Spawning Habitat, Length at Maturity, and Fecundity of Brown Trout in Tennessee Tailwaters

Fisheries Report 06-11

A Final Report Submitted to

Mr. Frank Fiss
Tennessee Wildlife Resources Agency
Nashville, TN 38204

by

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EXECUTIVE SUMMARY

(1) Surveys to locate potential spawning sites for brown trout *Salmo trutta* were conducted in 2005 in the South Fork of the Holston, Watauga, Caney Fork, and Clinch rivers. Adult brown trout were sampled in the fall of 2004 and 2005 to estimate fecundity and age-0 brown trout were sampled in the summer of 2005 to determine whether successful reproduction occurred at any site in any river.

(2) The number of potential spawning sites (e.g., near bridge pilings or in side channels around islands) ranged from four in the Clinch River to 16 in the Watauga River. Surface substrate size at potential spawning sites was the only habitat characteristic that differed among rivers. Mean substrate sizes at three rivers (South Holston, Clinch, and Caney Fork) were within the optimal size range for brown trout redd construction; mean substrate size at the Watauga River was much larger.

(3) The predicted length at which 50% of brown trout were mature was shortest in the Watauga River (255 mm) and longest in the Caney Fork River (360 mm). Fecundity was lowest in the Watauga River and highest in the Clinch River; mean fecundities were within the broad range of values reported for other U.S. rivers.

(4) Electrofishing surveys verified successful reproduction only in the South Fork of the Holston and Watauga rivers. Age-0 brown trout were collected at all six potential spawning sites in the South Fork of the Holston River and the catch ($\pm$ SE) averaged 160 ($\pm$ 59) fish–h^{-1}. Age-0 brown trout were collected at only 9 of 16 sites in the Watauga River and catches averaged 34 ($\pm$ 9) fish-h^{-1} at those 9 sites.

(5) In the Caney Fork and Clinch rivers, factors that would have prevented reproduction included high flows during winter when brown trout spawn and their eggs incubate, lack of suitable water temperatures (< 9^0 C) during the spawning season, and dewatering of potential spawning habitat (i.e., gravel bars).

(6) It is unlikely that winter flows or water temperatures will change in the Caney Fork and Clinch rivers; therefore, the stocking of brown trout must continue in those two rivers. Brown trout reproduction appeared sufficient to maintain fisheries wholly supported by wild brown trout in the South Fork of the Holston River and the upper 11 km of the Watauga River below Wilbur Dam.

INTRODUCTION

Hypolimnetic water released from some Tennessee reservoirs provides appropriate temperatures for rainbow trout *Oncorhynchus mykiss* and brown trout *Salmo trutta* to survive in a region where cold-water resources are limited (Mobley et al. 2000). However, trout populations are usually maintained by stocking because unsuitable spawning habitat and extreme fluctuations of stream discharge adversely affect natural reproduction in regulated rivers (Banks and Bettoli 2000; Orth et. al. 2001; Pender and Kwak 2002). Recent investigations in Tennessee suggested that natural reproduction by brown trout was occurring in the South Fork of the Holston River (South Holston Dam tailwater) and the Watauga River (Wilbur Dam tailwater)(Bivens et al. 1998; Nemeth 1999; Banks and Bettoli 2000). Natural reproduction was so prevalent in the South Fork of the Holston River that the Tennessee Wildlife Resources Agency (TWRA) discontinued stocking brown trout in 2004. Although the maximum turbine discharges were similar at South Holston Dam and Wilbur Dam, the substrate on the Watauga River was described as armored by Banks and Bettoli (2000), a condition that may limit reproduction by redd-building species. Armoring was defined by Armantrout (1998) as "the formation of an erosion-resistant layer of relatively large particles on the surface of a streambed, resulting from removal of finer particles by erosion, which resists degradation by water currents." The extent to which substrate is the limiting factor for trout spawning in Tennessee tailwaters is still unknown.

Salmonid reproduction has been thoroughly studied (e.g., Smith 1973; Ottoway et al. 1981; Dechant and West 1985; Grost et al. 1990; Beard and Carline 1991; Montgomery et al. 1996); however, there is still a paucity of published information on brown trout reproduction in regulated rivers of the eastern United States. October through December is the period of peak brown trout redd construction in unregulated rivers in the southeastern United States (Dechant and West 1985). The process of spawning begins when a female selects a suitable area to construct a redd. Suitability of stream reaches for spawning depends on at least four factors: (1) substrate is an appropriate size to allow water to continuously infiltrate gravel during incubation and larval development; (2) water depth and velocity are suitable for spawners to construct redds and mate; (3) interstitial spaces are free of fine sediments prior to the spawning season; and (4) river flows during egg incubation are less than those capable of mobilizing and transporting gravel (Orth et al. 2001). The optimum ranges of surface substrate size, stream depth, velocity, and temperature for redd site selection by brown trout have been reported (Raleigh et al. 1986; Table 1).

Redds commonly are found immediately upstream and downstream of riffles, presumably because these locations offer suitable substrate and upwelling or downwelling currents that promote egg incubation and alevin survival (Grost et al. 1990). Regulated rivers in the southeastern United States differ from rivers where redd site selection has been studied because they are larger and experience extreme fluctuations in flow and water level. Orth et al. (2001) reported that islands and associated side-channels were the only areas that provided suitable habitat for redd construction in many reaches of the Smith River, a regulated river in Virginia.

Redd counts are conducted to identify spawning areas, to confirm that spawning has occurred, and to quantify spawning activity (Mitro and Zale 2000). Redd counts performed on regulated rivers may be misleading in terms of accurately identifying successful spawning habitat. For instance, brown trout redds constructed during high flows near river margins were de-watered when flows receded (Pender and Kwak 2002), and Banks and Bettoli (2000) reported that some redds were subsequently leveled by high flows during hydropower releases.

The number of redds and age-0 brown trout density the following summer were correlated in Spring Creek, Pennsylvania (Beard and Carline 1991), suggesting that juvenile brown trout do not disperse far from the redds from which they emerge. In Maine rivers, the highest densities of juvenile Atlantic salmon *Salmo salar* were associated with natal areas (Beland 1996), and suitable habitat for cutthroat trout fry in the Colorado River usually was unoccupied unless spawning habitat was nearby (Griffith and Smith 1993). During a flood year, dispersal of age-0 brown trout from natal areas did not differ from dispersal during years of normal flows (Hayes 1995). If young-of-year brown trout do not disperse from natal areas, the presence of young-of-year brown trout should indicate the presence of suitable spawning habitat nearby, and vice versa.

Information on the fecundity and length at maturity of brown trout is needed to understand their population dynamics and select the proper angling regulations (Avery 1985). Brown trout fecundities have been characterized in Pennsylvania (McFadden et al. 1965), Michigan (Taube 1976), and Wisconsin (Avery 1985) in unregulated streams where fish grew slowly. In contrast, Pender and Kwak (2002) reported fecundity for fast growing brown trout in the White River, a regulated river in Arkansas. Large variations in fecundity have been noted between fast and slow growing populations and some authors have proposed a strong influence of local environmental conditions on fecundity (McFadden et al. 1965). Fecundity is highly correlated with length (Lobon – Cervia 1997); for instance, the fecundity of one 350-mm TL brown trout was roughly equivalent to that of two 254-mm TL females in a Wisconsin stream (Avery 1985). Average length at maturity may predict the reproductive potential for a particular population (Meyer et al. 2003); that is, a fast growing population in which brown trout mature at larger sizes may produce more eggs than an equally large population of slow growing brown trout. There is a paucity of literature relating trout fecundity to reproductive success, but that relation has been observed for other species. For instance, Mardsen and Robillard (2004) attributed low abundance of age-0 yellow perch *Perca flavescens* in Lake Michigan to low egg production.

A wild brown trout fishery in a medium-sized river provides anglers with a unique experience in the southeastern U.S. The four rivers in this study (Figure 1) were chosen based on their popularity among anglers (Hutt and Bettoli 2003) and varying degrees of brown trout reproductive success. The objectives of this study were to: (1) survey four Tennessee tailwaters for potential spawning areas; (2) identify and quantify habitat characteristics of potential spawning areas; (3) compare brown trout length at maturity and fecundity among rivers; and (4) assess reproductive success at each river.

STUDY AREAS

Clinch River

Norris Dam is located on the Clinch River in Anderson County, Tennessee. Hypolimnetic discharges maintain appropriate water temperatures for year-round brown trout survival between Clinch River km 128 (Norris Dam) to river km (rkm) 108 (headwaters of Melton Hill Reservoir). A flow reregulation weir built in 1984 approximately 3.2 km downstream of Norris Dam provides a minimum flow of 5.6 m^3/s; periodic pulses from Norris Dam maintain the weir-pool during periods of low discharge. An autoventing turbine system and the re-regulation weir were designed to maintain targeted dissolved oxygen concentrations of at least 6 mg/L. The vertical rise in the river during periods of full generation can approach 1.8 m and the discharge varies 43-fold between baseflow and maximum turbine discharge (241 m^3/s). At baseflow, the macrohabitat consists of long pools separated by short riffles. Upturned bedrock is the dominant substrate, interspersed with patches of cobble and gravel. About 20,000 catchable-size brown trout are stocked annually to maintain the population, and brown trout fry and fingerlings are stocked on an irregular basis. Stocked brown trout in the Clinch River grew at intermediate rates compared to other tailwaters in Tennessee (Meerbeek and Bettoli 2005). Wild rainbow trout fingerlings sometimes are observed in electrofishing samples (B. Carter, Tennessee Wildlife Resources Agency, personal communication); however, brown trout reproduction has not been verified in the Clinch River.

Watauga River

Wilbur Dam is located on the Watauga River in Carter County, Tennessee. Coordinated releases from Watauga Dam (4.8 km upstream from Wilbur Dam) and Wilbur Dam provide cold, hypolimnetic water that is suitable for brown trout survival and reproduction from Watauga River km 55 (Wilbur Dam) to rkm 29 (headwaters of Boone Reservoir). Hub baffles on the Watauga Dam turbines were designed to maintain a target dissolved oxygen concentration of at least 6 mg/L; discharges from Wilbur Dam often exceed that target and rarely are less than 4 mg/L. A minimum flow of 6.0 m^3/s is maintained by continually running one unit at Wilbur Dam. The vertical rise in the river during full generation is less than 1 m and the change between baseflow (6 m^3/s) and maximum discharge (75 m^3/s) is 13-fold. At baseflow, pools and riffles were equally represented in the tailwater and bedrock, cobble, and gravel were the dominant substrates (Bettoli 1999). Annual stockings of catchable-size brown trout and some reproduction maintain the population. Relative to populations elsewhere in Tennessee, stocked brown trout grew slowly in the Watauga River (Meerbeek and Bettoli 2005); however, their growth rates were similar to growth rates of brown trout in the Smith River, Virginia (Orth et al. 2001). Much of the substrate in the Watauga River was described as armored (Banks and Bettoli 2000), which makes it difficult for brown trout to build redds. Wild fingerling brown trout were routinely observed in electrofishing samples in the Watauga River (Bivens et al.1998; Bettoli 1999); however, specific spawning habitats for brown trout have not been identified in the Watauga River.

South Fork of the Holston River

South Holston Dam is located in Sullivan County, Tennessee, on the South Fork of the Holston River at river km 80. Suitable temperatures for trout survival and reproduction extend approximately 22 km from the dam (rkm 80) to the headwaters of Boone Reservoir (rkm 57.5). In 1991 an aerating labyrinth weir was built 2 km downstream from the dam to maintain a minimum flow of 2.5 m^3/s. Turbines are pulsed twice daily to maintain the weir pool and turbine venting and hub baffles help maintain target dissolved oxygen concentrations of 6 mg/L. The vertical rise in the river with the onset of full generation is less than 1 m and discharge varies 34-fold between baseflow (2.5 m^3/s) and maximum discharge (85 m^3/s). At baseflow, riffles were the most common macrohabitat, followed by runs and pools (Bettoli et al. 1999). Substrate in the river was comprised mostly of bedrock, cobble, and gravel. Cobble and gravel were common in hydraulic refugia. Brown trout were stocked annually through 2003 to maintain the population; stocking was discontinued after 2003 to allow the population to be sustained wholly by natural reproduction. Brown trout growth rates in the South Fork of the Holston River were intermediate compared to other Tennessee tailwaters (Meerbeek and Bettoli 2005). The substrate in hydraulic refugia associated with islands and bridges was suitable for redd building (Banks and Bettoli 2000).

Caney Fork River

Center Hill Dam in Dekalb County, Tennessee, is located on the Caney Fork River at rkm 43. The temperature in the tailwater is suitable for year-round trout survival; however, hypolimnetic releases from the reservoir become hypoxic during September and October and dissolved oxygen levels often fall below 1 ppm. The Caney Fork River is managed as a trout fishery between Center Hill Dam and rkm 17. Seepage from the reservoir produces a minimum flow of 2.6 m^3/s during periods of no generation. During periods of full generation, water levels in the tailwater can rise as much as 3 m and the difference between baseflow (2.6 m^3/s) and maximum discharge (350 m^3/s) is 134-fold. The Caney Fork River is a low gradient river (0.28 m/km) and high-quality trout habitat is scarce. Deep pools represented 86% of the total area of the tailwater (Devlin and Bettoli 1999). Erosion of the banks and riparian areas is common, leading to heavy deposits of sand and silt in the pools. Cobble and gravel were the dominant substrate in riffle areas; however, many riffles were dewatered during baseflow. Fingerlings and catchable-size brown trout are stocked annually and their growth rates exceeded those of other Tennessee tailwaters (Devlin and Bettoli 1999; Meerbeek and Bettoli 2005). There is no evidence that brown trout reproduce in the Caney Fork River.

METHODS

Habitat Survey of Potential Spawning Areas

The Clinch, Watauga, South Fork of the Holston and Caney Fork Rivers were surveyed by canoe in spring 2005 during baseflows. The South Fork of the Holston River was surveyed from River’s Way (rkm 75) to Weaver Pike Bridge (rkm 66). A known brown trout spawning site in the vicinity of the Bristol weir and Emmett Bridge in the upper reach of the South Holston Dam tailwater (Bettoli et al. 1999) was not surveyed in order to avoid repeated interactions with anglers in that popular, heavily used area. The Clinch River was surveyed from the reregulation weir (rkm 125) to the headwaters of Melton Hill Reservoir (rkm 108). The Caney Fork River was surveyed from Center Hill Dam (rkm 43) to Stonewall (rkm 17), and the Watauga River was surveyed from Wilbur Dam (rkm 55) to the industrial park in Watauga, TN (rkm 27). Areas of hydraulic refugia near all instream structures (i.e., channels, islands, and bridges) on each tailwater were identified *a priori* as potential spawning sites. A side-channel was defined as the narrow stream channel associated with an island. Data on the surface sediment size, depth, and velocity were collected at each potential spawning site. Pebble counts (Whalen et al. 2002) were used to characterize the surface substrate composition of potential spawning sites. Pebble counts were performed in a side-channel by walking parallel transects that were perpendicular to the stream bank. A transect began at the edge of the wetted width of the stream and continued across the channel to the opposite bank. Each transect was walked heel-to-toe and at each step a pebble was picked up at the tip of the toe and its intermediate axis was measured; the procedure was repeated until 50 pebbles were measured. All pebble counts at side channels were performed at the first riffle encountered at the downstream end of the island. Pebble counts at bridges were performed immediately downstream of bridge pilings. At the point at which the tenth pebble in the transect was encountered the depth was measured with a wading rod and water velocity was measured at a point 60% of the depth below the surface (McMahon et al. 1996) using a Marsh-McBirney Model 201D water current meter.

One-way analysis of variance (ANOVA) was used to independently test for differences among rivers in surface substrate size, depth, and velocity at potential spawning sites. Tukey’s test was used to test for differences among rivers in mean surface substrate size, mean depth, and mean velocity. Statistical Analysis System software was used for all analyses, and tests were considered significant at $\alpha = 0.05$.

Length at Maturity and Fecundity

Female brown trout ($n \geq 16$; 200 to 500 mm TL) were collected in October 2004 and October 2005 to assess length at maturity and fecundity in all four rivers. Brown trout were euthanized with overdoses of MS-222, measured for total length (TL, mm) and weighed (g). Females were classified as immature (i.e., ovaries were small, granular and translucent) or mature (i.e., large, well-developed eggs that filled much of the abdominal cavity: Strange 1996). Mature ovaries were removed, weighed to the nearest g and fixed in a 5% formalin solution (Forbes and Stewart 2002).

The length at which the probability of being mature was 50% (termed ML50) was estimated using the methods of Meyer et al. (2003). If there was no overlap between the largest immature fish and smallest mature fish, the ML50 was the midpoint between the lengths of those two fish. If the lengths of mature and immature fish overlapped, maturity was related to total length using logistic regression and the ML50 was the length at which the probability of being mature was 50%. The Hosmer and Lemeshow goodness-of-fit test was used to evaluate the fit of the data to a logistic regression model for each river. Simple linear regression was used to relate ML50 in each river to the growth rates of brown trout reported by Meerbeek and Bettoli (2005). The ML50 data were $\log_{10}$ transformed before performing the regression analysis.

Fecundity was determined by direct enumeration of all ova. Differences in fecundity among rivers were analyzed with analysis of covariance, where total length was the covariable and river was the independent variable. Fecundity and total length data were $\log_{10}$ transformed to linearize the relationships between the two variables. After adjusting for differences in mean total lengths, adjusted mean fecundities in each river were statistically compared using the least-squares multiple comparison test. The adjusted mean fecundity in each river was the predicted fecundity for a trout with a total length equal to the pooled mean total length of all trout examined.

Assessing Reproductive Success

The presence or absence of age-0 fish was used to determine whether or not reproduction had taken place at a potential spawning site. Potential spawning sites were electrofished in summer 2005 using a Smith-Root, Inc., Type LR-24 pulsed-DC backpack electrofisher. Sampling was conducted at baseflow to allow for full access to potential spawning areas. Age-0 brown trout inhabit stream margins (Harris 1992; La Voie and Hubert 1997; and Griffith and Smith 1993); therefore, the majority of electrofishing effort was aimed at stream margins. Sampling at side-channel sites consisted of a 200-m electrofishing pass on each bank of the side-channel and a 200-m electrofishing pass of the riverbank immediately downstream of the side-channel; thus, 600 m were electrofished per site (Figure 2). The entire length of the side-channel was electrofished in areas where the side channel was less than 200-m long. Sampling at bridge piling sites consisted of a 200-m electrofishing pass immediately downstream of the piling and a single 200-m electrofishing pass on the closest stream bank.

All age-0 trout were placed into a bucket filled with water. Trout were identified, counted, and measured (TL, mm) after each electrofishing pass. Age-0 brown trout were distinguished from age-0 rainbow trout based on distinct markings described in Pollard et al. (1997). Catch data were reported as age-0 brown trout/h of electrofishing effort.

GPS coordinates were recorded for each potential spawning site using a Garmin® eTrex Legend GPS. The coordinates were entered into a GIS database and ArcGIS 9.0 and river distance was measured from each site to its corresponding dam.

In rivers where wild age-0 brown trout were present, ANOVA and Tukey's test were used to independently test for differences in surface substrate size, depth, and velocity among sites within each river. Predictor variables were tested for collinearity ($P < 0.05$) using Pearson correlation coefficients. Stepwise linear regression was used to determine which independent variables or combination of variables best explained the variation in catch rates of age-0 brown trout.

Temperature and Discharge

Temperature loggers (Onset, Inc) recorded water temperatures at one location in each river at 30-min intervals during the spawning and incubation seasons (October 2004 through February 2005). Average daily temperatures were calculated to determine if and when temperatures were within the range of temperatures considered optimum for brown trout spawning (i.e., 6.1-8.9^{o}C; Raleigh et al. 1986). Average daily discharges for the spawning and incubation period in 2004 and 2005 were calculated from data obtained by the U.S. Army Corps of Engineers and the Tennessee Valley Authority.

RESULTS

Potential Spawning Areas

The number of potential spawning areas identified in the surveyed reaches of each river varied 4-fold. The Watauga River had the most potential spawning sites (n = 16) and the Clinch River had the fewest (n = 4). Three bridges and four islands occurred in the surveyed reach of the Clinch River, but only four potential spawning areas were identified (Figure 3). All potential spawning areas in the Clinch River were associated with side-channels because water surrounding bridge pilings was usually too deep (> 1 m) to be good spawning habitat. Complex shoreline structure was available in the form of large woody debris to provide cover for any age-0 brown trout produced in the Clinch River.

Seven bridges cross the Caney Fork River and there were eight islands at baseflow. Despite the abundance of instream structures, only seven potential spawning areas were identified (Figure 4). Many of the island side-channels were dewatered or cut off from the river channel during baseflow, and the water surrounding most of the bridge pilings was too deep (> 1 m). Large gravel bars with suitable spawning substrate and shoreline structure were common, but they were dewatered during baseflow; therefore, they were not considered potential spawning habitat.

Three bridges and seven islands occurred in the surveyed reach of the South Fork of the Holston River. Six potential spawning areas were associated with islands. The three bridges were adjacent to islands; thus, potential spawning areas associated with the bridges were incorporated into each island's potential spawning area (Figure 5). The wetted width at baseflow approximated bankfull width at all of the potential spawning areas; therefore, dewatering of spawning gravel did not occur. Vegetation, undercut banks and large woody debris were available to provide cover for age-0 brown trout at all potential spawning areas. Five of six potential spawning areas were protected by regulations that prohibited fishing in those areas during the spawning season (November 1st – January 31st). The island adjacent to the labyrinth weir dam was not sampled due to the high angler use in that reach.

Islands and associated side-channels were numerous in the Watauga River and 16 potential spawning sites were identified (Figure 6). In the upper 12 km of the survey reach the wetted width approximated bankfull width during periods of baseflow; however, deep pools were more common in the lower 16 km of the survey reach and shallow shoreline areas were dewatered at baseflow. Large woody debris was present only at sites 4 and 16; however, large boulders (≥ 0.5 m median axis) and vegetation were present at all other sites to provide cover for age-0 brown trout.

Mean surface sediment size at potential spawning areas varied significantly ($F = 176.66$; d.f. = 3, 1826; $P \leq 0.001$) among rivers; whereas, mean velocity and mean depth were similar ($F \leq 1.86$; d.f. = 3, 186; $P \geq 0.138$) among rivers (Table 2). Mean surface sediment sizes ranged from 31 to 90 mm and were smallest in the Caney Fork River and Clinch River and largest in the South Fork of the Holston River and Watauga River. Mean velocities at baseflow at potential spawning areas in each river ranged from 26 to 42 cm/s and mean depths ranged from 20 to 27 cm.

Length at Maturity

Logistic regression models estimating ML 50 provided a good fit to the data for the Clinch, South Fork of the Holston, and Watauga Rivers (Figure 7; Hosmer and Lemeshow goodness-of-fit test; $P \geq 0.2311$). Only four brown trout were collected in the

Caney Fork River; the ML50 was estimated as the midpoint between the longest immature fish and shortest mature fish because the lengths of immature fish and mature fish did not overlap (i.e., logistic regression could not be performed). The ML50 varied among the four rivers, ranging from 256 mm TL in the Watauga River to 360 mm TL in the Caney Fork River (Table 3). The variability in size at maturity among tailwaters was linearly related to growth rates (mm/month) for each tailwater ($r^2 = 0.86$) (Figure 8).

Fecundity

Fecundity was determined for 93 brown trout. $\log_{10}$ fecundity increased linearly with $\log_{10}$ length in all rivers ($r^2 \geq 0.60$; Table 4). Slopes of these lines were similar ($F = 1.91$; d.f. 3, 85; $P = 0.1342$); however, the elevations differed (ANCOVA; $F = 19.61$; d.f. 3, 88; $P < 0.0001$). Pooled mean total length of all mature female brown trout was 339 mm and the estimated fecundity of a brown trout that long ranged from 893 eggs in the Watauga River to 1,596 in the Clinch River (Figure 9). Brown trout in the Watauga River were less fecund and those in the Clinch River were more fecund than brown trout in the Caney Fork and South Fork of the Holston Rivers ($P < 0.05$).

Age-0 Sampling at Potential Spawning Areas

No age-0 brown trout were collected in any of the seven areas electrofished in the Caney Fork River. Mean catch varied by more than two orders of magnitude among the other three rivers (Figure 10). Four age-0 brown trout were collected in the Clinch River; however, their origin (i.e., wild or hatchery) was unknown because the Clinch River was stocked with 82,288 brown trout fry (mean TL = 45 mm) in February 2005. The four fingerlings collected from the Clinch River may have been stocked as fry; therefore, the Clinch River was excluded from the analysis of which habitat variables at potential spawning sites were important in predicting the abundance of wild age-0 brown trout.

Age-0 brown trout ($n = 909$) were collected at all six potential spawning sites in the South Fork of the Holston River. Site SH-01 yielded the highest catch of 335 age-0 brown trout /h of electrofishing effort, compared to only two age-0 brown trout/h at SH-

04 (Figure 11). All sites except SH-04 were located in reaches that were closed to fishing during the spawning season. Velocity, surface sediment size, and depth varied significantly among sites within the South Fork of the Holston River (Table 5). There were no correlations among variables ($P > 0.05$), and distance downstream from South Holston Dam explained most of the variation in catch rates among sites (partial $r^2 = 0.877$). The best model for explaining variations in catch rates among spawning areas included distance downstream from South Holston Dam, mean velocity, and mean surface sediment size ($r^2 = 0.995$; $P = 0.0069$):

$$\textit{Catch Per Hour} = 622.78 - 2.14\ (\textit{sediment, mm}) + 3.46\ (\textit{velocity, cm/s}) - 39.14\ (\textit{distance downstream, km}).$$

Age-0 brown trout (n = 255) were collected at nine of 16 sites on the Watauga River. Catch was highest at site WA-7 (90 age-0 brown trout/h) and lowest at sites WA-9 through WA-15, where no fish were collected (Figure 11). Age-0 brown trout were collected at the uppermost eight sites (rkm 55 - 43) and the lowermost site (WA-16) at rkm 26. Velocity, surface sediment size and depth varied significantly among sites in the Watauga River (Table 6). In general, no age-0 brown trout were collected from the sites with the highest velocities, largest surface sediment sizes, and greatest depths. Mean depth and mean velocity were correlated, and mean depth was the single most important factor in explaining the variation in catch among sites (partial $r^2 = 0.5147$). The best model for explaining variations among sites in catch of age-0 brown trout included mean depth and distance downstream from Wilbur Dam ($r^2 = 0.6072$; $P = 0.0023$):

$$\textit{Catch Per Hour} = 76.90 - 1.63\ (\textit{depth, cm}) - 0.90\ (\textit{distance downstream, km}).$$

Temperature and Discharge

During the spawning season (October through December) mean daily temperatures in all the rivers ranged from 6 – 15 ^{o}C and average daily discharge ranged from 10 m^3/s to 530 m^3/s. Mean daily temperatures in the South Fork of the Holston

River and the Watauga River during the spawning season were within the spawning range of 6.1 – 8.9 ^{o}C reported in the literature (Figure 12). Mean daily temperatures in the Clinch River and the Caney Fork River eventually fell within the spawning range; however, those temperatures were not reached until January 12th in the Clinch River and January 15th in the Caney Fork River, after the spawning season for brown trout (Figure 12). Once temperatures fell within the spawning range they remained consistently cold except in the Caney Fork River, where temperatures appropriate for spawning were recorded on only four days in January. The Clinch River and Caney Fork River experienced consistently high flows from October through December when brown trout normally spawn and their eggs incubate; whereas, average daily discharges in the Watauga River and South Fork of the Holston River were skewed towards low flows throughout the winter (Figure 13).

DISCUSSION

Habitat

In terms of velocity and depth, potential spawning habitats in the four Tennessee rivers were similar to brown trout spawning habitats elsewhere (Smith 1973; Dechant and West 1985; Raleigh et al. 1986; Grost et al. 1990; and Beard and Carline 1991). Likewise, mean surface sediment sizes in the South Fork of the Holston River (59 mm), Clinch River (39 mm) and Caney Fork River (31 mm) were similar to those found in spawning areas used by brown trout elsewhere in North America (Raleigh et al. 1986; Grost et al. 1990; Orth et al. 2001). The mean surface sediment size at potential spawning sites in the Watauga River (90 mm) was considerably larger than typical spawning gravel described in the literature; although Ottoway et al. (1981) noted that sediments in spawning areas used by brown trout in the Tees River, England, were large, ranging from 82 mm to 112 mm.

All habitat measurements were taken during baseflow; however, depths and velocities changed radically during periods of hydropower generation. The vertical rise during generation ranged from ~1 m in the South Fork of the Holston River to 2 m or more in the Caney Fork River and Clinch River. Such dramatic changes in flow may compromise the ability of trout to reproduce. A redd may be constructed and eggs deposited during baseflow; however, high flows commonly leveled the pit and tailspill configuration of some brown trout redds in the Clinch River, Watauga River, and South Fork of the Holston River (Banks and Bettoli 2000). The leveling of redds due to high flows led to 75% of the buried eggs becoming disinterred and had a deleterious affect on trout recruitment in Sheep Creek, Colorado (Corning 1969). The ability of peaking hydropower flows to mobilize and transport small gravel sizes, such as those found in the Caney Fork River and Clinch River, could have caused reproductive failure via leveling of redds. The dewatering of redds is another factor that would likely cause reproductive failure. For instance, large gravel bars with suitable spawning substrate were routinely dewatered in the Caney Fork River during baseflow. Pender and Kwak (2002) observed that redds constructed during peaking hydropower flows were dewatered during baseflow in the White River, Arkansas.

Water temperature undoubtedly plays a pivotal role in brown trout reproduction in Tennessee tailwaters. Brown trout typically spawn from October to December at water temperatures of 6.0^{o}C – 8.9 ^{o}C (Dechant and West 1985; Raleigh et al. 1986; Rohde et al. 1996; Avery and Niermeyer 1999; Orth et al. 2001). Water temperatures in the South Fork of the Holston River and Watauga River were within that temperature range during the fall and early winter spawning season. However, temperatures did not drop below 9 ^{o}C until January 12th in the Clinch River and January 15th in the Caney Fork River. The timing of brown trout spawning in hatcheries can be manipulated by changing the photoperiod; however, it is unknown whether brown trout exposed to a natural photoperiod can delay spawning to coincide with appropriate spawning temperatures that occur after the normal spawning season. It cannot be stated that the absence of suitable temperatures during the appropriate photoperiod was responsible for little or no brown trout reproduction in the Caney Fork and Clinch Rivers because those two rivers also experienced high flows during winter. It is interesting to note, however, that some rainbow trout reproduction has been documented in the Clinch River (Bettoli and Bohm 1997) and rainbow trout spawn in late winter and early spring (February – April) in other systems (Rohde et al. 1996; Fausch et al. 2001). That is, appropriate temperatures for rainbow trout spawning coincide with the appropriate photoperiod in the Clinch River; however, the scouring effect of high flows on redd integrity still appears to limit reproductive success of that species in that river.

Length at Maturity

Maturity in fish typically depends on the attainment of a physiologically critical size and the age at which that size is achieved (Meyer et al. 2003). Variations in ML50 for each population in this study were explained by differences in growth rates reported by Meerbeek and Bettoli (2005). Length at maturity data for brown trout is scarce; however, brown trout matured in each of the four tailwaters at a larger size than what was reported for other non-migratory brown trout populations (Taube 1976; Avery 1985).

Fecundity

The fecundity of brown trout is usually positively related to their growth rate (Bagenal 1969; Lobon-Cervia et al. 1997). Low fecundity of brown trout in the Watauga River can be attributed to their meager growth, which was the slowest of the four populations studied by Meerbeek and Bettoli (2005). Although fecundity of brown trout in the Watauga River was low compared to other rivers in this study, their fecundity was similar to the fecundities of other slow-growing, self-sustaining brown trout populations in the Platte River, Michigan (Taube 1976) and several Wisconsin streams (Avery 1985). Fecundity in the Clinch River was highest among rivers in this study and similar to the fecundity of fast-growing brown trout in the White River, Arkansas (Pender and Kwak 2002). The relationship observed in this study between fast growth of brown trout and high fecundity is a general trait of salmonids (Avery 1985; Elliot 1995; Trippel 1993). Lobon-Cervia et al. (1997) postulated that environmentally induced differences in fecundity could have adaptive value if survival of offspring is dependent on food availability. Fecundity data are scarce for brown trout in the U.S. and worldwide. Results from the present study are thus valuable because understanding the relationships between size of spawning stocks and number of eggs and young produced is fundamental to understanding the dynamics of many exploited sport fisheries (Avery 1985).

Age-0 Catches

The general inverse relationship between age-0 brown trout catch rates and river discharge observed in this study (i.e., higher catches in the rivers with lowest discharges) has been observed elsewhere. Hayes (1995) reported that flows greater than 290 m^3/s during early fry stages were associated with poor recruitment of brown trout in the Kakanui River, New Zealand. When eggs are incubating and fry are emerging in other North American rivers (i.e., November 1 – February 28), flows in the Caney Fork River and Clinch River often approached or exceeded 290 m^3/s.

In addition to the influence of habitat quality, different catch rates for age-0 brown trout in the South Fork of the Holston River and Watauga River might be attributed to differences in fecundity, abundance of adults, and the amount of wade fishing during the spawning and egg incubation season. Differences in the fecundity of fish might lead to more eggs being deposited in the South Fork of the Holston River than in the Watauga River and more eggs could produce more age-0 fish. Studies on the relationship between trout fecundity and subsequent age-0 abundance were not found. However, low abundance of age-0 yellow perch *Perca flavescens* were attributed to low egg production in southwestern Lake Michigan (Mardsen and Robillard 2004).

Total egg production also reflects the abundance of spawning fish and electrofishing catch rates of adult brown were more than twice as high in the South Fork of the Holston River compared to the Watauga River (Habera et al. 2005). The general positive relationship between age-0 catch rates and adult catch rates in the rivers in this study has also been observed for rainbow trout in Colorado streams (Latterell et al. 1998), lake trout *Salvelinus namaycush* in Lake Superior (Schram et al. 1995), and walleye *Sander vitreus* in Wisconsin lakes (Hansen et al. 1998; Nate et al. 2000).

Wade fishing during spawning and egg incubation can have harmful effects via harassment of spawning fish and the trampling of redds. Five of six sites sampled in the South Fork of the Holston River were in protected spawning areas that were closed to fishing from November 1 to January 31; whereas, most sites sampled in Watauga River were easily accessible to wade fisherman. Roberts and White (1992) demonstrated that heavy wading traffic killed up to 96% of eggs and pre-emergent fry.

The spatial variability we observed of age-0 brown trout in the South Fork of the Holston River and Watauga River is commonplace and largely a function of the availability of spawning habitat (Beard and Carline 1991; Griffith and Smith 1993; Hayes 1995; Beland 1996). Potential spawning areas were the only habitats electrofished in the present study; therefore, the relationship between spatial variability of spawning habitats and age-0 abundance on a riverwide-scale could not be assessed for the South Fork of the Holston River or Watauga River.

MANAGEMENT IMPLICATIONS

Brown trout reproduction occurs in Tennessee tailwaters; however, not all Tennessee tailwaters provide the habitat necessary for self-sustaining populations. Factors leading to reproductive failure in the Caney Fork River and Clinch River were numerous and compounding. Potential spawning substrates in both rivers were comprised of small gravel that could be transported by high flows that routinely occur during the brown trout spawning season; thus, high flows likely destroy any redds that might be constructed. Water temperatures in both rivers were not cold enough during the spawning season to prompt spawning activity and in the Caney Fork River, large areas of suitable spawning habitat were dewatered during periods of baseflow. Reproductive success cannot be improved in the Caney Fork River and Clinch River without substantially altering discharge regimes and releasing colder water in early winter. Given the overarching requirement of large tributary storage impoundments such as Norris Lake and Center Hill Lake to prevent downstream flooding, the substantive changes in dam operations needed to promote trout reproduction in those systems are not likely to occur. Brown trout fisheries in the Caney Fork River and Clinch River must continue to be supported by stocking because it is unlikely that wild brown trout fisheries will ever exist in those tailwaters.

Brown trout successfully reproduced in the South Fork of the Holston River and the Watauga River and the highest catches of juveniles occurred in two protected spawning areas of the South Fork of the Holston River. Closing those two areas to fishing (and wading) may have contributed to the high abundance of age-0 brown trout in the South Fork of the Holston River. However, this study did not include the upper reaches of the river (in the vicinity of the two weir dams) where wading was allowed; thus, this report cannot speak to the effectiveness of the closures in boosting natural reproduction. Additional electrofishing surveys in areas with and without wading that include measures of habitat quality as described in this report would be warranted to test the hypothesis that heavy wading traffic reduces brown trout reproduction.

Relative abundance of age-0 brown trout was variable between both rivers and among sites within each river and additional studies of the factors influencing spatial variability are warranted. The results of this study support the Tennessee Wildlife Resources Agency’s current trout management strategy to create a brown trout fishery wholly supported by natural reproduction in the South Fork of the Holston River. Brown trout stocking in that river should not resume unless future investigations revealed that the fishery would benefit from stocking fish in the lower reaches of the river where age-0 catch rates were low.

Brown trout reproduction was spatially variable in the Watauga River. The upper reach of the tailwater had areas where reproductive success (i.e., age-0 catch rates) was comparable to some areas of the South Fork of the Holston River; whereas, there was no evidence of successful reproduction in the lower reach of the Watauga River. A reduction or discontinuation of brown trout stocking in the upper reaches of the tailwater is justified based on the abundance of wild age-0 brown trout. The factors limiting reproductive success in the lower reaches of the tailwater (e.g., lack of suitable spawning substrate due) are not likely to be remedied. Therefore, stocking should continue in the lower reaches of the Watauga River.

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REFERENCES

Armantrout, N. B. 1998. Glossary of aquatic habitat inventory terminology. American Fisheries Society, Bethesda, Maryland.

Avery, E. L. 1985. Sexual maturity and fecundity of brown trout in central and northern Wisconsin streams. Wisconsin Department of Natural Resources Technical Bulletin 154, Madison

Avery, E. L., and K. Niermeyer. 1999. Timing of spawning and fry emergence of brown trout in a central Wisconsin stream. Transactions of the Wisconsin Academy of Sciences, Arts and Letters 87:63-72.

Bagenal, T. B. 1969. Relationship between egg size and fry survival in brown trout, *Salmo trutta*. Journal of Fish Biology 1:349-353.

Banks, S., and P. W. Bettoli. 2000. Reproductive potential of brown trout in Tennessee Tailwaters. Fisheries Report 00-19, Tennessee Wildlife Resources Agency, Nashville, Tennessee.

Beard, T. D., and R. F. Carline. 1991. Influence of spawning and other stream habitat features on spatial variability of wild brown trout. Transactions of the American Fisheries Society 120:711-722.

Beland, K. F. 1996. The relation between redd counts and Atlantic salmon (Salmo salar) parr populations in the Dennys River, Maine. Canadian Journal of Fisheries and Aquatic Sciences 53:513-519.

Bettoli, P. W., and L. Bohm. 1997. Clinch River trout investigations and creel survey. Fisheries Report 97-39, Tennessee Wildlife Resources Agency, Nashville, Tennessee.

Bettoli, P. W. 1999. Creel survey and population dynamics of salmonids stocked into the Watauga River below Wilbur Dam. Fisheries Report 99-41, Tennessee Wildlife Resources Agency, Nashville, Tennessee.

Bettoli, P. W., S. J. Owens, and M. Nemeth. 1999. Trout habitat, reproduction, survival, and growth in the South Fork of the Holston River. Fisheries Report 99-3, Tennessee Wildlife Resources Agency, Nashville, Tennessee.

Bivens, R. D., B. D. Carter, and C. E. Williams. 1998. Trout Fisheries Report; Region IV 1997. Tennessee Wildlife Resources Agency.

Corning, R. V. 1969. Water fluctuations, a detrimental influence on trout streams. Proceedings of the Annual Conference of the Southeastern Association of Game and Fish Commissioners 23:431-454.

Dechant, T., and J. L. West. 1985. Characteristics and success of wild brown trout in 2 western North Carolina streams. Proceedings of the Annual Conference of Southeastern Association of Fish and Wildlife Agencies 39:86-96.

Devlin, G. J., and P. W. Bettoli. 1999. Creel survey and population dynamics of salmonids stocked into the Caney Fork River below Center Hill Dam. Fisheries Report No. 99-8. Tennessee Wildlife Resources Agency, Nashville, Tennessee.

Elliot, J. M. 1995. Fecundity and egg density in the redd for sea trout. Journal of Fish Biology 47(5):893-901.

Fausch, K. D., Y. Taniguchi, S. Nakano, G. D. Grossman, and C. R. Townsend. 2001. Flood disturbance regimes influence rainbow trout invasions success among five holarctic regions. Ecological Applications 11(5):1438-1455.

Forbes, A., and D. Stewart. 2002. Guide to the preservation of research specimens. Center for Limnology, University of Wisconsin – Madison.

Griffith, J. S., and R. W. Smith. 1993. Use of winter concealment cover by juvenile cutthroat and brown trout in the South Fork of the Snake River, Idaho. North American Journal of Fisheries Management 13:823-830.

Grost, R. T., W. A. Hubert, and T. A. Wesche. 1990. Redd site selection by brown trout in Douglas Creek, Wyoming. Journal of Freshwater Ecology 5:365-371.

Habera, J. W., R. D. Bivens, B. D. Carter, and C. E. Williams. 2005. Region IV trout fisheries report 2004. Fisheries Report 05-02. Tennessee Wildlife Resource Agency.

Hansen, M. J., M. A. Bozek, J. R. Newby, S. P. Newman, and M. D. Staggs. 1998. Factors affecting recruitment of walleyes in Escanaba Lake, Wisconsin, 1958-1996. North American Journal of Fisheries Management 18:764-774.

Harris, D. D., W. A. Hubert, and T. A. Wesche. 1992. Habitat use by young-of-year brown trout and effects on weighted usable area. Rivers 3(2):99-105.

Hayes, J. W. 1995. Spatial and temporal variation in relative density and size of juvenile brown trout in the Kakanue River, North Otago, New Zealand. New Zealand Journal of Marine and Freshwater Research 29:393-407.

Hutt, C. P., and P. W. Bettoli. 2003. Recreational specialization, preferences, and management attitudes of trout anglers utilizing Tennessee tailwaters. Fisheries Report No. 03-01. Tennessee Wildlife Resources Agency, Nashville, Tennessee.

Latterell, J. J., K. D. Fausch, C. Gowan, and S. C. Riley. 1998. Relationship of trout recruitment to snowmelt runoff flows and adult trout abundance in six Colorado mountain streams. Rivers 6(4):240-250.

La Voie IV, W. J., and W. A. Hubert. 1997. Late summer and fall use of stream margins by young-of-year brown trout in a high-elevation stream. Journal of Freshwater Ecology 12(2):291-302.

Lobon-Cervia, J., C. G. Utrilla, P. A. Rincon, and F. Amezcua. 1997. Environmentally induced spatio-temporal variations in the fecundity of brown trout *Salmo trutta* L.: trade-offs between egg size and number. Freshwater Biology 38:277-288.

Mardsen, J. E., and S. R. Robillard. 2004. Decline of yellow perch in southwestern Lake Michigan, 1987-1997. North American Journal of Fisheries Management 24:952-966.

McFadden, J. T., E. L. Cooper, and J. K. Anderson. 1965. Some effects of environment on egg production in brown trout (*Salmo trutta*). Limnology and Oceanography 10(1):88-95.

McMahon, T. E., A. V. Zale, and D. J. Orth. 1996. Aquatic habitat measurements. Pages 83-120 in B. R. Murphy and D. W. Willis, editors. Fisheries Techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Meerbeek, J., and P. W. Bettoli. 2005. Survival, growth, condition, and diet of stocked brown trout in five Tennessee tailwaters. Fisheries Report No. 05-05. Tennessee Wildlife Resources Agency, Nashville, Tennessee.

Meyer, K. A., D. J. Schill, F. S. Elle, and J. A. Lamansky, Jr. 2003. Reproductive demographics and factors that influence length at sexual maturity of Yellowstone cutthroat trout in Idaho. Transactions of the American Fisheries Society 132:183-195.

Mitro, M. G., and A. V. Zale. 2000. Use of distance sampling to estimate rainbow trout redd abundances in the Henry's Fork of the Snake River, Idaho. Intermountain Journal of Sciences 6(3):223-231.

Mobley, M. H., G. E. Hauser, D. F. McGinnis, and R. J. Ruanne. 2000. Diffuser system modeling and design for dissolved oxygen enhancement of reservoirs and releases. Mobley Engineering Final Report. Tennessee Valley Authority.

Montgomery, D. R., J. M. Buffington, N. P. Peterson, D. Schuett-Hames, and T. P. Quinn. 1996. Stream-bed scour, egg burial depths, and influence of salmonid spawning on bed surface mobility and embryo survival. Canadian Journal of Fisheries and Aquatic Sciences 53:1061-1070.

Nate, N. A., M. A. Bozek, M. J. Hansen, and S. W. Hewett. 2000. Variation in walleye abundance with lake size and recruitment source. North American Journal of Fisheries Management 20:119-126.

Nemeth, M. L. 1999. As assessment of the stocked and wild trout fishery in the South Fork of the Holston River below South Holston Dam, Tennessee. Master's Thesis. Tenneessee Technological University, Cookeville, Tennessee.

Orth, D. J., T. J. Newcomb, A. C. Dollof, P. Diplas, D. C. Novinger, C. Krause, M. Anderson, A. Hunter, T. Smith, and Y. Shen. 2001. Influences of fluctuating releases on stream habitats for brown trout in the Smith River below Philpott Dam. Annual Report Contract No. 08220203. Virginia Department of Game and Inland Fisheries, Richmond, Virginia.

Ottoway, E. M., P. A. Carling, A. Clarke, and N. A. Reader. 1981. Observations on the structure of brown trout, *Salmo trutta* Linnaeus, redds. Journal of Fish Biology 19:593-607.

Pender, D. R., and T. J. Kwak. 2002. Factors influencing brown trout reproductive success in Ozark Tailwater Rivers. Transactions of the American Fisheries Society 131:698-717.

Pollard, W. R., G. F. Hartman, C. Groot, and P. Edgell. 1997. Field Identification of Coastal Juvenile Salmonids. Harbour Publishing, Madeira Park, British Columbia, Canada, 32 pp.

Raleigh, R. F., L. D. Zuckerman, and P. C. Nelson. 1986. Habitat suitability index models and instream flow suitability curves: brown trout. U.S. Department of the Interior, Fish and Wildlife Service Biological Report 82 (10.124), Washington, D.C.

Roberts, B. C., and R. G. White. 1992. Effects of angler wading on survival of trout eggs and pre-emergent fry. North American Journal of Fisheries Management 12:450-459.

Rohde, F. C., R. G. Arndt, D. G. Linquist, and J. F. Parnell. 1996. Freshwater Fishes of the Carolinas, Virginia, Maryland, & Delaware. The University of North Carolina Press, Chapel Hill, North Carolina, 222 pp.

Schram, S. T., J. H. Selgeby, C. R. Bronte, B. L. Swanson. 1995. Population recovery and natural recruitment of lake trout at Gull Island Shoal, Lake Superior. Journal of Great Lakes Research 21 (Supplement 1):225-232.

Smith, K. A. 1973. Development and application of spawning velocity and depth criteria for Oregon salmonids. Transactions of the American Fisheries Society 2:312-316.

Strange, R. J. 1996. Field examination of fishes. Pages 433-446 in B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Taube, C. M. 1976. Sexual maturity and fecundity in brown trout of the Platte River, Michigan. Transactions of the American Fisheries Society 4:529-533.

Trippel, E. A. 1993. Relations of fecundity, maturation, and body size of lake trout, implications for management in northwestern Ontario lakes. North American Journal of Fisheries Management 13:64-72.

Whalen, J. K., C. N. Roghair, D. R. Nuckols, J. D. Moran, and C. A. Dollof. 2002. Comparison of stream habitat, macroinvertebrate community, stream sediment, and channel condition data collection methodologies in the Chattooga River watershed, Chattahoochee National Forest, Georgia. U.S. Department of Agriculture, Southern Research Station, Center for Aquatic Technology Transfer. Unpublished file report, 154 pp.

Table 1. Ranges of water temperature and habitat variables for brown trout spawning reported by Raleigh et al. (1986).

	Depth (cm)	Mean velocity (cm/s)	Sediment size (mm)	Water temperature (^{0}C)
Optimum Ranges	24 - 92	21 – 52	6.4 – 76.2	6.1 – 8.9

Table 2. Mean surface sediment size (mm), mean velocity (m/s), mean depth, and ANOVA statistics for four Tennessee Rivers, 2005. Means in columns with different letters were significantly different ($P \leq 0.05$).

River or ANOVA Statistics	Mean surface sediment size (mm)	Mean velocity (cm/s)	Mean depth (cm)
SF Holston	59 ^{b}	26 ^{a}	22 ^{a}
Watauga	90 ^{c}	28 ^{a}	27 ^{a}
Clinch	39 ^{a}	42 ^{a}	20 ^{a}
Caney Fork	31 ^{a}	32 ^{a}	27 ^{a}
F	176.66	0.72	1.86
d.f.	3, 1826	3, 186	3, 186
P	<0.001	0.542	0.138

Table 3. Number of mature and immature brown trout, minimum length at which there is a 50% probability of maturity (ML50), and logistic regression coefficients for the model of maturity versus total length in four Tennessee rivers, 2004-2005. The ML50 for the Caney Fork River was estimated as the midpoint length between the longest immature fish and shortest mature fish.

				Logistic regression statistics		
River	Number mature	Number immature	ML50 (mm)	B_0	B_1	P
SF Holston	34	16	294	-102.22	0.3479	0.8086
Watauga	42	13	256	-66.03	0.2577	0.9431
Clinch	14	11	319	-5.59	0.0175	0.2311
Caney Fork	4	12	360	-	-	-

Table 4. Mean length, mean fecundity, mean gonad weight, mean eggs per gram of gonad weight, and regression coefficients for the $\log_{10}$ fecundity versus $\log_{10}$ length regression models for brown trout in four Tennessee rivers, 2004-2005; standard errors are in parentheses.

						Regression statistics			
River	N	Mean total length (mm)	Mean fecundity	Mean gonad weight (g)	Mean number of eggs/g of gonad weight	a	b	r^2	P
SF Holston	34	355 (7)	1365 (98)	63 (7)	25 (2)	-3.89	2.74	0.62	0.0001
Watauga	43	320 (6)	876 (56)	43 (4)	23 (1)	-4.88	3.10	0.72	0.0001
Clinch	14	375 (25)	2276 (347)	171 (49)	20 (3)	-1.99	2.06	0.90	0.0001
Caney Fork	4	450 (13)	2821 (346)	255 (32)	11 (1)	-7.74	4.20	0.94	0.0291

Table 5. Mean surface sediment size (mm), mean velocity (cm/s), mean depth (cm), number of age-0 brown trout caught per hour of electrofishing, distance (km) downstream from South Holston Dam and ANOVA statistics for the South Fork of the Holston River, Tennessee, 2005.

Site or ANOVA Statistics	Mean surface sediment size (mm)	Mean velocity (cm/s)	Mean depth (cm)	Catch/ Hour	Distance (km)
1	53	25	20	335	6.5
2	41	14	23	302	7.9
3	68	16	18	226	8.8
4	79	10	12	2	14.1
5	59	43	26	37	16.5
6	55	54	22	59	17.4
F	4.78	10.89	3.09	-	-
d.f.	5, 272	5, 24	5, 24	-	-
P	0.003	< 0.001	0.027	-	-

Table 6. Mean surface sediment size (mm), mean velocity (cm/s), mean depth (cm), number of age-0 brown trout caught per hour of electrofishing, distance (km) downstream from Wilbur Dam, and ANOVA statistics for the Watauga River, Tennessee, 2005.

Site or ANOVA Statistics	Mean surface sediment size (mm)	Mean velocity (cm/s)	Mean depth (cm)	Catch/ Hour	Distance (km)
1	64	11	17	56	0.8
2	85	16	15	25	1.9
3	93	12	28	30	3.4
4	102	17	37	20	3.5
5	71	43	24	21	4.7
6	71	11	31	7	7.2
7	69	12	14	90	9.5
8	105	38	20	36	11.1
9	69	86	38	0	12.9
10	133	40	42	0	17.2
11	104	15	24	0	17.7
12	104	30	33	0	20.1
13	82	47	44	0	22.0
14	71	39	35	0	24.1
15	98	49	29	0	26.1
16	62	12	24	10	28.4
F	8.86	7.60	2.59	-	-
d.f.	15, 758	15, 64	15, 64	-	-
P	< 0.001	< 0.001	0.004	-	-

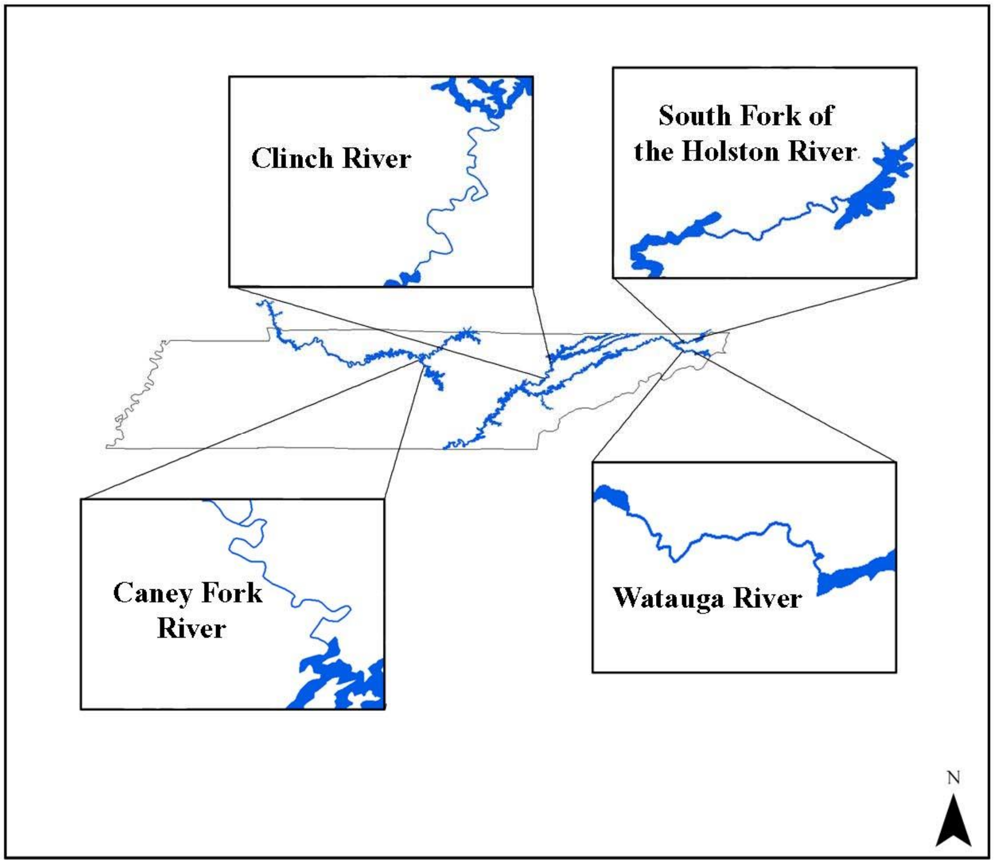

Figure 1. Locations of the four Tennessee rivers surveyed in 2005-2006..

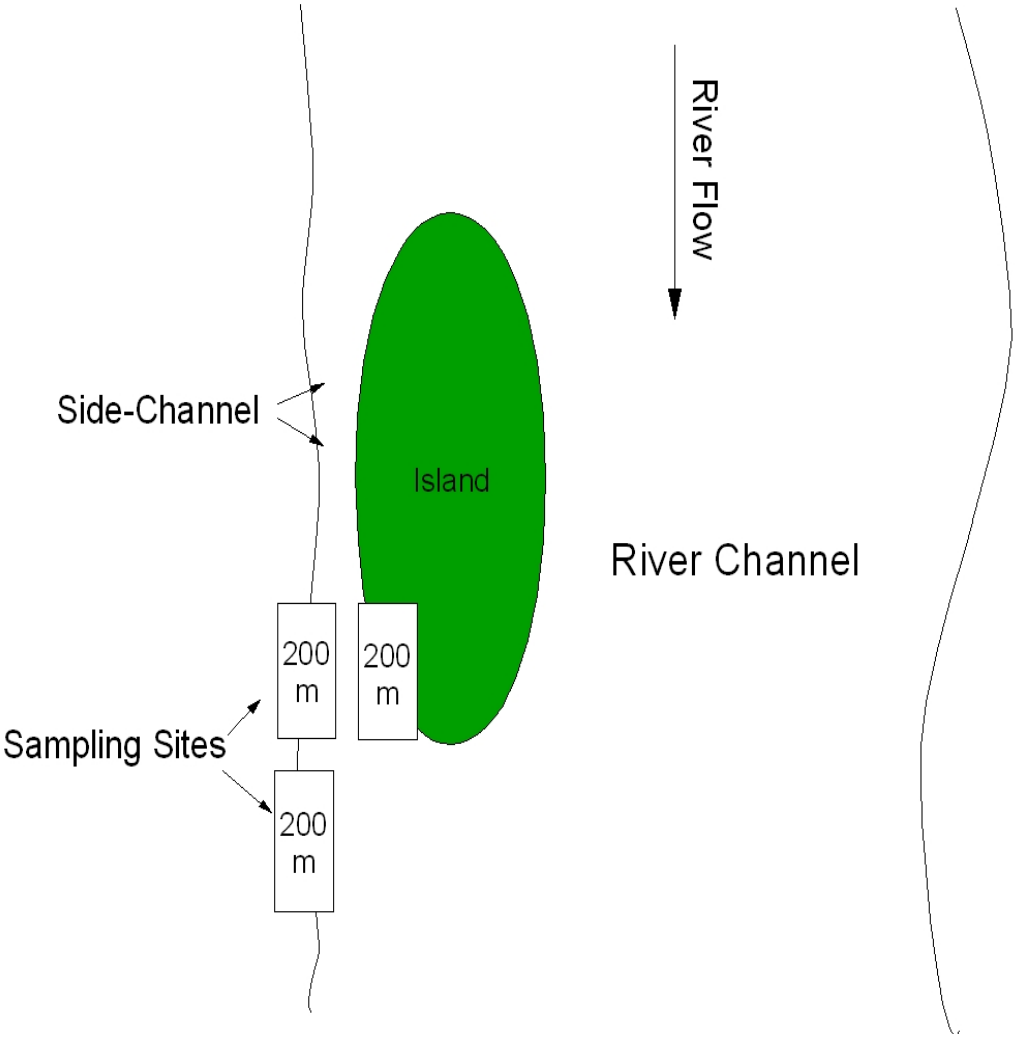

Figure 2. Sampling design for the assessment of brown trout potential spawning areas in Tennessee rivers surveyed in 2005

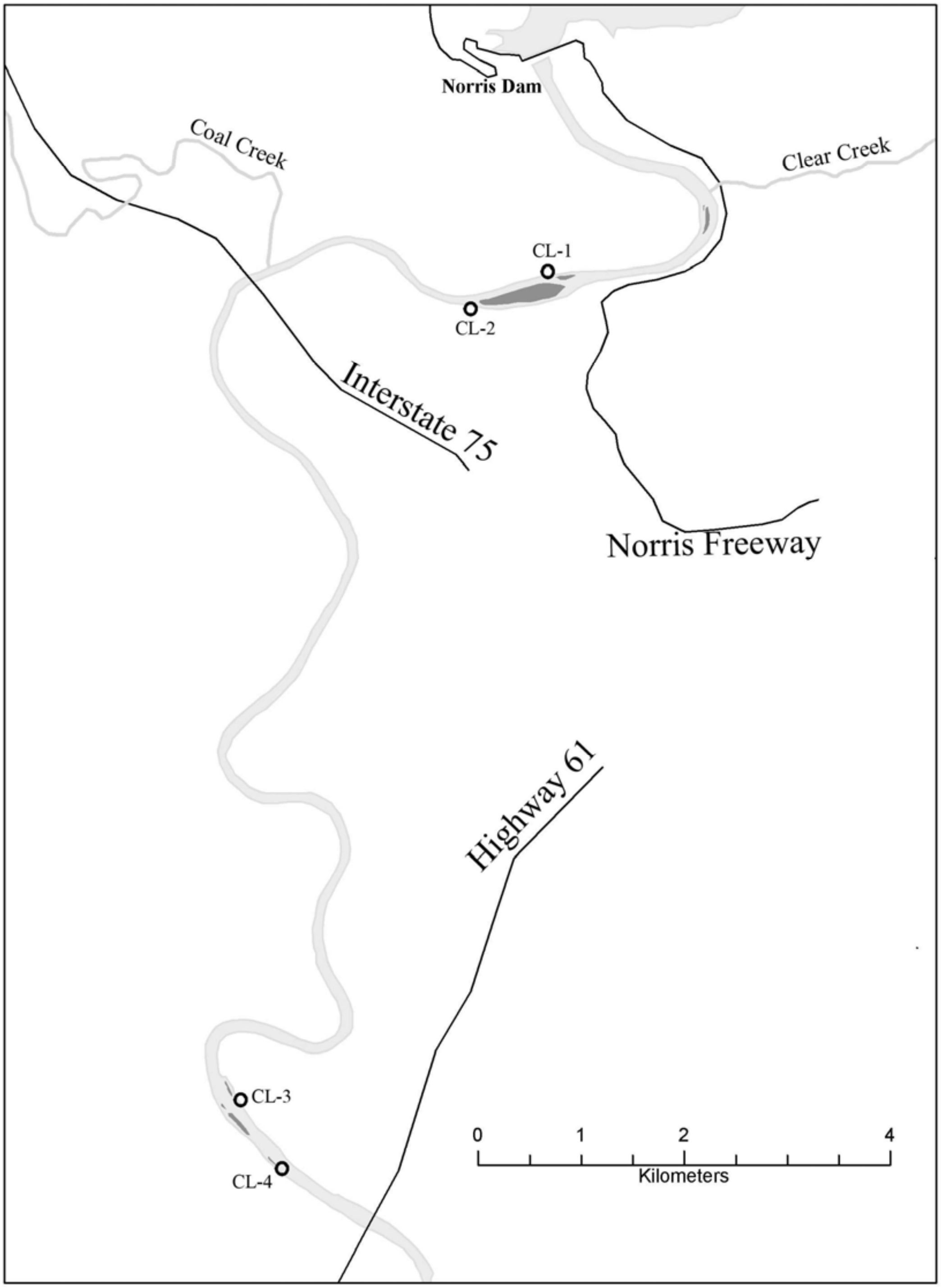

Figure 3. Locations of potential spawning areas surveyed in the Clinch River, June 2005. Age-0 brown trout were not collected at any sites

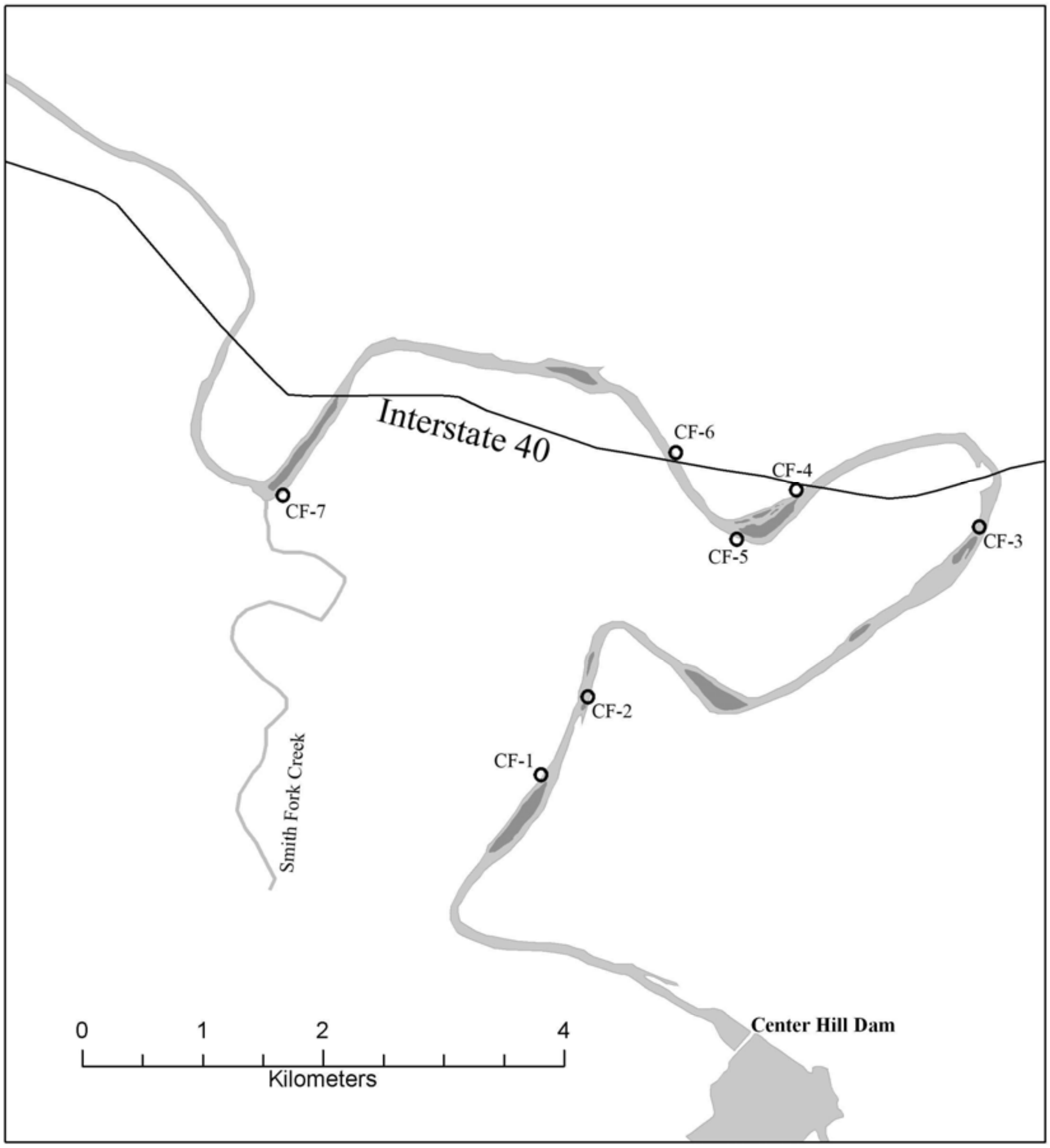

Figure 4. Locations of potential spawning areas surveyed in the Caney Fork River, July 2005. Age-0 brown trout were not collected at any sites.

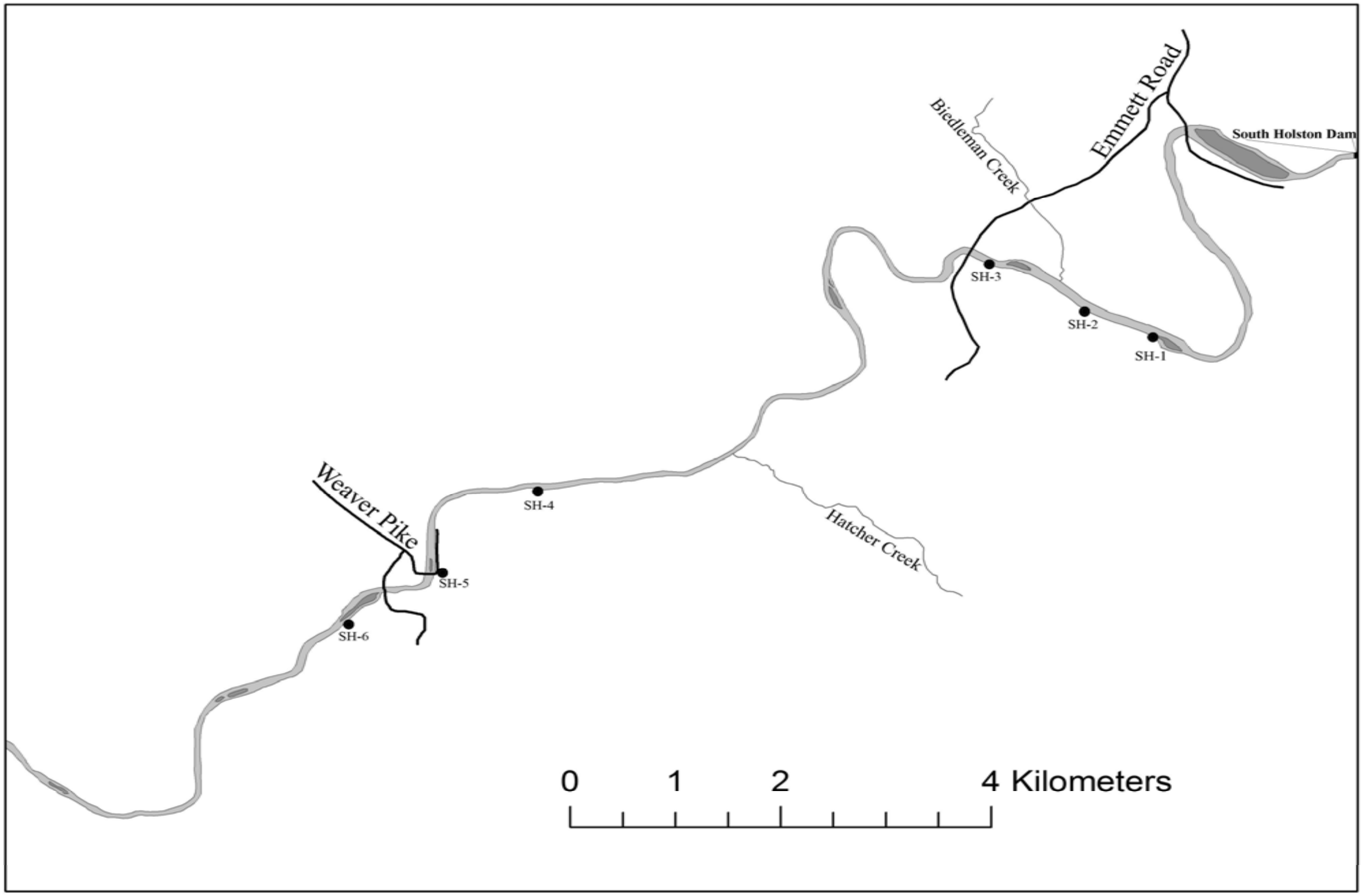

Figure 5. Locations of potential spawning areas surveyed in the South Fork of the Holston River, July 2005. Age-0 brown trout were collected at all sites.

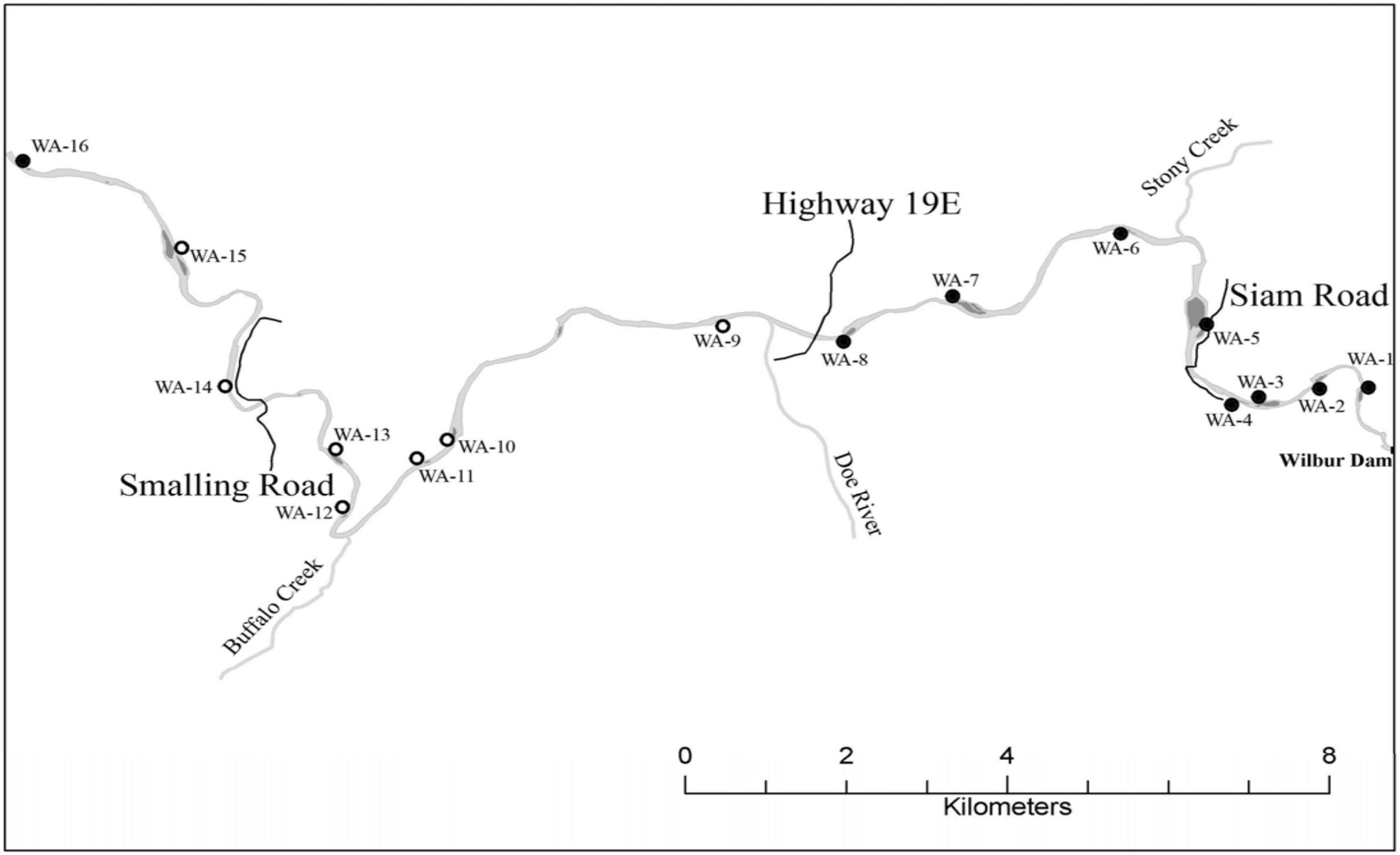

Figure 6. Locations of potential spawning areas surveyed in the Watauga River, August 2005. Age-0 brown trout were collected only at sites with closed circles.

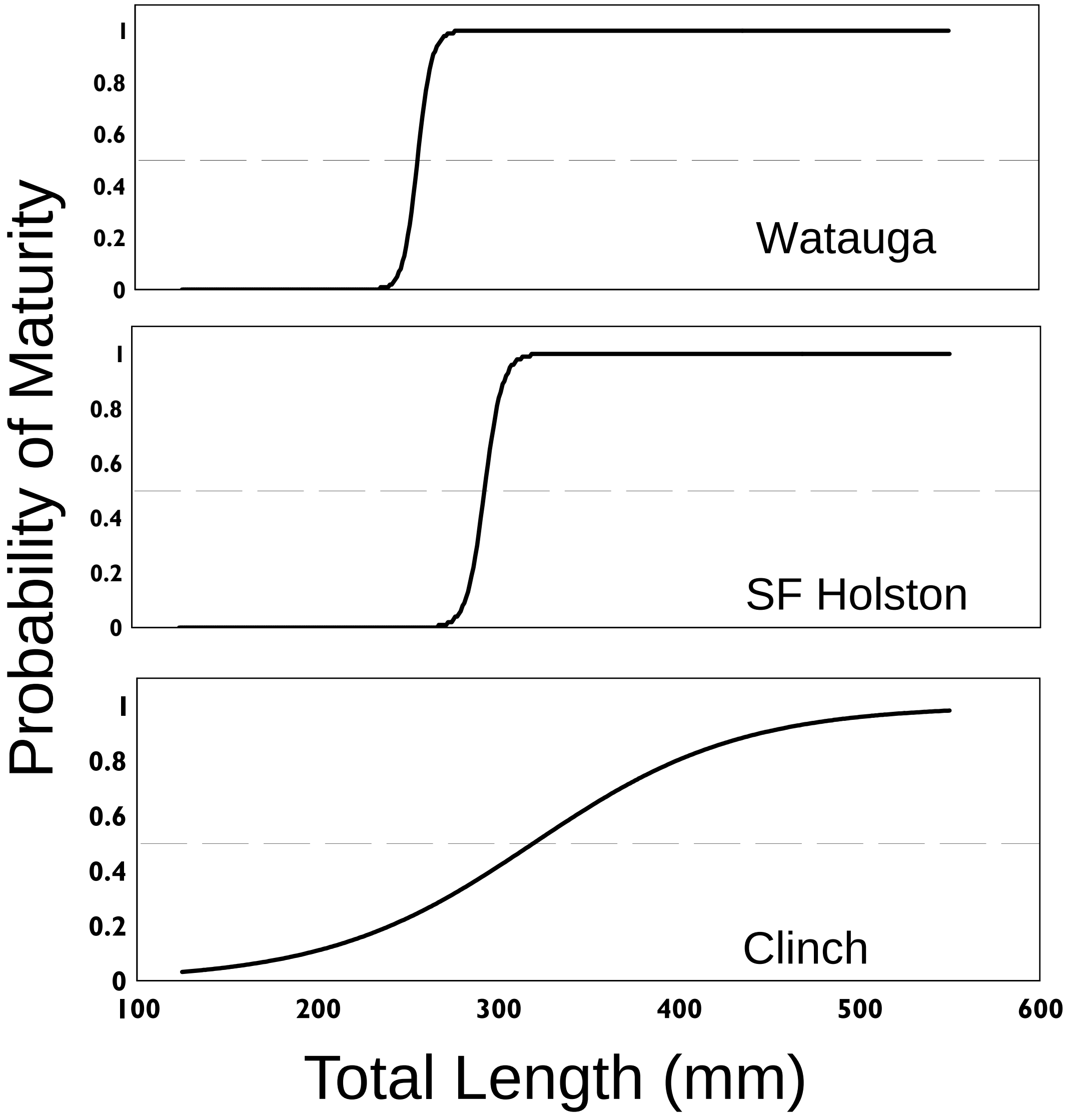

Figure 7. Logistic regression models describing the probability of maturity based on total length (mm) in three Tennessee Rivers, 2004-2005. The dashed line represents 50% probability of maturity. .

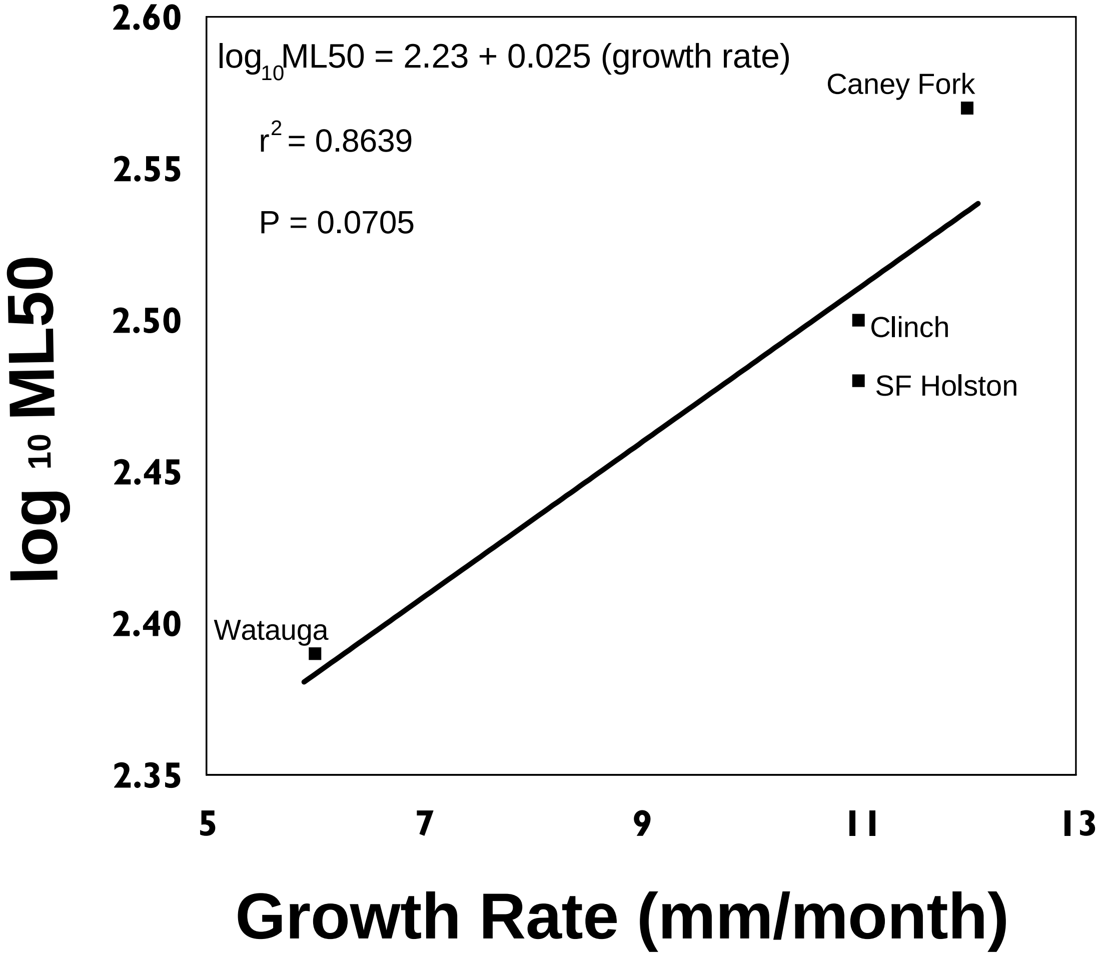

Figure 8. Linear relation between $\log_{10}$ ML50 and growth rates (Meerbeek and Bettoli 2005) for brown trout in four Tennessee rivers, 2004-2005.

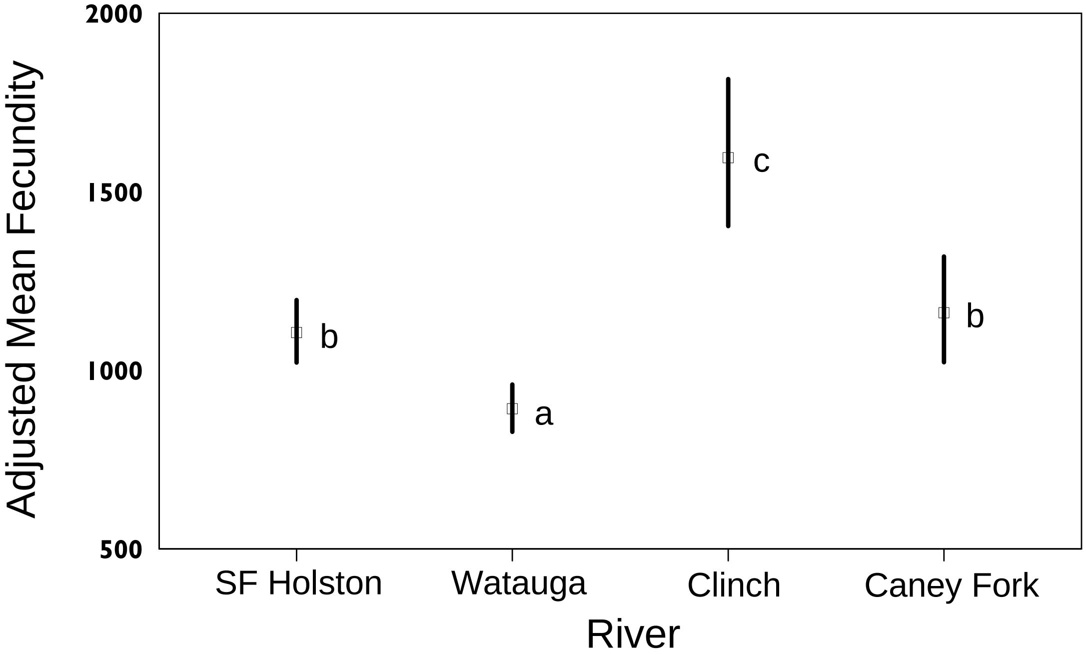

Figure 9. Mean fecundity (adjusted to a TL of 339 mm) and approximate 95% confidence intervals for brown trout in four Tennessee rivers. Means with different letters were significantly different ($P \leq 0.05$).

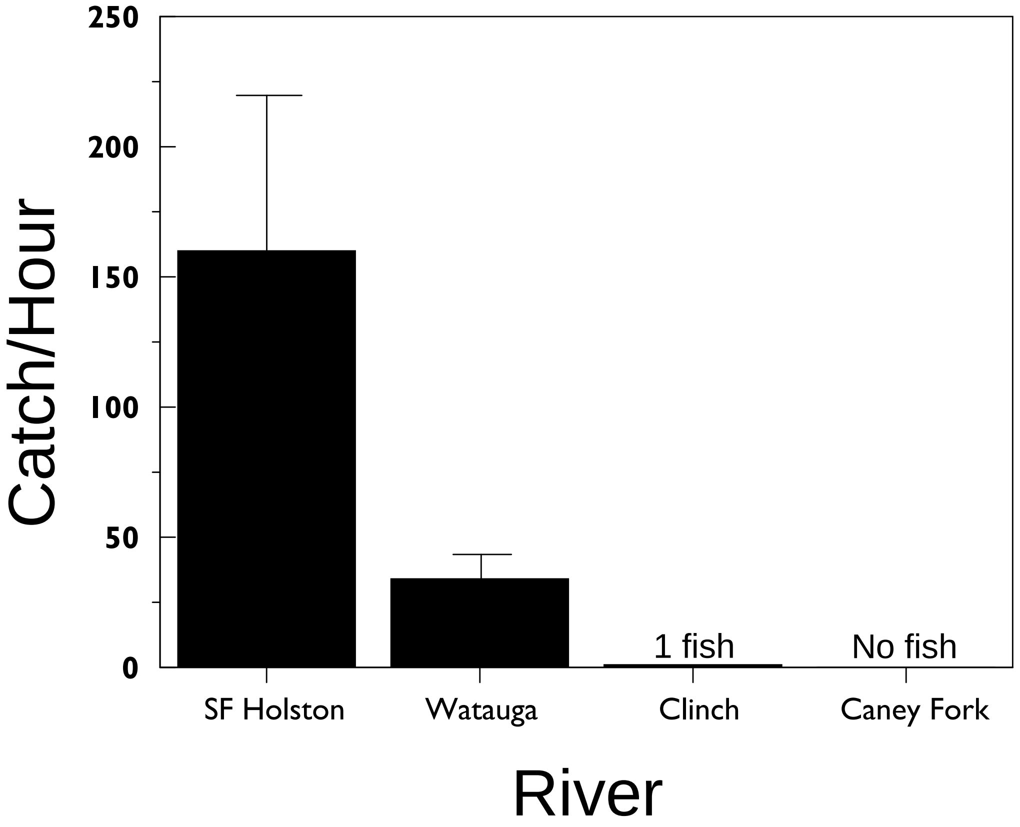

Figure 10. Mean number of age-0 brown trout collected per hour of electrofishing effort at reproductively successful sites (i.e. sites where age-0 brown trout were observed) in four Tennessee rivers, 2005. Vertical bars represent standard errors.

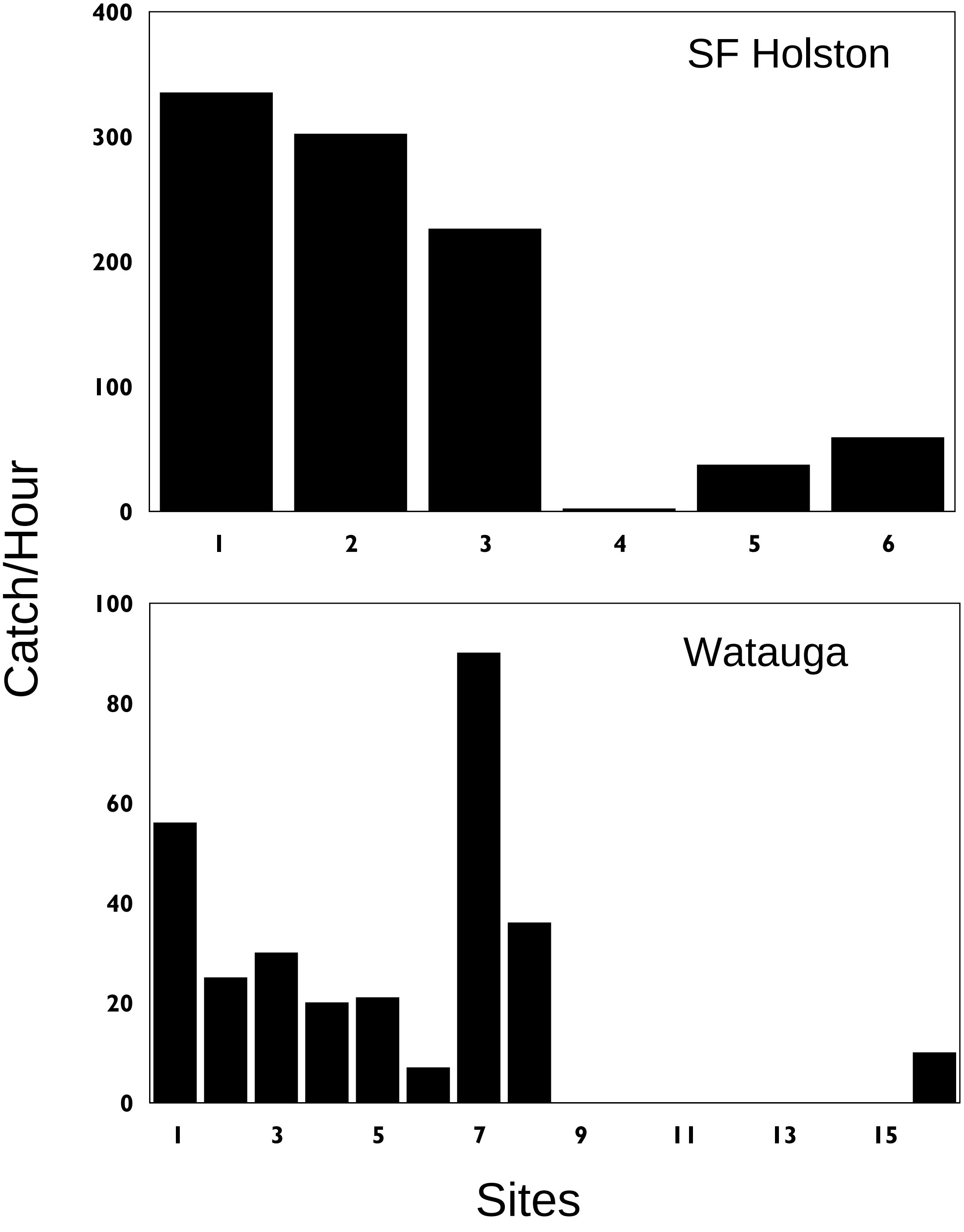

Figure 11. Number of age-0 brown trout collected per hour of electrofishing effort at potential spawning sites in the South Fork of the Holston River and Watauga River, Tennessee, 2005.

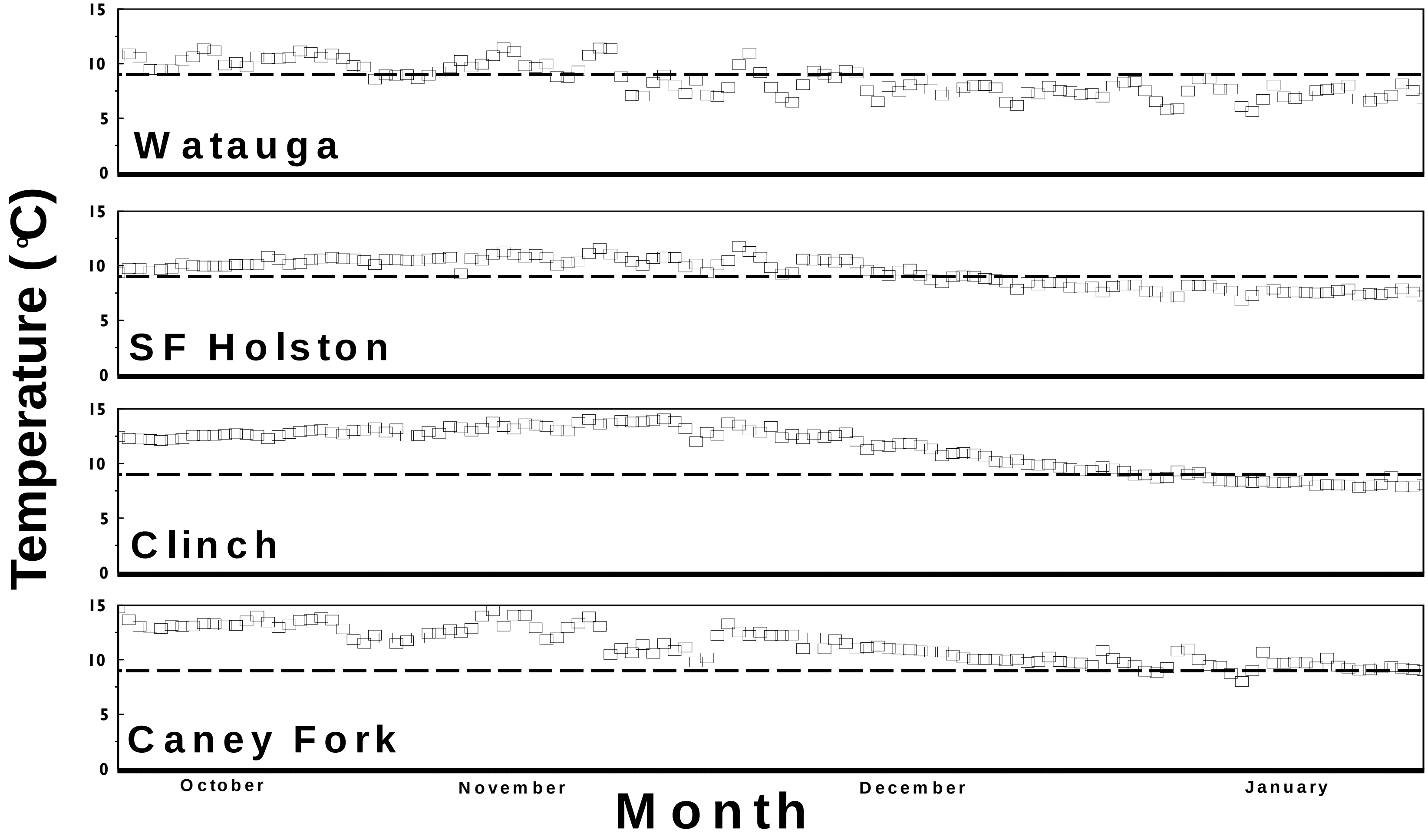

Figure 12. Mean daily temperatures in four Tennessee rivers during the presumed brown trout spawning season (October 2004 – December 2004) and incubation period (December 2004 – January 2005). The dashed line represents the warmest temperature at which brown trout begin to spawn (8.9 °C) according to Raleigh et al. (1986) and Rohde et al. (1996).

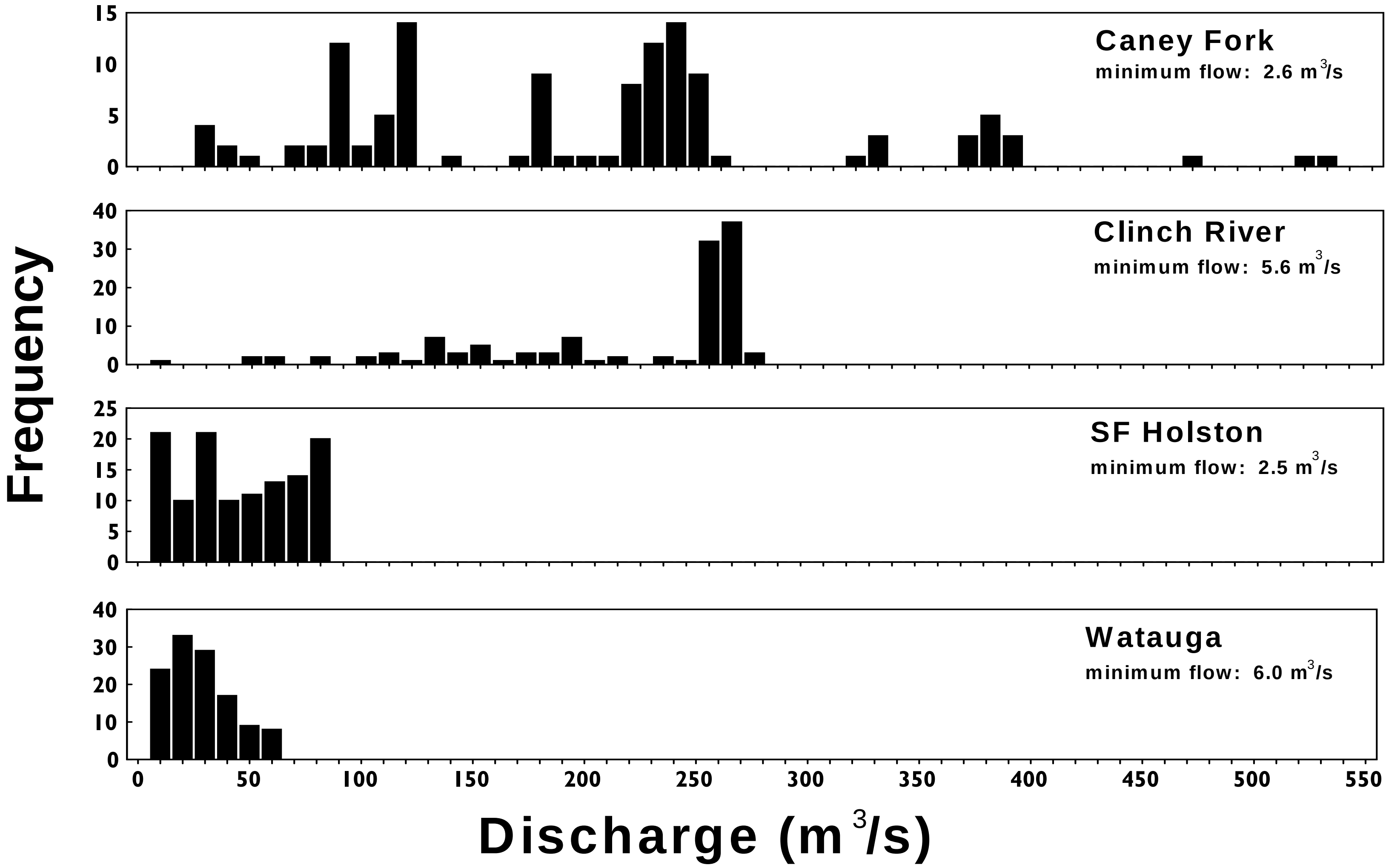

Figure 13. Frequency of average daily discharges from each of four Tennessee rivers between 1 October 2004 and 31 January 2005.