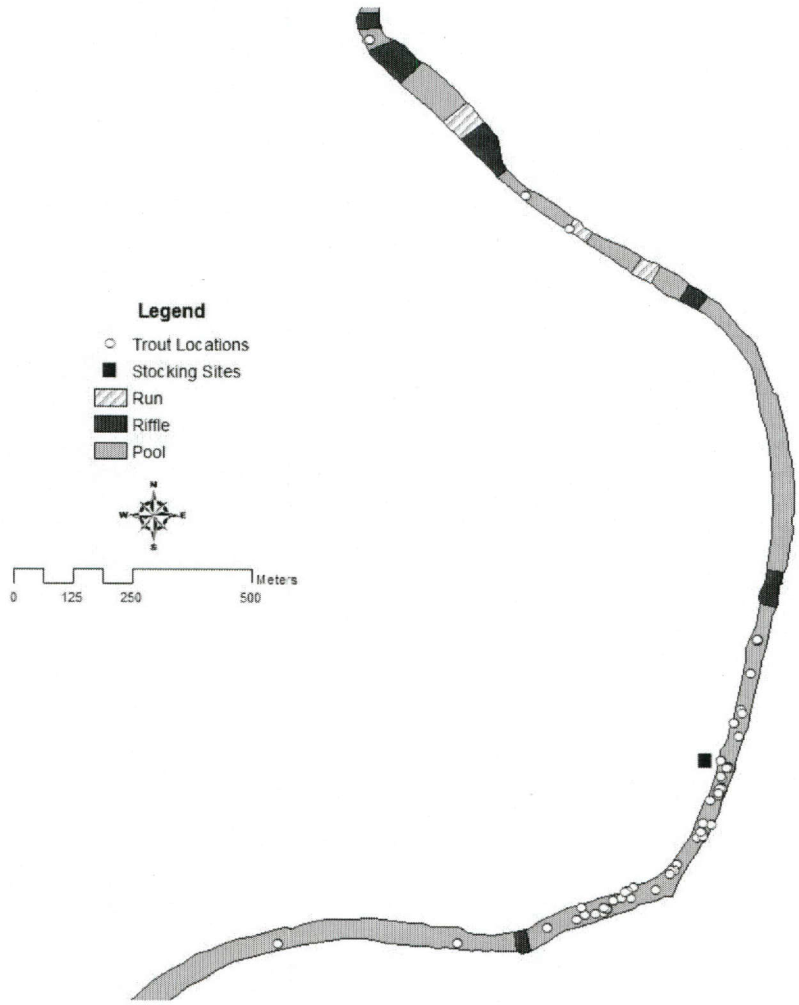


Figure 5. Continued.

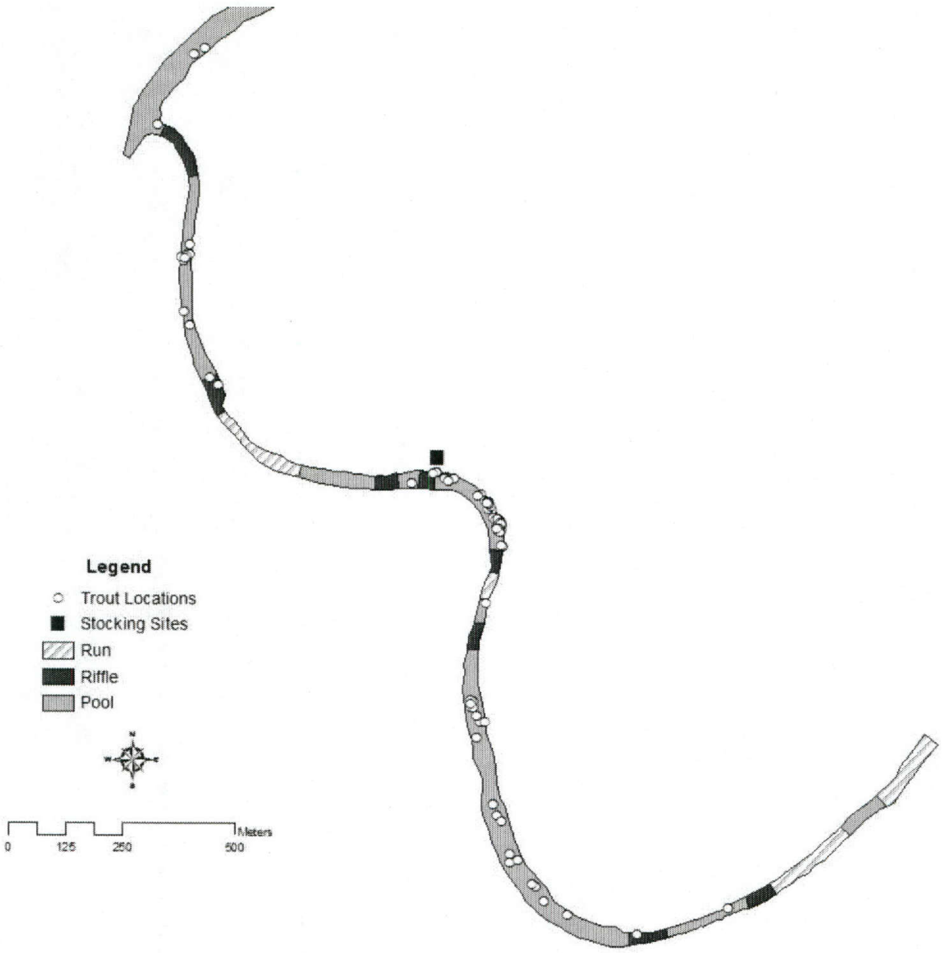
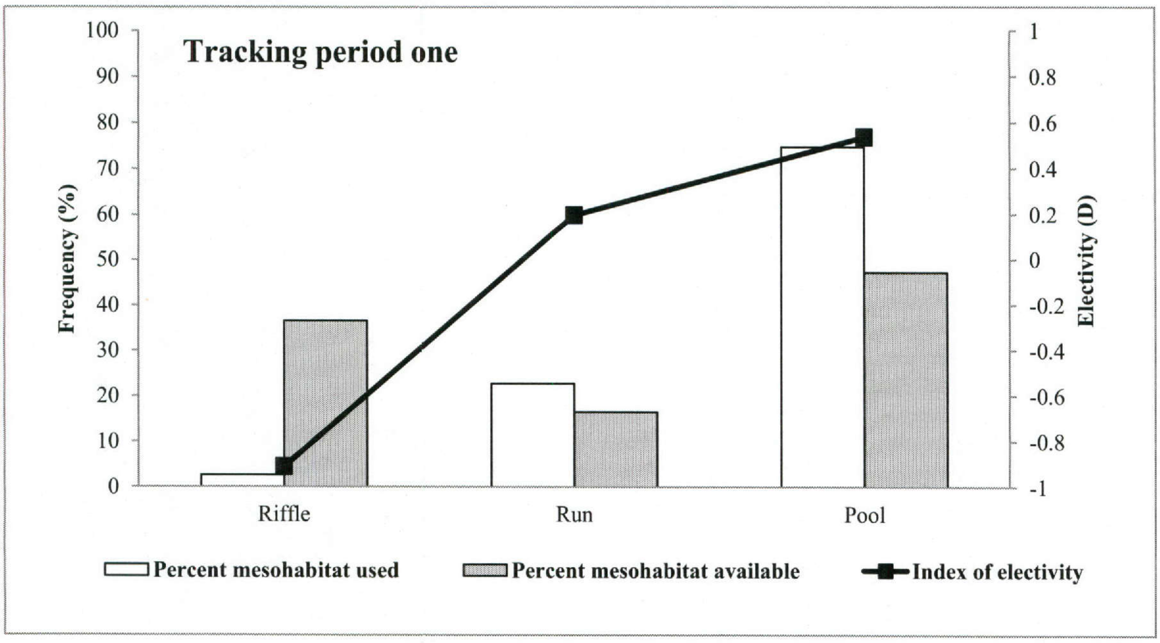


Figure 5. Continued.



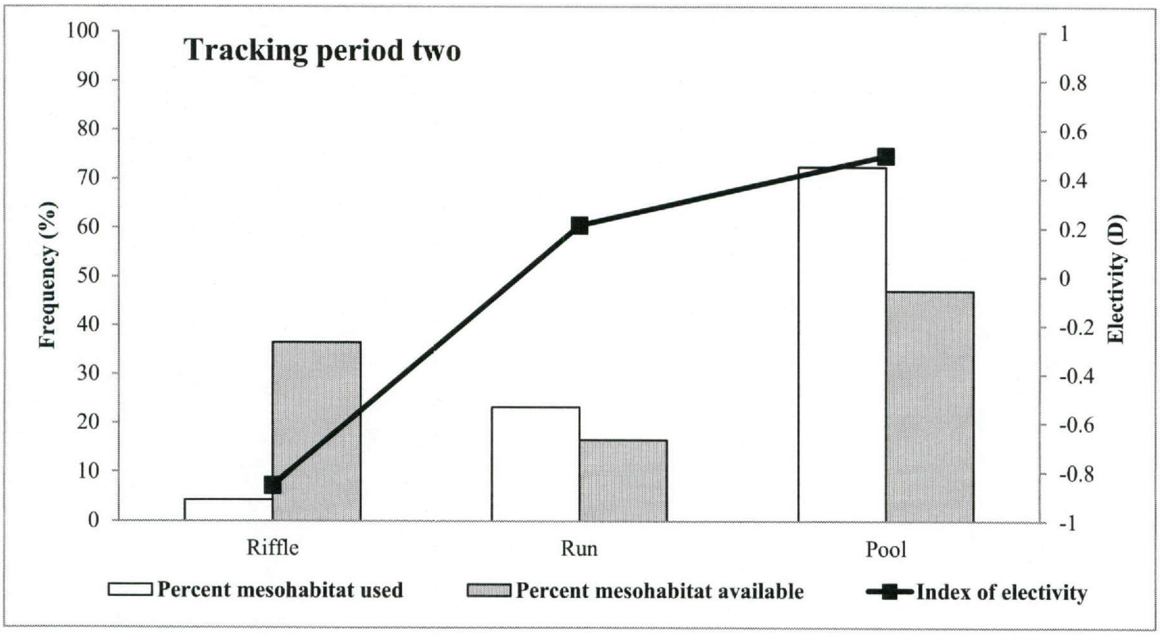


Figure 6. Percent mesohabitat (riffle, run, pool) occurrence and use (bars), and electivity index (D) (solid squares and line) by Rainbow Trout in the Canyon Reservoir Tailrace, Texas, during tracking periods one and two. Negative electivity values indicate avoidance and positive values indicate preference.

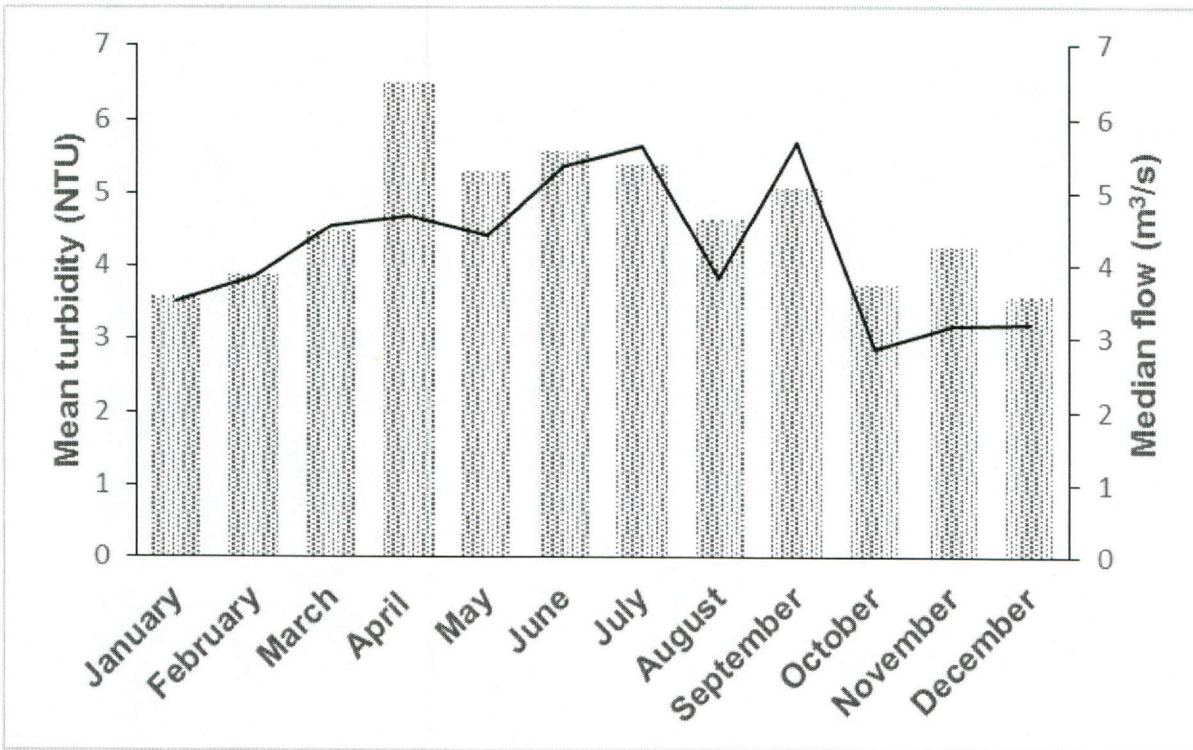


Figure 7. Mean turbidity (NTU) (bars) and median flow (m^3/s) by month (line) in the Canyon Reservoir Tailrace, Texas. Mean turbidity was calculated from a once-per-month measurement made by the GBRA at the second bridge crossing on River Road approximately 22.2-km downstream from Canyon Reservoir discharge, March 1987 to January 2019. Median flow by month was calculated from mean daily flow measurements at the Sattler USGS gage, January 1, 1997 to April 16, 2019.

Texas Parks and Wildlife Department
4200 Smith School Road, Austin, Texas 78744