MOVEMENT AND FATE OF STOCKED RAINBOW TROUT IN AN ALABAMA TAILWATER

by

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ABSTRACT

Hypolimnetic discharge from reservoirs in the southern U.S. provides water temperatures cold enough to support Rainbow Trout *Oncorhynchus mykiss* fisheries in regions where they otherwise could not exist. The Sipsey Fork tailwater in Alabama provides such an opportunity and is stocked with Rainbow Trout monthly. In a recent creel survey, less than 25% of the Rainbow Trout stocked each month were harvested and few trout appeared to persist in the system more than 3-4 weeks. The objective of this study was to describe post-stocking dispersal and fate of the non-harvested Rainbow Trout. In March, June, and October 2017, and January 2018, cohorts of Rainbow Trout were radio tagged and tracked to document movement patterns and to determine longevity in the fishery. Tagged Rainbow Trout from all cohorts dispersed an average of 4.1 km (SE = 0.3075 km). Only 30% of tagged Rainbow Trout remained alive 5-weeks post-stocking. The extent of predation on Rainbow Trout was assessed using a bioenergetics approach. Electrofishing surveys and diet analysis of predators identified Striped Bass as the primary predators of Rainbow Trout in the Sipsey Fork. Bioenergetics simulations revealed that approximately 500 Striped Bass living continuously in the tailwater from March through October could consume all Rainbow Trout stocked each month. Knowledge regarding the dispersal and fate of stocked Rainbow Trout in this system can improve management of the fishery.

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CHAPTER I

INTRODUCTION AND STUDY SITE

Rainbow Trout *Oncorhynchus mykiss* are among the most widely introduced fishes in the world, with stockings beyond their native ranges for the purpose of recreational angling beginning as early as the 1860s (Welcomme 1988; Jenkins and Burkhead 1994). Beginning in the late 1930s, hypolimnetic releases from dams operated for hydropower, provided new, altered habitats in downstream tailwaters that could support salmonids in areas where waters commonly exceeded typical lethal temperatures during summer months (Axon 1975). Tailwaters in the southern United States maintain cold enough water temperatures year-round (< 25° C) to support successful Rainbow Trout fisheries (Cherry et al. 1977; United States Fish and Wildlife Service [USFWS] 1984; Biagi and Brown 1997; Krause et al. 2005). These fisheries are relatively common; in 2007, 50 tailwaters in 11 states in the southeastern U. S. were stocked with Rainbow Trout (Caudill 2007). Rainbow Trout are typically used in these fisheries due to their relatively rapid growth rate, low cost per unit of production, and high recreational value (Pawson and Purdom 1987; Pawson 1991). Public response to put-and-take trout fisheries has been favorable; programs are considered successful and serve as a source of economic significance (White 1968; Swink 1983; Owens 2002; Hutt and Bettoli 2007; Plummer et al. 2010). For instance, in 2004 the USFWS estimated that the social benefits, as measured by net economic value, of recreational angling for National Fish Hatchery-stocked Rainbow Trout in the U. S. generated US$197.9 million to the U. S. economy (USFWS 2006). Furthermore, Caudill (2007) estimated the overall benefit/cost of trout tailwaters in the southeastern U. S. was $7.41 for every dollar spent stocking.

Hydroelectric facilities are operated according to peak power, flood control, and navigation demands, and rarely consider downstream biota (Parsons 1957; Cushman 1985; FERC 2012). Often, these demands result in irregular discharge schedules causing frequent and significant changes in current velocity, water depth, dissolved oxygen (DO) concentrations, and temperatures (Goldsmith and Hildyard 1986). Discharge patterns from hydroelectric facilities can mediate the success of put-and-take trout fisheries by rapidly altering temperature and flow regimes (Cheslak and Carpenter 1990). McKinney et al. (2001) found that highly variable discharges from dams lower the carrying capacity of Rainbow Trout in downstream reaches. Peaking generation discharge in summer and fall often depress water temperature rapidly in the tailwater (Cushman 1985; Krause 2002; Orth et al. 2001, 2002), and drastic temperature changes can induce 'cold shock' in fishes, resulting in loss of equilibrium, reduced swimming ability, or even mortality (Chavin 1973; Reynolds and Casterlin 1979; Ottaway and Forrest 1983; Saltveit et al. 1995; Smythe and Sawyko 2000). Often hypolimnetic discharge from hydroelectric dams is characterized by low DO concentrations due to thermal stratification of upstream reservoirs resulting in hypoxic or anoxic conditions below the thermocline (Ward and Stanford 1987; Hayes et al. 1998; Higgins and Brock 1999). Rainbow Trout are considerably less tolerant to low DO concentrations than many other fishes (Downing and Merkens 1957; Doudoroff and Shumway 1970) and may experience reduced feeding rates when subjected to DO levels below 3 mg/L (Gutsell 1929; Doudoroff and Shumway 1970; Davis 1975; Matthews and Berg 1997). Moreover, extended periods of DO < 4 mg/L can result in high mortalities in Steelhead Trout (Frodge et al. 1995).

Discharge during hydropeaking can be more than 10-fold higher than base-flow conditions (Trotzky and Gregory 1974; Cushman 1985; Bain et al. 1988) and can reduce fish growth and survival (Grizzle 1981; Weisburg and Burton 1993). Benthic invertebrate communities are particularly impacted by flow regimes in tailwaters (Blanz et al. 1969; McGary and Harp 1972), creating low-diversity communities dominated by chironomids and other tolerant species, all of which provide a poor forage base for Rainbow Trout (Tippets and Moyle 1978). Also, habitat features such as large woody debris and instream aquatic vegetation that provide salmonids with necessary cover and refugia (McMahon and Hartman 1989) are often washed out in tailwaters during discharge events, resulting in less Rainbow Trout habitat (Pert and Erman 1994). Moreover, discharge fluctuations contribute to unsuitable spawning habitats for salmonids, often preventing salmonid recruitment (Pender and Kwak 2002; Holbrook and Bettoli 2006).

In addition to being limited by temperature, DO, and discharge fluctuations, hatchery Rainbow Trout exhibit disadvantageous behaviors that have been linked to higher mortality rates (Jenkins 1971). Newly stocked fish move more than resident fish (Bachman 1984; Mesa 1991; Bettinger and Bettoli 2002; Biro et al. 2004) resulting in increased energy expenditures and commensurate higher consumptive demands (Beamish 1978; Barton 1996). Inability to meet those demands prevents growth and can result in starvation. Furthermore, hatchery reared fish have demonstrated deficits in antipredator behavior, making them more vulnerable to predation (Suboski and Templeton 1989; Brown and Smith 1998).

Thus, it is unsurprising that mortality rates of stocked salmonids are often high (Bachman 1984; Stuber et al. 1985; Weithman and Haas 1984; Berg and Jorgensen 1991; O'Bara and Eggleton 1995). Catchable size (> 200 mm total length [TL]) stocked Rainbow Trout often experience poor survival (3-4%) within the first six months (Näslund 1992; Bettoli and Bohm 1997; Bettoli et al. 1999; Pedersen et al. 2003). For instance, cohorts of Rainbow Trout in the Clinch River, Tennessee, persisted less than 20 days despite low angler exploitation (<7%; Bettinger and Bettoli 2002). Often, less than 1-2% of stocked, catchable-size Rainbow Trout survive more than one year in streams (Miller 1952; Heimer et al. 1985; Wiley et al. 1993; Dillon et al. 2000). Cresswell (1981), in his review of 18 Rainbow Trout fisheries throughout the U. S. and U. K., found that on average anglers harvested only 32% of stocked Rainbow Trout. Due to these low survival and return-to-creel rates, Rainbow Trout are usually stocked frequently in order to maintain the productivity of the fishery (Weiland and Hayward 1997; Heidinger 1999; Habera et al. 2018).

Several studies have linked stocked Rainbow Trout mortality to fish predation (Bettoli 2000; Baldwin et al. 2003; Ivasauskas and Bettoli 2011). Piscivorous species often demonstrate a preference for soft-rayed, fusiform shaped fish (Hoyle and Keast 1987; Wahl and Stein 1988; McMahon and Bennett 1996; Baldwin et al. 2003; Walrath et al. 2015; Scheibel et al. 2016). Within one week of a stocking event, Rainbow Trout accounted for 40% of the volume of food consumed by Striped Bass *Morone saxatilis* in the Illinois River below Tenkiller Dam, Oklahoma (Deppert and Mense 1980). Predation on stocked fishes is likely highest soon after stocking because predator feeding responses are stimulated with high densities of stocked fish (Buckmeier and Betsill 2002; Buckmeier et al. 2005; Lundgren and Schoenebeck 2014). High predation rates on stocked Rainbow Trout further reduce the amount of fish available to anglers and likely contribute to the observed poor return rate found by many studies.

Tailwater Rainbow Trout fisheries across the U. S. face management problems associated with low stocked trout survival. Quantifying mortality and dispersal of stocked Rainbow Trout may provide insight into the availability of stocked fish to anglers and therefore may help to determine what management actions could be taken to improve the fishery. Thus, the objectives of this study are to (1) describe post-stocking persistence, dispersal, activity, and range of Rainbow Trout cohorts stocked in the Sipsey Fork tailwater (Chapter 2); and to (2) assess the extent of predation on stocked Rainbow Trout in the Sipsey Fork tailwater (Chapter 3). Results of the project will help managers to better understand the dynamics of this fishery and to improve opportunities for anglers targeting Rainbow Trout.

Study Site

The Sipsey Fork tailwater is a fifth-order tributary of the Black Warrior River located below Lewis Smith Dam in Walker and Cullman counties in north central Alabama (Pierson et al. 2008; Figure 1). The Sipsey Fork tailwater has been stocked with Rainbow Trout since 1974 (Jay Haffner; Alabama Division of Conservation and Natural Resources (ADCNR), personal communication). Lewis Smith Dam is a hydroelectric power generation facility operated by Alabama Power Company (APC) that provides hypolimnetic discharge cool enough to sustain this Rainbow Trout fishery. The dam has two generators, each rating 78,750 kilowatts and capable of generating 4,777 m^3/s of water at full capacity (Keith Chandler; APC, personal communication). Typical of hydropower operations, generation schedules and subsequent water releases are inconsistent and often change with little notice due to unanticipated changes in weather conditions and power system requirements. The tailwater experiences dramatic water-level changes during power generations and warning sirens notify anglers to evacuate from the banks prior to generation. Shortly after generation begins, discharge in the tailwater can increase from near 0 to 283 m^3/s and water levels can rise up to 3 m (FERC 2012). A year-round minimum discharge of 1.42 m^3/s has been established to maintain cool temperatures and increase late summer DO concentrations (McKee and Haffner 2017). To achieve the minimum flow requirements APC maintains two aeration systems at Lewis Smith Dam, one for minimum flow and another during generation. These systems operate to keep the DO above 4.0 mg/L at all times to meet the Alabama state standard (FERC 2012). The minimum flow system operates when the tailwater elevation declines to 256.2 msl following generation (Keith Chandler; APC, personal communication; FERC 2012).

The ADCNR has maintained a put-and-take fishery in the Sipsey Fork tailwater below Lewis Smith Dam since the mid-1970s (Figure 1). Approximately 1,100 to 3,500 catchable size (200 – 406 mm total length [TL]) Rainbow Trout are stocked monthly into this tailwater. Rainbow Trout are obtained from either Dale Hollow National Fish Hatchery (DHNFH) in Celina, Tennessee, or private hatcheries. Rainbow Trout from DHNFH are given in exchange for ADCNR's participation in the U.S. Fish and Wildlife Service's (USFWS) work on Gulf-strain Striped Bass restoration plan and fish from private hatcheries are purchased with annual mitigation funds from APC. This fishery has offered historical economic and recreational importance to Alabama and is still the only year-round Rainbow Trout fishery in the state. This fishery is a popular destination for both local and out-of-state anglers, as McKee and Haffner (2017) estimated 32,500 h of angling effort occurred on the Sipsey Fork from June 2014 through May 2016. However, anglers caught less than 25% of Rainbow Trout stocked each month, and harvested only 16%. Few Rainbow Trout appear to persist in the system greater than 3-4 weeks. Little other information has been collected about the movements and fate of Rainbow Trout stocked in the Sipsey Fork. The presence of large Striped Bass in the tailwater during summer and fall months has been commonly reported by anglers who believe that Striped Bass predation might be reducing angler opportunity and benefit from the Rainbow Trout fishery.

CHAPTER II

PERSISTENCE, DISPERSAL, ACTIVITY, AND RANGE OF STOCKED RAINBOW TROUT IN THE SIPSEY FORK TAILWATER, ALABAMA

Introduction

Tailwaters located downstream of hydropower dams have been utilized by fisheries managers since the 1930s to enhance angling opportunities through the establishment of put-and-take salmonid fisheries (Axon 1975). Rivers that can support year-round Rainbow Trout fisheries are uncommon in the southern United States, and the novelty of these trout fisheries makes them particularly attractive to anglers. Despite their popularity, tailwater salmonid fisheries often experience minimal catch rates and poor long-term fish survival (Bachman 1984; Näslund 1992; O'Bara and Eggleton 1995; Bettoli and Bohm 1997; Bettoli et al. 1999; Magnelia 2007). Attempts have been made to improve these fisheries by implementing gear regulations, catch-and-release zones, and frequent stocking plans, but these efforts have rarely been successful (Magnelia 2007).

The Sipsey Fork Rainbow Trout *Oncorhynchus mykiss* tailwater fishery below Lewis Smith Dam, Alabama has served as a recreationally and economically important fishery since the mid-1970s. State regulations allow anglers to harvest five Rainbow Trout daily, but a recent study by McKee and Haffner (2017) found that relatively few of these stocked Rainbow Trout could be accounted for by angler catch or harvest. Furthermore, few Rainbow Trout appear to persist in the system, and the fate of stocked Rainbow Trout in this system remains unknown. Therefore, the objective of this study was to describe the persistence, dispersal, activity, and fate of Rainbow Trout stocked into the Sipsey Fork.

Methods

Study Site

This project was conducted over the 22.5-km reach extending from Lewis Smith Dam downstream to the public boat ramp located at the confluence of the Sipsey and Mulberry forks of the Black Warrior River (Figure 1). The lower boundary was assumed to be the furthest distance downstream where oversummer survival of stocked Rainbow Trout might occur based on observed water temperatures (> 25ºC). Rainbow Trout are stocked approximately 100 m downstream of the dam, near the fishing platform on the west side of the river, typically during generation. Eight angler access sites along the first 4 km downstream of the dam on the eastern side of the tailwater are maintained by APC (Figure 1). A water pumping station operated by Birmingham Water Works is located approximately 1.6 km downstream of the dam. In the early 2000s, a habitat enhancement project was initiated by APC, ADCNR, and the USFWS to improve the fishery. This project included the installation of rock points, boulders, and in-stream woody structures to create 0.8 km of riffle, run, and pool habitat just upstream of the pumping station (McKee and Haffner 2017). Similar to most tailwaters, the Sipsey Fork below Lewis Smith Dam is deeply incised with steep banks and minimal instream cover; thus most of the study site is too deep to wade and angler access is generally limited to the eight sites maintained by APC. Downstream of the Highway 69 Bridge, the river channel widens and deepens, restricting anglers to watercraft. Primary habitat in this reach shifts from rock to large woody debris and aquatic vegetation.

Tagging and Tracking

Four cohorts of adult Rainbow Trout ranging from 191– 432 mm TL (mean = 280 mm; SE = 6.5 mm) were surgically implanted with Advanced Telemetry Systems (ATS) Model

F1560 radio tags (Advanced Telemetry Systems, Isanti, Minnesota; Table 1). These radio tags were equipped with a 20-cm whip antenna, possessed a 198-d battery life expectancy, and weighed 2.5-g in air. Fish were anesthetized with a 75 mg/L concentration of tricaine methanesulfonate (MS-222). Radio transmitters were inserted through an incision slightly off the midventral line and anterior to the pelvic girdle using the shielded-needle technique (Ross and Kleiner 1982; Bettinger and Bettoli 2002). Each incision was closed with two, 3-0 polypropylene non-absorbable monofilament sutures. All tagging was completed at DHNFH, and fish remained at the hatchery for at least 24 d prior to stocking to comply with the 21-d withdrawal period for fish anesthetized with MS-222. Mortality of tagged fish prior to stocking occurred only in the October cohort in which 3 of the 29 tagged fish were found dead; 2 outside and 1 within the raceways at the hatchery. Three Rainbow Trout from the October cohort expelled their tags before being stocked into the Sipsey Fork. Before loading into the hatchery trucks for transport, tagged fish were assessed by DHNFH personnel for their tag scars and overall health. Tagged fish were loaded with the rest of the untagged Rainbow Trout cohort, transported to the Sipsey Fork, and stocked by DHNFH personnel at the fishing platform. Cohorts with tagged fish were stocked on March 23, 2017 (N = 20 tagged fish), June 22, 2017 (N = 21), October 26, 2017 (N = 23), and January 18, 2018 (N = 28).

A dummy tag study was conducted in September, 2017 to estimate the frequency of radio tags being expelled from Rainbow Trout. Twenty-one Rainbow Trout were tagged with dummy tags using the same surgical procedure as with the radio tags. Rainbow Trout remained at the hatchery under hatchery personnel supervision for four months. Four Rainbow Trout in this study had expelled their tags, all within 30 d.

Rainbow Trout were manually tracked over a three-month period using an ATS R2000 receiver and a four-element fixed yagi antenna twice a week for the first four weeks post-stocking, once a week during the next four weeks, and then biweekly for the following month. Fish were tracked along the entire study reach during daylight hours from a 4.6-m canoe when power generation did not occur, and from a 4.9-m jon boat during generation. Tracking was occasionally conducted outside the study reach when tagged fish were not located. A location point for each fish was recorded using a Garmin eTrex 20 handheld Global Positioning System (GPS), either where the strongest signal was achieved or when a strong signal faded rapidly, indicating fish movement (Bettinger and Bettoli 2002). Due to GPS accuracy, a mean error of 10 m associated with each location was assumed (Garmin Ltd. 2019). Surface water temperatures (°C), and dissolved oxygen concentrations (mg/L) were recorded at each tagged fish location. Discharge data per turbine (m^3/s) from Lewis Smith Dam in hourly increments were obtained for the duration of each tracking event (Jason Carlee, APC, unpublished data; Figure 2).

By the end of tracking for each cohort, three possible fates for radio-implanted Rainbow Trout in the Sipsey Fork were determined. Fish could remain alive in the fishery, could be considered lost from the fishery, or could have an unknown fate. If a fish was tracked to a different location (i.e., > 10 m from previous location) each tracking period, it was considered to be alive. Transmitters that were within 100 m of the dam could not be accurately located due to interference with the dam structure; thus, movement or lack thereof could not be determined (Pine et al. 2012). Tagged fish that remained within this area were therefore considered to have an unknown fate. A fish was assumed lost from the fishery when a transmitter was found in the channel or on the bank. If a fish was tracked to the same location (i.e., ≤ 10 m from previous location) after three tracking periods, this fish was considered lost from the fishery during the first week that movement ceased (Lee and Bergersen 1996; Bettoli and Osborne 1998; Pine et al. 2012). Because water temperatures downstream of the study reach often exceeded lethal limits of Rainbow Trout, fish were also considered lost from the fishery when their transmitter could not be located within the study reach. Signs were posted at all major access points informing the public of the telemetry study and instructing anglers to contact researchers if they harvested a tagged Rainbow Trout. Only after a transmitter was received from an angler was the fish considered to be harvested, and therefore considered lost from the fishery. When tracking tagged fish, water clarity often allowed for visual observation of fish. Occasionally, the fish tracked was a Striped Bass *Morone saxatilis* which indicated predation of a tagged Rainbow Trout. Observations were noted, and future trackings of these eaten fish were conducted to confirm predation. If movement ceased within two weeks of tracking, tags were assumed to have passed through the digestive tract of the Striped Bass, and predation was assigned as the fate of the tagged Rainbow Trout.

Data Analyses

Persistence, dispersal, activity, and range of each cohort of tagged Rainbow Trout were estimated for the first five weeks post-stocking. Persistence was defined as the number of days (up to 35) a tagged Rainbow Trout remained alive in the fishery (Bettinger and Bettoli 2002). Dispersal was defined as the average weekly (m) distance traveled by individual fish from the stocking site and was calculated to the nearest m. Activity was defined as the distance travelled between consecutive locations of individual fish within each week (m; Bettinger and Bettoli 2002). Range (m) was defined as the distance between the farthest upstream and downstream locations for individual fish. Fish with unknown fates were excluded from persistence, dispersal, and activity analyses. Because range was defined as only a difference between locations, it could be estimated regardless of a fish's fate. ArcMap (version 4.0, 2016) was used to calculate distances between tracking events.

All statistical analyses were conducted in Program R (version 3.5.3, 2019). A Bartlett's test, Shapiro Wilks test, and Levene test were conducted for each dataset to determine normality of data. Data were assumed to follow parametric assumptions when variances were homogenous (Levene test; *P* value = 0.05), and were $\log_e$ transformed when necessary to meeting the assumption of homogenous variances (Guy and Brown 2007). When using parametric procedures, the mean of the sample population was used as a measure of central tendency (Fowler et al. 1998).

An analysis of variance (ANOVA) was used to determine if mean persistence of tagged fish varied across cohorts. To identify which sampling groups differed, a Tukey's Post-Hoc test (*P* value = 0.05) was used within the multcomp package in R. A Chi-Square Test of Independence was used to determine if survival varied across cohorts, followed by a Post-Hoc Pairwise Comparison test to determine which Rainbow Trout cohorts exhibited greater survival.

Dispersal was analyzed with a linear mixed-effects model to test for the main effects of cohort, week, discharge, and the associated interactions. If the model failed to converge, an additive model was used. Individual tagged fish were included as a random variable to account for a behavior effect. Pairwise comparisons (*P* value = 0.05) among significant interactions were assessed using a least-squares means test within the lsmeans package in R.

Activity was analyzed with a linear mixed effect model to test for the main effects of cohort, week, and discharge as well as the interaction of the three. If the model failed to converge, an additive model was used. Individual tagged fish were included as a random effect as described above. Pairwise comparisons (P value = 0.05) among significant interactions were assessed using a least-squares means test within the lsmeans package in R.

Range was analyzed with an ANOVA to evaluate mean differences of tagged fish across cohorts. Significant multiple comparisons were determined using a Tukey Post-Hoc test (P value = 0.05) within the multcomp package in R. The results of all tests were considered significant at P value < 0.05.

Results

Discharge, Temperature and Dissolved Oxygen

Average discharge was highest in the third week of March (151 m^3/s) and lowest in the third and fourth weeks of January (0 m^3/s; Figure 2). Average discharge from generation events five weeks post-stocking were 523%, 526%, and 448% higher during the March, June, and October stocking months than in the January stocking month, respectively (Figure 2). Average DO levels recorded during tracking events did not fall below the state's minimum standard of 4.0 mg/L. However, DO as low as 2.17 mg/L was recorded at a tagged fish location while tracking the June cohort (Figure 3). Similarly, average water temperatures in the Sipsey Fork did not exceed Rainbow Trout lethal limits but the maximum temperature recorded at a tagged fish location in March did exceed the lethal limit (26.2° C; Figure 4).

Fate and Persistence

A total of 678 fish locations was obtained from 46 tracking surveys on the Sipsey Fork. 51% of all of the tagged Rainbow Trout were lost from the fishery (4% were reported harvested), 30% remained alive in the fishery, and 19% had unknown fates after five weeks post-stocking. Throughout the study, only four fish were reported as harvested; all were from the January cohort and were caught near the stocking location. Rainbow Trout survival differed among cohorts ($\chi^2 = 20.563$; df = 3; $P = 0.0001$; Figure 5). Rainbow Trout stocked in January (14 of 19 known fates) exhibited greater survival than those stocked in June (3 of 20 known fates) or October (2 of 18 known fates; $P = 0.0023$; Figure 5). Unknown fates were higher in January than in all other cohorts (9 of 28 total unknown fates; Figure 6) because more fish remained in close proximity to the dam. Rainbow Trout stocked in January persisted in the fishery an average of 13 d longer than those stocked in October ($F_{3,71}$ = 4.25; P = 0.0081). Tagged fish in the March, June, and October cohorts (15%; 14%; and 17% respectively) were identified as being eaten by Striped Bass; overall, only 11% (10 of 92) of transmitted fish were considered eaten by Striped Bass.

Dispersal

Tagged Rainbow Trout from all cohorts dispersed an average of 4.1 km (SE = 0.3075 km; Figure 7). The linear mixed-effects model examining Rainbow Trout dispersal did not converge with the inclusion of discharge due to singularity. The main effect of discharge did not affect dispersal (F = 0.37; df = 1; P = 0.5451) and was therefore removed from analysis. After removing discharge from the analysis, the interaction of cohort and week was significant (F = 5.88; df = 12; P < 0.0001), indicating that the relationship between dispersal and week varied among cohorts (Figure 8). Tagged Rainbow Trout stocked in January dispersed less than those stocked in March and June in weeks two through five. Almost half (45 of 92) of all tracked Rainbow Trout moved more than 3 km downstream at some point during the five weeks post-stocking.

Range

Average range of all tracked Rainbow Trout in the Sipsey Fork was 5.8 km (SE = 0.6928 km). Ranges of tagged Rainbow Trout differed across cohorts ($F_{3,88}$ = 15, P < 0.0001). January stocked Rainbow Trout exhibited lower range of movement than all other cohorts (Table 2). The maximum range a fish travelled downstream of the stocking site was 22.3 km.

Activity

Average activity for the 92 tagged Rainbow Trout across all cohorts was 2.4 km (SE = 0.2561). Similar to dispersal, the linear mixed-effects model examining Rainbow Trout activity failed to converge with the inclusion of discharge due to singularity. Therefore, an additive model with discharge, week, and cohort was used. The main effect of discharge did not impact activity ($F = 0.02$; df = 1; $P = 0.8988$) and was therefore removed from analysis. After removing flow from the analysis, the interaction of cohort and week were significant ($F = 6.35$; df = 12; $P < 0.0001$), indicating that the relationship between activity of tagged Rainbow Trout and week varied among cohorts (Figure 9). Rainbow Trout stocked in June, October and January exhibited greater average activity in week one than in weeks three through five. Rainbow Trout stocked in March had higher levels of activity than those stocked in January over all weeks.

Discussion

The dispersal of most stocked Rainbow Trout in the Sipsey Fork trout fishery was extensive compared to dispersal observed in other stocked trout fisheries. Previous studies have documented that most stocked Rainbow Trout exhibit low dispersal (Cooper 1953; Cresswell 1981; Kendall and Helfrich 1982; Heimer et al. 1985; Fay and Pardue 1986; Baird et al. 2006; High and Meyer 2009). Typically, more than 85% of Rainbow Trout stay within 1 – 3 km of their stocking site (Cooper 1953; Fay and Pardue 1986; High and Meyer 2009). Other studies have reported even less movement away from stocking areas, from 50 to a few hundred m of the release site (Heimer et al. 1985; Gido et al. 1999; Cummings 2015). In contrast, Rainbow Trout in the Sipsey Fork dispersed 13 to 22,268 m away from their stocking site. Similarly, studies have also documented extensive dispersal by some stocked Rainbow Trout (Shetter 1947; Heimer et al. 1985; and High and Meyer 2009). Movement patterns of fish within a population usually vary among individuals, with some individuals moving longer distances than others (Grant and Noakes 1987; Hughes and Dill 1992; Pert and Erman 1994; Baird et al. 2006). Maximum downstream movement of tracked Rainbow Trout in the Sipsey Fork was in the range of those reported in other studies (i.e., 15.2-27.4 km; Bjorn and Mallet 1964; Gido et al. 1999; Bettinger and Bettoli 2002; High and Meyer 2009). Thus, although Rainbow Trout in the Sipsey Fork exhibited higher average dispersal than those in most other studies, maximum dispersal was relatively similar.

Results from this study indicate that Rainbow Trout dispersal and activity varied across seasons similar to results found by Cresswell (1981) and Cobb (1933), who suggested that season of stocking affected post-stocking movements. Bjornn and Mallett (1964) observed more stocked Rainbow Trout (90%) remained within 3 km downstream of the stocking site in autumn compared to those stocked in spring (50%). Likewise, Meyers et al. (1992) documented increased movement by Brown Trout *Salmo trutta* during the spring. In the Sipsey Fork, tagged Rainbow Trout dispersed less in January than any other month stocked. Bowen (1996) also observed minimal Rainbow Trout movement during winter. Water temperatures in the Sipsey Fork were noticeably lower in January compared to the other months. Salmonids have been found to shift from diurnal to nocturnal activity in winter months (Heggenes et al. 1993; Riehle and Griffith 1993; Fraser et al. 1995; Harvey et al. 1999; Metcalfe et al. 1999; Bremset 2000; Giannico and Hinch 2003) which may be the reason for observed lower movement rates by tagged Rainbow Trout in the Sipsey Fork during the month of January as tracking only occurred during daytime hours.

Generation events have been shown to impact tailwater Rainbow Trout fisheries as available trout habitat can be changed by even small daily fluctuations (1.6-5.1 m^3/s) from generation events (Pert and Erman 1994). Rainbow Trout in the Canyon Reservoir tailwater, Texas, dispersed further from the stocking site when flows were higher (Cummings 2015). Bettinger and Bettoli (2002) attributed high Rainbow Tout dispersal distances in the Clinch River to the inability of hatchery Rainbow Trout to cope with high stream velocities associated with generation in a tailwater. In this study, discharge did not appear to be related to Rainbow Trout dispersal or activity in the Sipsey Fork, similar to what Gido et al (1999) found in the San Juan River, New Mexico. However, tracking events were not conducted daily and therefore discharge effects on Rainbow Trout behavior may have occurred at finer scales than could be detected in this study.

The effect of discharge on Rainbow Trout may be mediated by fish size. Small Rainbow Trout (< 306 mm) have been found to move more during unstable discharge and use much higher water velocities than larger adults, possibly because smaller fish have less experience than larger fish and therefore do not locate profitable positions as effectively (Bowen 1996). Adult salmonids decrease movement during increased discharge because of higher energetic costs associated with moving to find refuges (Heggenes 1988; Bowen 1996). Small Rainbow Trout can also be more strongly influenced by flow variation and mean discharge than larger fish (Schlosser 1985, McKinney et al. 2001). Most tagged Rainbow Trout in my study were small (78.5% of tagged individuals were < 306 mm), but discharge was not a significant determinant of trout dispersal or activity.

Recently stocked Rainbow Trout in the Sipsey Fork exhibited high levels of activity, similar to results found by Bettinger and Bettoli (2002). Excessive energy expenditure by hatchery salmonids compared to resident salmonids has been attributed to behavioral traits adapted from hatchery conditions (Jenkins 1971; Bachman 1984). Another reason extensive dispersal and high levels of activity of stocked Rainbow Trout were observed in the Sipsey Fork may be due to the lack of available substrate for fish to utilize. Bed roughness and instream cover are critical in providing fish with low-velocity refuges (Bachman 1984; Heggenes 1988; Webb 2006; Cummings 2015) and Rainbow Trout have been documented using bedrock crevices as velocity refugia at high flows (Quinn and Kwak 2000). Compared to natural streams, highly regulated tailwaters, including the Sipsey Fork, often lack an abundance of bed roughness and instream cover (Gore and Hamilton 1996; Gore et al. 1998). Furthermore, increasing instream cover has been shown to enhance macroinvertebrate habitat (Kondolf et al. 1996; Gore et al. 1998; Merz and Setka 2004), which in turn, provides greater forage opportunities for Rainbow Trout. Although instream cover was recently added to an 800-m reach of the Sipsey Fork as part of a habitat restoration project (Jay Haffner, ADCNR, personal communication), the restored area is likely not large enough to accommodate the number of Rainbow Trout stocked. Extending the habitat restoration project to cover the first 4000 m below Lewis Smith Dam may increase flow refugia and macroinvertebrate availability, thereby providing anglers with greater opportunities to catch fish.

Of all of the tagged Rainbow Trout stocked in the Sipsey Fork, 51% were lost from the fishery (4% were reported harvested), 30% remained alive in the fishery, and 19% had unknown fates after five weeks post-stocking. Mortality of tagged fish prior to stocking was rare, occurring only in the October cohort (3 of 29 fish). Rainbow Trout that went missing from the tailwater could have swam downstream outside of the tracking range, or could have expired and floated downstream, could have been eaten by a predator and transported out of the study area, or they were harvested but not reported. Two Rainbow Trout that had initially been considered as having unknown fates were harvested near the dam four months post-stocking; thus, some of the unknown trout may have actually been alive. Fish were assumed to be dead when a transmitter in the river channel was found, or after the fish did not move after three locations. Nevertheless, tag expulsion has been well documented (Chisholm and Hubert 1985; Lucas 1989; Ivasauskas et al. 2012). Ivasauskas et al. (2012) documented 25% of tagged Rainbow Trout sutured using the same method as in this study expelled their transmitter within 65 d. Three of the radio-implanted Rainbow Trout from the October cohort expelled their transmitter during the 24-day recovery period in the hatchery. In addition, 19% of dummy tagged Rainbow Trout expelled their tags within 30 d of surgery, but none were expelled from Rainbow Trout between 30 d and 4 mo. Although some Rainbow Trout may have expelled their transmitters during the tracking period, biasing persistence estimates, observations from the 24-d post tagging period on DHNFH and the results from the dummy-tag study indicate that this was a rare event. Thus, transmitters were not assumed to have been expelled during the five weeks after being stocked.

Many studies have documented high mortality rates of stocked Rainbow Trout (Bachman 1984; Weithman and Haas 1984; Stuber et al. 1985; Berg and Jorgensen 1991; O'Bara and Eggleton 1995). Median persistence of stocked Rainbow Trout cohorts in the Sipsey Fork ranged from 19 to 35 d with fish stocked in January persisting longer than in October. Poor survival of stocked Rainbow Trout in the Sipsey Fork is consistent with other studies (Bettoli and Besler 1996; Bettinger and Bettoli 2002; High and Meyer 2009). Often, low persistence of stocked salmonids is not directly estimated, but inferred by lower return rates to anglers (Weithman and Haas 1984; Stuber et al. 1985). Fishing pressure and harvest can contribute greatly to stocked Rainbow Trout mortality and persistence (Besler 1996; Bettoli et al. 1999; Heidinger 1999), but put-and-take fisheries are often managed to provide harvest opportunities to anglers, and loss of trout to angler harvest may not necessarily be detrimental. The Sipsey Fork, however, does not appear to have extensive Rainbow Trout harvest as indicated by very low harvest return rates for radio implanted trout (4%), especially compared to other studies (> 20%; Cresswell 1981; Bettinger and Bettoli 2002). Only 32,500 hours of fishing effort occurred in the Sipsey Fork from August 2014 through May 2016 (McKee and Haffner 2017) which is nearly 10 times lower than fishing pressure reported for tailwaters in Tennessee. (Bettoli and Besler 1996; Bettoli and Xenakis 1996; Bettoli et al. 1999). Additionally, average stocking rates in the Sipsey Fork were roughly half that of the Holston River, Tennessee (Bettoli et al. 1999). Given the lower stocking rates and fishing effort in the Sipsey Fork, it makes sense that fewer fish would be harvested. However, few Rainbow Trout appear to persist past 5 weeks post-stocking in this fishery despite low harvest rates. Efforts to adjust the stocking to angling effort ratio may improve the overall harvest percentage and therefore reduce the number of unharvested Rainbow Trout.

However, harvest of radio-tagged Rainbow Trout in this study may have been underestimated. For March, June, and October stockings, flyers were posted at each angler access site that informed anglers of the study and gave them contact information to report harvest of a tagged fish. Transmitters from ATS did not include a contact number because of their small size. However, transmitters for the January stocking of Rainbow Trout had a contact number manually pasted to each. Since the only four reported harvested Rainbow Trout were from the January cohort, including a contact number on the transmitter likely encouraged angler harvest reports; whereas not having contact numbers on the transmitters from the March, June, and October cohorts may have underestimated the estimates of harvest rates. In the future, labeling radio tags with researcher contact information may help to improve harvest rate estimates.

Management strategies to improve tailwater salmonid fisheries often include efforts to increase minimum flows (Cushman 1985; Yeager et al. 1987; Krause et al. 2005; Cummings 2015). Increasing minimum flow increases feeding rate, growth rate, and abundance of fishes (Weisberg and Burton 1993; Travnichek et al. 1995). In addition, establishing minimum flows can improve macroinvertebrate communities in tailwaters (Scott et al. 1996). Minimum flow in the Sipsey Fork is two to three times lower than comparable tailwaters (Bettoli et al. 1999; Magnelia 2007; Cummings 2015). Increasing minimum flows to similar levels as other tailwaters may have a positive effect on macroinvertebrate communities and in turn, increase available salmonid habitat and food availability (Scott et al. 1996; Fiss and Young 2003).

Water temperatures can also limit salmonid populations when they exceed upper lethal limits for long periods of time (7 d at ≥, 25°C; Cherry et al. 1977; United States Fish and Wildlife Service [USFWS] 1984; Biagi and Brown 1997). Reduced growth of salmonids has been observed even at sublethal warm temperatures (Hokanson et al. 1977; Drake and Taylor 1996). Average water temperatures in the Sipsey Fork did not exceed lethal limits however, the maximum temperature recorded at a tagged Rainbow Trout's location (26.2° C) did exceed the lethal limit for at least a few days in the month of July. Water temperatures in tailwaters often exceed recommended limits (21.1° C) during summer months (Magnelia 2007; Axon 1975; Harper 1994; Runge et al. 2008). To resolve elevated water temperatures concerns, reservoir release agreements have been implemented in several tailwaters to keep water temperatures below 21.1° C (Magnelia 2007; Axon 1975; Harper 1994).

Low DO concentrations in tailwaters are often caused by discharges from anoxic hypolimnetic water from reservoirs (Bettoli and Xenakis 1996). The Federal Energy Regulatory Commission (2012) reported that DO levels in the Sipsey Fork tailwater often failed to meet the state standard of 4.0 mg/L during the summer and early fall months. In this study, DO levels as low as 2.17 mg/L were recorded while tracking the June cohort, and hypoxic stress in salmonids has been recognized to develop at 6 mg/L (Townsend and Ernest 1939). Increasing efforts to aerate discharge, specifically during summer months (June through September), within the first two miles of river below Lewis Smith Dam may improve water quality and therefore increase the productivity of the fishery. The combination of high water temperatures and DO concentrations less than 6 mg/L, may have been responsible for some Rainbow Trout mortality, however, these unsuitable levels only occurred during the June cohort which had similar persistence to the March and October cohorts. Therefore, temperature and DO were likely minor factors contributing to Rainbow Trout mortality.

Predation is a contributor to the low survival of Rainbow Trout stocked in the Sipsey Fork. Striped Bass stocked in reservoir systems occupy available cool water (< 25ºC) as thermal refuges during summer and spawning seasons (Coutant 1985; Moss 1985). Although overlap of Rainbow Trout and Striped Bass rarely occurs in natural systems, consistently cool tailwaters that are stocked with trout can attract adult landlocked Striped Bass in reservoir systems (Hess and Jennings 2000; Bettoli 2005). Predation of stocked Rainbow Trout by Striped Bass has been recorded in several southeastern tailwaters (Walters et al. 1997; Bettoli 2000; Bettinger and Bettoli 2002; Hess and Jennings 2000; Magnelia 2007). In an Oklahoma tailwater fishery, Rainbow Trout comprised 28% of Striped Bass diets (Deppert and Mense 1980). Hess and Jennings (2000), predicted that Striped Bass could consume 14-100% of Rainbow Trout stocked annually in the Chattahoochee River. Striped Bass were observed in the Sipsey Fork tailwater throughout the study period but especially during the stocking of the October cohort of tagged Rainbow Trout. During the October cohort, large numbers of sizeable Striped Bass were observed preying on newly stocked Rainbow Trout for ten minutes prior to power generation. This cohort had the lowest survival of all cohorts, and the most tagged fish identified as being eaten by Striped Bass. This suggests that low survivability of Rainbow Trout could be related to predation. Investigation of Striped Bass movement patterns and population size in the Sipsey Fork may provide greater insight into how significantly these predators negatively impact the stocked Rainbow Trout population.

Management Implications

Results from this study indicate that few Rainbow Trout contribute long-term to the Sipsey Fork fishery, as a majority of radio-implanted hatchery Rainbow Trout were lost from the study area within five weeks post-stocking. Although Striped Bass predation was clearly a large factor mediating Rainbow Trout survival in some seasons, other factors may also regulate trout persistence. Water temperature and DO concentrations were occasionally observed outside preferred limits for Rainbow Trout during tracking surveys despite the fact that tracking was not conducted during months when these conditions would be expected to be the most severe (i.e., late summer, early fall). Managers should be aware that DO concentrations in the reservoir available to be discharged into the tailwater during summer months can vary across years, depending on precipitation patterns (Sammons and Glover 2013).

This economically important tailwater Rainbow Trout fishery could be further enhanced by determining stocking densities specific to the Sipsey Fork that would provide maximum fishery benefits from a limited number of fish (Miko et al. 1995; Bettoli and Xenakis 1996). After determining the seasonal presence of predators in this tailwater, stockings may be adjusted to seasons when predators are least common within the tailwater or according to seasons experiencing greater angler pressure. Angling pressure in the Sipsey Fork increases through the spring and peaks in late summer, then declines steadily (McKee and Haffner 2017). Continued efforts to increase bed roughness and instream cover within the first 3.5 km below Smith Dam will provide fish with more low-velocity refuges, and may therefore reduce downstream dispersal (Cushman 1985). Concentrating Rainbow Trout within the angler access locations would offer anglers maximum access to the fish in the tailwater, and would likely increase catch rates.

In conclusion, persistence rates of stocked Rainbow Trout in the Sipsey Fork are low. If the economic benefits of fish that remain alive in the fishery are considered large enough to outweigh the costs of producing and stocking fish that do not survive in the fishery, low persistence rates may be acceptable. Economic and recreational trade-offs will need to be carefully examined to assess the costs and benefits of the stocking program. No explicit management goals have been established for the Sipsey Fork tailwater Rainbow Trout fishery. In order for managers to consider management options, it is necessary for objectives to be clearly defined for this fishery.

Tables

Table 1. Fish identification number, length (TL, mm), tagging and stocking date of hatchery Rainbow Trout tracked in the Sipsey Fork, Alabama. Number of locations (N), days active in the fishery and the fate of each fish. Fate: Alive = fish tracked to different locations (> 10 m) during each tracking event; Lost from fishery = fish harvested, tag retrieved, fish tracked to the same location (< 10 m) more than three consecutive times, fish disappeared from fishery; Unknown = fish who remained within 100 m of Lewis Smith Dam throughout study period.

Fish ID	TL	Date Tagged	Date Stocked	N	Days Active	Fate
1	406	2/28/17	3/23/17	14	55	Alive
2	432	2/28/17	3/23/17	5	18	Lost
3	394	2/28/17	3/23/17	16	839	Alive
4	258	2/28/17	3/23/17	9	13	Lost
6	419	2/28/17	3/23/17	11	55	Alive
7	406	2/28/17	3/23/17	6	-	Unknown
8	406	2/28/17	3/23/17	17	109	Alive
9	381	2/28/17	3/23/17	2	8	Lost
10	394	2/28/17	3/23/17	1	1	Lost
11	406	2/28/17	3/23/17	16	113	Alive
12	268	2/28/17	3/23/17	11	55	Alive
14	394	2/28/17	3/23/17	7	29	Alive
15	280	2/28/17	3/23/17	8	29	Lost
17	381	2/28/17	3/23/17	9	22	Lost
18	381	2/28/17	3/23/17	8	25	Lost
19	406	2/28/17	3/23/17	8	33	Alive
20	274	2/28/17	3/23/17	6	22	Lost
22	356	2/28/17	3/23/17	3	8	Lost
23	394	2/28/17	3/23/17	14	109	Alive
24	406	2/28/17	3/23/17	2	8	Lost
5	419	5/25/17	6/23/17	7	25	Lost
13	356	5/25/17	6/23/17	7	17	Lost
16	330	5/25/17	6/23/17	7	78	Alive
21	394	5/25/17	6/23/17	1	5	Lost
26	281	5/25/17	6/23/17	4	12	Lost
27	257	5/25/17	6/23/17	1	5	Lost
28	276	5/25/17	6/23/17	9	21	Lost
29	263	5/25/17	6/23/17	7	35	Lost

30	267	5/25/17	6/23/17	7	78	Alive
32	260	5/25/17	6/23/17	1	19	Lost
34	260	5/25/17	6/23/17	3	2	Lost
35	282	5/25/17	6/23/17	6	35	Lost
36	273	5/25/17	6/23/17	8	17	Lost
37	261	5/25/17	6/23/17	8	21	Lost
41	275	5/25/17	6/23/17	6	3	Lost
43	225	5/25/17	6/23/17	7	35	Lost
44	269	5/25/17	6/23/17	8	19	Lost
45	285	5/25/17	6/23/17	9	-	Unknown
25	246	9/14/17	10/26/17	4	13	Lost
31	252	9/14/17	10/26/17	8	-	Unknown
38	259	9/14/17	10/26/17	9	34	Lost
40	263	9/14/17	10/26/17	3	14	Lost
42	234	9/14/17	10/26/17	6	19	Lost
47	257	9/14/17	10/26/17	1	34	Lost
48	259	9/14/17	10/26/17	7	-	Unknown
49	240	9/14/17	10/26/17	9	21	Lost
50	261	9/14/17	10/26/17	7	12	Lost
52	205	9/14/17	10/26/17	9	33	Alive
53	216	9/14/17	10/26/17	6	14	Lost
54	263	9/14/17	10/26/17	11	-	Unknown
55	194	9/14/17	10/26/17	9	-	Unknown
56	219	9/14/17	10/26/17	8	19	Lost
58	230	9/14/17	10/26/17	6	19	Lost
59	241	9/14/17	10/26/17	6	12	Lost
61	229	9/14/17	10/26/17	2	8	Lost
62	213	9/14/17	10/26/17	3	8	Lost
64	232	9/14/17	10/26/17	8	-	Unknown
65	248	9/14/17	10/26/17	9	51	Alive
67	213	9/14/17	10/26/17	7	-	Unknown
68	223	9/14/17	10/26/17	7	14	Lost
69	260	9/14/17	10/26/17	3	12	Lost
33	254	12/11/17	1/18/18	6	24	Lost
39	228	12/11/17	1/18/18	6	34	Lost
46	283	12/11/17	1/18/18	9	78	Alive
51	217	12/11/17	1/18/18	10	25	Lost
57	244	12/11/17	1/18/18	10	-	Unknown

60	269	12/11/17	1/18/18	12	84	Alive
63	252	12/11/17	1/18/18	6	29	Lost
66	247	12/11/17	1/18/18	7	-	Unknown
70	214	12/11/17	1/18/18	9	14	Lost
71	219	12/11/17	1/18/18	7	12	Lost
72	243	12/11/17	1/18/18	6	-	Unknown
73	243	12/11/17	1/18/18	11	84	Alive
74	227	12/11/17	1/18/18	10	64	Alive
75	231	12/11/17	1/18/18	9	-	Unknown
76	230	12/11/17	1/18/18	10	-	Unknown
77	221	12/11/17	1/18/18	6	-	Unknown
78	261	12/11/17	1/18/18	9	-	Unknown
79	259	12/11/17	1/18/18	12	84	Alive
80	191	12/11/17	1/18/18	12	-	Unknown
81	270	12/11/17	1/18/18	10	42	Alive
82	263	12/11/17	1/18/18	8	-	Unknown
83	261	12/11/17	1/18/18	7	29	Lost
84	275	12/11/17	1/18/18	10	84	Alive
85	263	12/11/17	1/18/18	10	49	Alive
86	241	12/11/17	1/18/18	12	84	Alive
87	283	12/11/17	1/18/18	11	84	Alive
88	258	12/11/17	1/18/18	11	84	Alive
89	253	12/11/17	1/18/18	9	84	Alive
90	257	12/11/17	1/18/18	11	84	Alive
91	275	12/11/17	1/18/18	11	84	Alive
92	234	12/11/17	1/18/18	11	84	Alive

Table 2. Tukey HSD Post-Hoc pairwise comparisons of average range by cohort. Rainbow Trout stocked in January exhibited lower range than those stocked in March, June, or October.

	P-Value (LCI; UCI[a])		
	June	October	January
March	0.775 (-1.812; 0.666)	0.775 (-1.654; 0.770)	0.000* (-3.764; (-1.446)
June	NA	0.992 (-1.066; 1.328)	0.000* (-3.178; -0.889)
October		NA	0.000* (-3.280; -1.049)

[a] LCI = lower 95% confidence interval; UCI = upper 95% confidence interval

* Significant pairwise comparison using $P = 0.05$

Figures

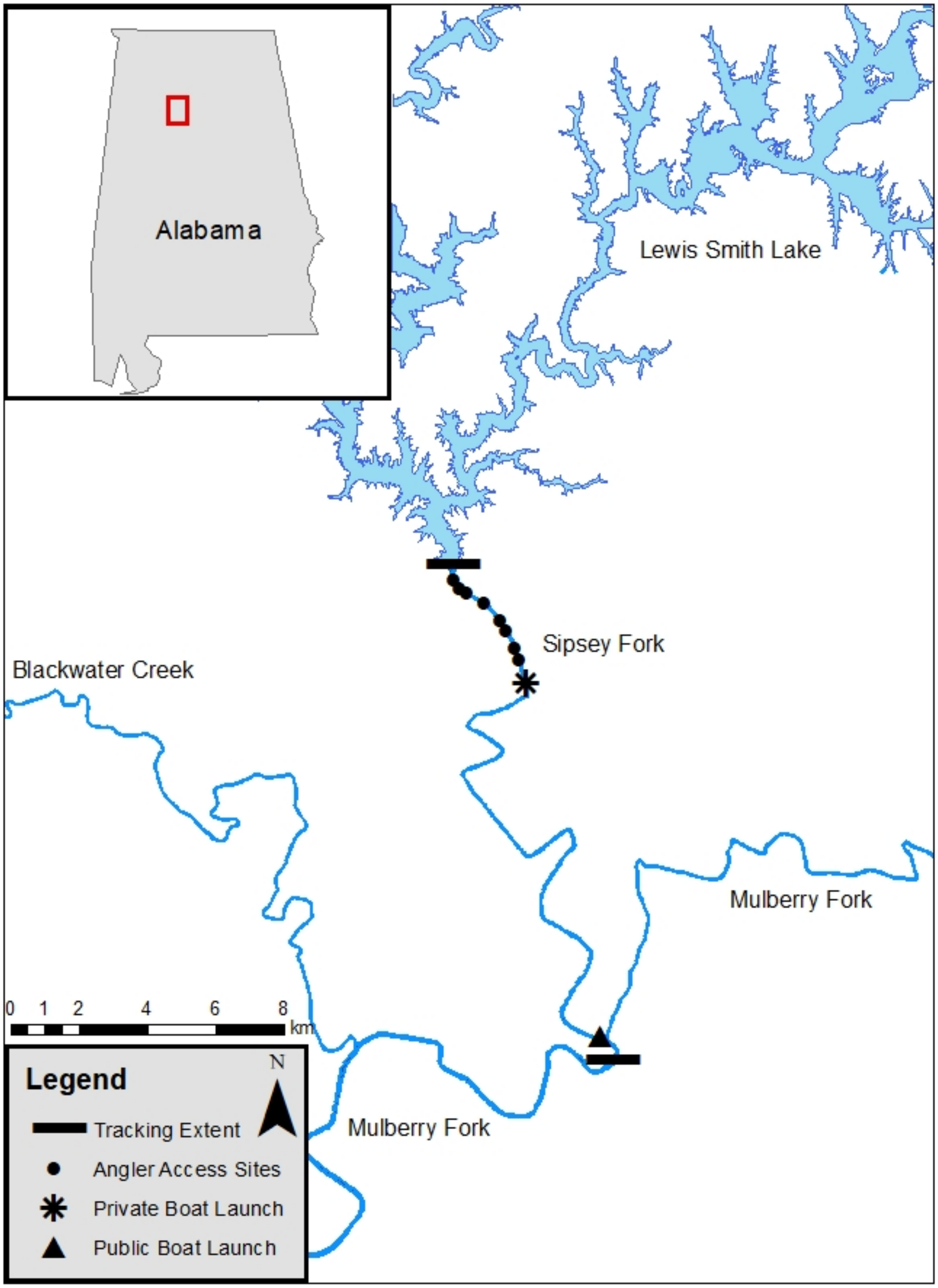

Figure 1. Map of the Sipsey Fork tailwater, Alabama, USA.

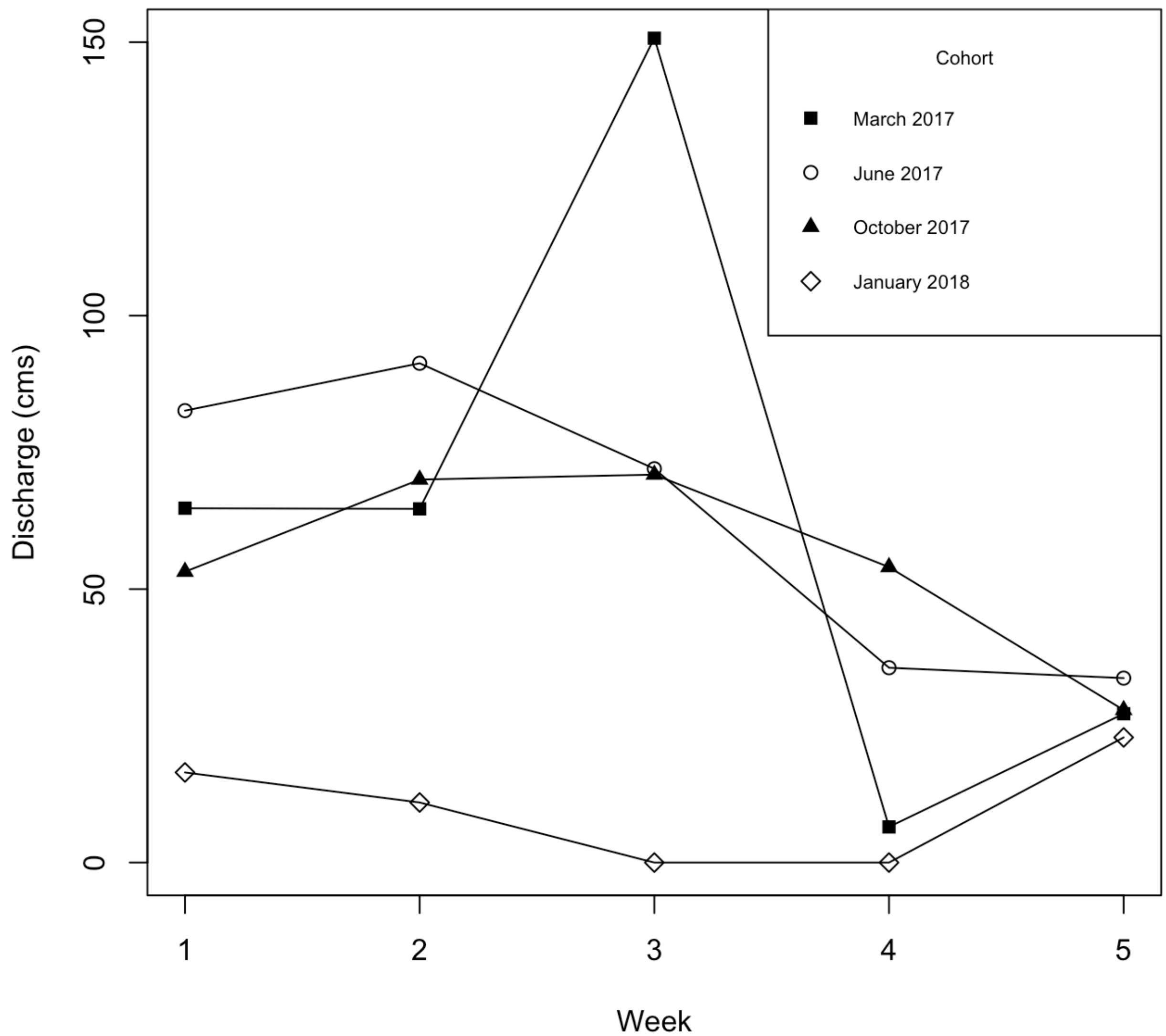

Figure 2. Mean weekly discharge (cms) from Lewis Smith Dam into the Sipsey Fork tailwater that occurred during tracking of each stocked cohort of Rainbow Trout.

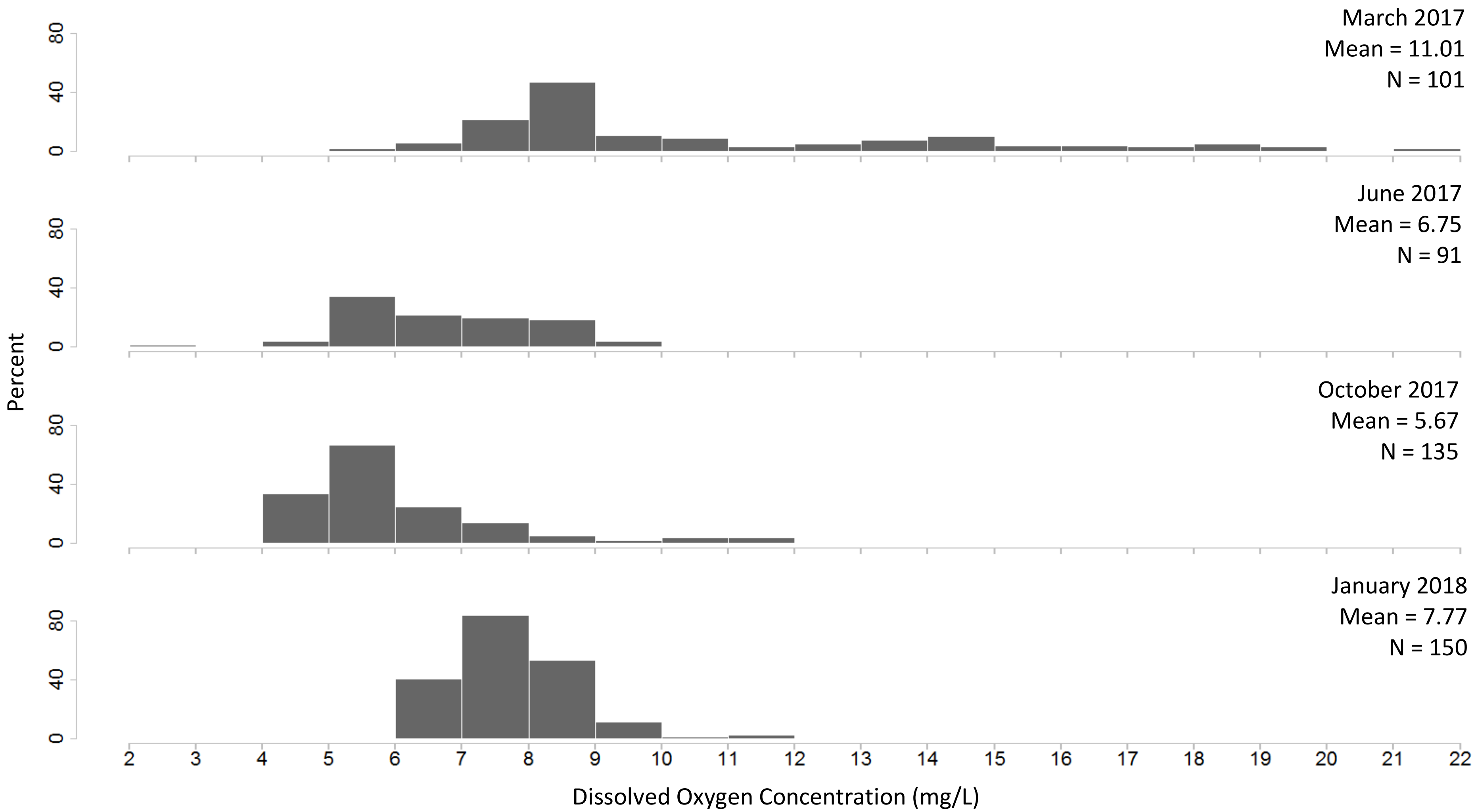

Figure 3. Frequency distribution of dissolved oxygen concentration measured at locations of radio-tagged Rainbow Trout along the Sipsey Fork Tailwater study reach in 2017 and 2018. N = number of locations.

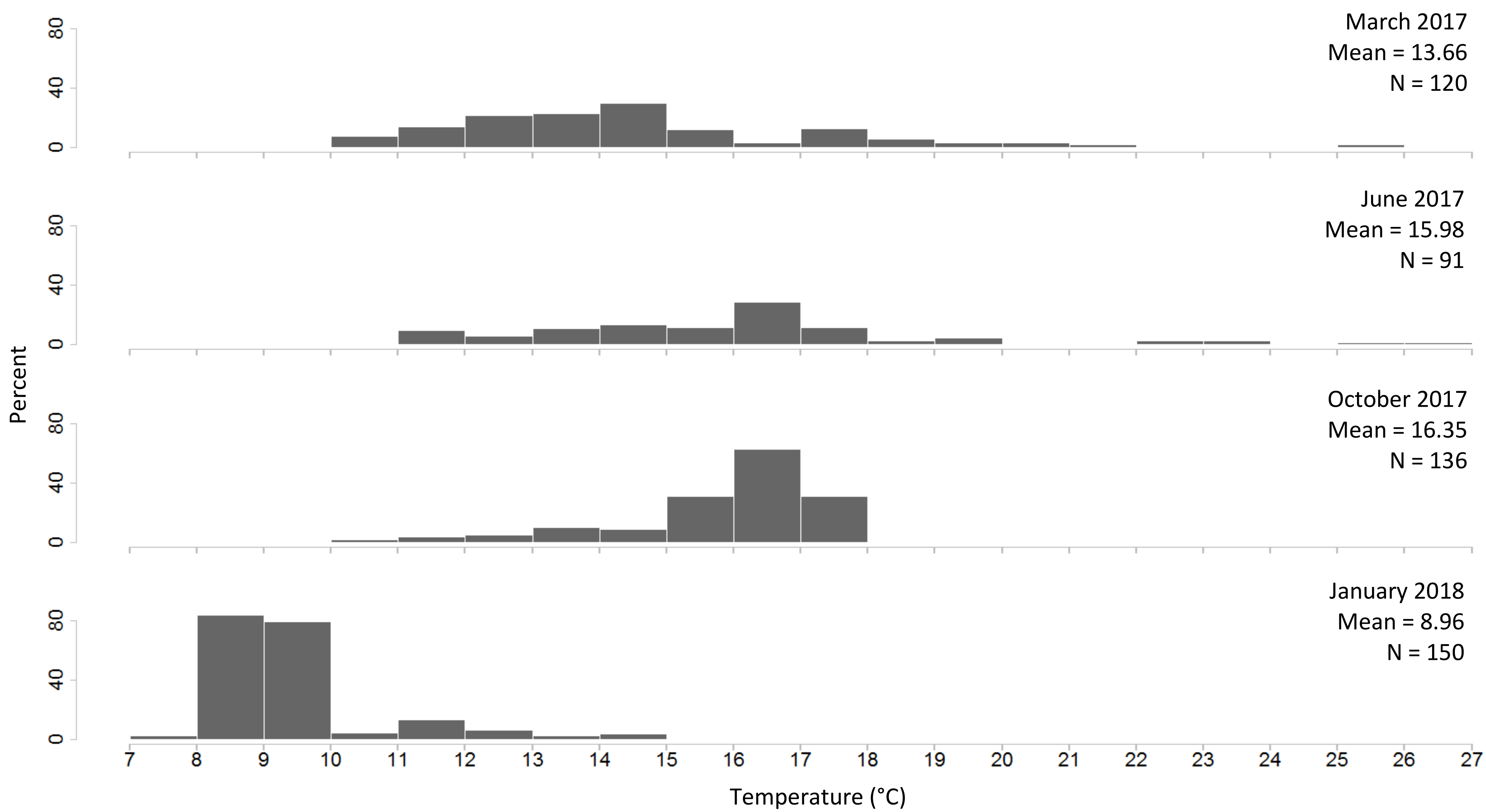

Figure 4. Frequency distribution of surface water temperature measured at locations of radio-tagged Rainbow Trout along the Sipsey Fork Tailwater study reach in 2017 and 2018. N = number of locations.

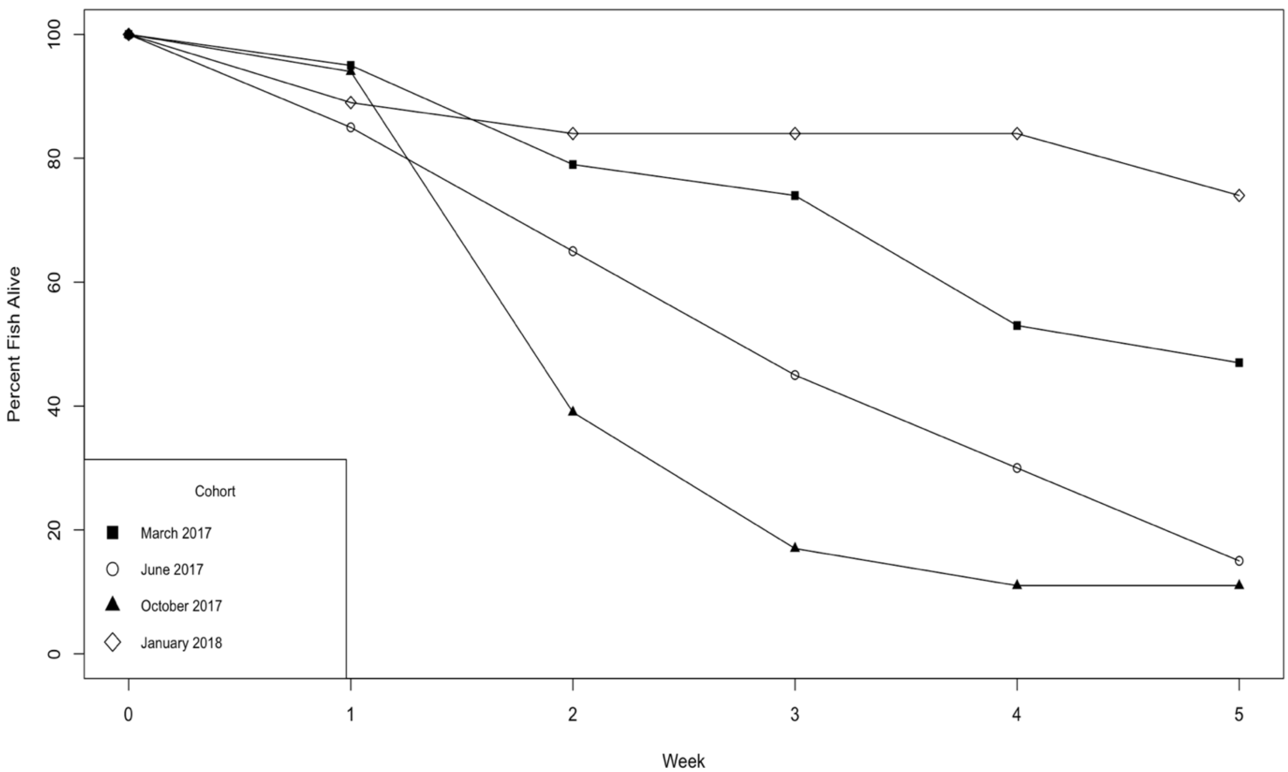

Figure 5. Percent survival of tagged Rainbow Trout in the Sipsey Fork by cohort and week for the first five weeks post-stocking.

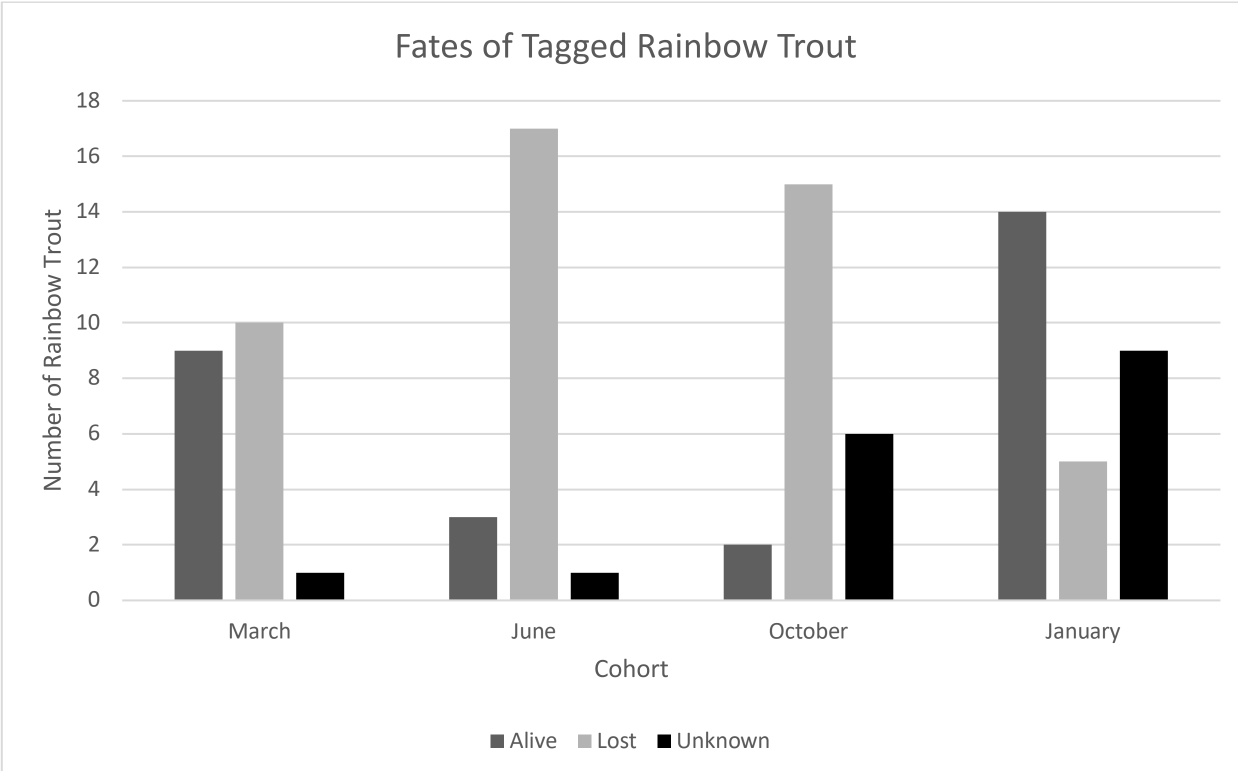

Figure 6. Number of tagged Rainbow Trout in the Sipsey Fork tailwater with alive, dead or unknown fates 35-d post-stocking.

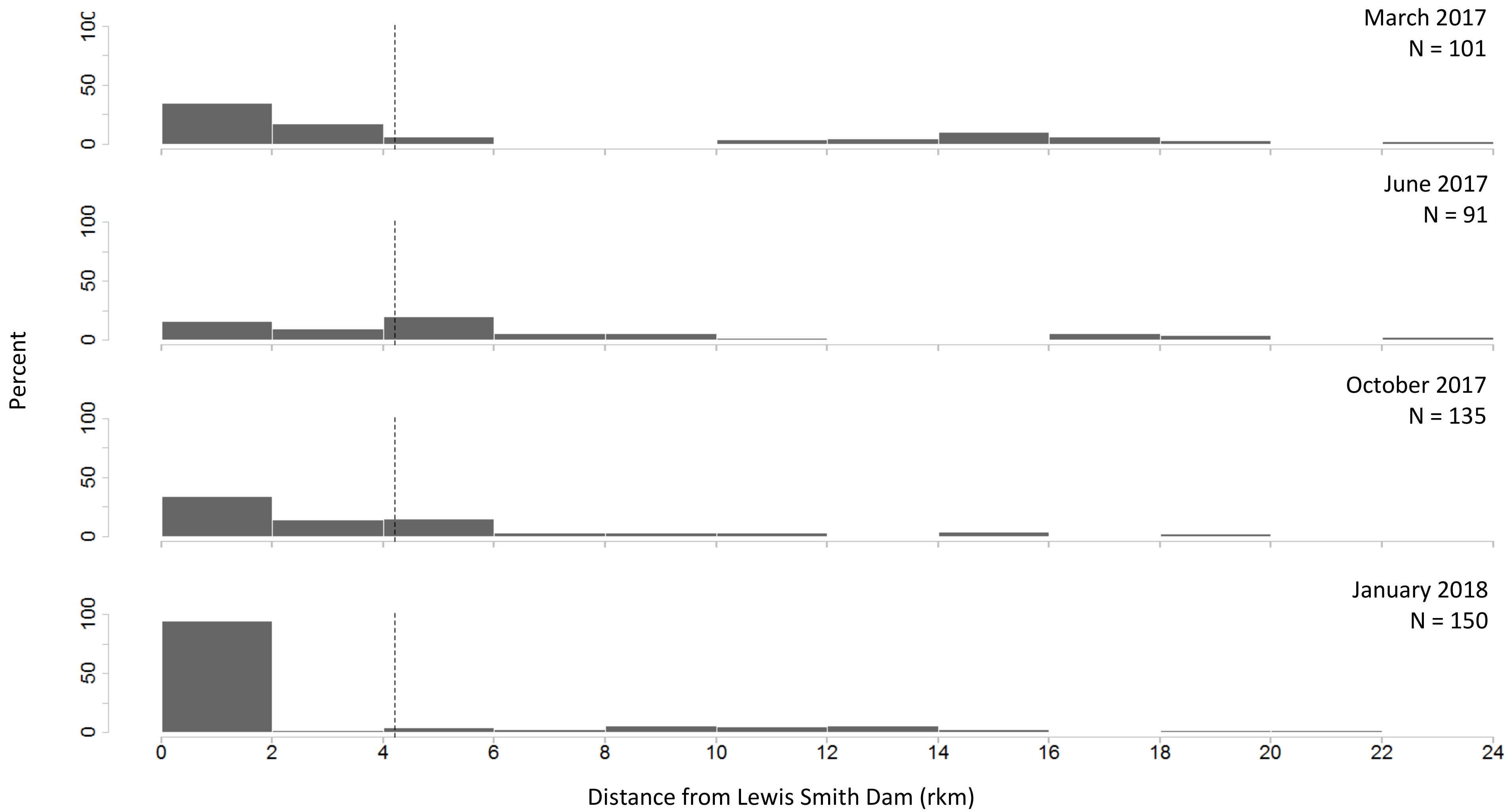

Figure 7. Frequency distribution showing location of radio-tagged Rainbow Trout along the Sipsey Fork Tailwater study reach in 2017 and 2018. Dashed lines denote the location of the Highway 69 Bridge 4.2 km below Lewis Smith Dam. The area below the dam to the bridge provides the most access to anglers. N = number of locations.

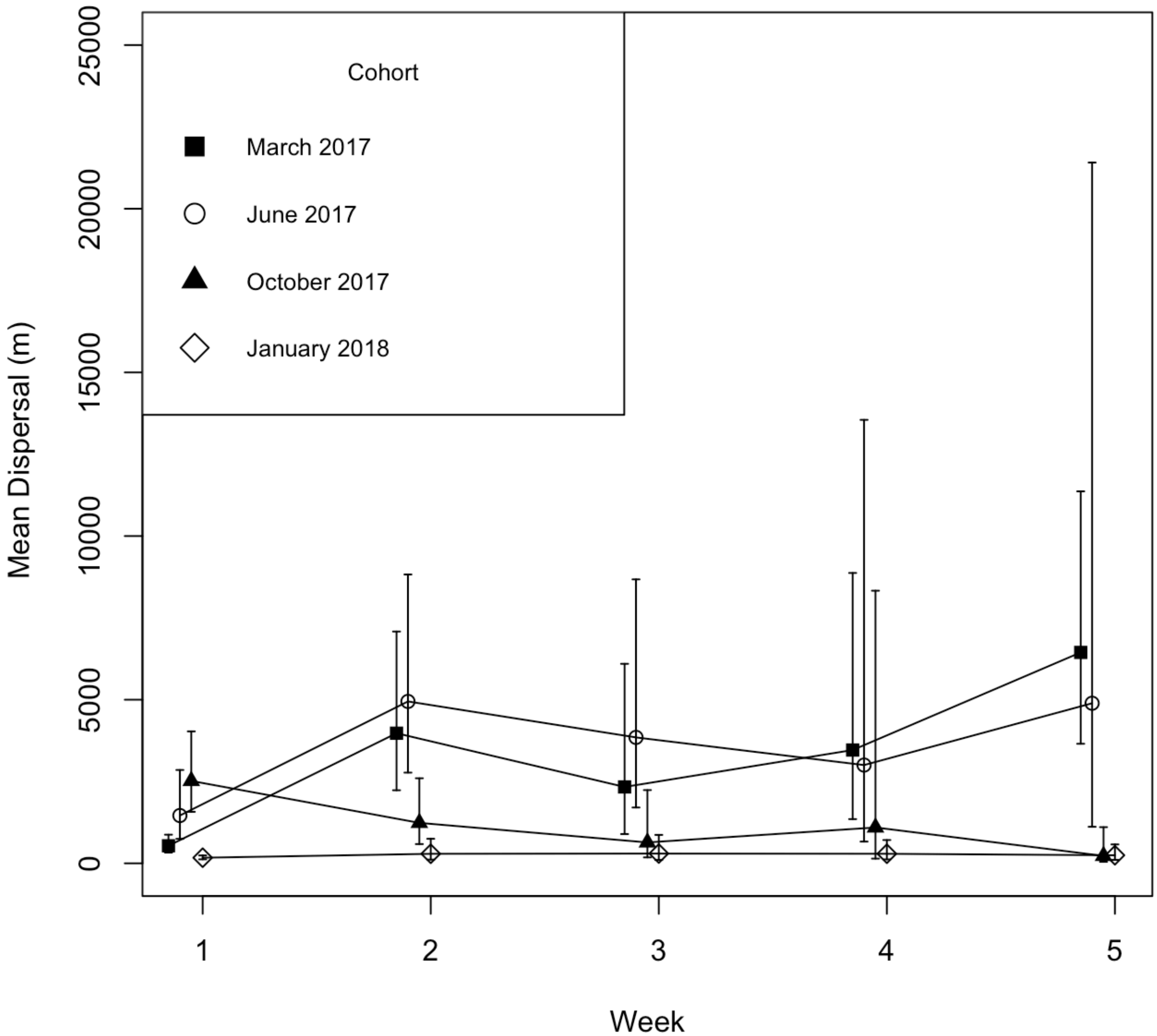

Figure 8. Mean dispersal of stocked Rainbow Trout in the Sipsey Fork by cohort and week (March 2017 – January 2018). 95% confidence intervals shown.

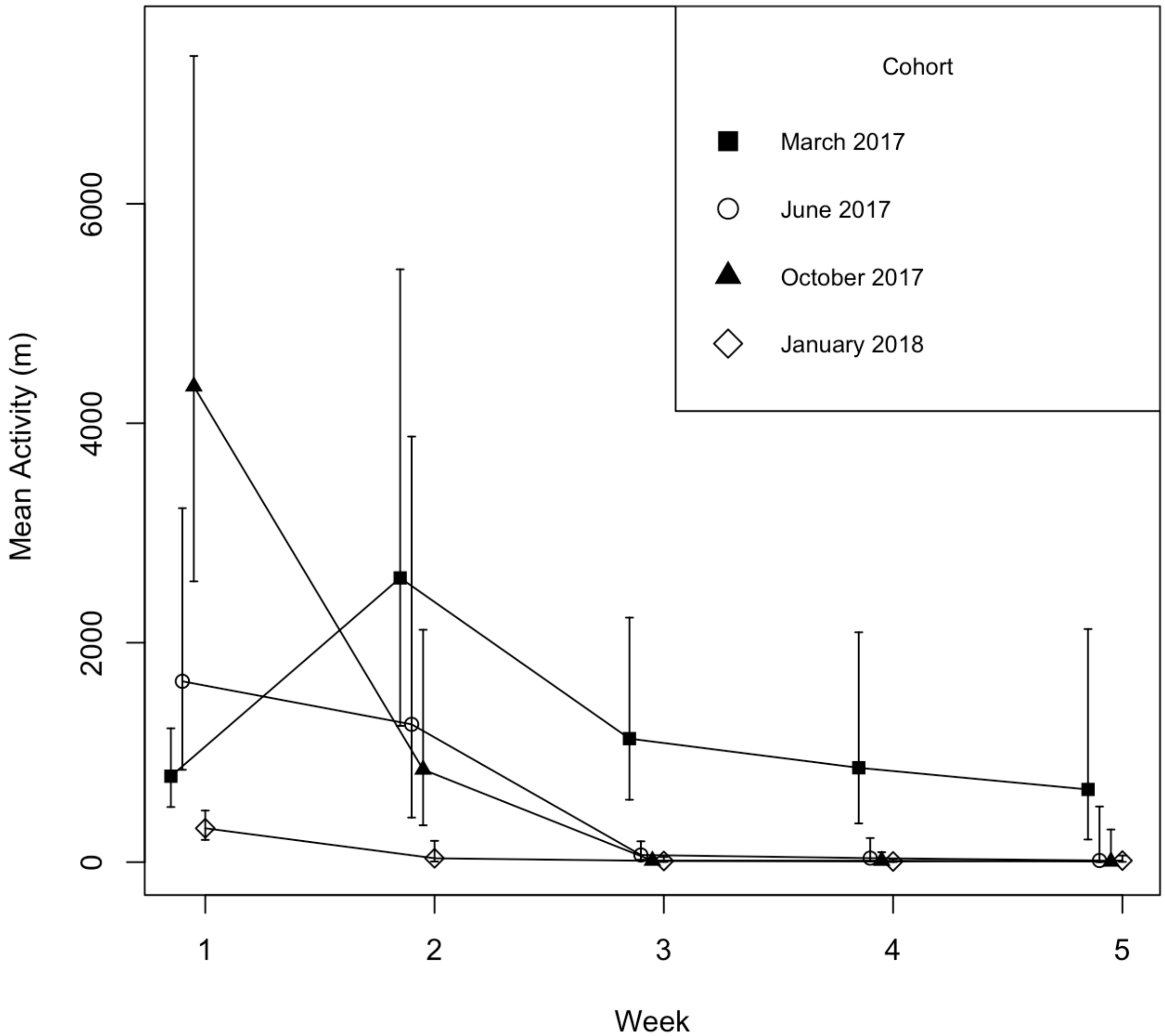

Figure 9. Mean activity of stocked Rainbow Trout in the Sipsey Fork by cohort and week (March 2017 – January 2018. 95% confidence intervals shown.

CHAPTER III

PREDATION OF STOCKED RAINBOW TROUT BY STRIPED BASS IN AN ALABAMA TAILWATER

Introduction

Introductions of Gulf-strain Striped Bass *Morone saxatilis* into Mobile Basin rivers have been made to support recreational angling interests, to provide a biological control for Gizzard Shad *Dorosoma cepedianum* and Threadfin Shad *Dorosoma petenense,* and to restore the genetic integrity of the Gulf strain (Wooley and Crateau 1983; Wirgin et al. 1991; Boschung and Mayden 2004). Although historical occurrence of Gulf-strain Striped Bass in the Black Warrior River system is undocumented (Boschung and Mayden 2004), stockings in the Black Warrior system began in the late 1970s (Jay Haffner, Alabama Division of Conservation and Natural Resources [ADCNR], personal communication). Since 2007, the ADCNR has stocked two Gulf-strain Striped Bass fingerlings per acre each year in Bankhead Reservoir, Alabama (Chris McKee, ADCNR, personal communication). Bankhead Reservoir covers 37.2 km^2 (ADEM 2015) and is located approximately 97 km downstream of Lewis Smith Dam. The Sipsey Fork tailwater below Lewis Smith Dam has been managed by ADCNR as a put-and-take Rainbow Trout fishery; approximately 1,100 to 3,500 catchable size (200 – 406 mm total length [TL]) Rainbow Trout *Oncorhynchus mykiss* are stocked monthly. Because the tailwater maintains cool water temperatures (< 24° C) and ample forage, the Sipsey Fork also serves as an ideal thermal refuge during summer for Striped Bass stocked in the reservoir downstream (Coutant 1985; Moss 1985). Striped Bass also congregate below Lewis Smith Dam each spring during the spawning season. The overlap of these two species is a concern for managers as evidence suggests predation of Rainbow Trout by Striped Bass is considerable (see Chapter 2). Excessive predation on Rainbow Trout may be reducing the opportunity for anglers to utilize and benefit from the trout fishery. Thus, the objective of this study was to quantify the amount of predation that occurs on Rainbow Trout in the Sipsey Fork tailwater.

Methods

Study Site and Fish Sampling

This study was conducted in the first 5 km below Lewis Smith Dam, which is the area where stocked Rainbow Trout and piscivorous predators would likely overlap (Figure 10). This 5-km reach represents the area where anglers have the most access and where Striped Bass have been observed. Predation of stocked Rainbow Trout in the Sipsey Fork tailwater was assessed in March, May, July, and October 2018 using DC electrofishing gear. The reach was divided in 5 sections and sampling was conducted using a 4.3-m johnboat equipped with a 5,000-W generator and boom-mounted electrodes. Sampling was conducted at night during periods when no hydropower generation occurred, to maximize effectiveness of the sampling gear (Pierce 1985; Paragamian 1989). Sampling for each stocked cohort was conducted on three consecutive nights beginning on the day of stocking, two consecutive nights one-week post stocking, and one night two weeks post stocking, for a total of six sample nights. Two 15-min transects were surveyed in each of the five sections, one along each shoreline. Potential Rainbow Trout predators were netted for the entire 15-min transect, placed in a livewell, measured (TL), and weighed (g). Stomach contents of predators were removed using clear acrylic tubes (Van Den Avyle and Roussel 1980); fish were fin clipped to distinguish recaptured individuals and were then returned to the water. Stomach contents were placed in sample bags, labeled, and stored on ice.

Stomach Content Identification

Stomach contents were transported to the laboratory and stored in a freezer. Prey items were identified to the lowest taxonomic level possible and grouped into one of seven categories: (1) insects, (2) Rainbow Trout, (3) shad, (4) Skipjack Herring *Alosa chrysochloris*, (5) sunfish,

(6) Creek Chub *Semotilus atromaculatus*, (7) unidentified fish (Table 3). Standard length (SL, mm) was measured for consumed prey fish and regression equations were used to estimate total length of these diet items (Table 4). Otoliths recovered in stomachs were measured to the nearest µm and identified using an otolith species key (Grove, DeVries, and Wright, Auburn University, unpublished data) to identify unknown prey fish. Estimates of total length and weight of consumed fishes were made with existing regression equations using SL or otolith radii (Table 5). Total length (TL, mm) was not estimated for unidentified fish or insects, and the TL of Creek Chub was measured directly. Rainbow Trout were easily identified in diets due to their distinct vertebrae, size, and partial digestion. Unidentified fish that were not Rainbow Trout were assigned the total weighted average from the identified non-Rainbow Trout fish categories found in the samples for each cohort. The regression for shad was used to estimate the weight for Skipjack Herring. Head capsule width was measured for insects and an existing regression equation was used to estimate total weight (Table 5).

Diet items were quantified by frequency of occurrence. Frequency of occurrence is the percentage of the total number of predatory fish examined containing a particular prey type:

$$\frac{J_i}{P} \times 100$$

where J_i = number of fish containing prey i and P = number of fish with food in their stomachs (Garvey and Chipps 2012).

Bioenergetics Model

The Wisconsin bioenergetics model (Fish Bioenergetics 3.0; Hanson et al. 1997) was used to estimate age-specific cumulative consumption of Rainbow Trout by Striped Bass from March through October (210 d). The model was only run for Striped Bass because they were the most common Rainbow Trout predator that was captured. The model is an energy balance equation:

$$C = M + SDA + F + U + G$$

where C is the total consumed energy, M represents respiration, SDA is specific dynamic action, F is waste lost due to egestion, U is waste due to excretion, and G represents somatic and gonadal growth (Winberg 1956). Physiological parameters used in the model were based on laboratory-derived data for adult Striped Bass (Hartman and Brandt 1995; Appendix Table 1).

Mean length-at-age data predicted from von Bertalanffy (1938) models using empirical data from Lewis Smith Lake (Bart 2018) were used to back calculate growth of Striped Bass over the 210-d period (i.e., days 75 through 285 of the calendar year; Beverton and Holt 1957). The population indices used in the model for Striped Bass were structured into two of the most commonly surveyed age classes determined from lengths of fish: age-7 and age-14 (Figure 11). A $\log_e$-transformed length-weight regression from collected Striped Bass was used to predict start and final weights (g) for the 210 d sample period for each age class. Seasonal growth variation of Striped Bass in this system are unknown, therefore growth (g) was assumed to be consistent throughout the year. Due to small sample sizes for each age class ($\leq$ 7 individuals), all Striped Bass collected were included in each age-class simulation. Population size of Striped Bass in Bankhead Reservoir and the Sipsey Fork tailwater is unknown, thus, bioenergetics models were run over a variety of hypothetical population sizes. Simulated population sizes ranged from unrealistically low to what might be considered a likely maximum, to explore the full range of potential impacts that Striped Bass predation might have on stocked Rainbow Trout in this system. Initial simulated Striped Bass population sizes were 25, 75, 125, 300, and 375 beginning at age-7. Population estimates for age-14 individuals were then derived by applying low (0.09) and high (0.16) annual mortality rates from age 7 to age 14 (Hightower et al. 2001). These mortality rates were also included in the bioenergetics simulations. Predicted consumption estimates of Rainbow Trout from the simulations were compared to the total weight of Rainbow Trout stocked from March to October (~ 680.4 kg) into the Sipsey Fork tailwater. The p-value, the total mass of prey consumed by a predator, was derived from the simulation with the observed diet proportions.

The proportion of each prey item consumed by Striped Bass was averaged for each month sampled and then used in the bioenergetics model (Appendix Table 2). Energy densities of prey items were used from existing empirical laboratory studies (Cummins and Wuycheck 1971; Miranda and Muncy 1990; Bryan et al. 1996; Johnson et al. 2017; Bart 2018; Table 3). Seasonal variation of caloric values were used for certain prey items when available (Bart 2018; Table 3).

Dissolved oxygen concentrations were assumed to be greater than 4 mg/L throughout the study site during the predator sampling period. An Onset HOBO data logger (Water Temp Pro v2) was deployed near the Highway 69 Bridge where most Striped Bass were captured (Figure 10). The logger recorded water temperature once every hour from February 2018 through February 2019. Mean daily water temperatures were calculated for the study period (March through October) and used in the model. Striped Bass residency within the Rainbow Trout fishery is unknown, so a second bioenergetics model was used to examine the possibility that Striped Bass do not reside in the Rainbow Trout fishery throughout the 210 d period. Because a recent creel survey documented catch rates of Rainbow Trout were lowest 21-30 days post-stocking (Haffner and McKee 2017), consumption proportions of Striped Bass included trout for only the first 20 days after stocking trout. For this model, estimated Rainbow Trout consumption proportions by Striped Bass for Days 21 through 30 were instead applied to that of shad, the most commonly observed prey item in the Sipsey Fork, thereby eliminating Striped Bass feeding on Rainbow Trout until the next month's stocking. Only the consumption proportion values were altered; all other parameters from the initial bioenergetics model were used for this model.

Results

Collection and Diet Composition of All Predators

A total of 186 potential predators of Rainbow Trout was sampled for diet analysis in 23 electrofishing collection events. Of all stomachs, 68% contained diets and 467 items were identified. In addition to Rainbow Trout, diet items included shad, insects, Skipjack Herring, Sunfish, Creek Chub, unidentified fish, and other (i.e., crayfish, frog, and Mobile Logperch *Percina kathae*). Rainbow Trout were found in stomachs of Striped Bass, hybrid striped bass *Morone chyrsops x Morone saxatilis*, Largemouth Bass *Micropterus salmoides*, and Chain Pickerel *Esox niger*.

A total of 56 Striped Bass were sampled for diet analysis. Only one Striped Bass was recaptured throughout the study. Striped Bass averaged 871 mm TL (range, 522 – 1,080 mm) and weighed on average 10,846 g (range, 1,970 – 21,500 g; Figure 12; Figure 13). Striped Bass were captured only in the first week during the March and October surveys (Figure 14). The greatest number of Striped Bass was collected in the March survey. Overall, Striped Bass were the second most common predator collected and 75% of them had eaten at least one Rainbow Trout. All but one Striped Bass was captured in a shallow flat area adjacent to the Highway 69 Bridge. Striped Bass collection was variable between sampling months (Figure 14). In March and October, Striped Bass were only captured in the first week of sampling (right after Rainbow

Trout had been stocked into the Sipsey Fork); whereas in May/June and June/July, Striped Bass were collected in other weeks sampled.

Hybrid striped bass were collected during sampling events for each cohort. Seventeen individuals were collected during the study; mean length was 682 mm TL (range, 425 – 765 mm) mean weight was and 4,550 g (range, 425 – 8,140 g). Hybrid striped bass were less commonly collected than Striped Bass but still more than a third of them had consumed at least one Rainbow Trout (Table 6). Most hybrid striped bass stomachs contained unidentified fish (38.6% of all diet items; Table 6).

Largemouth Bass comprised 35% of the predators collected but Rainbow Trout were only found in 4.2% of their stomachs (Table 6). Largemouth Bass primarily consumed shad (60.6% of all diet items). The highest number of Largemouth Bass were collected in May (N = 35). The mean length of Largemouth Bass was 386 mm TL (range, 291 – 673 mm) and mean weight was 962 g (range, 334 – 2565 g). Ten Largemouth Bass were recaptured throughout the study.

Chain Pickerel were the least common predator collected, but 50% of them had Rainbow Trout in their stomach. Mean length and weight of Chain Pickerel was 426 mm TL (range, 330 – 567 mm) and 518 g (range, 210 – 1,150 g) respectively. They were only collected in the March and May surveys and only one Chain Pickerel was recaptured during the study.

Alabama Bass *Micropterus henshalli* and Bowfin *Amia calva* were also collected, but did not contain Rainbow Trout in their diets. Seventeen Alabama Bass were captured in the March, May and July electrofishing events. Mean TL of captured Alabama Bass was 446 mm (range, 343 – 542 mm) and mean weight was 1,273 g (range, 394 – 2,236 g). Only 65% of Alabama Bass contained stomachs with diet contents. Unidentified fish made up 61.9% of all diet items in their stomachs. The majority of Alabama Bass were collected in May (N = 13); only five fish were ever recaptured. Of the twelve Bowfin sampled, only one contained diet contents. Bowfin sampled measured on average 569 mm TL (range, 461 – 715 mm) and weighed 1,729 g (range, 550 – 3,380 g).

Striped Bass Diet Composition

Striped Bass diets had the greatest average proportion of Rainbow Trout compared to other prey items in June (91%), and the least in October (37%; Table 7). Ninety-one percent of Striped Bass stomachs contained prey, with an overall total of 306 items. Rainbow Trout numerically comprised 38% of all food consumed by Striped Bass. Unidentified fish (52%), shad (5%), insects (4%), Skipjack Herring (0.3%), sunfish (0.3%), and chub (0.3%) comprised the remaining Striped Bass diet numerically (Table 6). On average, three Rainbow Trout were recovered from each Striped Bass stomach (range, 1-8). Estimated length of consumed Rainbow Trout averaged 225 mm TL (range, 134 – 415 mm).

Bioenergetics Modeling

Based on observed prey proportions, simulations revealed that at both low and high natural mortality rates, as few as 500 Striped Bass living continuously in the tailwater from March through October could consume all Rainbow Trout stocked during those months in the Sipsey Fork (Table 8). A minimum population of 38 Striped Bass individuals (25 age-7; 13 age-14) could consume 9% of the total Rainbow Trout stocked each month. Nearly half of all Rainbow Trout stocked in the Sipsey Fork could be consumed if as few as 190 Striped Bass individuals existed in the fishery (Table 8). Rainbow Trout consumption was reduced by 43% if Striped Bass ceased to eat trout or left the tailrace for 10 days each month (Table 9). Under this scenario, a population of 455 Striped Bass at a low natural mortality rate (300 age-7; 155 age-14) has the potential to consume nearly 60% of the total Rainbow Trout stocked each month. At a high natural mortality rate, a minimum Striped Bass population of 486 individuals (375 age-7; 111 age-14) would be required to consume half of the total Rainbow Trout stocked each month (Table 9).

Discussion

Results from this study indicate that Striped Bass are the primary predators of Rainbow Trout in the Sipsey Fork tailwater. Striped Bass seldom contribute to declines in recreationally valuable piscine populations because they primarily consume clupeids in the reservoirs in which they are stocked (Slipke et al. 2001; Raborn et al. 2002; Shepherd 2008). However, predation on Rainbow Trout by Striped Bass has been documented in systems where Striped Bass occupy tailwaters with salmonid fisheries (Walters et al. 1997; Bettoli 2000; Hess and Jennings 2000). Seventy-five percent of Striped Bass collected in the Sipsey Fork tailwater contained Rainbow Trout in their stomachs, suggesting extensive predation of Rainbow Trout by Striped Bass. Rainbow Trout were also the most common prey type consumed by Striped Bass. Bioenergetics models suggested that a population of 500 Striped Bass could consume all Rainbow Trout stocked in the fishery. However, this assumed that Striped Bass resided continuously in the Sispey Fork tailwater. Reducing residency by a third resulted in more than 50% less Rainbow Trout being consumed.

Movement and residency of Striped Bass in this system are unknown, but in some months these fish were only collected during the first week following Rainbow Trout stocking, suggesting transience. Previous studies indicate that Striped Bass populations and their piscine prey populations maintain a tightly coupled relationship (Morris and Follis 1979; Cyterski et al. 2003; Vatland et al. 2008). Other studies have found that consumption of stocked Rainbow Trout was highest soon after stocking (Buckmeier and Betsill 2002; Buckmeier et al. 2005; Lundgren and Schoenebeck 2014). Rainbow Trout may acquire visual and chemical recognition of potential predators after being stocked and become more successful at avoiding predators in later weeks (Olla and Davis 1989; Brown and Chivers 2005). Goodyear (1980) suggests that feeding efficiency by predators may be increased at greater prey densities, which may be artificially created at monthly intervals in the Sipsey Fork shortly after Rainbow Trout stockings. Alternatively, the collection pattern could have been an artifact of sampling efficiency as Striped Bass often occupied deep waters that were difficult to electrofish. Most of the Striped Bass collected in this study came from a shallow flat located at the Highway 69 bridge and may have been a resting area for fish that had been feeding on Rainbow Trout. Understanding more about the movement patterns of Striped Bass in the Sipsey Fork tailwater would greatly contribute to a more accurate estimation of Rainbow Trout consumption.

Results of the bioenergetics models indicated that the predation threat of Striped Bass on Rainbow Trout was primarily dependent on Striped Bass population size, which is currently unknown in the Sispey Fork. Given that Bankhead Reservoir is stocked annually with 18,400 Striped Bass fingerlings, it may be likely that several hundred predators inhabit the tailwater. The average size of Striped Bass collected during this study was large (871 mm TL; 10,846 g), similar to sizes of Striped Bass captured in the Norris Dam tailwater, Tennessee (Bettoli 2000). These larger individuals may possibly be those that are capable of making large migrations into the tailwater from a downstream reservoir. As individuals recruit into larger size classes, they may become a part of the established tailwater subpopulation.

The lack of growth data for Striped Bass in the Sipsey Fork tailwater may have affected results from the bioenergetics simulations. Although annual growth data from the upstream reservoir (Lewis Smith Lake) were used, Striped Bass growth in the tailwater may have been much greater due to fish feeding on calorically dense Rainbow Trout compared to those in the reservoir that primarily feed on Threadfin Shad (Shepherd and Maceina 2009). Moreover, Striped Bass living in cooler water temperatures consume less prey and achieve similar growth rates compared to those living in warm waters (Clarke and Johnston 1999). During summer months in reservoir systems, Striped Bass move to deeper, cooler limnetic areas as lakes stratify and water temperatures increase (Matthews et al. 1985; Farquhar and Gutreuter 1989; Matthews et al. 1989; Schaffler et al. 2002; Sammons and Glover 2013). Because temperature and DO concentrations in the Sipsey Fork tailwater remained within optimal ranges for Striped Bass growth and survival in this study (Hartman and Brandt 1995), Striped Bass could occupy the tailwater throughout the year or during periods of increased water temperatures and achieve high growth potential. Additionally, when prey densities are high, predators may consume more prey and therefore grow faster (Murdoch and Oaten 1975).

As with all bioenergetics simulations using laboratory derived, species-specific physiological parameters, conclusions must be interpreted with careful consideration. These parameters may not reflect the specific population being examined. Several studies have shown that physiological rates used in bioenergetics models vary significantly and that variation can exist even within a population (Ney 1993; Tyler and Bolduc 2008). Furthermore, the physiological rates used in this study are from Atlantic-strain Striped Bass from Maryland

(Hartman and Brandt 1995). Striped Bass found in Bankhead Reservoir and the Sipsey Fork tailwater are Gulf-strain fish. Gulf-strain Striped Bass may have higher temperature and lower DO tolerances than Atlantic-strain fish (Wooley and Crateau 1983; Van Den Avyle and Evans 1990; Sammons and Glover 2013). Although more accurate bioenergetics models could be developed using physiological parameters derived for Gulf-strain Striped Bass, these differences are unlikely to be large enough to substantially change the overall results of this study.

Management Implications

Results of this study has demonstrated that Striped Bass are significant predators on Rainbow Trout in the Sipsey Fork and are likely one of the main factors mediating Rainbow Trout survival and persistence in this fishery. Striped Bass presence in the tailwater appears to be concentrated in the first week following stocking and may decrease throughout the following weeks. Striped Bass were collected during each survey suggesting long-term residency in the tailwater, but Striped Bass residency during winter months is yet to be determined. The potential of Striped Bass to eliminate an entire cohort of Rainbow Trout soon after stocking is dependent upon this predator's population size. Given the large number of Striped Bass that are stocked annually in the reservoir below Lewis Smith Dam, it is likely that a large enough population exists to consume at least half of all Rainbow Trout stocked.

Further assessment of the population size, movement patterns, and annual growth of Striped Bass in the Sipsey Fork is needed to more accurately evaluate their predation impact on the Rainbow Trout fishery. In an effort to reduce Rainbow Trout predation, Hess et al. (1999) suggested stocking larger trout as they may be more successful at avoiding Striped Bass. Yet, Rainbow Trout up to 363 mm TL were found in Striped Bass stomachs during this study, meaning it would be highly unlikely trout that could be raised large enough to avoid Striped Bass. The highest proportion of Rainbow Trout in Striped Bass diets occurred in spring and summer months. Stocking Rainbow Trout in late fall and winter months may limit predation however, these months experience the least amount of angling pressure (Haffner and McKee 2017). Considering that the Rainbow Trout fishery in the tailwater is very popular among anglers, efforts to minimize predation on trout by reducing Striped Bass stockings in Bankhead Reservoir would be advantageous.

Tables

Table 3. Caloric densities (cal/g wet weight) of prey fish used for bioenergetics modeling of striped bass in the Lewis Smith Tailwater.

Items	Category	Caloric Density (cal/g)	Source
Diptera	Insects	4276[a]	Cummins and
Oncorhynchus mykiss	Trout	1350	Wuycheck (1971)
Dorosoma petenense	Shad	870; 1029; 980; 1019	Johnson et al.
		(Winter; Spring; Summer;	(2017)
Alosa chrysochloris	Skipjack Herring	Fall respectively)	Bart (2018)
Lepomis spp.	Sunfish	1927	
Semotilus	Chub	1160	Cummins and
atromaculatus,	Unidentified fish	1072	Wuycheck (1971)
Vertebral columns		870; 1029; 1032 (Winter;	Miranda and Muncy
		Spring; Fall respectively)[b]	(1990)
			Bryan et al. (1996)

[a]Caloric value is dry weight
[b]Estimated by authors to be within caloric density range (i.e., 870-1032) of other fishes in this assessment. Vertebral columns did not belong to Rainbow Trout.

Table 4. Regression equations ($TL = b_0 + b_1SL$) used for estimating total length (TL, mm) of diet items from SL in the Sipsey Fork tailwater. Intercepts (b_0), slopes (b_1) and r^2 are reported. [a, b]

Category	b_0	b_1	r^2	Notes
Trout				[c]Carlander 1969
Shad	1.34	1.26	0.98	Raborn et al. 2002
Skipjack Herring				Used Shad
Sunfish	4.65	1.22	0.92	Raborn et al. 2002

[a] TL was not estimated for unidentified fish or insects

[b] TL of Creek Chub was known

[c] Rainbow Trout conversion factor TL = 1.145(SL)

Table 5. Weight-length regression equations used for estimating wet weight of diet items in the Sipsey Fork tailwater. Unless specified, Y is weight (g) and TL and other measures of length were in mm. [a, b]

Category	Equation	Reference
Insects		
Diptera	$\ln Y = (\ln) 1.673 + 2.30 * \ln$ (Head Capsule Width	Smock 1980
Megaloptera	$\ln Y = (\ln) 0.227 + 2.53 * \ln$ (Head Capsule Width)	Smock 1980
Trout	$Y = -5.14777 + 3.05253$ (TL)	Schneider et al. 2000
Shad	$\log_{10} Y = -4.49 + 2.70 * \log_{10}$ (TL)	Miranda et al. 1998
	$Y = 0.4991 + 4.108$ (Otolith Diameter)	Grove, DeVries, and Wright; unpublished data
Sunfish	$\log_{10} Y = -5.27 + 3.26 * \log_{10}$ (TL)	Irwin 2001
Creek Chub	$\log_{10} Y = -5.099 + 3.223 * \log_{10}$ (TL)	Schemske 1974

[a] Applied Shad equation to estimate Skipjack Herring weight

[b] Unidentified fish that were not Rainbow Trout were assigned the total weighted average from the identified fish categories found in the samples for each cohort

Table 6. Number of predators sampled from the Sipsey Fork tailwater: STB = Striped Bass; ALB = Alabama Bass; HYB = hybrid striped bass; LMB = Largemouth Bass; BFN = Bowfin; CHP = Chain Pickerel. The percent of each that contained food and the total number of diet items consumed by each predator type (TDI), and the total number (N) and total percent (%N) of each diet item: RBT = Rainbow Trout; SHD = Shad; INS = Insect; SKIP = Skipjack Herring; SUN = Sunfish; CHUB = Creek Chub; UNID = Unidentified fish; OTH = Other. Percent frequency of occurrence of each diet item (%F)[a].

PRED (N)	% With Food	TDI	RBT			SHD			INS			SKIP			SUN			CHUB			UNID			OTH		
			N	% N	% F	N	% N	% F	N	% N	% F	N	% N	% F	N	% N	% F	N	% N	% F	N	% N	% F	N	% N	% F
STB (56)	91	306	117	38.2	75	15	4.9	14	13	4.2	8	1	0.3	2	1	0.3	2	1	0.3	2	158	51.6	37	0	-	0
ALB (17)	65	21	0	-	0	4	19.0	27	1	4.8	9	0	-	0	1	4.8	9	0	-	0	13	61.9	64	2	9.5	18
HYB (20)	80	57	18	31.6	38	5	8.8	31	6	10.5	19	0	-	0	5	8.8	19	1	1.8	6	22	38.6	38	0	-	0
LMB (66)	65	71	3	4.2	3	43	60.6	63	1	1.4	2	0	-	0	2	2.8	5	0	-	0	16	22.5	30	6	8.5	14
BFN (12)	8	1	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	1	100	1
CHP (16)	44	8	4	50	57	2	25	14	0	-	0	0	-	0	0	-	0	0	-	0	1	12.5	14	1	12.5	14

[a] Values rounded to the 0.1%

Table 7. Average proportion of diet items by number consumed by Striped Bass in the Sipsey Fork tailwater by stocked Rainbow Trout cohort.

Sample Period	Rainbow Trout	Shad	Insects	Unidentified	Skipjack Herring	Sunfish	Chub
1 March	0.64	0.02	0	0.34	0	0	0
2 May	0.69	0.08	0.03	0.09	0.11	0	0
3 June	0.91	0	0	0	0	0	0.09
4 October	0.37	0.06	0.09	0.40	0	0.08	0

Table 8. Bioenergetics simulations of Striped Bass (STB) consumption (kg)[a] of Rainbow Trout (RBT) every day from March to October at different population densities of age-7 and age-14 Striped Bass individuals. Simulations consider low (9%) and high (16%) rates of annual mortality (A). Age 7: $P = 0.262695$; Age 14: $P = 0.254883$. Total percent of RBT consumed was calculated using the predicted consumption estimates of RBT by STB from the simulations and was compared to the weight of RBT stocked from March to October (~ 680.4 kg) into the Sipsey Fork tailwater.

	Number of STB			RBT Consumption (kg)			
A	Age 7	Age 14	Total	Age 7	Age 14	Total	% of RBT Consumed
0.09	25	13	38	219.6	191.9	411.5	9
	75	39	114	658.8	575.7	1,234.5	26
	125	65	190	1,098.0	959.5	2,057.5	43
	300	155	455	2,635.2	2,288.0	4,923.2	100
	375	194	569	3,294.0	2,863.7	6,157.7	129
0.16	25	7	32	2,16.3	101.8	318.1	7
	75	22	97	649.0	320.0	969.0	20
	125	37	162	1,081.7	538.1	1,619.8	34
	300	89	389	2,596.0	1,294.5	3,890.5	82
	375	111	486	3,245.0	1,614.5	4,859.5	100

[a] Values rounded to the nearest 0.1

Table 9. Bioenergetics simulations of Striped Bass (STB) consumption (kg)[a] of Rainbow Trout (RBT) for the first 20 d of each month from March to October at different population densities of age-7 and age-14 STB individuals. Simulations consider low (9%) and high (16%) rates of annual mortality (A). Age 7: $P = 0.29834$; Age 14: $P = 0.289551$. Total percent of RBT consumed was calculated using the predicted consumption estimates of RBT by STB from the simulations and was compared to the weight of RBT stocked from March to October (~ 680.4 kg) into the Sipsey Fork tailwater.

	Number of STB			RBT Consumption (kg)			
A	Age 7	Age 14	Total	Age 7	Age 14	Total	% of RBT Consumed
0.09	25	13	38	125.4	109.7	235.1	5
	75	39	114	376.3	329.0	705.3	15
	125	65	190	627.1	548.4	1,175.5	25
	300	155	455	1,505.1	1,307.6	2,812.7	60
	375	194	569	1,881.4	1,636.6	3,518.0	74
0.16	25	7	32	123.8	58.3	182.2	4
	75	22	97	371.5	183.3	554.8	12
	125	37	162	619.2	308.3	927.5	19
	300	89	389	1,486.2	741.5	2,227.7	47
	375	111	486	1,857.7	1,014.6	2,872.3	60

[a] Values rounded to the nearest 0.1

Figures

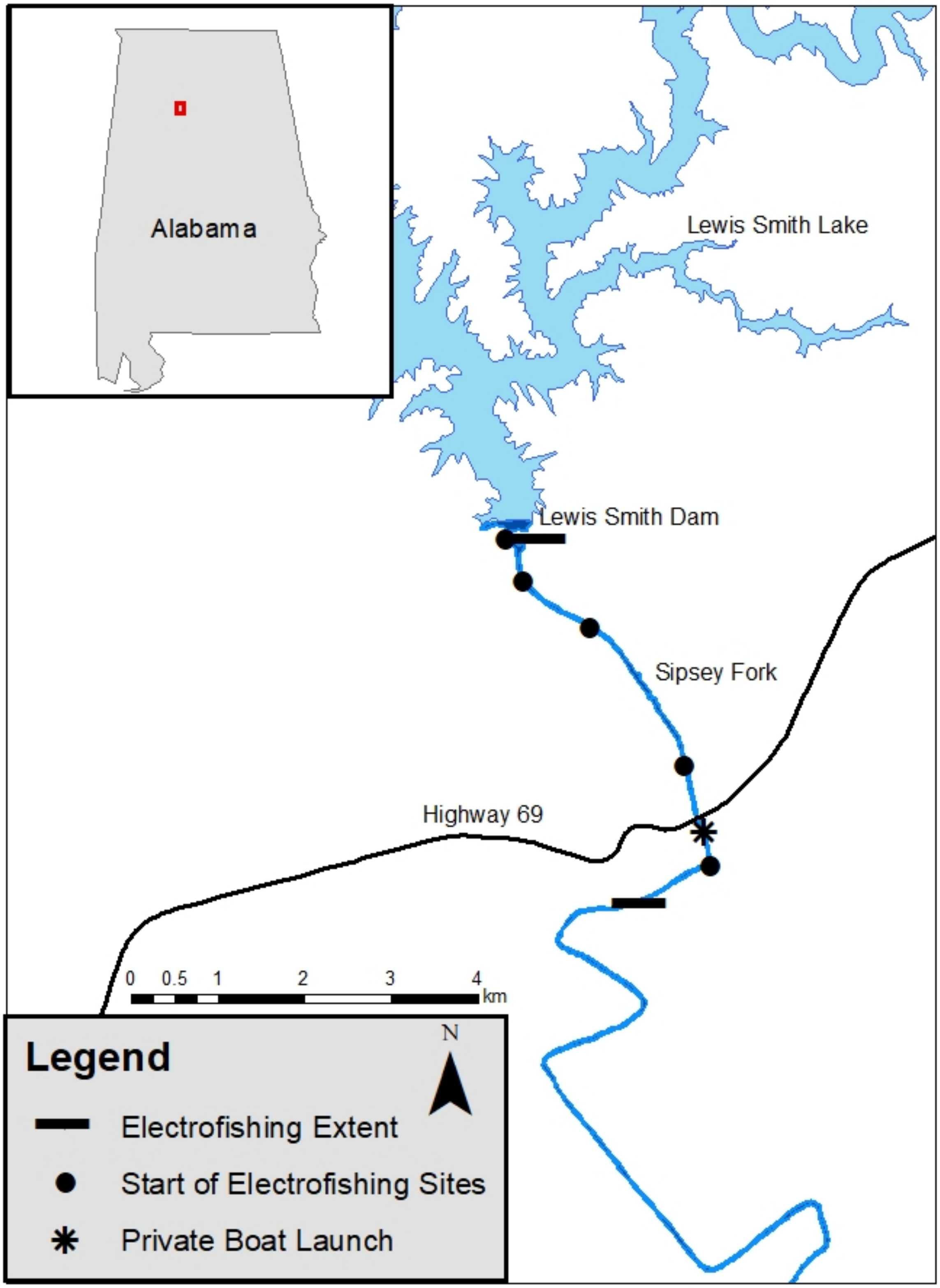

Figure 10. Map of electrofishing survey sites on the Sipsey Fork tailwater.

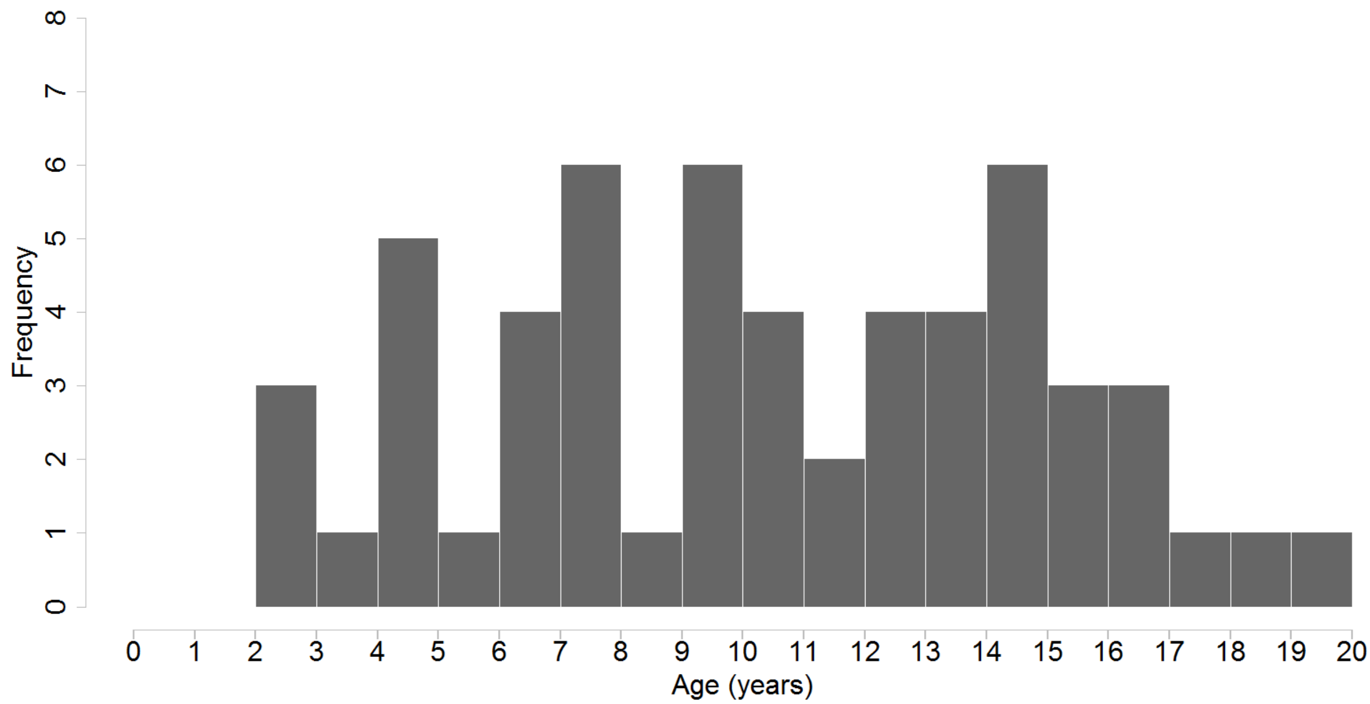

Figure 11. Frequency of ages of captured Striped Bass estimated using von Bertalanffy growth equation (Bart 2018).

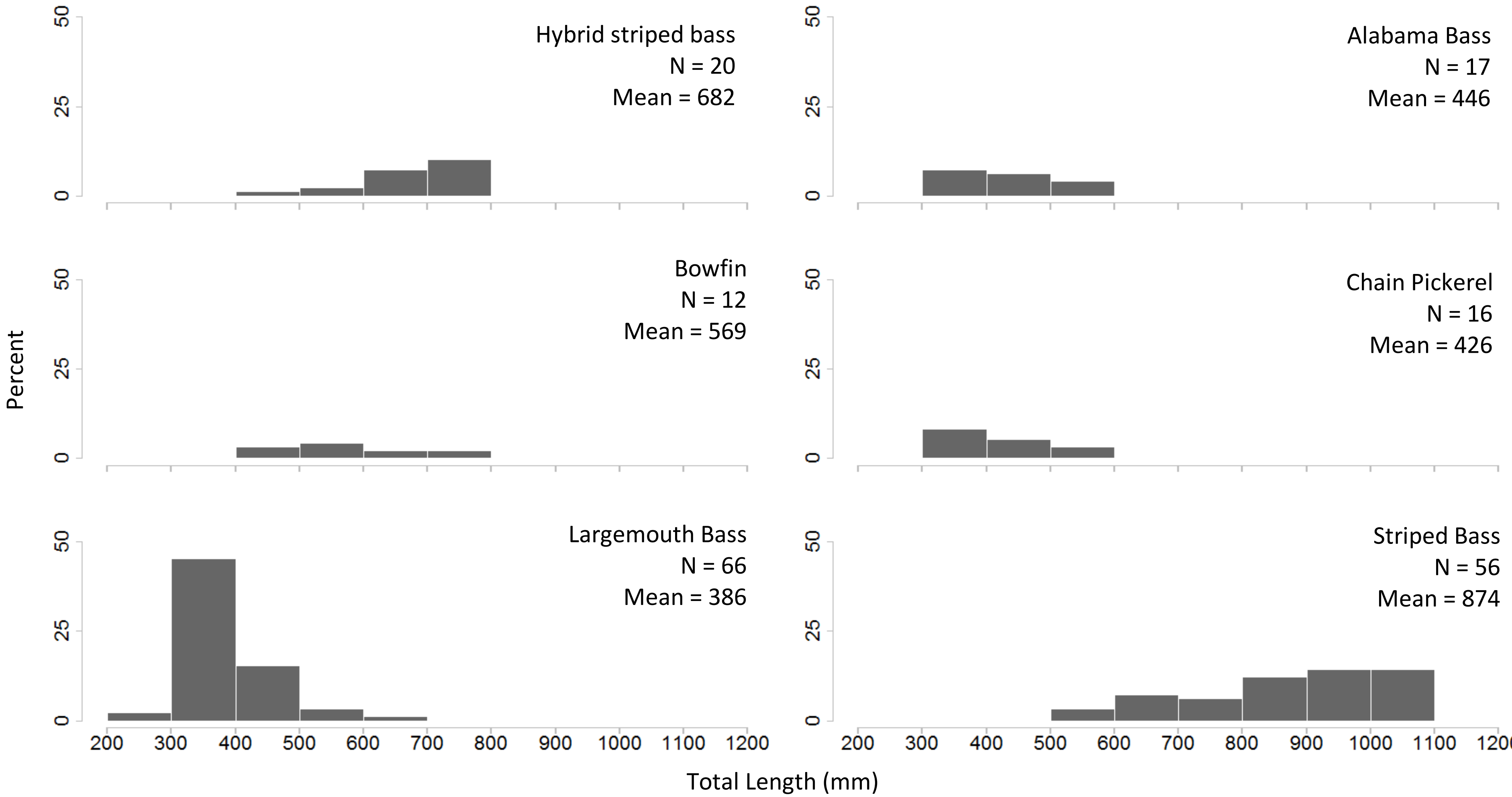

Figure 12. Frequency distribution of total lengths of all predators captured throughout the Sipsey Fork in all four surveys (March, May July, and October) in 2018. N = number of predators. Mean = Average TL; mm.

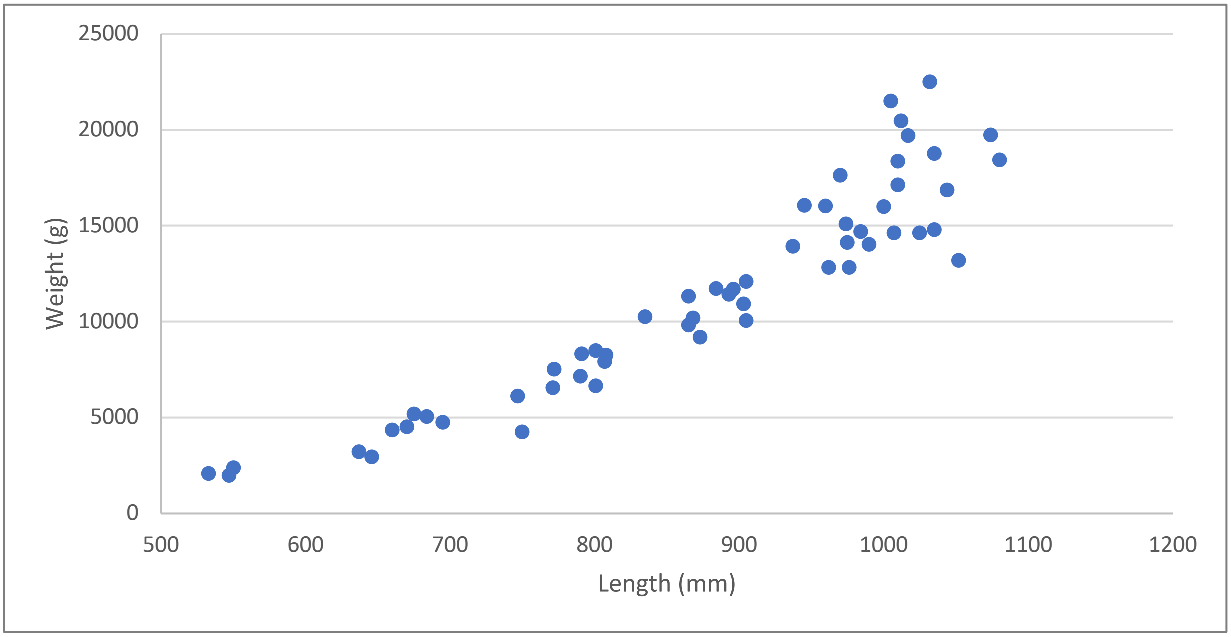

Figure 13. Length-weight regression for captured Striped Bass in the Sipsey Fork tailwater. Equation of regression line: log(Weight) = 3.3147*log(Length) – 13.21; $r^2 = 0.9522$.

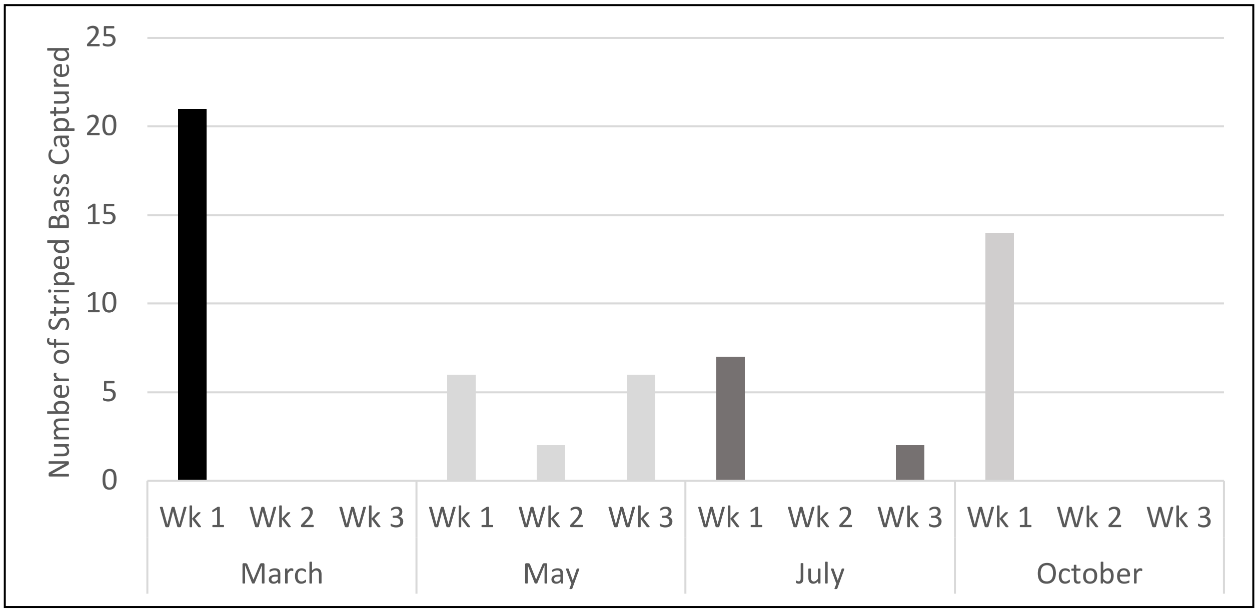

Figure 14. Weekly Striped Bass capture by sample month.

APPENDIX

Appendix Table 1. Physiological parameters used in the bioenergetics simulations for adult Striped Bass from Hartman and Brandt (1995).

Parameters	Striped Bass Adult
CA	0.3021
CB	-0.2523
CQ	7.4
CTO	15
CTM	28
CTL	30
CK1	0.323
CK4	0.85
RA	0.0028
RB	-0.218
RQ	0.076
RTO	0.5002
RTM	0
RTL	0
RK1	1
RK4	0
ACT	1
BACT	0
SDA	0.172
FA	0.104
UA	0.068
PED	6488

Appendix Table 2. Proportion of Prey Items Consumed by Each Striped Bass Captured

Sample Cohort	Date Sampled	STB ID	TL	Weight	Rainbow Trout	Shad	Insects	Unidentified	Skipjack Herring	Sunfish	Chub
1	3/15/2018	1	550	2381	0	0	0	1	0	0	0
March	3/15/2018	2	547	1985	0	0	0	1	0	0	0
	3/15/2018	3	533	2086	0	0.25	0	0.75	0	0	0
	3/15/2018	4	1080	18420	1	0	0	0	0	0	0
	3/16/2018	5	896	11680	1	0	0	0	0	0	0
	3/16/2018	6	1017	1970	1	0	0	0	0	0	0
	3/16/2018	7	1032	2250	1	0	0	0	0	0	0
	3/16/2018	8	801	8480	0	0	0	0	0	0	0
	3/16/2018	9	960	16040	0	0.11	0	0.89	0	0	0
	3/16/2018	10	970	17620	1	0	0	0	0	0	0
	3/16/2018	11	962	12840	1	0	0	0	0	0	0
	3/16/2018	12	835	10260	1	0	0	0	0	0	0
	3/16/2018	13	1012	20480	0.5	0	0	0.5	0	0	0
	3/17/2018	14	684	5040	0.57	0	0	0.43	0	0	0
	3/17/2018	15	903	10940	1	0	0	0	0	0	0
	3/17/2018	16	990	14040	1	0	0	0	0	0	0
	3/17/2018	17	984	14680	1	0	0	0	0	0	0
	3/17/2018	18	976	12840	0.67	0	0	0.33	0	0	0
	3/17/2018	19	1000	16000	0	0	0	1	0	0	0
	3/17/2018	20	675	520	0.5	0	0	0.5	0	0	0
2	5/17/2018	21	1010	18380	1	0	0	0	0	0	0
May	5/17/2018	22	884	11740	1	0	0	0	0	0	0
	5/18/2018	23	974	15100	1	0	0	0	0	0	0
	5/18/2018	24	750	4240	0.67	0	0	0.33	0	0	0
	5/18/2018	25	873	9180	0.5	0	0	0.5	0	0	0
	5/18/2018	26	905	10060	0	0	0	0	1	0	0
	5/23/2018	27	790	7140	0	0	0	0	0	0	0
	5/23/2018	28	695	4740	0	0.67	0.33	0	0	0	0

	6/4/2018	29	637	3200	0	0	0	0	0	0	0
	6/4/2018	30	865	9820	0	0	0	0	0	0	0
	6/4/2018	31	1005	21500	0	0	0	0	0	0	0
	6/4/2018	32	945	16060	1	0	0	0	0	0	0
	6/4/2018	33	1035	14.8	0	0	0	0	0	0	0
	6/4/2018	34	791	8.32	1	0	0	0	0	0	0
3	6/28/2018	35	1052	13200	1	0	0	0	0	0	0
June	6/28/2018	36	893	11420	1	0	0	0	0	0	0
	6/28/2018	37	1007	14620	1	0	0	0	0	0	0
	6/28/2018	38	1035	18780	0.5	0	0	0	0	0	0.5
	6/28/2018	39	937	13940	0	0	0	0	0	0	0
	6/29/2018	40	1044	16860	1	0	0	0	0	0	0
	6/29/2018	41	1025	14640	1	0	0	0	0	0	0
	7/11/2018	42	807	7929	0	0	0	0	0	0	0
	7/11/2018	43	646	2960	0	0	0	0	0	0	0
4	10/11/2018	44	1010	17140	0.6	0	0.4	0	0	0	0
October	10/11/2018	45	868	10200	0.2	0	0	0.8	0	0	0
	10/11/2018	46	975	14120	0	0	0	0	0	1	0
	10/11/2018	47	670	4520	0.33	0	0.6	0.07	0	0	0
	10/11/2018	48	771	6560	0.42	0.58	0	0	0	0	0
	10/11/2018	49	801	6660	0.02	0.02	0	0.96	0	0	0
	10/11/2018	50	772	7520	0.375	0	0	0.625	0	0	0
	10/11/2018	51	905	12080	0.88	0	0	0.12	0	0	0
	10/11/2018	52	808	8240	0.31	0.04	0	0.65	0	0	0
	10/11/2018	53	865	11320	0.8	0	0.1	0	0	0.1	0
	10/11/2018	54	660	4360	0.14	0.05	0	0.81	0	0	0
	10/11/2018	55	1074	19740	0.3	0	0	0.7	0	0	0
	10/12/2018	56	747	6124	0	0	0	0	0	0	0

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