Fisheries Report 08-03

THE FATE OF BROOK TROUT STOCKED IN THE WATAUGA RIVER BELOW WILBUR DAM




A Final Report Submitted To

Tennessee Wildlife Resources Agency
Nashville, Tennessee

By

John Damer, M.S., and Phillip W. Bettoli, Ph.D.

Tennessee Cooperative Fishery Research Unit
Tennessee Technological University
Cookeville, Tennessee

February 2008

THE FATE OF BROOK TROUT STOCKED IN THE WATAUGA RIVER BELOW WILBUR DAM

A Final Report Submitted To

Tennessee Wildlife Resources Agency
Nashville, Tennessee

By

John Damer, M.S., and Phillip W. Bettoli, Ph.D.
Tennessee Cooperative Fishery Research Unit
Tennessee Technological University
Cookeville, Tennessee

February 2008

Development of this report was financed in part by funds from Federal Aid in Fish and Wildlife Restoration (Public Law 91-503) as documented in Federal Aid Project FW- 6 (TWRA Project 7307).

Executive Summary

1. Brook trout *Salvelinus fontinalis* have been stocked below Wilbur Dam on the Watauga River since 2001, but were rarely caught by anglers and only one brook trout has ever been collected in annual monitoring samples. This study was designed to investigate the poor performance of brook trout stocked in this system.

2. Cohorts of brook trout were stocked in July and October 2006 and April 2007 and their survival, growth, and diet were studied. Brown trout *Salmo trutta* and rainbow trout *Onchorynchus mykiss* were stocked concomitantly with the April 2007 brook trout cohort to compare fates among species. Trout were sampled with barge- and boat-mounted electrofishing gear at approximately monthly intervals post-stocking.

3. Interval survival over 100 d was low (1.8 – 4.4%) for the first two cohorts of brook trout. Survival over 100-d was low (5.4%) for brown trout and rainbow trout stocked in April 2007, but their survival was more than an order of magnitude higher than the survival of brook trout (0.1%) stocked at the same time.

4. Brook trout stocked in July and October 2006 grew slowly in length (4-15 mm per month) and weight (0-7 g per month). Ration weights for brook trout were low ($\leq$ 0.045 g) throughout most of the study.

5. Stomach contents of large (> 250 mm total length) brown trout were examined after brook trout were stocked in October 2006 and April 2007. Brook trout losses to brown trout predation were substantial (up to 20% of each cohort) within the first 1-2 d after each cohort was stocked.

6. Two tributaries of the Watauga River were sampled with backpack electrofishing gear in May 2007 to document emigration from the. river up into the tributaries. One hundred and fifty-three brook trout were collected up to 4.9 km upstream from the Watauga River. Native southern Appalachian brook trout reside in the headwaters of both tributaries and the northern strain of brook trout stocked in the Watauga River may threaten the genetic integrity of those native brook trout populations.

7. Anglers were generally content with the trout fishing at the Watauga River; only 13% reported catching a brook trout and only 23% were aware of the brook trout stocking program.

INTRODUCTION

In 2001, the Tennessee Wildlife Resources Agency (TWRA) began stocking brook trout *Salvelinus fontinalis* into the Watauga River below Wilbur Dam (Habera et al. 2003). The purpose of these stockings was to diversify this tailwater fishery by providing anglers the chance of catching brook trout along with brown trout *Salmo trutta* and rainbow trout *Onchorynchus mykiss*. Brook trout are native to coldwater rivers and streams in the Appalachian Mountains in eastern Tennessee (Larson et al. 1995), but they are generally small and individuals longer than 229 mm total length (TL) are rare (Habera and Moore 2005). Maximum size of native brook trout is limited by low productivity and the amount of habitat that small mountain streams can provide (Neves and Pardue 1983; Whitworth and Strange 1983). Stocking brook trout into a large tailwater provides the possibility of producing larger brook trout.

Brook trout were initially stocked into the Watauga River as fingerlings (~25 mm TL), but after several years of negligible returns, the size at stocking was increased to approximately 125 mm TL to improve survival. Despite the increase in size at stocking, angler catch rates have remained low (Bettoli 2007). Also, TWRA has collected only one brook trout in annual late winter electrofishing surveys of the Watauga River (Jim Habera, TWRA, personal communication); whereas, catch rates for the two other trout species in the Watauga River remain high.

Reasons for poor performance of brook trout in the Watauga River are not known. Although brook trout have been stocked widely throughout North America, there is little information in the published literature about stocking in large regulated rivers such as the Watauga River below Wilbur Dam. The Arkansas Game and Fish Commission (AGFC) has had varying success stocking advanced fingerling (152 mm TL) brook trout in several Arkansas tailwaters, although brook trout longer than 356 mm TL are not uncommon in electrofishing samples (Williams et al. 2005). The North Carolina Wildlife Resources Commission (NCWRC) annually stocks a short (< 1.6 km) reach of the Linville River (a tailwater) with about 4,000 catchable (> 254 mm TL) brook trout. Most of these fish are quickly harvested due to their high vulnerability to anglers in relation to brown trout and rainbow trout (Doug Besler, NCWRC, personal communication). Population dynamics of brook trout in the Watauga River are not affected by high rates of fishing mortality because they have not persisted long enough to grow to a catchable size (Bettoli 2003).

Stocked brook trout and resident brown trout and rainbow trout compete for habitat and food when these resources are limited. In a study of a small Michigan stream, brown trout out-competed brook trout for advantageous resting positions (Fausch and White 1981). Ersbak and Haase (1983) attributed low survival of brook trout stocked in the presence of wild brown trout to their relative inability to forage adequately. Rainbow trout grew larger than brook trout when the two species shared the same raceway; whereas, brook trout grew larger than rainbow trout when the two species were reared separately (Isely and Kempton 2000). These studies suggest that brown trout and rainbow trout out-compete brook trout when resources are limited. Bettoli (1999) indicated that productivity of the Watauga River is low and high stocking rates may contribute to slow growth. Thus, competition between brook trout and the two other trout species may be limiting brook trout growth and survival.

Brook trout do not necessarily remain in the same river reach where they are stocked (Trembley 1943; Alexander et al. 1990). Fish often move upstream or downstream, depending on the strain stocked (Van Offelen et al. 1993). Bachman (1984) found that stocked brown trout moved much more than resident wild brown trout. Excessive movements of newly stocked trout are energetically costly compared to the normal, energetically conservative behavior of a drift-feeding fish. Also, excessive activity by hatchery fish might increase exposure to potential piscine predators, which can abound in large regulated rivers (Bettinger and Bettoli 2000). Brown trout are suspected predators of brook trout (Needham and Sumner 1941) and are abundant in the Watauga River, with some individuals exceeding 750 mm TL (Habera et al. 2007).

The objectives of this study were to: (1) estimate the number and biomass of each species of trout in the Watauga River at the beginning of the 2006 stocking season; (2) compare the survival, growth, and diet of three cohorts of stocked brook trout; (3) compare the survival, growth, and diet of stocked brook trout, brown trout, and rainbow trout; (4) assess predation on stocked brook trout by large resident brown trout; (5) monitor dispersal of stocked brook trout into tributaries; and (6) describe angler perceptions about brook trout in the Watauga River.

STUDY AREA

Wilbur Dam was completed in 1912 and was originally equipped with only two hydroelectric turbines. A third turbine was added in 1926, and a fourth was installed in 1945 after the Tennessee Valley Authority (TVA) purchased the facility, bringing total generating capacity to 10,700 kW at a flow of 75.8 m^3/s. The dam, located at Watauga River km (WRkm) 55 in Carter County, measures 23.5 m in height and stretches 114 m across the river valley. Due to its small storage capacity and proximity to Watauga Dam, releases from Wilbur Dam closely mimic those of Watauga Dam, which is located only 4 km upstream (TVA 2007).

When the Watauga River exits Wilbur Dam, it is well-oxygenated due to hub baffles and vents that were installed on the turbines of Watauga Dam in the 1990s to raise concentrations of dissolved oxygen (DO). In subsequent years, DO concentrations have generally remained above the TVA's target of 6 ppm; even when that target is not reached, concentrations rarely fall below 4 ppm. Prior to these modifications, DO concentrations in the river would plummet in late summer when the hypolimnetic water drawn from Watauga Lake was nearly anoxic.

From Wilbur Dam, the Watauga River flows 26 km through riffles, deep pools, and long shoals before it empties into Boone Reservoir. A habitat survey of the tailwater in 1999 revealed a riffle:run:pool ratio of 2.0 : 1.6 : 1.0; such diverse habitat provides many choices for newly-stocked trout (Bettoli 1999).

The Watauga River has two main tributaries, the Doe River and Stony Creek. The Doe River begins at a high elevation on Iron Mountain in Carter County. It then passes through Roan Mountain State Park and the town of Elizabethton before emptying into the Watauga River 12 km below Wilbur Dam. Stony Creek flows from Cross Mountain near the border of Johnson and Carter Counties and enters the Watauga River 6 km below Wilbur Dam. Water temperatures in both streams stay cool enough year-round in their headwaters and upper reaches to support healthy populations of wild rainbow trout and brown trout. More notably, both watersheds harbor populations of southern Appalachian brook trout (Habera et al. 1999, 2007).

The Watauga River had poor water quality through the late 1980s due to industrial pollution. Only pollution-resistant fish and macroinvertebrates inhabited the river between 1970 and 1982 (Mullican and Leming 1970; McKinney et al. 1987). When point sources of industrial pollution were removed, the food base recovered and TWRA implemented a trout-stocking program. From 1990 to 1999, stocking rates for all trout species combined averaged 89,000 fish per year. A massive fish kill occurred in 2000 after chemicals entered the river as result of a large industrial fire at the North American Corporation facility at WRkm 24. Nearly all fish in the Watauga River downstream of Elizabethton were killed. Later that same year, TWRA increased stocking rates (at one point up to an average of 287,000 trout per year) in order to help the fishery recover. Those high stocking rates were successful; electrofishing catch rates (CPUE) in the affected reach quickly returned to pre-fish kill levels by 2002 (Habera et al. 2005).

METHODS

Population Estimate

Approximately 13,470 snout-tagged brown trout (mean TL: 188 mm) were stocked into the Watauga River in April 2006 for the purpose of estimating the number and biomass of resident trout in the river using a change-in-ratio (CIR) experiment. These trout were tagged at a hatchery using uncoded wire microtags implanted using Northwest Marine Technologies (NMT) Mark IV tag injectors. Trout were anesthetized using tricaine methanesulfonate (MS-222) to reduce handling stress and to facilitate faster marking. All marked trout were held at the hatchery for at least 21 d prior to stocking following US Food and Drug Administration guidelines; tag retention was estimated at the end of the 21-day interval by checking a subsample of fish using an NMT microtag detection wand.

Brown trout were stocked 24-26 April 2006 at 14 locations throughout the tailwater to facilitate mixing of marked individuals with resident trout (Figure 1). Twenty-nine electrofishing transects were each sampled along the shoreline for 10 min during daylight hours 27-28 April 2006 (Figure 1). Sampling was conducted with flows at or exceeding 57 m^3/sec (2000 cfs) using a 4.9 m Alumacraft tunnel-hull electrofishing boat equipped with a 60/40 horsepower jet-drive outboard motor. Current was supplied to five boom-mounted electrodes via a Smith-Root model GPP 2.5 electrofishing unit powered by a Honda 4,500W generator. All trout were netted and placed into a livewell. At the end of each transect, trout were identified to species, checked for microtags using a detection wand, weighed (g), measured for total length (mm), and released back into the river.

The ratio of tagged to untagged trout in the sample provided estimates of the population size of each trout species following the methods of Paulik and Robson (1969) using the formula:

$$N_1 = \frac{R_x - P_2 R}{P_2 - P_1}$$

where N_1 is the total population size at time 1 (before stocking), R_x is the net change in the number of X-type animals (snout-tagged brown trout), P_2 is the proportion of X-type animals in the sample at time 2 (after stocking), R is the net change in the total population (same as R_x), and P_1 is the proportion of X-type animals in the sample at time 1. The variance of N_1 was calculated using the formula (Paulik and Robson 1969):

$$V(N_1) = (P_2 - P_1)^{-2}\left[N_1^{\,2}V(P_1) + (N_1 + R)^2 V(P_2) + (1 - P_2)^2 V(R_x) + P_2^{\,2} V(R_y)\right]$$

where V is the variance, and R_y is the net change in the number of Y-type animals (untagged brook trout, brown trout, and rainbow trout). Because of the size selectivity of the sampling gear (small fish are poorly recruited to the gear type), population estimates were limited to those fish greater than 150 mm TL. Estimates of standing crop (kg/ha) were calculated using the mean weights of fish in the sample and the total area of the tailwater (135 ha) at baseflow (Bettoli 1999).

Survival and Growth

Three cohorts of brook trout were stocked into the Watauga River between July 2006 and April 2007 for the purpose of comparing survival and growth rates among different sizes of stocked brook trout (Table 1). The first cohort (n = 35,913) was stocked 6 July 2006 at an estimated average length of 106 mm TL. In order to reduce the high labor costs inherent in marking large numbers of fish, this batch received no mark. This “no mark” approach was possible because preliminary sampling indicated that there were no brook trout present from stocking efforts in previous years. The remaining two cohorts were batch marked so they could be distinguished in the field. One cohort (n = 31,544) was stocked 11-12 October 2006 at a mean total length of 163 mm. These fish received uncoded wire microtags implanted in the musculature just below the dorsal fin. Tagging procedures and holding period were the same as previously mentioned for brown trout. A third cohort (n = 4,106) was stocked 9-10 April 2007 at an average size of 182 mm TL. Individuals in this group were marked by removing their adipose fins. Clipped adipose fins can regenerate if not removed completely (Thompson and Blankenship 1997); therefore, a subsample from each cohort of adipose fin-clipped trout was checked for partial clips.

Brown trout and rainbow trout of similar size and numbers were stocked alongside the brook trout cohort stocked 9-10 April 2007 to compare survival and growth rates among the three trout species (Table 1). Brown trout (n = 4,191) and rainbow trout (n = 4,870) averaged 166 and 181 mm TL, respectively, and were adipose fin-clipped and stocked in the same locations as the April 2007 cohort of brook trout.

Trout sampling was conducted using a tow-barge electrofishing unit at approximately monthly intervals from 12 July 2006 to 24 January 2007. These samples targeted the brook trout stocked in July and October, which were relatively small in size and would have been poorly recruited to traditional boat-mounted electrofishing gear. The tow-barge unit consisted of a Smith-Root model GPP 2.5 electrofishing unit, a Honda 4,500W generator, and two hand-held anodes. The electrofishing crew consisted of two netters and two people working the probes (one of whom would also pull the barge unit). Tow-barge samples (Figure 2) were made moving upstream along the shoreline at minimum flow (< 8.5 m^3/sec) for 10 min each, and trout were netted and placed in a livewell on the barge. Recaptures were identified to species, weighed (g), measured for total length (mm), and returned to the river.

Samples targeting the April 2007 cohorts of brook, brown, and rainbow trout were collected using the same boat-mounted electrofishing gear that was used to generate the April 2006 population estimate. Fish stocked in April 2007 were larger than brook trout stocked in 2006; thus, poor recruitment to the gear was not considered problematic. Trout captured during each 10-minute sample were identified to species, weighed, measured for total length, and returned to the river. Nine sites were sampled on each boat-sampling date with the exception of 12 April 2007 when mechanical difficulties prevented further sampling after the first site. On subsequent sampling dates, Site 1 was omitted (Figure 3) due to navigational hazards.

Catch per unit effort data (CPUE) from each sampling event was used to generate estimates of survival of stocked trout over 100-day intervals. CPUE was defined as the number of trout caught per 10 min of electrofishing effort (pedal time), and was calculated for each sampling date and for each cohort sampled. Values of 0.1 were added to all CPUE estimates whenever zeros were present and catch curve regression analyses were then performed on $\log_e$-transformed CPUE data. CPUE data were excluded if less than seven sites were sampled on any particular date. Catch curves included data from each sampling event until two consecutive sampling events yielded catches of zero, and only data collected prior to those zero-catch sampling events were included in the analysis. The slope of each regression line was the instantaneous daily mortality rate (*Z*), which was then multiplied by 100 and converted to a 100-day interval survival rate using the formula:

$$S = e^{-Z(100)}$$

Instantaneous mortality rates (i.e., slopes) among cohorts were compared using an F-test. Low sample sizes prohibited the use of regression analysis and catch curves to estimate mortality of the cohorts of brook trout, brown trout, and rainbow trout stocked in April 2007. Therefore, equivalent instantaneous daily mortality rates were calculated as:

$$Z = (\log_e N_t - \log_e N_{t+1}) / \Delta t$$

where N_t is the CPUE in the first sample, N_{t+1} is the CPUE in the second sample, and Δt is the interval in days (Miranda and Bettoli 2007).

Growth rates in terms of length and weight were estimated by plotting lengths and weights against days post-stocking. The slopes of regression lines fitted to these data represented daily growth rates. Growth rates for each cohort and species of trout were compared using F-tests.

Diet

Over the course of the study, at least 10 brook trout (when numbers allowed) from each sampling event were sacrificed for diet analysis. Up to 10 stocked brown trout and rainbow trout were also sacrificed during the April 2007 samples. Trout were euthanized with MS-222 in order to prevent regurgitation of stomach contents. Fish smaller than ~150 mm TL were placed whole into a 10% formalin solution; only the stomachs of larger fish were put into the same solution. In the laboratory, stomach contents were wet-weighed (mg), placed into a Ward counting wheel, identified taxonomically to order, and counted. Contents were then divided based on whether an individual item was digestible or non-digestible (e.g., rocks, woody stems) and placed into separate pre-weighed metal trays. Trays and their contents were dried at 65˚ C for 24 h and weighed again to obtain dry weight. Relative abundance (percent by number) and frequency of occurrence of prey taxa were calculated to allow comparisons between cohorts and species (Meerbeek and Bettoli 2005). A χ^2 test compared proportions of empty stomachs among the three trout species. A two-way ANOVA was used to test for differences in mean ration weight among species and between sampling dates. Diet overlap indexes were calculated to compare the diet of brook trout to brown trout and rainbow trout using the formula (Schoener 1971):

$$C_{xy} = 1 - 0.5\left(\sum \left| p_{xi} - p_{yi} \right|\right)$$

where C_{xy} is the index value, p_{xi} is the proportion of taxa *i* used by species *x*, and p_{yi} is the proportion of taxa *i* used by species *y*. Values of 0.60 and greater indicate a significant overlap in diet between two species (Zaret and Rand 1971; Mathur 1977; Wallace 1981).

Predation

On 13 October 2006 and 26 April 2007, large (> 250 mm TL) brown trout were collected to determine the extent to which brown trout piscivory contributed to mortality of stocked brook trout. Boat-mounted electrofishing equipment was used to collect brown trout and these fish were given overdoses of MS-222 and immediately placed on ice. Non-lethal stomach content removal methods, such as glass tubing and gastric lavage, are ineffective for removing large prey items (fish) from the digestive tract of trout (Meehan and Miller 1978; Bohm 1997). Trout were returned to the laboratory and their stomachs were removed within 24 h. The contents of brown trout stomachs were wet weighed (g) and checked for the presence of fish. In most cases, individual prey fish could be identified to species using dichotomous keys (Etnier and Starnes 2001), weighed (g), and measured for total length (mm).

The extent of predation by brown trout on stocked brook trout was estimated by the equation:

$$B = N \times \bar{x}$$

where B is the total number of brook trout in brown trout stomachs at the time of sampling, N is the population estimate of brown trout longer than the size of the smallest brown trout that ate brook trout in the sample (calculated using the CIR formula), and $\bar{x}$ is the mean number of brook trout present in the stomachs of those brown trout.

Dispersal

In a preliminary, 15-min electrofishing sample of Stony Creek on 27 April 2007, 42 brook trout were collected. Fifteen of those brook trout had been adipose fin-clipped. Only five clipped brook trout were collected in the nine samples taken on the Watauga River just the day before, suggesting that a relatively large number of brook trout stocked in April 2007 might have entered the tributaries. In contrast, only one clipped brown trout and no rainbow trout were collected during this preliminary sample. Additional electrofishing samples were subsequently collected on Stony Creek and the Doe River on 14-17 May 2007. Sample sites began near the mouth of each tributary and continued upstream at intervals of approximately 1 km, depending on site access (Figure 4). Trout were collected using pulsed DC current supplied by a Smith Root LR-24 backpack unit. Current was applied for 15 min per site while two netters collected all trout. Trout were identified to species, checked for marks, measured (TL), and released. Sampling continued at upstream sites until no brook trout were collected.

Angler Perceptions

A roving creel survey sponsored by TWRA was conducted on the Watauga River in 2006. This survey followed methods used in previous surveys (Bettoli 1999; Bettoli 2003). In order to collect information on angler attitudes toward the TWRA's brook trout stocking program on the Watauga, the following questions were asked of all anglers interviewed by the creel clerk:

- *Have you ever caught a brook trout on the Watauga River?*
- *Are you aware that the TWRA stocks brook trout in the Watauga River?*
- *How confident are you in your ability to identify a brook trout from a brown or rainbow trout (Not Confident, Somewhat Confident, or Very Confident)?*
- *On a scale of 1 to 5 (poor → excellent), how would you rate TWRA's management of this fishery?*

In order to keep frequent anglers from biasing results, anglers previously interviewed during the survey were not asked to respond to these questions again.

RESULTS

Population Estimate

The April 2006 electrofishing census sample yielded 595 trout. Forty-six trout measured less than 150 mm TL (i.e., considered not fully recruited to the gear) and were removed from the dataset. The remaining 549 trout consisted of 392 brown trout, 156 rainbow trout, and one lake trout (*Salvelinus namaycush*); no brook trout were collected. Eighty-six of the brown trout were recaptures (i.e., snout tagged) and at least one trout was collected at each of the 29 sites sampled. The single lake trout (an emigrant from Watauga Reservoir) observation was removed from the dataset.

The population estimate of trout greater than 150 mm TL in the Watauga River below Wilbur Dam was 72,362 fish (95% CI = 55,366 - 89,359) (Table 2), which equates to 2,783 trout (> 150 mm TL) per river km. Brown trout represented nearly two thirds of the trout community (47,928; 95% CI = 36,229 – 59,627) and rainbow trout made up the remaining third (24,434; 95% CI = 17,871 – 30,997). Microtagged brown trout stocked in previous years accounted for only 10% of all brown trout (5,012; 95% CI = 2,936 – 7,088), indicating that recruitment of wild fish to the population was high. On average, brown trout weighed 275 g (SE = 14), which was more than the average weight of rainbow trout (219 g; SE = 11).

Survival and Growth

The catches of stocked brook trout in barge electrofishing samples were initially high but declined precipitously in subsequent samples (Table 3). Only 4.4% of brook trout stocked 6 July 2006 persisted in the tailwater to 100 d post-stocking (Figure 5); thus, only 1,580 fish (of 35,913 stocked) would have remained on 14 October 2006 (100 d post-stocking). The survival rate of the October 2006 cohort of brook trout was slightly lower (1.8%), but did not differ significantly from that of the July cohort ($F = 0.17$; df = 1, 7; $P = 0.6891$).

The 100-day interval survival rate for the larger brook trout stocked in April 2007 was essentially nil (0.1%: Table 4). Survival of brown trout and rainbow trout stocked in April 2007 was also relatively low (5.4%), but substantially exceeded that for brook trout.

Brook trout stocked in July 2006 grew slowly in terms of length (4.0 mm/month; $P = 0.0001$) and did not grow in weight ($P = 0.064$). Brook trout stocked in October 2006 grew in length (15 mm/month; $P < 0.0001$) and weight (7 g/month; $P < 0.0001$), and those fish grew significantly faster in length ($F = 23.60$; df = 1, 449; $P < 0.0001$) and weight ($F = 23.73$; df = 1, 449; $P < 0.0001$) than fish stocked in July. Growth could not be calculated for brook trout stocked in April 2007 because sample sizes were too small (i.e., only one brook trout was collected on 23 May 2007). Brown trout and rainbow trout stocked in April 2007 exhibited no growth ($P \geq 0.0951$) over 32 d.

Diet

The stomach contents of 98 brook trout collected from July 2006 to May 2007 were examined. Brook trout averaged 154 mm TL (range: 74 – 246 mm TL, SE = 3.9) with a mean weight of 30 g (SE = 2.0). Thirteen percent of all brook trout stomachs were empty (n = 13). Most (n = 10) empty stomachs occurred in July, October, and the beginning of April, just after each new cohort of brook trout was stocked. Mean number of prey items per trout and mean total ration weight were also at their lowest levels during the July, October, and early April samples ($\leq$ 3 organisms per stomach, and $\leq$ 0.009 g). Mean ration weight was low ($\leq$ 0.045 g) for most months of the study. The exceptions were samples taken in late April and in May when ration weights increased at least an order of magnitude over all previous samples (Table 5).

Contributions of different prey taxa to the diet of brook trout were highly variable over time. Diptera pupae represented 81% of the total number of prey organisms consumed, but nearly all (2,240 of 2,301 total) dipterans were eaten during September when brook trout averaged 224 Diptera pupae per stomach (Table 6). Diptera pupae were only an important source of food for brook trout during September, when they were present in all stomachs examined and accounted for 97.3% of all prey consumed (Tables 6 and 7). Gastropods were the second most common prey item in the diet of stocked brook trout throughout the study (7.3% of total number) and were the most important taxon during November, April, and May (Tables 6 and 7).

The stomach contents of brown trout (n = 29) and rainbow trout (n = 26) stocked in April 2007 were also examined in order to compare their food habits with stocked brook trout. Diet overlap was significant (i.e., $C_{xy} \geq 0.60$) between brook trout and brown trout ($C_{xy} = 0.712$), but not between brook trout and rainbow trout ($C_{xy} = 0.485$). Brown trout and rainbow trout relied most heavily on ephemeropterans, whereas brook trout consumed mainly gastropods. Brown trout also consumed gastropods, but at a lower frequency than brook trout (Figure 6). The proportion of brook trout stomachs that were empty in April 2007 was 57%, compared to only 26% of brown trout and 4% of rainbow trout stomachs that were empty during the same period. There was no significant difference in the proportions of empty stomachs between brook trout and brown trout ($\chi^2 = 1.04$, df = 1, $P = 0.307$), but the proportions of brook trout and rainbow trout with empty stomachs differed ($\chi^2 = 6.99$, df = 1, $P = 0.008$). Mean digestible prey biomass varied with sampling date in April (F = 32.00; df = 1, 60; $P < 0.0001$) but not among the three trout species (F = 0.43; df = 2, 60; $P = 0.6542$); the interaction between sampling date and species was not significant (F = 0.28; df = 2, 60; $P = 0.7546$). Mean digestible prey biomass in trout stomachs increased from 0.004 g/stomach on 12 April (3-4 d post-stocking) to 0.138 g/stomach on 26 April (17-18 d post-stocking) (Figure 7).

Predation

One hundred thirty-five large (> 250 mm TL) brown trout were collected in October 2006 and April 2007. The stomachs of these brown trout contained 40 fish, 25 of which were brook trout. In addition, one rainbow trout, seven sculpins (*Cottus* spp.), and one central stoneroller *Campostoma anomalum* were identified in the stomachs of brown trout. The remains of another six fish were present, but could not be identified. Brown trout as small as 308 mm TL consumed brook trout.

Seventy-one of those 135 brown trout were collected 13 October 2006, 1-2 d after the October cohort of brook trout was stocked (Note: those brook trout were stocked over two d). Seven of those brown trout had recently consumed at least one brook trout.

Those seven brown trout consumed a total of 17 brook trout; the number of brook trout averaged 2.43 per stomach (range = 1 - 4 per stomach). Brown trout that preyed upon stocked brook trout ranged from 339 to 480 mm TL. Although most (72%) brown trout examined in this size range had not consumed brook trout, the estimated number of brown trout greater than 339 mm TL in the Watauga River was 10,494 (95% CI = 7,074 – 13,914). Based on the percentage of brown trout that consumed brook trout and the mean number of brook trout consumed, brown trout ate 7,136 brook trout within 1-2 d of the October stocking event, or 23% of the October 2006 cohort.

Sixty-four brown trout were examined in the April 2007 sample. Eight of these brown trout had recently consumed at least one brook trout. In contrast to the October 2006 sample, each of these eight brown trout had consumed only one trout, possibly because brook trout stocked in April 2007 were larger ($\bar{x}$ = 182 mm TL) than those stocked in October 2006 ($\bar{x}$ = 163 mm TL). For this reason, brook trout eaten by brown trout in April 2007 were larger ($\bar{x}$ = 162 mm TL) than those eaten in October 2006 ($\bar{x}$ = 134 mm TL). Piscivorous brown trout that preyed upon stocked brook trout in April 2007 ranged in length from 308 to 543 mm TL. Twenty-four percent of the brown trout examined in this size range consumed brook trout, and the number of brown trout greater than 308 mm TL in the Watauga River was 15,193 (95% CI = 10,692 – 19,693). Thus, an estimated 3,575 brook trout were consumed by brown trout 16-17 d after the April 2007 cohort was stocked.

The experimental stocking of marked brook trout in April 2007 was compromised by an unexpected release of brook trout (n = 59,365) into the tailwater over a 13-day period between 19 April and 1 May 2007. These unmarked brook trout could not be differentiated in the stomachs of brown trout from the adipose fin-clipped brook trout that were stocked on 9-10 April 2007 because the fins are normally the first part of any fish to be digested. Although it was impossible to differentiate between adipose fin-clipped and unclipped fish in brown trout stomachs, the 3,575 brook trout eaten was still a large number regardless of stocking date. That is, brown trout consumed roughly 8% of all brook trout stocked between 9 and 26 April (n = 44,025) within only a few days.

Dispersal

Six sites on Stony Creek and five sites on the Doe River were electrofished 14-17 May 2007. Brook trout were collected as far as 4.9 and 2.4 km upstream from the confluences of Stony Creek and the Doe River, respectively (Figure 8). Seventy-two brook trout were collected from Stony Creek, of which seven were adipose fin-clipped. Also collected were 52 brown trout (2 of which were fin clipped) and 180 rainbow trout (none were clipped). No microtagged brook trout (stocked in October 2006) were collected in Stony Creek. The TWRA does not stock brook trout in Stony Creek; thus, all unmarked brook trout collected were either wild fish residing in the lower reaches of Stony Creek or stocked fish that had emigrated from the Watauga River. Brook trout catches declined approximately exponentially as distance increased from the Watauga River (Figure 8), suggesting that stocking events in Watauga River acted as the source for these fish. Furthermore, newly-stocked trout of all species typically differ substantially in appearance from wild fish in terms of coloration (e.g., newly stocked trout are not as brightly colored) and morphology (e.g., stocked trout tended to have eroded fins). All of the brook trout collected in Stony Creek (and the Doe River) had the appearance of stocked fish. These factors considered together suggest that most (if not all) of the brook trout captured in Stony Creek were stocked fish.

Eighty-one brook trout were collected from the Doe River; only one was microtagged and none were adipose fin-clipped. All of these fish were presumed to be hatchery-reared based on coloration and morphology. Most of the brook trout were collected at Sites 1 and 2 (Figures 4 and 8). Just above Site 2 there is a low-head dam, which was breached during flooding associated with Hurricane Ivan in 2004. The dam was reconstructed in November 2006 and the new design incorporated a pool-and-weir type fishway. The purpose of this structure was to allow native fish (and trout) to pass from the Watauga River into the upper reaches of the Doe River (J. Zimmerman, Natural Resources Conservation Service, personal communication). Although two brook trout were found above the dam, neither was marked; thus, they could have been stocked either in July 2006 or April 2007. It is not known whether those two brook trout used the new fishway or simply moved up the river channel before the new low-head dam was closed.

Angler Perceptions

Survey questions relating to brook trout management in the Watauga River were posed to 304 anglers on the Watauga River between 4 April 2006 and 30 July 2006. Only 13% of anglers said they had ever caught a brook trout while fishing the Watauga River (Figure 9); most (73%) anglers were unaware that TWRA had been stocking brook trout into the tailwater (Figure 10). Approximately half (53%) of the anglers interviewed were "very confident" in their ability to distinguish a brook trout from a brown trout or rainbow trout, while equal numbers (24%) of respondents were "somewhat confident" or "not confident" in their brook trout identification skills (Figure 11). Anglers interviewed during the survey generally viewed TWRA's management of the Watauga River very positively (mean rating = 4.1, where 1 = poor and 5 = excellent) (Figure 12).

DISCUSSION

Population Estimate

The April 2006 population estimate was consistent with previous change-in-ratio (CIR) estimates on the Watauga River. The estimated number of trout in the tailwater in 2006 (N_1 = 72,362) was higher than in 1998 (N_1 = 55,231; Bettoli 1999), although 95% confidence intervals for these estimates overlapped considerably (1998: 39,964 - 70,497; 2006: 55,366 - 89,359). Biomass increased slightly from 122 kg/ha in 1998 to 137 kg/ha in 2006 despite a reduction in the overall mean weight of trout in the census sample (299 g to 256 g). A CIR experiment conducted in 2003 estimated that the number of brown trout in the tailwater was a bit higher than in this study (N_1 = 53,046), but this estimate included fish as small as 120 mm TL; whereas, the estimates made in 1998 and in the present study were limited to fish 150 mm TL and larger.

When compared to other tailwater systems in the southeastern U.S. and other regions, the Watauga River ranked high in terms of trout biomass. Standing crop was much higher in the Watauga River than in most other tailwaters in Tennessee, including the Caney Fork River (41-74 kg/ha; Devlin and Bettoli 1999), the Clinch River (112 kg/ha; Bettoli and Bohm 1997), and the Hiwassee River (13-20 kg/ha; Luisi and Bettoli 2001). The South Fork of the Holston River was the only Tennessee tailwater that surpassed the Watauga in terms of trout biomass (170-232 kg/ha; Bettoli et al. 1999). Overall standing crop of trout was higher in the Watauga River than in the Green River, Wyoming (55 g/ha; Wily and Dufek 1980), but less than in some reaches of the White River in Arkansas (155-342 kg/ha; Quinn 1998).

The absence of brook trout in the change-in-ratio census sample confirms the low survival rates observed during this study and confirms that very few, if any, stocked brook trout survive in any year. The census sample was large (n = 595) and had there been a biologically significant population of brook trout in the tailwater, at least one specimen should have been collected. More lake trout, which are not stocked into the Watauga River, were observed in electrofishing samples than brook trout.

Unmarked brown trout were common in the census sample, indicating that recruitment of wild brown trout to the fishery was high. During the census sample, unmarked brown trout outnumbered microtagged brown trout stocked in previous years (not including the snout-tagged fish stocked for the CIR experiment) by more than seven-fold. Holbrook and Bettoli (2006) reported high catch rates of young-of-year brown trout in the upper portion of the Watauga River and suggested that stocking brown trout was not necessary in the upper reaches of the tailwater. The findings of the present study suggest that a reduction or discontinuation of brown trout stocking into the Watauga River is biologically feasible.

Survival and Growth

Survival rates for brook trout were very low when compared to survival of other species of trout stocked in the Watauga River. Bettoli (1999) reported much higher survival rates over 100-day intervals for fingerling (~127 mm TL) rainbow trout (52.2%) and catchable (193 mm TL) brown trout (67.9%) stocked in the Watauga River in 1998; also, 67% percent of brown trout (173 mm TL) stocked in the Watauga in 2003 survived to 100 d (Meerbeek and Bettoli 2005). Brook trout are stocked in several tailwaters in Arkansas including the Greer's Ferry tailwater on the Little Red River, where annual survival was estimated at "essentially 0%" (Todd et al. 2003).

Stocked brook trout often experience high rates of fishing mortality because they are less selective than other species in their feeding habits and are more vulnerable to anglers. As evidenced by the 2006 creel survey conducted on the Watauga River (Bettoli 2007), brook trout do not experience any significant fishing mortality. Anglers reportedly caught only 25 brook trout during 2006 (an unexpanded estimate) and all of those fish were released. Two cohorts of brook trout were stocked during the 2006 creel survey and individuals from both cohorts were, on average, small. In fact, individuals in the first cohort (mean TL = 106 mm) were much smaller than the statewide minimum length limit for brook trout (152 mm TL). Individuals in the second cohort had a mean length of 163 mm TL when stocked, which was greater than the length limit but anglers did not catch brook trout frequently.

Historically, stocked trout grow slowly in the Watauga River compared to other tailwaters. Brown trout growth averaged only 6-7 mm and 8-9 g per month (Bettoli 1999; Meerbeek and Bettoli 2005) and rainbow trout grew at a monthly rate of 5-8 mm and 9-19 g (Bettoli 1999). Brook trout in the Greer's Ferry tailwater in Arkansas grew about 2 mm/month (Todd et al. 2003). Growth of brook trout in this study was highly variable between the cohorts stocked in July and October. Monthly growth between July and September was slow in terms of length (4 mm/month) and fish did not gain weight, but fish grew faster in length (15 mm/month) and weight (7 g/month) between October and December. Mean digestible stomach biomass was consistently low through both of these time periods and could not account for the differences in observed growth. It is common for growth of rainbow trout and brown trout in Tennessee tailwaters to become depressed in the late summer and early fall when water temperatures are at their highest (Bettoli et al. 1999; Luisi and Bettoli 2001; Meerbeek and Bettoli 2005).

Diet

The high incidence of empty stomachs and low ration weights observed during most of this study suggested that brook trout in the Watauga River were food-limited. The mean number of prey items per stomach was consistently low (< 7) except in April, when ration weights increased considerably and in September when Diptera pupae were consumed in large quantities. Cada et al. (1987) noted similarly low mean numbers of prey items per stomach for rainbow and brown trout in small Appalachian streams where productivity is low. Bettoli (1999) concluded that productivity was low on the Watauga River (based on alkalinity values) and that overall trout biomass was limited by prey abundance. Other studies have shown that brown trout and rainbow trout hold a competitive advantage over brook trout when resources are limited (Fausch and White 1981; Ersbak and Haase 1983; Isely and Kempton 2000). Although there was no significant difference in the amount of digestible prey biomass in brook, brown, and rainbow trout stomachs, there were qualitative differences in diet. Food items with high nutritional value such as ephemeropterans were consumed more often by brown trout and rainbow trout; whereas, brook trout consumed more "low quality" food items such as gastropods and small Diptera pupae.

Interspecific competition can be a major factor in determining the diet of fishes. Bluegill *Lepomis macrochirus* will shift their feeding strategy from selecting large prey associated with vegetation (preferred) to smaller benthic prey when in the presence of a competitively dominant species, the green sunfish *Lepomis cyanellus* (Werner and Hall 1977). In allopatric populations of arctic char *Salvelinus alpinus* and brown trout, both species preferred similar food items associated with shallow weedy areas, but when they occurred sympatrically, char were forced to feed on smaller, offshore prey such as zooplankton (Nilsson 1963). Brook trout in the Watauga River may experience similar pressure from either rainbow trout or brown trout (or a complex interaction among all three species) that may cause them to forage for less desirable prey items in marginal habitats.

Predation

The losses of stocked brook trout to brown trout piscivory were high. Only 1-2 d after brook trout were stocked in October 2006, about 23% were consumed by brown trout. Baldwin et al. (2000) noted that salmonid predator-prey interactions were most severe in the first two d after a stocking event, but attributed the short duration to exhaustion of the prey base. If the rate of predation observed in October continued for even a few more days, the impact on the brook trout population would have been severe and would have accounted for the low survival rates observed for that cohort. Baldwin et al. (2000) concluded that piscivory accounted for the low (1%) initial survival of hatchery cohorts of cutthroat trout *Oncorhynchus clarki* and survival rates were similar in the present study. Piscivory rates declined in April 2007, most likely because brook trout were larger. Assuming that brown trout fed on brook trout for more than just a few days, the observed predation rate was still high enough to result in substantial losses over the long-term.

Dispersal

Many salmonid species display a certain degree of migratory behavior and brook trout are no exception. Several studies have found that brook trout have a tendency to move upstream after they are stocked (Cobb 1933; Hazzard and Shetter 1938), while others have found that hatchery-raised brook trout are more prone to downstream migrations after stocking (Smith 1941; Helfrich and Kendall 1982). Upstream movement was confirmed in the present study, as many fish were found upstream in two tributaries where stocking does not occur. One stocked brook trout moved (at a minimum) nearly 5 km up Stony Creek. The movements of some brook trout into those tributaries would have contributed to the low survival rates estimated for brook trout in the Watauga River, although the impact of emigration on survival rates was likely negligible.

The movement of stocked brook trout from the Watauga River into its tributaries is troubling considering the presence of native southern Appalachian brook trout (SABT) in the headwaters of Stony Creek and the Doe River. The Southern Division of the American Fisheries Society recently issued a position statement with regard to the conservation of SABT populations (Habera and Moore 2005). In that document, the authors stated, "It is imperative that fishery managers restrict the use of hatchery produced (nonnative) brook trout to areas where SABT genetic integrity cannot be compromised through interbreeding or altered selective pressures related to ecological interactions." Brook trout stocked into the Watauga River originate from a northern hatchery strain (Owhi) and could theoretically spawn with native SABT if they survive long enough and swim high enough (at least 18 stream km) into the tributaries of the Watauga River. Waterfalls prevent upstream migration of stocked brook trout in some, but not all, headwater streams of the Watauga River, particularly in the Doe River watershed. Thus, stocked brook trout could theoretically mix with SABT populations in most of the streams in the Watauga River watershed in which SABT occur.

Angler Perceptions

Anglers are overwhelmingly content with the TWRA's management of the Watauga River, even without a successful introduction of brook trout. Most anglers were unaware of the brook trout stocking program in the Watauga River, but still rated management of the fishery very highly. Hutt and Bettoli (2007) found that, on average, anglers fishing on the Watauga River did not prefer to catch any particular species of trout and were most content when they caught lots of trout. Brown trout and rainbow trout are plentiful, and although a three-species fishery might be an attractive draw for some, it certainly is not necessary to keep overall angler approval high.

MANAGEMENT IMPLICATIONS

The current five-year management plan for the Watauga River below Wilbur Dam (Habera et al. 2003) concludes in 2008, at which time managers will consider the future of the brook trout stocking program. The efforts of the TWRA over the last seven years (i.e., more than 400,000 brook trout stocked) have not resulted in a fishable population of brook trout and anglers rarely had the opportunity to catch (and harvest) brook trout because of their small size at stocking. Stocking larger brook trout would likely reduce losses due to brown trout predation and provide anglers with an immediate opportunity to catch brook trout; however, the problem of introgression with native stocks would still need to be addressed. Waterfall barriers are not present to protect all populations of native southern Appalachian brook trout in the headwaters of the Watauga River from possible introgression with stocked brook trout. Stocking large triploid brook trout might be explored as an option if efforts to establish a brook trout fishery in the Watauga River are continued. Sterile triploid salmonids have been stocked elsewhere to provide angling opportunities where interbreeding with native stocks is a concern (Dillon et al. 2000).

Efforts are underway by the TWRA to establish brook trout fisheries in other tailwaters in the state. The Clinch River below Norris Dam and the Caney Fork River below Center Hill Dam have already received experimental stockings of brook trout in 2007-2008. Although concerns with introgression and maintaining biological integrity are not present in those watersheds, the size-at-stocking issue cannot be ignored because both of those rivers harbor substantial populations of piscivorous brown trout.

ACKOWLEDGEMENTS

The Tennessee Wildlife Resources Agency, the Tennessee Cooperative Fishery Research Unit, and the Center for the Management, Utilization, and Protection of Water Resources at Tennessee Technological University provided funding for this research. Drs. Steven Hayslette and S. Bradford Cook critiqued the study plan and reviewed an early draft of this report. Terry Campbell and the crew at Dale Hollow National Fish Hatchery were always flexible and glad to assist whenever possible. We thank all the graduate students, staff, and volunteers that assisted in field sampling and marking at the hatcheries.

REFERENCES

Alexander, G. R., H. Gowing, and A. J. Nuhfer. 1990. Population characteristics of Assinica and Temiscamie strains of brook trout. Fisheries Research Report No. 1966, Michigan Department of Natural Resources, Ann Arbor, Michigan.

Bachman, R. A. 1984. Foraging behavior of free-ranging wild and hatchery brown trout in a stream. Transactions of the American Fisheries Society 113:1-32.

Baldwin, C. M., D. A. Beauchamp, and J. J. Van Tassell. 2000. Bioenergetic assessment of temporal food supply and consumption demand by salmonids in the Strawberry Reservoir food web. Transactions of the American Fisheries Society 129:429–450.

Bettinger, J. M., and P. W. Bettoli. 2000. Movements and activity of rainbow trout and brown trout in the Clinch River, Tennessee, as determined by radio telemetry. Fisheries Report No. 99-41. 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 No. 99-41. Tennessee Wildlife Resources Agency, Nashville, Tennessee.

Bettoli, P. W. 2003. Survey of the trout fishery in the Watauga River: March-October 2002. Fisheries Report No. 03-05. Tennessee Wildlife Resources Agency, Nashville, Tennessee.

Bettoli, P. W. 2007. Surveys of the trout fisheries in the Watauga River and South Fork of the Holston River: March-October 2006. Fisheries Report No. 07-07. Tennessee Wildlife Resources Agency, Nashville, Tennessee.

Bettoli, P. W., and L. A. Bohm. 1997. Clinch River trout investigations and creel survey. Period: September 1995 – June 1997. Fisheries Report No. 97-39. Tennessee Wildlife Resources Agency, Nashville, Tennessee.

Bettoli, P. W., S. Owens, and M. Nemeth. 1999. Trout habitat, reproduction, survival, and growth in the South Fork of the Holston River. Fisheries Report No. 99-03. Tennessee Wildlife Resources Agency, Nashville, Tennessee.

Bohm, L. A. 1997. Spatial and temporal variations in habitat and prey use by trophy rainbow trout and brown trout in the Clinch River below Norris Dam, Tennessee. Fisheries Report No. 97-24. Tennessee Wildlife Resources Agency, Nashville, Tennessee.

Cada, G. F., J. M. Loar, and M. J. Sale. 1987. Evidence of food limitation of rainbow and brown trout in southern Appalachian soft-water streams. Transactions of the American Fisheries Society 116:692–702.

Cobb, E. W. 1933. Results of trout tagging to determine migrations and results from plants made. Transaction of the American Fisheries Society 63:308-313.

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. Tennessee Wildlife Resources Agency, Nashville, Tennessee.

Dillon, J. C., D. J. Schill, and D. M. Teuscher. 2000. Relative return to creel of triploid and diploid rainbow trout stocked in eighteen Idaho streams. North American Journal of Fisheries Management 20:1–9.

Ersbak, K., and B. L. Haase. 1983. Nutritional deprivation after stocking as a possible mechanism leading to mortality in stream stocked brook trout. North American Journal of Fisheries Management 3:142-151.

Etnier, D. A., and W. C. Starnes. 2001. The Fishes of Tennessee. University of Tennessee Press, Knoxville.

Fausch, K. D., and R. J. White. 1981. Competition between brook trout (*Salvelinus fontinalis*) and brown trout (*Salmo trutta*) for positions in a Michigan stream. Canadian Journal of Fisheries and Aquatic Sciences 38:1220-1227.

Habera, J. W., R. D. Bivens, B. D. Carter, and C. E. Williams. 1999. Region IV Trout Fisheries Report 1998. Fisheries Report 99-4. Tennessee Wildlife Resources Agency, Nashville, Tennessee.

Habera, J. W., R. D. Bivens, and B. D. Carter. 2003. Management Plan for the Wilbur Tailwater Trout Fishery 2004-2008. Tennessee Wildlife Resources Agency, Nashville, Tennessee.

Habera J. W., and S. Moore. 2005. Managing southern Appalachian brook trout: a position statement. Fisheries 30:10–20. Tennessee Wildlife Resources Agency, Nashville, Tennessee.

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 Resources Agency, Nashville, Tennessee.

Habera, J. W., R. D. Bivens, B. D. Carter, and C. E. Williams. 2007. Region IV Trout Fisheries Report 2006. Fisheries Report 07-02. Tennessee Wildlife Resources Agency, Nashville, Tennessee.

Hazzard, A. S., and D. S. Shetter. 1938. Results from experimental plantings of legal-sized brook trout (*Salvelinus fontinalis*) and rainbow trout (*Salmo irideus*). Transactions of the American Fisheries Society 68:196-210.

Helfrich, L. A., and W. T. Kendall. 1982. Movements of hatchery-reared rainbow, brook and brown trout stocked in a Virginia mountain stream. Progressive Fish Culturist 44:76-80.

Holbrook, S. C., and P. W. Bettoli. 2006. Spawning habitat, length at maturity, and fecundity of brown trout in Tennessee tailwaters. Fisheries Report 06-11. Tennessee Wildlife Resources Agency, Nashville, Tennessee.

Hutt, C. P., and P. W. Bettoli. 2007. Preferences, specialization, and management attitudes of trout anglers fishing in Tennessee tailwaters. North American Journal of Fisheries Management 27:1257-1267.

Isely, J. J., and C. Kempton. 2000. Influence of costocking on growth of young of year brook trout and rainbow trout. Transactions of the American Fisheries Society 129:613-617.

Larson, G. L., S. E. Moore, and B. D. Carter. 1995. Ebb and flow of encroachment by nonnative rainbow trout in a small stream in the southern Appalachian Mountains. Transactions of the American Fisheries Society 124:613-622.

Luisi, M. P., and P. W. Bettoli. 2001. An investigation of the trout fishery in the Hiwassee River. Fisheries Report 01-13. Tennessee Wildlife Resources Agency, Nashville, Tennessee.

Mathur, D. 1977. Food habits and competitive relationships of the bandfin shiner in Halawakee Creek, Alabama. The American Midland Naturalist 97:89-100.

McKinney, A. D., D. L. Melgaard, J. A. Wojtowicz, and R. D. Martin. 1987. Restoration of the Watauga River in upper east Tennessee through reduction in textile mill effluent toxicity. Tennessee Department of Health and Environment, Division of Water Pollution Control, Knoxville, Tennessee.

Meehan, W. R., and R. A. Miller. 1978. Stomach flushing: effectiveness and influence on survival and condition of juvenile salmonids. Journal of the Fisheries Research Board of Canada 35:1359-1363.

Meerbeek, J., and P. W. Bettoli. 2005. Survival, growth, condition, and diet of stocked brown trout in five Tennessee tailwaters. Fisheries Report 05-05. Tennessee Wildlife Resources Agency, Nashville, Tennessee.

Miranda, L. E., and P. W. Bettoli. 2007. Mortality. Pages 229-277 *in* C. S. Guy and M. L. Brown, editors. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland.

Mullican, H. N., and E. C. Leming. 1970. Biological conditions of the Watauga River as presented to the Tennessee Stream Pollution Control Board. Tennessee Department of Public Health, Tennessee Stream Pollution Control Board, Nashville, Tennessee.

Needham, P. R., and F. K. Sumner. 1941. Fish management problems of high western lakes with returns from marked trout in Upper Angora Lake, California. Transactions of the American Fisheries Society 71:249-269.

Nilsson, N. 1963. Interaction between trout and char in Scandinavia. Transactions of the American Fisheries Society 58:869-876.

Neves, R. J., and G. B. Pardue. 1983. Abundance and production of fishes in a small Appalachian stream. Transactions of the American Fisheries Society 112:21–26.

Paulik, G. J., and D. S. Robson. 1969. Statistical calculations for change-in-ratio estimators of population parameters. Journal of Wildlife Management 33:1-27.

Quinn, J. W. 1998. Fish populations and trout microhabitat use of rehabilitated habitat in an Ozark tailwater river. MS thesis, University of Arkansas, Fayetteville.

Schoener, T. W. 1971. Theory of feeding strategies. Annual Review of Ecology and Systematics 2:369-404.

Smith, L. L. 1941. The results of planting brook trout of legal length in the Salmon Trout River, northern Michigan. Transactions of the American Fisheries Society 70:249-258.

Thompson, D. A., and H. L. Blankenship. 1997. Regeneration of adipose fins given complete and incomplete clips. North American Journal of Fisheries Management 17:467-469.

Todd, C. S., T. Bly, and D. W. Bowman. 2003. Evaluation of trout growth, survival, movement, and exploitation in the JFK catch-and-release area, Greer's Ferry Tailwater. Arkansas Game and Fish Commission Trout Program Report Number TP-05-03.

TVA (Tennessee Valley Authority). 2007. Reservoir Information for Wilbur Dam. http://www.tva.com/sites/wilbur.htm.
Trembley, G. L. 1943. Results from plantings of tagged trout in Spring Creek, Pennsylvania. Transactions of the American Fisheries Society 73:158-172.
Van Offelen, H. K., C. C. Krueger, and C. L. Schofield. 1993. Survival, growth, movement and distribution of two brook trout strains stocked into small Adirondack streams. North American Journal of Fisheries Management 13:86-95.
Wallace, R. K. 1981. An assessment of diet-overlap indexes. Transactions of the American Fisheries Society 110:72-76.
Werner, E. E., and D. J. Hall. 1977. Competition and habitat shift in two sunfishes (Centrarchidae). Ecology 58:869-876.
Whitworth, W. E., and R. J. Strange. 1983. Growth and production of sympatric brook and rainbow trout in an Appalachian stream. Transactions of the American Fisheries Society 112:469–475.
Wiley, R. W., and D. J. Dufek. 1980. Standing crop in the Fontenelle tailwater of the Green River. Transactions of the American Fisheries Society 109:168-175.
Williams, J. S., D. W. Bowman, C. S. Todd, M. Bivens, R. Moore. 2005. Multispecies trout management. Proceedings of the Annual Conference of Southeastern Association of Fish and Wildlife Agencies 58:1-11.
Zaret, T. M., and A. S. Rand. 1971**.** Competition in tropical stream fishes: support for the competitive exclusion principle. Ecology 52:336-342.

Table 1. Stocking summary for brook, brown, and rainbow trout stocked into the Watauga River from July 2006 to April 2007. "Effective number stocked" indicates the number of marked fish released after taking into account estimates of mark retention. Mean total lengths sharing the same superscript letter were similar (Tukey's test; P > 0.05).

Date Stocked	Species	Mean Total Length (mm)	SE	Mark or Tag	Number Marked	Retention (%)	Effective Number Stocked	River Reach Stocked
6 July 2006	Brook	106[1]	N/A	None	35,913	N/A	35,913	Dam to Hunter Bridge
10-11 October 2006	Brook	163[A]	1.21	Dorsal Tag	33,011	96	31,544	Dam to Blevins Bend
9-10 April 2007	Brook	182[B]	3.52	Adipose clip	4,106	100	4,106	Dam to Hunter Bridge
9-10 April 2007	Brown	166[C]	2.54	Adipose clip	4,191	100	4,191	Dam to Hunter Bridge
9-10 April 2007	Rainbow	181[B]	2.4	Adipose clip	4,870	100	4,870	Dam to Hunter Bridge

[1] – This cohort of fish was stocked before a subsample of fish could be measured; they averaged about 4.2 inches (TL) according to hatchery records.

Table 2. Calculations and subsequent standing crop estimates from an April 2006 change-in-ratio population estimate for resident trout (≥ 150 mm TL) in the Watauga River. Snout-tagged brown trout (n = 13,470) were stocked 24-26 April 2006.

Parameter	Both Species	Rainbow Trout	All Brown Trout	Brown Trout Stocked in Previous Years
Size of census sample[1]	548	242	392	118
Number of target fish[2] in census sample	462	156	306	32
Population estimate	72,362	24,434	47,928	5,012
Variance	7.2×10^7	1.1×10^7	3.4×10^7	1.1×10^6
95% confidence interval	55,366 - 89,359	17,871 - 30,997	36,229 - 59,627	2,936 - 7,088
Mean weight of unmarked fish in census sample (kg)	0.256	0.219	0.275	0.185
Standing crop (kg/ha)	137	40	98	7

[1] Includes all individuals from target group (i.e., both species combined; rainbow trout; all brown trout; only brown trout stocked in previous years) and all recaptures (snout-tagged brown trout).

[2] Census sample minus 86 recaptured (tagged) brown trout

Table 3. Summary of trout collected from the Watauga River during electrofishing samples taken from July 2006 to May 2007. Electrofishing effort was held constant at 10 min per site. Sampling between July 2006 and January 2007 was conducted using barge-mounted gear; sampling in April and May 2007 was conducted using boat-mounted gear. Numbers in parentheses are the number of sites sampled on each date.

Date Stocked	Species	Tag/Mark	Number Stocked	Jul 12 2006 (7)	Aug 15 2006 (7)	Sep 21-22 2006 (7)	Oct 17-18 2006 (10)	Nov 16 2006 (10)	Dec 19 2006 (10)	Jan 24 2007 (10)	Apr 12 2007 (1)	Apr 26 2007 (9)	May 23 2007 (9)	Total
7/6/06	Brook	None	35,913	711	81	30	0	2	0	4	0	0	0	828
10/11-12/06	Brook	Dorsal Tag	31,544	-	-	-	238	59	27	3	1	0	0	328
4/9-10/07	Brook	Adipose Clip	4,106	-	-	-	-	-	-	-	5	5	1	11
4/9-10/07	Brown	Adipose Clip	4,191	-	-	-	-	-	-	-	9	20	9	38
4/9-10/07	Rainbow	Adipose Clip	4,870	-	-	-	-	-	-	-	7	20	9	36

Table 4. Interval 100-d survival rates (%) for cohorts of brook trout, brown trout, and rainbow trout stocked in the Watauga River between July 2006 and April 2007.

Species	July 6 2006	October 11-12 2006	April 9-10 2007
Brook Trout	4.4	1.8	0.1
Brown Trout	-	-	5.4
Rainbow Trout	-	-	5.4

Table 5. Summary of the contents of brook trout stomachs collected from the Watauga River, July 2006 to May 2007.

Variable	Jul 12 2006	Aug 15 2006	Sep 21-22 2006	Oct 17-18 2006	Nov 16 2006	Dec 19 2006	Jan 24 2007	Apr 12 2007	Apr 26 2007	May 23 2007
Number Trout Examined	10	10	10	10	18	25	3	6	5	1
Mean Total Length (mm)	99	105	117	143	167	175	159	207	211	213
Mean Weight (g)	9	9	13	27	40	47	35	88	81	61
Percent Empty (number)	40.0(4)	0	0	20.0(2)	0	12.0(3)	0	66.7(4)	0	0
Organisms per Stomach	2	18	230	2	6	5	7	3	19	58
Mean Digestible Biomass (g)	0.005	0.017	0.027	0.006	0.036	0.022	0.007	0.005	0.169	0.440
Mean Indigestible Biomass (g)	0.004	0.006	0.001	0.001	0.009	0.002	0.002	0.000	0.002	0.030
Mean Total Ration Weight (g)	0.009	0.023	0.028	0.006	0.045	0.024	0.009	0.005	0.172	0.470

Table 6. Total number, percent of overall number, and percent of total number on each of 10 dates for prey taxa consumed by brook trout in the Watauga River, July 2006 - May 2007.

Taxon	Total Number	% Total Number	Jul 12 2006	Aug 15 2006	Sep 21-22 2006	Oct 17-18 2006	Nov 16 2006	Dec 19 2006	Jan 24 2007	Apr 12 2007	Apr 26 2007	May 23 2007
Diptera	2304	81.1	9.1	25.0	97.3	23.5	2.0	6.2	13.6	65.0	8.5	
Gastropoda	208	7.3	0.0	23.7	0.3	5.9	68.0	30.0	13.6	0.0	52.1	41.4
Amphipoda	89	3.1	4.6	6.6	0.5	29.3	24.0	3.1	68.3	15.0	2.1	36.3
Terrestrial	55	1.9	81.8	26.3	0.2	5.9	0.0	3.8	0.0	10.0	4.3	0.0
Trichoptera	53	1.9	0.0	0.0	1.2	5.9	2.0	3.8	0.0	5.0	13.8	5.2
Cladocera	51	1.8	0.0	0.0	0.1	11.8	0.0	35.4	0.0	0.0	0.0	0.0
Isopoda	48	1.7	4.5	17.1	0.2	5.9	1.0	14.6	4.5	0.0	5.3	3.4
Ephemeroptera	16	0.6	0.0	0.0	0.0	11.8	0.0	0.8	0.0	5.0	11.7	1.7
Plecoptera	2	0.1	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	1.1	0.0
Other	14	0.5	0.0	1.3	0.2	0.0	3.0	1.5	0.0	0.0	1.1	3.4
Total	2304	100	100	100	100	100	100	100	100	100	100	100

Table 7. Frequency of occurrence of prey items consumed by brook trout from July 2006 to May 2007. Frequency of occurrence is defined as the percentage of fish that had eaten a particular prey item on a given date.

Taxon	Total Number	% Total Number	Jul 12 2006	Aug 15 2006	Sep 21-22 2006	Oct 17-18 2006	Nov 16 2006	Dec 19 2006	Jan 24 2007	Apr 12 2007	Apr 26 2007	May 23 2007
Diptera	2304	81.1	10	90	100	30	11	32	66	17	60	100
Gastropoda	208	7.3	0	60	30	10	77	60	33	0	80	100
Amphipoda	89	3.1	10	40	30	20	67	12	100	17	20	100
Terrestrial	55	1.9	40	50	20	10	0	8	0	33	40	0
Trichoptera	53	1.9	0	0	70	10	11	20	0	17	60	100
Cladocera	51	1.8	0	0	20	20	0	8	0	0	0	0
Isopoda	48	1.7	0	50	30	10	6	32	33	0	60	100
Ephemeroptera	16	0.6	0	0	0	20	0	4	0	17	60	100
Plecoptera	2	0.1	0	0	0	0	0	4	0	0	20	0
Other	14	0.5	0	10	40	0	17	8	0	0	20	100

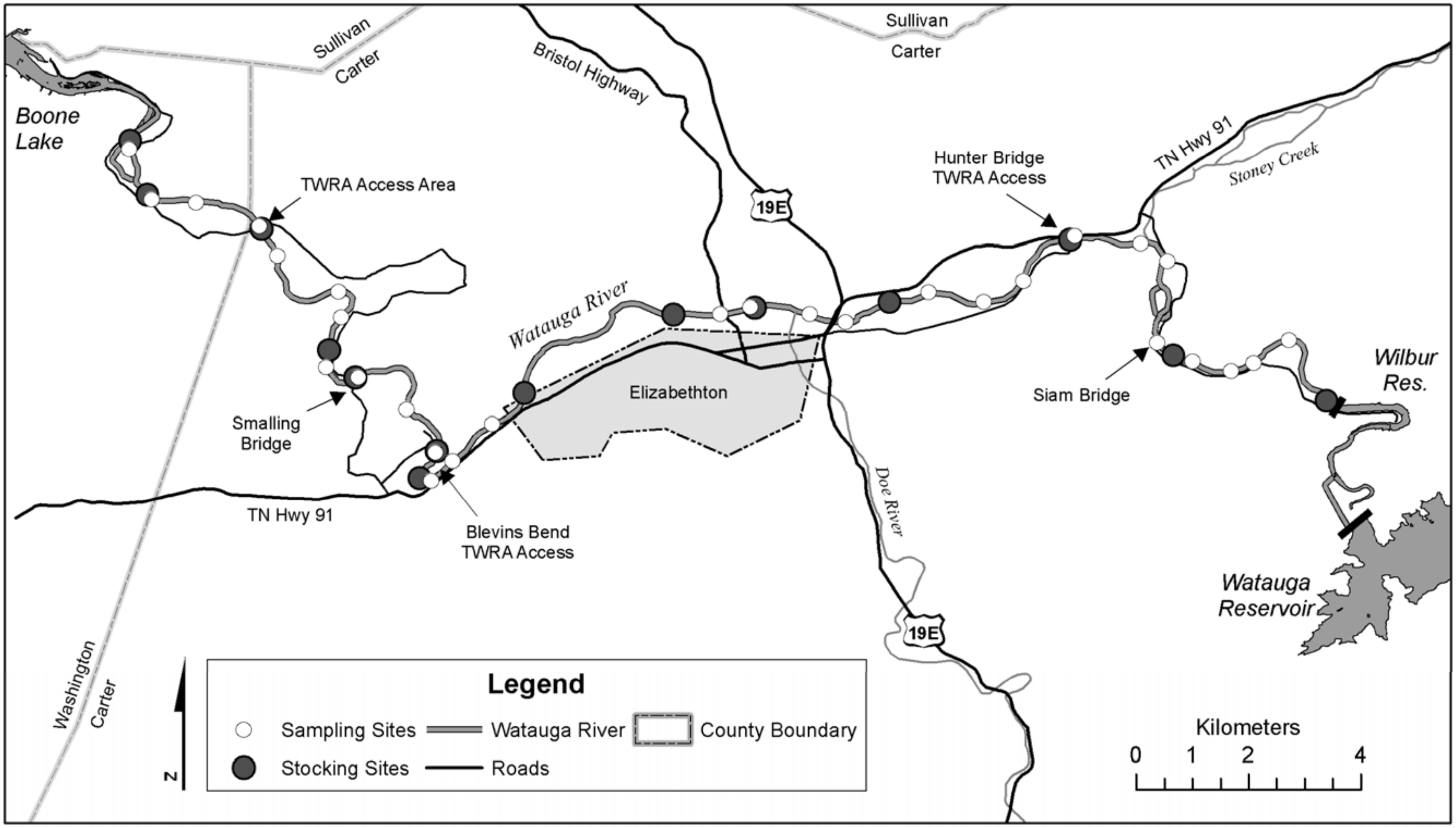

Figure 1. Locations of 29 sampling sites and 14 stocking sites used during an April 2006 change-in-ratio (CIR) population experiment conducted on the Watauga River.

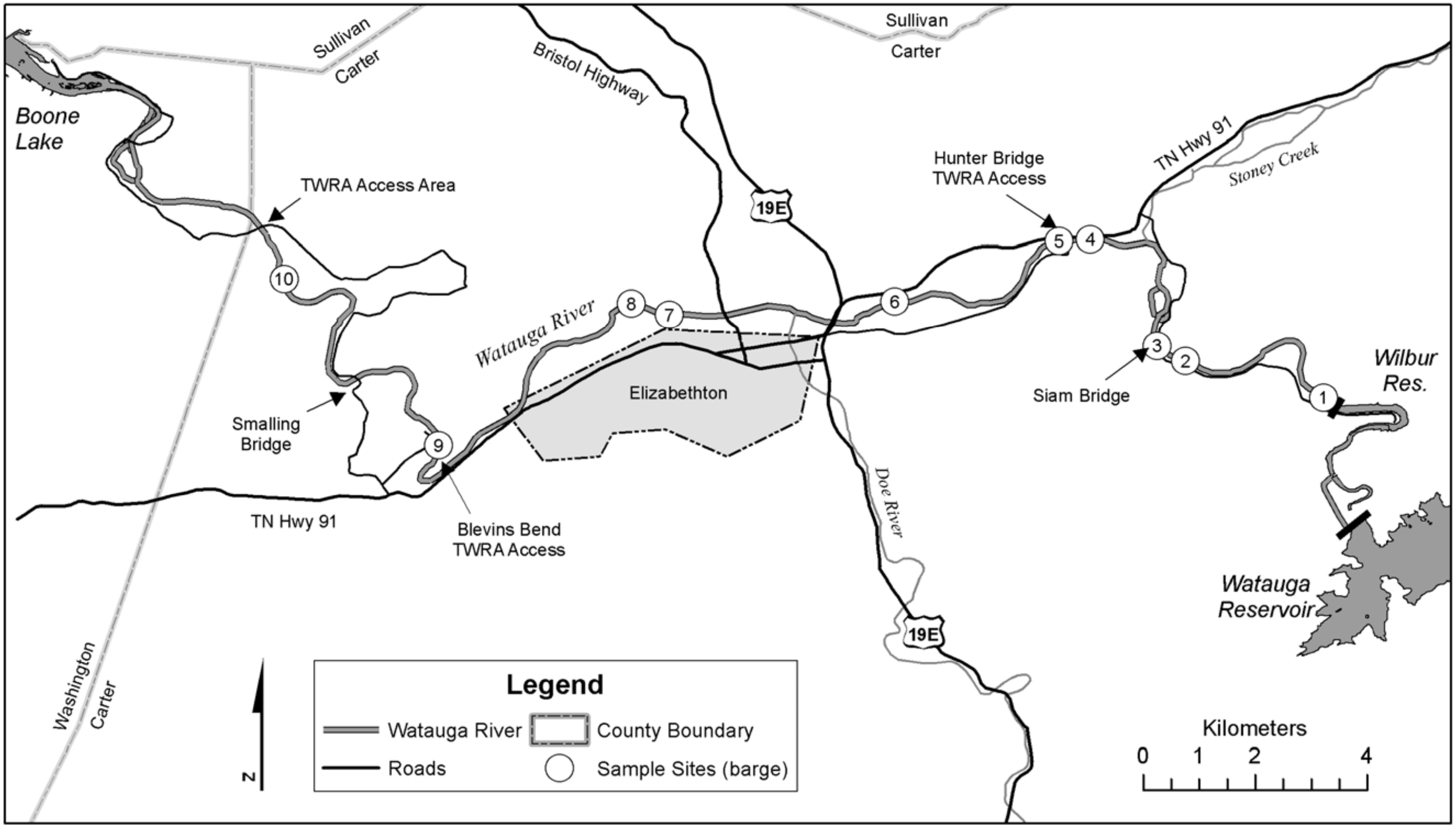

Figure 2. Locations of sites sampled on the Watauga River using barge-mounted electrofishing equipment. Sites 1-7 were sampled from 7/06 to 9/06, and sites 1-10 were sampled 10/06 to 1/07. Differences in the number and locations of sites sampled during these periods were due to differences in the river reaches stocked (Wilbur Dam to Hunter Bridge was stocked 7/06, Wilbur Dam to Blevins Bend was stocked 10/06).

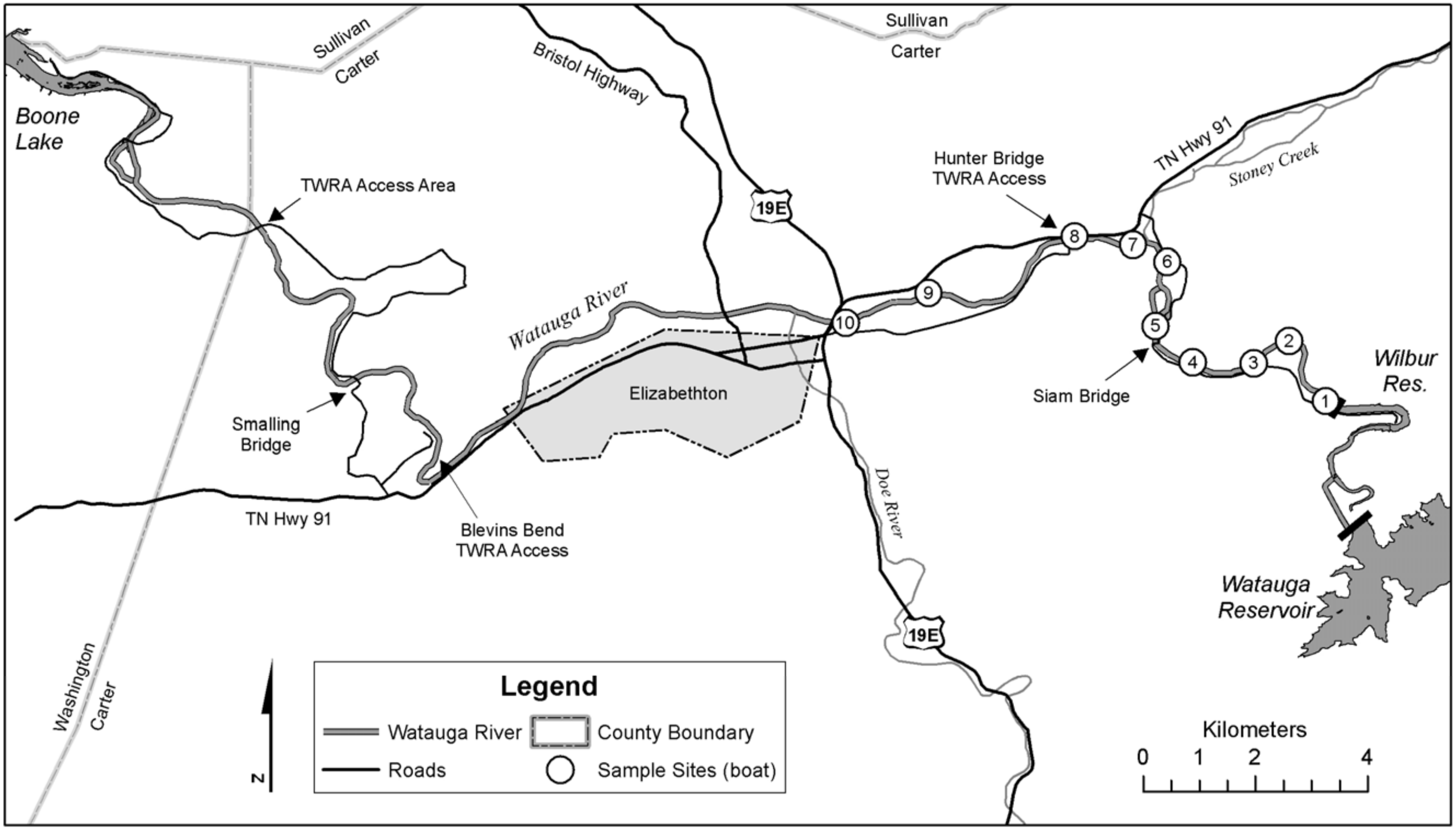

Figure 3. Locations of sites sampled on the Watauga River using boat-mounted electrofishing equipment, April-May 2007. Samples targeted fin-clipped trout stocked between Wilbur Dam and Hunter Bridge. Site 1 was only sampled once (4/12/07).

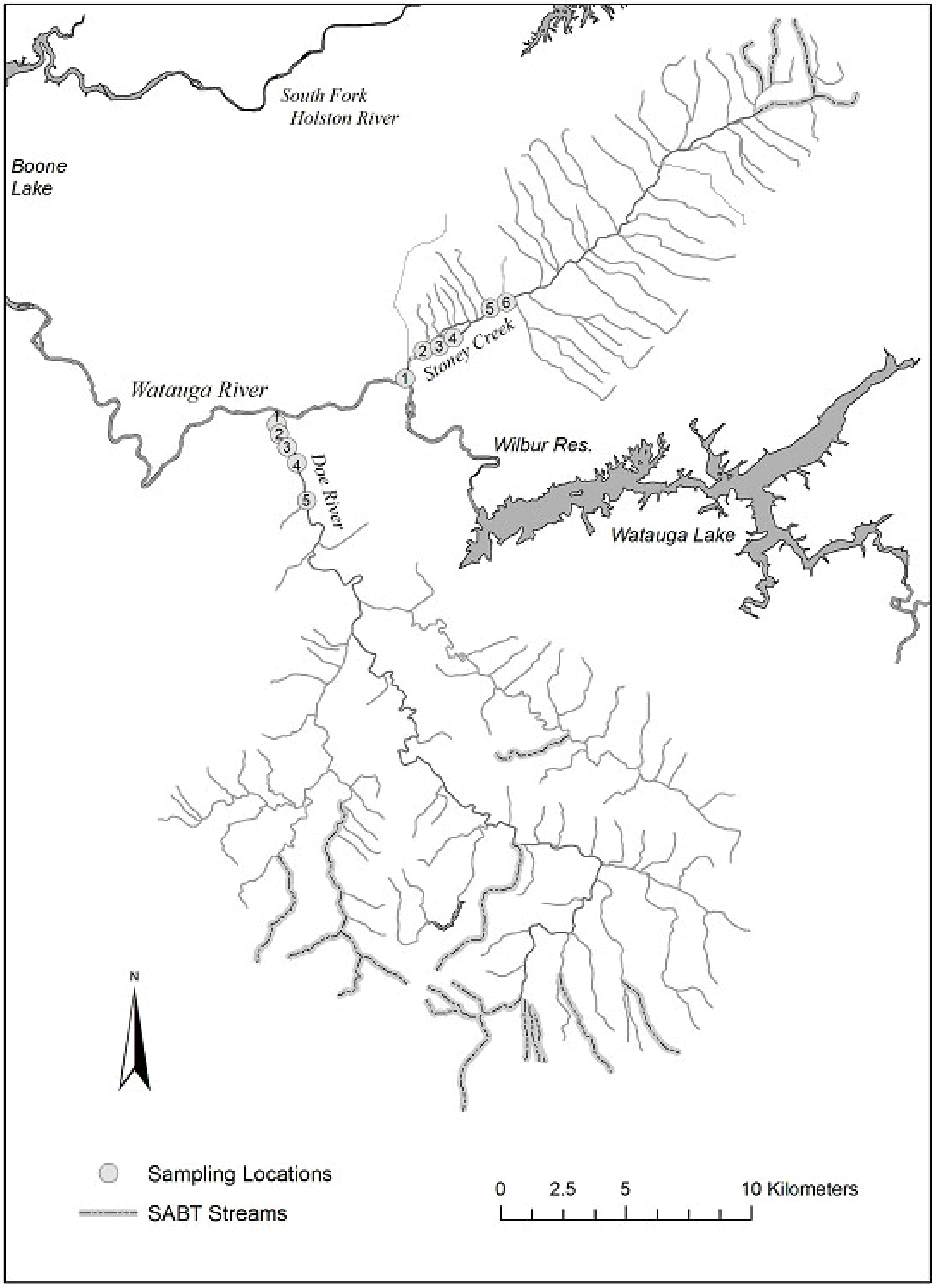

Figure 4. Locations of backpack electrofishing samples taken to monitor dispersal of brook trout into the two main tributaries of the Watauga River, 14-17 May 2007. Highlighted streams are known to contain native Southern Appalachian brook trout (SABT) populations (Jim Habera, TWRA, personal communication).

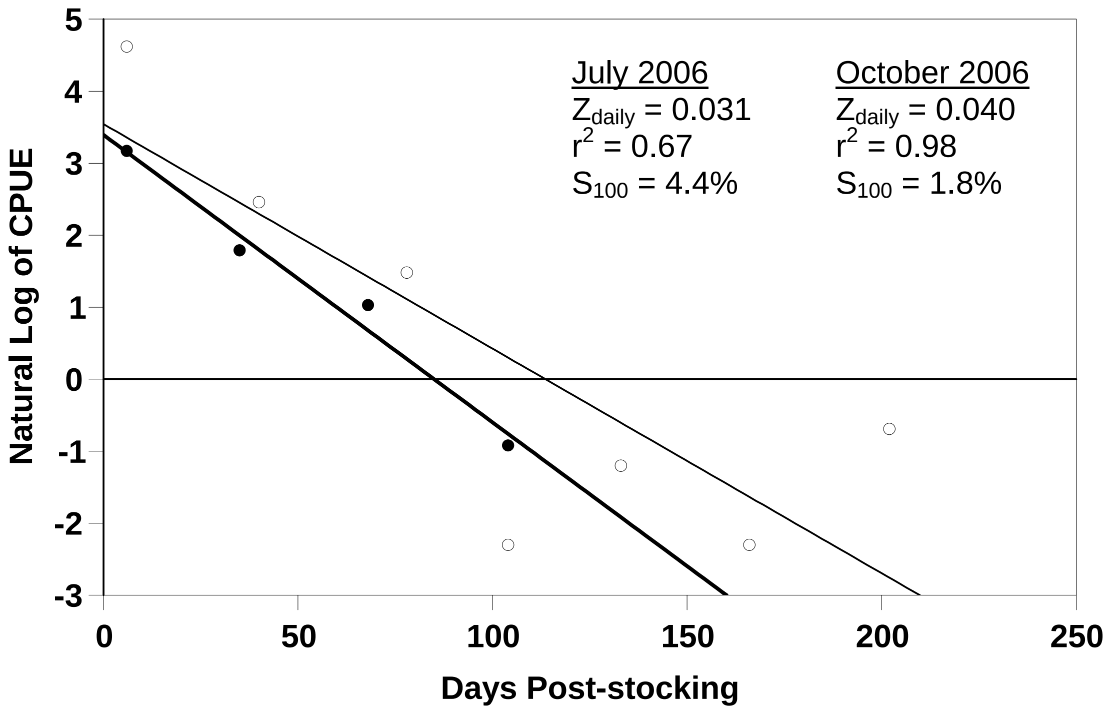

Figure 5. Catch curves for brook trout stocked into the Watauga River in July and October 2006. Open and closed circles represent natural log-transformed catch-per-unit-effort (CPUE) data from July and October, respectively. CPUE was defined as the number of trout collected per 10 min of electrofishing. A value of 0.1 was added to all catch data whenever zeros were present. Z_{daily} (the slope of the regression line) represents the instantaneous daily mortality rate, and S_{100} represents the 100-day interval survival rate.

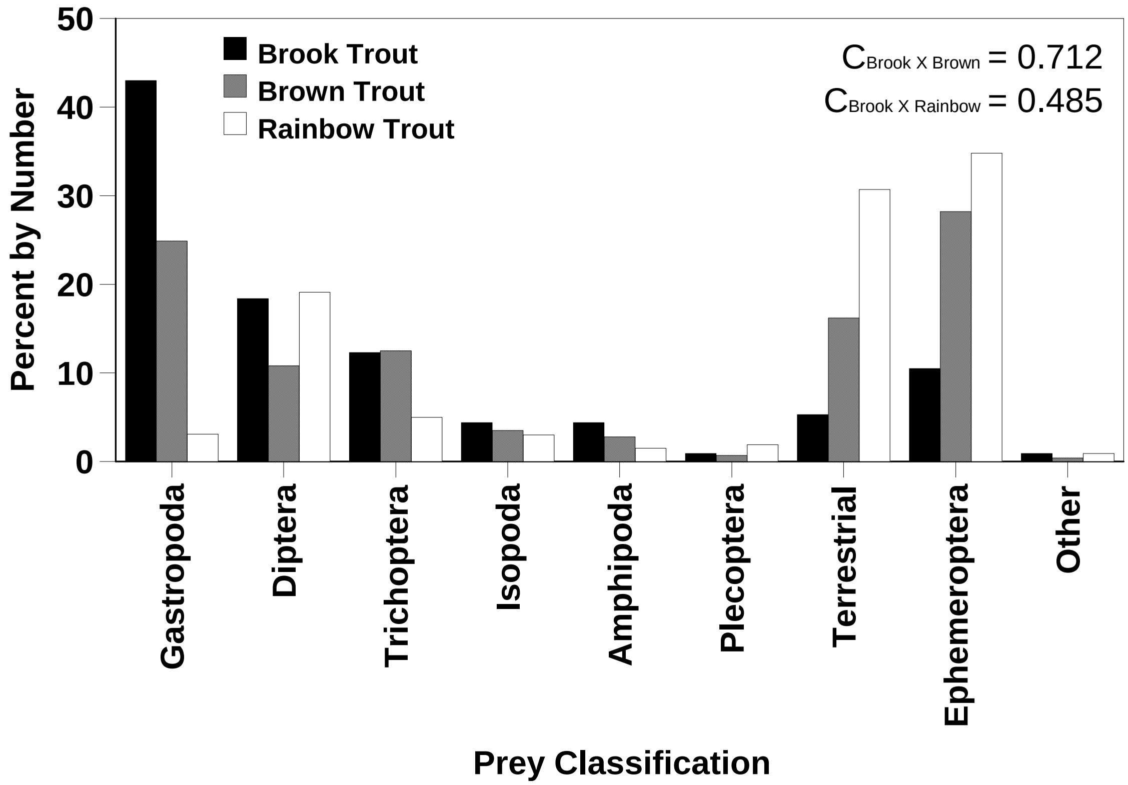

Figure 6. Consumption of different prey taxa by recently stocked brook trout, brown trout, and rainbow trout, April 2007. Values of *C* represent diet overlap indices between brook trout and brown trout, and brook trout and rainbow trout.

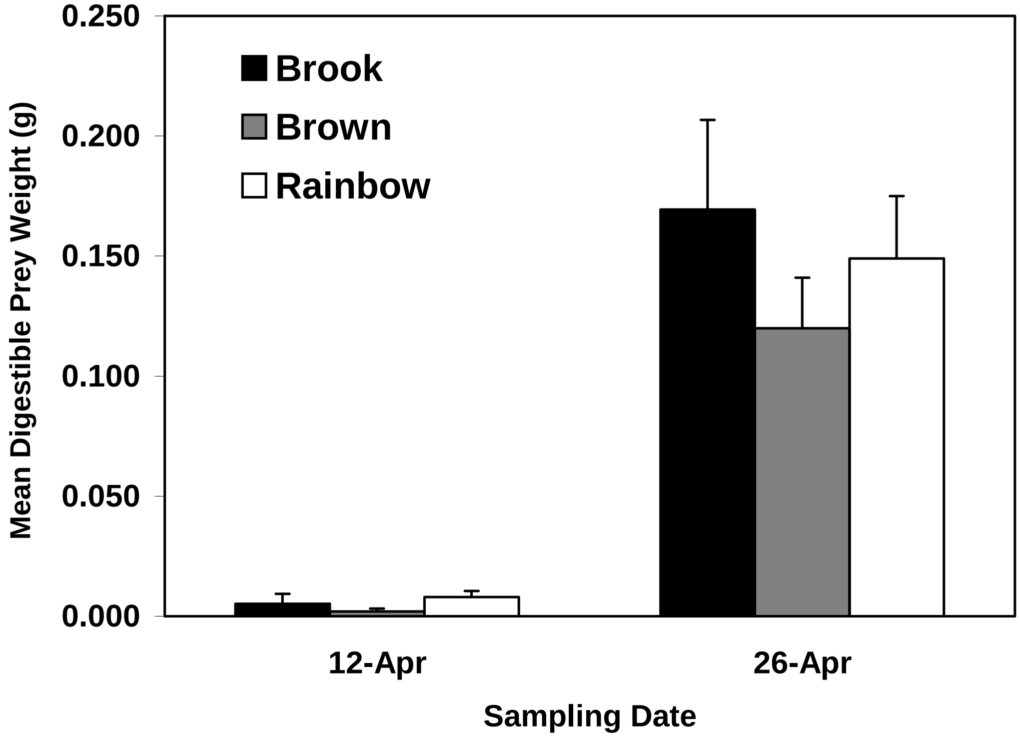

Figure 7. Mean digestible prey weight for brook trout, brown trout, and rainbow trout in the Watauga River, April 2007. Bars represent standard error.

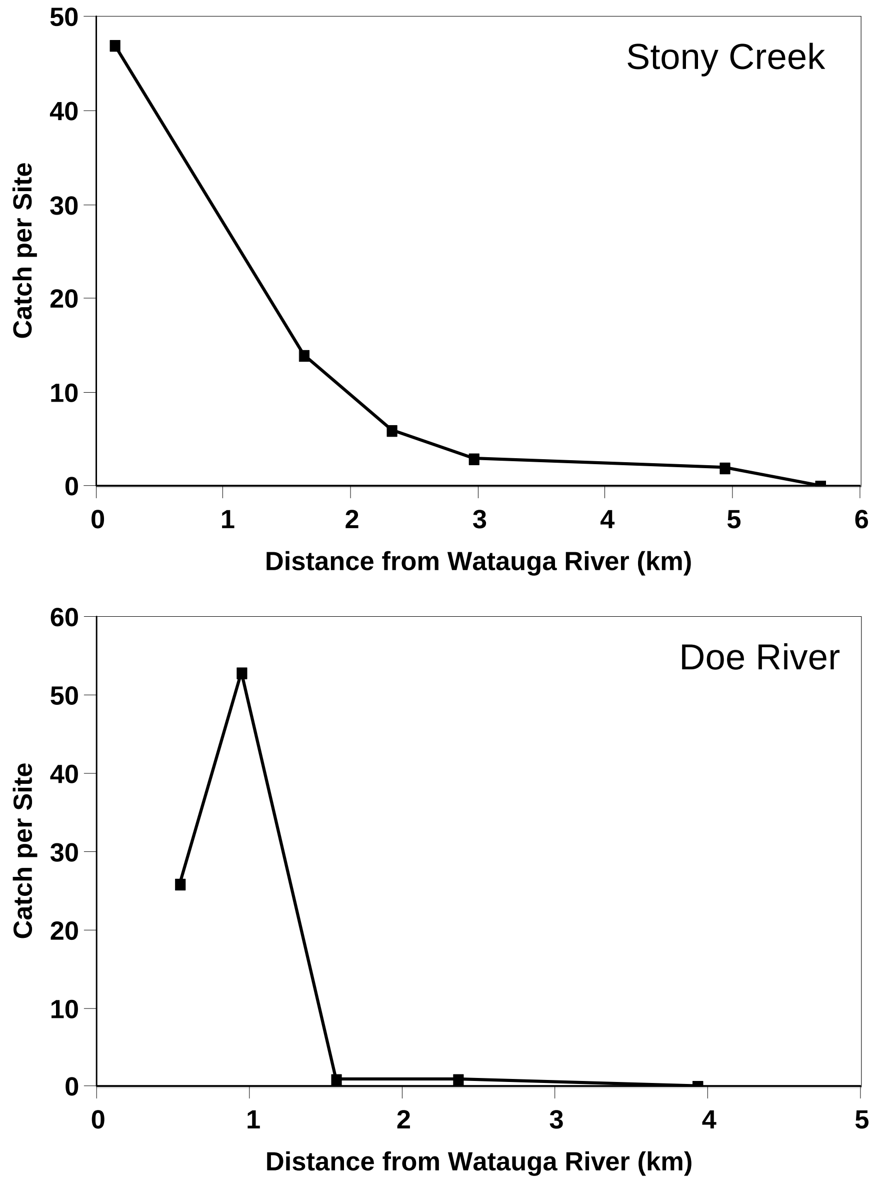

Figure 8. Catch of brook trout in two tributaries at increasing distances from the Watauga River. Fish movement is unobstructed in Stony Creek, but there is a low-head dam on the Doe River approximately 1 km upstream from the mouth of the river.

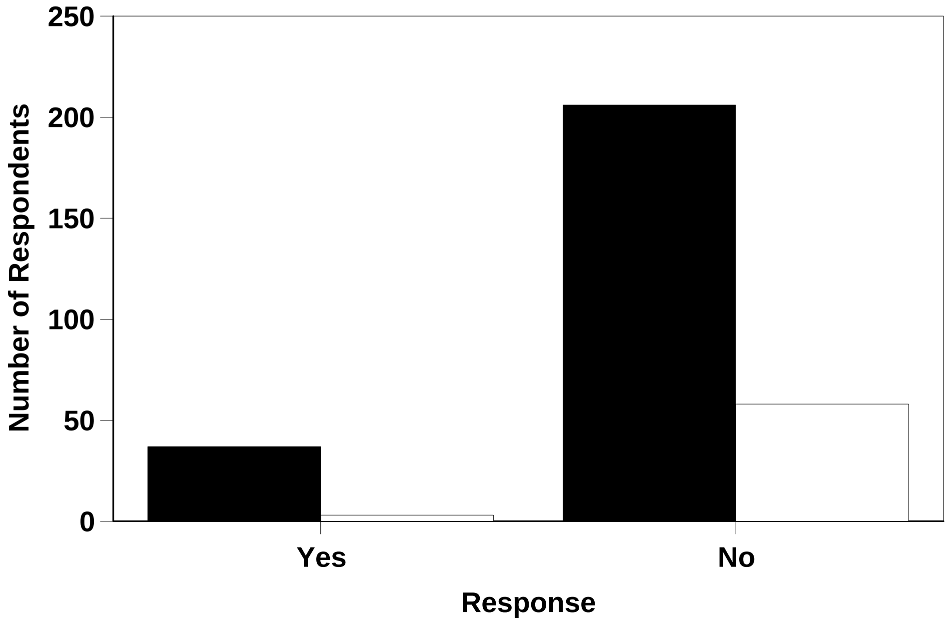

Figure 9. Responses of anglers asked the question, "*Have you ever caught a brook trout on the Watauga River?*" Black bars represent in-state residents while white bars represent out-of-state anglers.

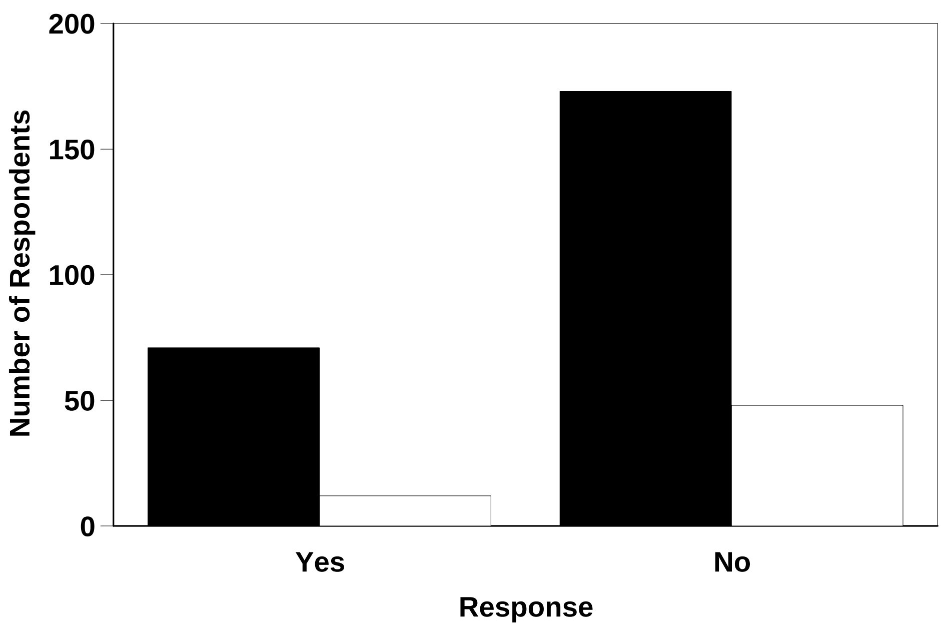

Figure 10. Responses of anglers asked the question, "*Are you aware that the TWRA stocks brook trout in the Watauga River?*" Black bars represent in-state residents while white bars represent out-of-state anglers.

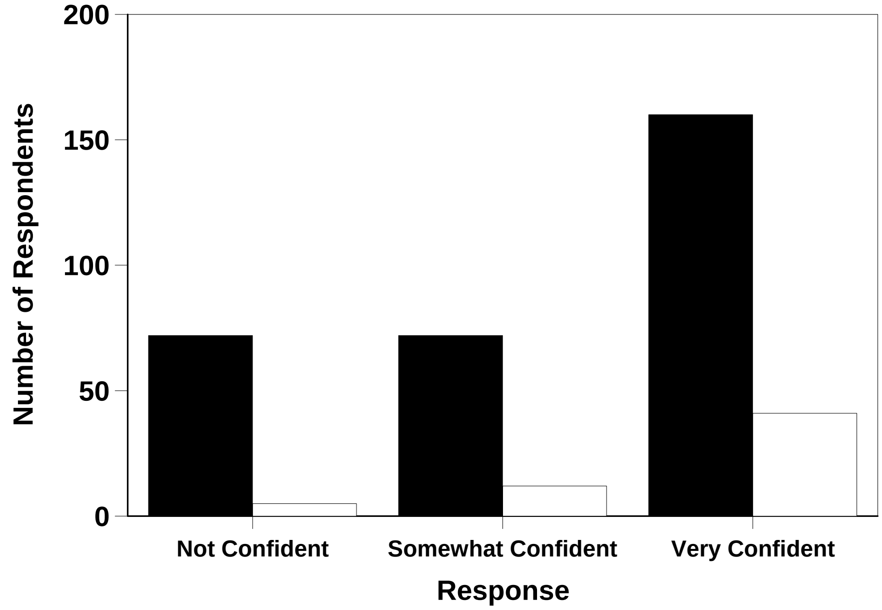

Figure 11. Responses of anglers asked the question, "*How confident are you in your ability to identify a brook trout from a brown or rainbow trout* (*Not Confident, Somewhat Confident, or Very Confident)?*" Black bars represent in-state anglers while white bars represent out-of-state anglers.

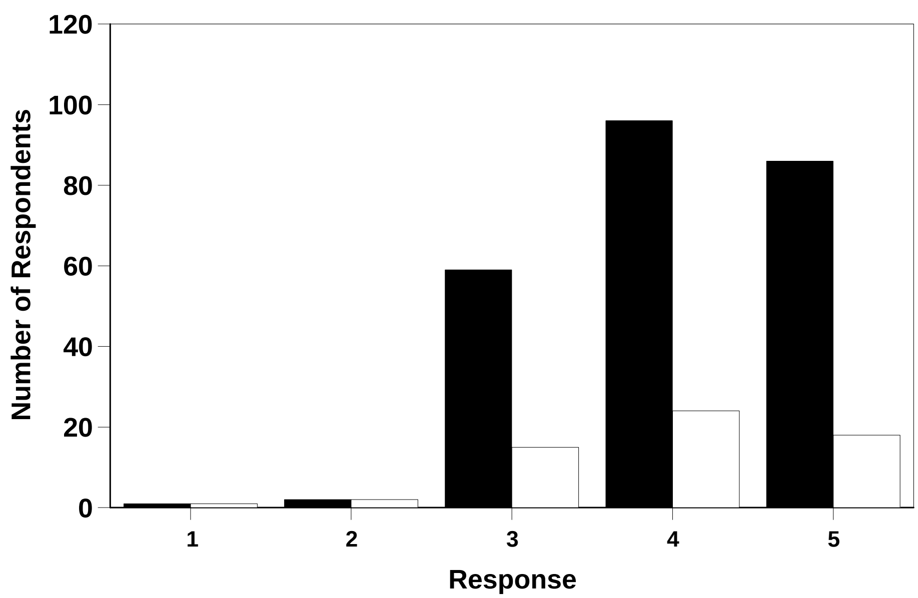

Figure 12. Responses of anglers asked the question, "*On a scale of 1 to 5 (poor → excellent), how would you rate TWRA's management of this fishery?*" Black bars represent in-state residents while white bars represent anglers from other states.