Fisheries Report 05-05

SURVIVAL, GROWTH, CONDITION, AND DIET OF STOCKED BROWN TROUT IN FIVE TENNESSEE TAILWATERS

A Final Report To

Mr. Frank C. Fiss
Tennessee Wildlife Resources Agency
Nashville, Tennessee

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Executive Summary

1. The performance of brown trout *Salmo trutta* stocked into five Tennessee tailwaters was evaluated using boat-mounted electrofishing gear at monthly or bimonthly intervals from April 2003 to April 2004. Over 97,000 brown trout were tagged with wire microtags or received adipose fin clips and 17,000-22,000 of these fish were stocked into each tailwater during spring 2003. The influence of water temperatures, dissolved oxygen concentrations, and diet on survival, growth, and condition of stocked brown trout was examined.

2. Survival was highest (90% over 200 d) in the South Fork of the Holston River, which had the lowest temperatures (< 20 °C), highest dissolved oxygen (> 6 mg/L), best habitat, and most consistent food base. Survival was lowest (26% over 200 d) in the Caney Fork River, where a combination of high discharge throughout the year, poor habitat, and low dissolved oxygen concentrations in late summer and fall existed. Intermediate rates of survival (43-55%) occurred in systems with high water temperatures (Hiwassee River) and high stocking rates (Clinch and Watauga Rivers).

3. Stocked brown trout in the Caney Fork, Clinch, and South Fork of the Holston Rivers grew faster than in the Hiwassee and Watauga Rivers. Brown trout in all rivers grew fastest in weight (0.78-1.51%-d^{-1}) in early or late spring when water temperatures were low (< 12.5 ºC) and food consumption rates were usually high. Slowest growth (-0.29-0.08%-d^{-1}) occurred in late summer and fall when water temperatures were the highest (13.4-21.2 ºC), regardless of food consumption rates.

4. Body condition declined or remained unchanged the first two weeks post-stocking in all rivers. Brown trout were not consistently in the best or worst condition in any river; however, fish in the South Fork of the Holston River were usually in the best condition and fish in the Hiwassee River were usually in the poorest condition.

5. When data from all rivers were pooled, growth (in weight) and body condition were significantly related to water temperatures. The amount of digestible biomass consumed by stocked brown trout explained little of the variation in growth or condition; however, in rivers with low alkalinity (Hiwassee and Watauga Rivers) where trout either preyed on low quality food items or consumed few items, fish grew significantly slower.

6. Overwintering brown trout biomass was highest in the South Fork of the Holston River (207 kg/ha), intermediate in the Caney Fork (41 kg/ha) and Watauga Rivers (85 kg/ha) and lowest in the Clinch River (34 kg/ha) and Hiwassee River (24 kg/ha).

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INTRODUCTION

In the early 1900s, the Tennessee Valley Authority (TVA) and the United States Army Corps of Engineers (USACE) constructed 40 dams in the Cumberland River and Tennessee River basins for flood control, hydroelectric power generation, and recreation (Moss 1967). In Tennessee, hypolimnetic discharges below 10 large storage facilities create coldwater habitats suitable for brown trout *Salmo trutta* (Parsons 1955). Since the early 1950s these systems have supported put-take and put-grow-take trout fisheries that are highly valued by many anglers (Parsons and Crossman 1956; Hutt 2003).

Reservoir releases subject tailwaters to large flow variations over a short period of time, with simultaneous changes in depth, water temperature and quality, and particulate matter load. Although the frequency and amount of discharge at each facility varies with regional power demands and seasonal rainfall in each watershed, it is not uncommon to experience 50-fold increases in daily discharge during normal operations. Prior to the early 1980s, trout populations suffered in many Tennessee tailwaters due to low dissolved oxygen (DO) concentrations and rapid temperature fluctuations during late summer and early fall. In an effort to improve reservoir releases, the TVA established minimum flows below all of its dams and constructed weirs and installed hub baffles and autoventing turbines at several facilities (Yeager et al. 1987; Scott et al. 1996).

Brown trout require high quality redd habitat and minimal water level fluctuations to reproduce. Below some TVA dams where minimum flow criteria and good habitat exists, natural reproduction is possible (Banks and Bettoli 2000). However, to maintain harvestable populations and provide opportunities for trophy angling, the Tennessee Wildlife Resource Agency (TWRA) annually stocks about 57,000 catchable (> 200 mm total length, TL) and 64,000 fingerling (< 150 mm TL) brown trout in Tennessee tailwaters (F. Fiss, TWRA, personal communication).

Much attention in Tennessee has been focused on determining the fate of stocked salmonids and measuring fishing pressure on tailwaters. Anglers typically catch few brown trout (0.02-0.52 fish/hr) and harvest even fewer fish (0.01-0.12 fish/hr; Bettoli and Besler 1996; Bettoli and Bohm 1997). Additionally, the percentage of stocked brown trout that are returned to the creel in the first fishing season is typically low (4-24%; Bettoli et al. 1999; Luisi and Bettoli 2001).

Concurrent with low catch and harvest rates are good overwintering survival rates of stocked brown trout in several Tennessee tailwaters (Bettoli and Bohm 1997; Bettoli 1999; Bettoli et al. 1999). Survival of stocked trout is variable among tailwaters and years; however, brown trout always survive better than rainbow trout *Oncorhynchus mykiss* (e.g., Besler 1996; Devlin and Bettoli 1999; Luisi and Bettoli 2001). Many factors affect trout survival in southeastern U.S. tailwaters, but high water temperatures and low DO concentrations in summer and fall are most influential (Grizzle 1981; Todd and Bly 2000; Luisi and Bettoli 2001). Water temperatures in Tennessee tailwaters may approach or exceed lethal limits for brown trout, resulting in poor growth and survival (Luisi and Bettoli 2001). In addition to direct mortality, increased water temperatures can disorient fish and increase their risk of predation (Davison et al. 1959; Coutant 1973). Low (< 2 mg/L) DO concentrations are lethal to unacclimated trout and negatively affect trout feeding behavior, growth (Davison et al. 1959), and susceptibility to bacterial pathogens (Grizzle 1981). Dissolved oxygen concentrations in the Caney Fork River below Center Hill Dam, Tennessee, frequently fall below 2.0 mg/L during September and October and influence the carrying capacity of trout (Devlin and Bettoli 1999).

Brown trout typically persist longer and reach trophy size more often than rainbow trout and many studies have examined their growth. Multiple variables interact on a seasonal basis to affect fish growth (Moyle and Cech 2000), but water temperature is thought to be the most influential factor for trout (Swift 1961). Although no consensus exists on the precise water temperature that maximizes brown trout growth, the influence of water temperature on growth rates is well established (Elliott 1975a; Allen 1985; Jensen and Berg 1995).

Water temperature directly affects metabolic rates of poikilotherms and consequently the amount of food required to support their growth (Elliott 1973). Sockeye salmon *Oncorhynchus nerka* fed maximum rations had optimum growth rates at 15 ºC; however, on maintenance rations the optimum growth temperature decreased to 5 ºC (Brett et al. 1969). Similarly, Elliott (1975b) reported that optimum growth temperatures for brown trout decreased from 13 ºC at maximum rations to about 5 ºC at maintenance rations. These studies indicated that at reduced rations and higher water temperatures, more energy was devoted to metabolism than to growth. Growth rates increased at lower water temperatures because metabolic energy costs were reduced and more energy was devoted to growth (Cada et al. 1987). When water temperatures exceed 19.5 °C, the energy required to maintain metabolism in some trout species exceeds the amount that can be ingested, leading to negative growth rates (Allen 1985; Cada et al. 1987).

Growth rates of trout are also influenced by quantity and quality of food available in the drift (Ellis and Gowing 1957; Cada et al. 1987; Filbert and Hawkins 1995). When water temperatures were optimal for growth (12-13 °C), brown trout in a Spanish stream ceased growing during winter because of a lack of food in the drift (Lobon-Cervia and Rincon 1998). There are several indications that trout growth in Tennessee tailwaters is limited in some seasons by food availability. Brown trout in the Caney Fork River grew faster in winter (17 mm and 61 g/month) than in summer and fall (8 mm and 10 g/month; Devlin and Bettoli 1999); whereas, stocked brown trout in two eastern Tennessee tailwaters grew faster during summer (15-18 mm and 22-28 g/month) than in fall and winter (5 mm and 5-10 g/d; Bettoli and Bohm 1997; Bettoli et al. 1999). Additionally, stocked brown trout grew fastest (15 mm and 13 g/month) in the spring in the Hiwassee River (Luisi and Bettoli 2001). These distinct differences in seasonal growth rates of stocked brown trout in Tennessee tailwaters suggest that food availability plays a large role in regulating their growth.

The diet of brown trout in southeastern U.S. tailwaters has been poorly documented. Large-scale flow fluctuations adversely affect macroinvertebrate abundance and diversity (Trotzky and Gregory 1974; Cushman 1985) and adequate trout forage may not be available year-round. Brown trout in the Elk River below Tims Ford Dam, Tennessee, frequently consumed terrestrial invertebrates and rarely had engorged stomachs (Besler 1996). A high proportion of terrestrial invertebrates in trout stomachs implied poor benthic production and resulted in poor growth and condition in that tailwater.

The condition of brown trout is known to vary among seasons in Tennessee tailwaters. In the Caney Fork River, brown trout condition decreased from May through

October, and then increased from November through March, which corresponded with increases in DO concentrations (Devlin and Bettoli 1999). Odenkirk (1987) and Kanehl (1989) also observed better condition of stocked brown trout in winter in the Caney Fork River. They concluded that more favorable water quality in winter and predation on entrained threadfin shad *Dorosoma petenense* increased the condition of trout. In several eastern Tennessee tailwaters, the condition of brown trout declined steadily after they were stocked (Bettoli 1999; Bettoli et al. 1999; Luisi and Bettoli 2001).

The objectives of this study were to: (1) compare the survival, growth, and condition of brown trout stocked into the Caney Fork, Clinch, Hiwassee, South Fork of the Holston, and Watauga rivers; (2) compare their seasonal food habits; (3) estimate brown trout population sizes and overwintering rates; and (4) relate body condition and growth to diets and water quality, particularly temperature.

STUDY AREAS

Caney Fork River.- Center Hill Dam is located on river kilometer 43 of the Caney Fork River in DeKalb County, Tennessee (Figure 1). The dam is about 32 km west of Cookeville, Tennessee, and 97 km east of Nashville, Tennessee. Construction of the dam by the USACE was completed in 1948. The reservoir formed by the dam is 103 km long and has a surface area of approximately 9,332 ha (USACE 1996). The Caney Fork River flows northwesterly 43 km to its confluence with the Cumberland River at Cumberland River km 492 in Smith County, Tennessee. Trout are managed by the TWRA from Caney Fork River km 43 to 69. Average discharge during power generation is 96, 201, and 303 m^3/s depending upon whether one, two, or three turbines are operating (Ramachandran 1986); maximum discharge can reach 382 m^3/s (Devlin 1998). During periods of generation, water levels in the tailwater may fluctuate more than 3 m. A minimum baseflow of 0.6 m^3/s occurs due to leakage at the dam during periods of no generation (Devlin and Bettoli 1999). The riffle:run:pool ratio in the Caney Fork River is 1.2:1.0:1.85 and instream cover is principally woody debris (Devlin and Bettoli 1999). Thermal stratification and high nutrient loads during late summer and early fall can expose fish to thermal shocks of up to 11 ºC and DO levels less than 2 mg/l (Ramachandran 1986; Devlin and Bettoli 1999).

Clinch River.- Norris Dam is located on river kilometer 128 of the Clinch River in Anderson County in east Tennessee (Figure 1), approximately 32 km northwest of Knoxville, Tennessee. Construction of the dam by the USACE was completed in 1936, forming the 13,846 ha Norris Reservoir. The Clinch River flows 22.5 km southwesterly to the headwaters of Melton Hill Reservoir. Hypolimnetic discharges through the facility's two turbines create coldwater habitat suitable for trout between Clinch River km 128 and 108. Maximum discharge for each turbine is approximately 114 m^3/s (Bettoli and Bohm 1997). Seepage from the reservoir is minimal and a flow re-regulation weir (3.2 km downstream) maintains a minimum flow of 5.7 m^3/s when the turbines are idle (TVA 1983, Yeager et al. 1987). Habitat in the Clinch River is mostly pools, shoals, and isolated rock formations (Bohm 1997). The Clinch River is relatively productive, with alkalinity levels ranging from 110-120 mg/L $CaCO_3$ (Luisi and Bettoli 2001). Dissolved oxygen concentrations in the fall were as low as 1 mg/L before the re-regulation weir was built and a more efficient autoventing system was installed in 1996. Higher DO concentrations (usually above 6 mg/L in summer and fall) and minimum flows have increased the abundance and distribution of benthic invertebrates, as well as trout carrying capacity and condition (Yeager et al. 1987; Scott et al. 1996).

Hiwassee River.- Appalachia Dam is located on river kilometer 106 of the Hiwassee River in Cherokee County, North Carolina, approximately 50 km east of Cleveland, Tennessee (Figure 1). The Tennessee Valley Authority completed construction of the dam in 1943, forming the 440 ha Appalachia Reservoir. Discharge from Appalachia Dam is piped approximately 14 km downstream to the Appalachia Powerhouse at Hiwassee River km 86.2 in Polk County, Tennessee. Maximum discharge from the two-turbine facility is approximately 80 m^3/s with an additional flow of approximately 2 m^3/s from the original river channel. In 1991, a minimum flow of 5.6 m^3/s was implemented by pulsing one generator every 4 h. Habitat composition in the upper section of the Hiwassee River is dominated by pools and shoals with a riffle:run:pool ratio of 0.9:1.0:1.2 (Luisi and Bettoli 2001). Alkalinity levels are the lowest of five Tennessee tailwaters (9-12 mg/L $CaCO_3$; Luisi and Bettoli 2001). Hub baffles were installed in 1993 to aerate the discharge, and in 1995 TVA initiated turbine venting and oxygen injection to achieve DO concentrations above 6 mg/L (Scott et al. 1996; Banks and Bettoli 2000).

South Fork of the Holston River.- The South Holston Dam is located on river kilometer 80.1 of the South Fork of the Holston River in Sullivan County, Tennessee, about 10 km southeast of Bristol, Tennessee-Virginia (Figure 1). Construction of the dam by TVA was completed in 1952, creating a reservoir with a 3,069 ha surface area at full pool (Moss 1967). The tailwater extends approximately 22 km to the headwaters of Boone Reservoir. The South Holston Dam is equipped with one generating turbine with a mean discharge of 28.4 m^3/s and maximum discharge of 85.5 m^3/s (Bettoli et al. 1999). An aerating labyrinth weir was constructed in 1991 about 2 km downstream of the dam and maintains a minimum flow of 2.5 m^3/s. Forty min pulses every 12 h from South Holston Dam maintain the weir pool during non-generation periods (Scott et al. 1996). Bettoli et al. (1999) calculated a riffle:run:pool ratio of 2.0:2.0:1.0 and the substrate is mostly scattered cobble and gravel. Good DO concentrations (> 6 mg/L), water temperatures (4-21 ºC), and alkalinity (94-110 mg/L $CaCO_3$) are present year round (Bettoli 1999; Luisi and Bettoli 2001).

Watauga River.- Wilbur Dam is located on river kilometer 55 of the Watauga River in Carter County in east Tennessee, 8 km east of Elizabethton (Figure 1). Wilbur Dam serves to re-regulate the releases from Watauga Dam, a much larger facility located just 4 km upstream. Construction of Wilbur Dam was completed in 1951 and created a small (2,603 ha) reservoir (Moss 1967). The Watauga River flows northwest 28 km to the headwaters of Boone Lake. Trout are managed in the Watauga River between Wilbur Dam and the town of Watauga, a distance of 26 river km. Wilbur Dam is equipped with three turbines capable of releasing 8.6 m^3/s and one turbine that releases 50 m^3/s. A minimum flow of 3 m^3/s was established in 1991 by generating one turbine for 1 h every 4 h. Habitat in the Watauga River most resembles the South Fork of the Holston River. The riffle:run:pool ratio is 2.0:1.6:1.0 (Bettoli 1999), but alkalinity levels are much lower in the Watauga River (32-43 mg/L $CaCO_3$; Luisi and Bettoli 2001). Hub baffles and turbine venting were installed on the Watauga Dam turbines, which elevated DO concentrations above 6.0 mg/L (Scott et al. 1996; Bettoli 1999).

METHODS

Marking and Stocking

Dale Hollow National Fish Hatchery (DHNFH) and TWRA stocked approximately 97,000 catchable brown trout in the Caney Fork, Clinch, Watauga, Hiwassee, and South Fork of the Holston Rivers in March or April 2003 (Table 1). Brown trout were stocked at locations traditionally used by TWRA and DHNFH in each tailwater. Stocking and fixed electrofishing transect location for each tailwater are provided by the following Tennessee Wildlife Resource Agency Fisheries Reports: Bettoli and Bohm 1997; Bettoli 1999; Bettoli et al. 1999; Devlin and Bettoli 1999; and Luisi and Bettoli 2001. All catchable brown trout stocked into the Caney Fork, Watauga, Clinch, and South Fork of the Holston Rivers were marked with uncoded wire microtags using Mark IV Automatic Tag Injectors (Northwest Marine Technology, Inc., Olympia, Washington). Fish stocked into the Caney Fork, Clinch, and South Fork of the Holston Rivers were tagged in the nape, and fish stocked into the Watauga River were tagged below the dorsal fin. Catchable brown trout stocked in the Hiwassee River were marked using adipose fin clips. To reduce handling stress, brown trout were anaesthetized using tricaine methanesulfonate (MS-222). The Food and Drug Administration (FDA) prohibits the immediate release of MS-222 treated foodfish; therefore, all brown trout were tagged a minimum of 21 d prior to stocking.

Field Sampling Procedures

Brown trout were sampled between March 2003 and March 2004 during periods of hydroelectric generation using a 4.9 m Tunnel Jon boat powered by a 60/45 horsepower jet-drive outboard motor. The DC electrofishing gear consisted of a 4500W generator, a Smith-Root Model GPP 2.5 electrofishing unit and five boom-mounted steel cable anodes. In the upper section of the Hiwassee River, brown trout were sampled using a 3.7 m SOTAR whitewater raft equipped with a 2.5 GGP Smith-Root electrofishing system and two boom-mounted anode arrays. Each stocking event in 2003 was followed within 10 d by an electrofishing survey and additional surveys were conducted approximately every 30-60 d to obtain diet, growth, and condition data. Survival was estimated by sampling fixed electrofishing transects (12 or 13 transects per river; 10 min runs) in the Caney Fork, Clinch, South Fork of the Holston, and Watauga Rivers during the first sample period and at approximately 4, 8, and 12 months post-stocking. Four electrofishing transects were established on the Hiwassee River and the amount of electrofishing on-time ranged from 15-39 min for each station; total on-time ranged from 1.9-2.0 h. In addition to the initial sample in March 2003, the Hiwassee River was sampled 4, 5, and 8 months post-stocking.

Brown trout captured in electrofishing samples were placed in an aerated livewell and anaesthetized using carbon dioxide. Lengths (mm; TL) and weights (nearest 1.0 g) were recorded for all brown trout. Hatchery brown trout were identified using a tag detection wand or by observing an adipose fin clip. Fixed sampling sites were not sampled twice within any three-month period because excessive electrofishing may negatively impact growth and long-term survival of salmonids (Gatz et al. 1986; McMichael 1993; Thompson et al. 1997).

Survival

Catch-per-unit-effort (CPUE) data from consecutive fixed-site electrofishing samples were used to calculate the instantaneous mortality rate (Z) of tagged brown trout in each tailwater. Catch-per-unit-effort is defined as the number of brown trout collected per 10 min of electrofishing. The instantaneous mortality rate for any Δt is described by the equation:

$$Z = \frac{\log_e \overline{X}_i - \log_e \overline{X}_{i+1}}{\Delta t}$$

where $\overline{X}_i$ and $\overline{X}_{i+1}$ are the average CPUE in consecutive samples. Two-hundred day and overwintering (i.e., percent surviving through April 1) survival rates were estimated by using the relationship between instantaneous mortality rates and survival

$$S = e^{-Zt}$$

where Z is the instantaneous mortality rate and S is the survival rate for t days. Mortality rates over the entire survey period ($\geq$ 9 months) were calculated in the same manner for each tailwater.

Growth and Condition

Specific growth rates (%-d^{-1}) were calculated using the following equation (Jensen and Berg 1995):

$$\frac{100(\log_e \overline{W}_2 - \log_e \overline{W}_1)}{\Delta t}$$

where $\overline{W}_1$ equals initial mean weight (g) and $\overline{W}_2$ equals final mean weight over Δt days. Rate of growth in length (TL, mm) was calculated by substituting mean length for mean weight in the same equation.

Interval growth rates (mm- or g-month^{-1}) in each tailwater were calculated by regressing mean lengths and weights against days post stocking. Mean total lengths and weights were calculated for each sample when six or more fish were captured. The slope of the regression line was declared significant at $\alpha = 0.10$. Analysis-of-covariance (ANCOVA) was subsequently used to detect differences among interval growth rates, where days post-stocking was the covariable and mean TL (or mean weight) was the dependent variable.

The slopes of the $\log_{10}$weight-$\log_{10}$length regression lines were not homogenous ($P < 0.05$) and adjusted mean weights could not be compared. Instead, mean relative weights of marked brown trout stocked into each tailwater were calculated (Milewski and Brown 1994) and a two-way ANOVA was used to assess differences in brown trout condition among the five tailwaters each sampling period. Mean relative weights were compared using Tukey's multiple comparison procedure.

Specific growth in length and weight, mean relative weight, mean digestible biomass, and mean interval water temperatures were pooled for all rivers on all dates and simple correlation analysis was used to determine the influence of diet and water temperature on growth and condition. Linear models were considered significant at $P = 0.05$.

Stomach Content Analysis

Tippets and Moyle (1978) reported that the contents from at least seven stomachs gave an adequate sample of taxa consumed by trout; therefore, sampling at each tailwater continued until a minimum of 7 marked brown trout were captured. To limit regurgitation of food items, brown trout were sacrificed with MS-222 overdoses, injected with 10% formalin, and put on ice. In the laboratory, stomachs were removed, fixed in 10% formalin, and placed in a numbered vial. Stomach contents were then placed into a Ward counting wheel and viewed under a dissecting microscope.

Stomach contents were separated into digestible (i.e., food items providing nutritional value) and non-digestible (e.g., plant material, pebbles, Trichoptera stone cases) material. Invertebrates were then identified to the lowest taxon (Merritt and Cummins 1996) and counted. In instances where stomach contents were predominantly microcrustaceans (i.e., cladocerans), contents were pooled and subsampled by placing the microcrustacean fraction into a graduated plastic Imhoff settling cone fitted with an aquarium air stone sealed into the bottom and connected to a compressed air supply (Wrona et al. 1982). The apparatus was filled to a total volume of 1 L, followed by agitation for 2-5 min. Five subsamples were taken from the solution with a 50-ml test tube and these samples were collectively filtered to obtain the microcrustacean fraction. Contents were then placed in the Ward counting wheel and identified to the lowest possible classification and counted. The number for each microcrustacean taxon was calculated by multiplying the subsample value by four.

After taxa were identified and enumerated, stomach contents from each trout were filtered and dried for 24 h at 60 ºC. Stomach contents were then weighed to the nearest 0.001 g to estimate mean digestible biomass per trout. Monthly diet was characterized by reporting pooled estimates of percent by number (number of prey items of a given taxa divided by total number of food items) and frequency of occurrence (percent of fish containing a given prey taxa). Numbers of major prey taxa consumed per trout during all sampling events were plotted to identify periods of increased importance of different taxa.

Two diet samples were collected during spring (April-June), summer (July-September), fall (October-December), and winter (January-March) at each tailwater. Samples were pooled by season and percent contributions (by number) of major prey taxa were plotted to examine seasonal diet patterns. Pooled estimates of mean biomass of prey per trout were calculated for each month and compared in each tailwater using Tukey's multiple comparison procedure and statements written for the Statistical Analysis System (SAS Institute 2001).

Population Estimates

Population estimates of holdover brown trout (i.e., any brown trout residing in a river prior to the first stocking of brown trout in the calendar year) were conducted in March and April 2003 in each tailwater using the change-in-ratio (CIR) technique (Paulik and Robson 1969):

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

where N_1 is the number of brown trout in the tailwater at time 1 (i.e., before stocking), R_x is the net change in the number of tagged trout in the tailwater (number of tagged brown trout stocked in April), R is the net change in the number of trout in the tailwater (equal to R_x), P_2 is the proportion of tagged trout in the sample at time 2, and P_1 is the proportion of tagged fish in the population at time 1 (equals 0). Variance of each estimate was calculated following 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 change in number of untagged trout. It was assumed that all fish greater than 120 mm TL were equally vulnerable to electrofishing. The standing crop of brown trout was estimated by multiplying the population estimate by the mean weight of fish in the census sample, and then dividing by the area (ha) stocked and sampled in each tailwater.

Temperature Recording and Dissolved Oxygen Readings

Water temperatures were recorded at each tailwater at 72-min intervals from March 2003 through March 2004 with temperature loggers. Two or three temperature loggers (Onset, Inc.) were placed in secure locations at each tailwater and data were uploaded using an m515 Palm Pilot®. Average daily temperatures between trout collections were calculated and daily minimum and maximum temperatures were plotted to identify periods where temperatures approached lethal levels. Dissolved oxygen readings were taken at irregular intervals (typically during fish sampling events) throughout the study using a YSI ® Model 55 D.O. meter.

RESULTS

Survival

The survival of brown trout stocked into the Caney Fork River in 2003 was poor and the lowest of any river; only 26% survived 200-d and only 9% survived to April 1, 2004. Few fish were collected after December 2003 (Table 2).

Brown trout stocked into the Clinch River in 2003 were observed in good numbers (n = 21-122 fish per sample) over the entire survey. Survival rates were 43% over 200-d and 22% to April 1, 2004.

Brown trout stocked into the Hiwassee River were routinely observed in all subsequent electrofishing samples, but the number of fish collected each sample was usually low (n = 6-25 fish per sample). The 200-d and overwintering survival rates were 55 and 33%, respectively.

The number of stocked brown trout collected in the South Fork of the Holston River was consistently high over 323 d (n = 34 - 68 fish per sample). Overwintering and 200-d survival rates were the highest observed for any river. Nearly 90% of the stocked brown trout survived 200-d and 83% survived to April 1, 2004.

Brown trout stocked into the Watauga River experienced poor survival; only 45% survived 200-d and only 25% survived to April 1, 2004. The number of fish collected in electrofishing samples plummeted after September 2003.

Growth

Stocked brown trout grew in length and weight in all five tailwaters ($P < 0.05$); however, growth was not similar among tailwaters (ANCOVA; $F > 8.54$; d.f. = 4, 30; $P = 0.0001$). Brown trout in the Caney Fork, Clinch, and South Fork of the Holston Rivers grew faster than fish in the Hiwassee and Watauga Rivers (ANCOVA; $F \geq 4.40$; d.f. = 1, 12; $P \leq 0.0577$). Brown trout grew at similar rates in the Caney Fork, Clinch, and South Fork of the Holston Rivers (ANCOVA; $F \leq 2.82$; d.f. = 1, 12; $P \geq 0.1184$). Brown trout grew in length at the same rates in the Hiwassee and Watauga Rivers (ANCOVA; $F = 2.27$; d.f. = 1, 12; $P = 0.1578$); however, they grew faster in weight in the Watauga River (ANCOVA; $F = 3.75$; d.f. = 1, 12; $P = 0.0766$). Instantaneous growth in length followed similar patterns as growth in weight in all tailwaters.

Microtagged brown trout in the Caney Fork River grew 13 mm and 27 g per month over the entire study, which was the fastest growth observed in this study. Brown trout nearly tripled in weight during the winter and grew at a mean rate of 54 g per month (Figure 2). Growth during the spring, summer, and fall was exceptional and ranged from 7-17 mm and 13-19 g per month. Instantaneous growth in weight ranged from –1.8 $\%\text{-d}^{-1}$ to 0.99 $\%\text{-d}^{-1}$ and fastest growth occurred in late spring 2003 and winter 2004 (Figure 3). Slowest growth occurred immediately post-stocking and from August to October 2003.

Monthly growth of brown trout stocked into the Clinch River averaged 12 mm and 22 g. During winter, average weight increased from 156 g to 305 g and fish grew 42 g per month (Figure 4). Growth during the spring, summer, and winter was faster (13-17 mm and 16-42 g/month) than growth during the fall (3 mm and -0.4 g/month). Instantaneous growth in weight ranged from –1.91 $\%\text{-d}^{-1}$ to 1.51 $\%\text{-d}^{-1}$; fastest growth occurred in late spring 2003 and late winter 2004 (Figure 5). Fish lost weight immediately post-stocking and between October and December 2003.

Stocked brown trout grew the slowest (5 mm and 5 g per month) in the Hiwassee River. Fastest growth occurred during the winter months when fish grew 16 mm and 27 g/month (Figure 6). Growth in weight during the spring and summer was slow (5-7 g/month) and negative during the fall (–4 g/month). Instantaneous growth in weight ranged from –0.29 $\%\text{-d}^{-1}$ to 0.78 $\%\text{-d}^{-1}$; fastest growth occurred in early spring of 2003 and late winter of 2004 (Figure 7). Growth was slow between June and August 2003 and negative between September and December 2003.

Microtagged brown trout stocked into the South Fork of the Holston River grew an average of 10 mm and 19 g/month. During the summer, fall, and winter they grew 9-13 mm and 19-23 g/month (Figure 8). Instantaneous growth in weight ranged from 0.008 $\%\text{-d}^{-1}$ to 0.43 $\%\text{-d}^{-1}$ (Figure 9). Fish experienced periods of fast growth (early spring, summer, early fall), slow growth (winter), and no growth (late spring, late fall).

Monthly growth of microtagged brown trout in the Watauga River averaged 7 mm and 8 g. Fastest growth (6-13 mm and 11-15 g/month) occurred during the spring, summer, and fall months; growth was negative during the winter months (–2 g/month; Figure 10). Instantaneous growth in weight ranged from -0.101 $\%\text{-d}^{-1}$ to 0.82 $\%\text{-d}^{-1}$ (Figure 11). Stocked brown trout in the Watauga River experienced periods of fast growth (late spring, late summer, late fall, late winter), slow growth (early spring, early summer), no growth (early fall), and negative growth (early winter).

Condition

Mean lengths and weights of brown trout when they were stocked differed among rivers; consequently, mean relative weights at stocking also differed (Table 1; $P < 0.05$). The main effect (i.e., river) and Date*River interaction term in the two-way ANOVA model were significant ($P < 0.0001$) and transformations would not eliminate the interaction. Brown trout were not consistently in the best, or worst, condition in any river on all dates; however, fish in the South Fork of the Holston River were usually in the best condition and fish in the Hiwassee River were usually in the poorest condition (Figure 12). In lieu of separately comparing relative weights among rivers on each of eight dates, a brief summary of trout condition over time in each river is provided below.

Relative weights of brown trout stocked into the Caney Fork River decreased after stocking and remained low through the winter (Figure 3). The decline in condition was linear for the first 302 days (June 2003 – January 2004; $P = 0.004$; $r^2 = 0.77$). Their condition improved significantly by March 2004, when the mean relative weight was 102 (Table 2).

The condition of brown trout stocked into the Clinch River varied considerably over the 359 d study (Figure 5). Following an initial drop in condition after stocking, mean relative weights were very high (104-113) in June and July 2003, but declined steadily through late summer and fall. The condition of brown trout was poor (Mean W_r = 82-83) by winter, but their condition improved significantly by April 2004 (Table 2).

Following an initial drop in condition after stocking, mean relative weights of brown trout stocked into the Hiwassee River remained stable (Mean W_r = 92-95) through mid-summer 2003, but then declined precipitously through late summer and fall (Figure 7; Table 2). Their condition in late November 2003 (Mean W_r = 78) was the lowest observed for any tailwater on any date, and they remained in poor condition through the last sample (January 2004).

Condition of brown trout stocked into the South Fork of the Holston River increased after stocking and relative weights never fell below 99 throughout the 323 d study (Table 2; Figure 9). Although condition was always high, mean relative weights were the lowest ($W_r = 99$) the first 42 d post-stocking and highest in December 2003 ($W_r = 105$).

The condition of brown trout stocked into the Watauga River increased slightly post-stocking, then remained fairly stable through October 2003 (Figure 11). Mean relative weights increased between October and December 2003 before dropping to their lowest level ($W_r = 87$-89) in January and March 2004 (Table 2).

Prey Utilization

Caney Fork River. - The mean size of 198 brown trout examined for food habits was 222 mm total length. Minimum and maximum total lengths were 130 mm and 346 mm, respectively. Few (15%) empty stomachs were observed and most of those (93%) occurred within one week of stocking. In that initial sample, 89% of brown trout consumed vegetation or algae and 46% consumed only these items. After 68 d, only 13% of brown trout consumed vegetation and invertebrate prey were consumed by all trout (N = 30). Over the entire study, cladocerans were consumed in the greatest quantity (66% of total number); however, cladocerans were not consumed in the fall (Table 3; Figure 13). On the basis of number of prey consumed, only three other taxonomic groups (Isopoda, terrestrial organisms, and Gastropoda) contributed substantially to the diet. Isopods were consumed frequently in the fall and winter, but were absent from the diet in summer and rarely consumed in the spring. Terrestrial organisms were only common in the diet in winter (41% by number). Fish made up less than one percent of the total number of food items consumed, but were an important food source during January 2004 when threadfin shad accounted for 90% of the dry weight prey biomass.

The number of organisms per stomach and mean digestible biomass was the lowest one week post-stocking (0.009 g and 1.7 food items/trout; Table 2). Mean digestible biomass was highest (≥ 1.6 g) in winter when trout consumed threadfin shad; whereas, the highest number of organisms consumed (147 food items/trout) occurred in July 2003 when fish consumed Cladocera.

Clinch River. - The mean size of 239 brown trout examined for food habits was 238 mm total length. Minimum and maximum total lengths were 129 mm and 365 mm, respectively. Similar to the Caney Fork River, few (2%) brown trout in the Clinch River had empty stomachs and most of those (80%) occurred within the first 9 d post-stocking. Of the 34 stomachs examined in April 2003, 35% contained vegetation or algae and 9% of fish consumed only these items. Over the entire study, Cladocera were consumed in the greatest quantity (83% of total number); however, cladocerans were consumed only in late spring and early summer (Table 3; Figure 14). Brown trout stomachs in June 2003 averaged 1,732 Cladocera; few other prey items were consumed in June and July 2003. No other brown trout cohort relied so heavily on cladocerans; only brown trout in the Caney Fork River consumed cladocerans in substantial numbers, and those fish relied much less on cladocerans than Clinch River brown trout. The only other prey taxon that contributed substantially to the diet (11% of total number consumed) was Diptera pupae, particularly in the fall and winter (Figure 8). Terrestrial organisms were most important in April 2003, August 2003, and January 2004 (Table 3). Gastropoda were infrequently consumed, but represented 18-22% of the total number of organisms consumed in August and December 2003.

Although fish never represented more than 1% of the total number of prey items consumed any month, fish (principally Clupeidae) made up 47 and 58% of the total dry weight biomass in January and March 2004, respectively. Mean dry weight of the digestible biomass was higher in January and March 2004 than on most other dates ($P < 0.05$; Table 2). From April 2003 to December 2003, the amount of digestible biomass per trout remained relatively stable.

Hiwassee River. - The mean size of 133 brown trout examined for food habits was 203 mm total length. Minimum and maximum total lengths were 145 mm and 271 mm, respectively. Empty stomachs were rare (2%); however, the number of food organisms consumed and mean digestible biomass were usually the lowest compared to all other rivers (Table 2). Over the entire study, Diptera pupae and terrestrial organisms were consumed in the greatest quantity (38 and 35%, respectively). Diptera pupae were consumed frequently in the spring and late fall to early winter. Terrestrial organisms were consumed during all seasons, but were more frequently consumed from June to October 2003 (Table 3; Figures 15). Only three other taxa (Trichoptera, Gastropoda and Ephemeroptera) made substantial numerical contributions to the diet. Mean digestible biomass was greatest in January 2004 when brown trout consumed fish, principally entrained Clupeidae (69% by weight; Table 3).

South Fork of the Holston River. - The mean size of 255 brown trout examined for food habits was 236 mm total length. Minimum and maximum total lengths were 146 mm and 352 mm, respectively. Of the 255 stomachs examined, only one stomach was empty. Trout consumed a diverse array of food items throughout the year; five of the nine classes of prey taxa each represented at least 10% of the total number of organisms consumed (Table 3). Sixty-four percent of all stomachs contained at least four different prey groups and 37% contained at least five different prey groups. Isopods and amphipods were the most common prey items consumed over the entire study (28% and 23% of total number, respectively) and were consumed in the greatest quantity (20-90 organisms/stomach) from late fall to late winter (Figure 16). Diptera pupae were consumed frequently (18-43% by number) from spring to early fall, and to a lesser degree from December 2003 to March 2004. Ephemeropterans were consumed frequently in the spring, summer, and winter, but were rarely consumed in fall. Gastropods were present in the diet in all months, but never represented more than 24% of all organisms consumed. The number of organisms per stomach and the mean digestible biomass were greatest in March 2004 when brown trout preyed heavily on isopods, ephemeropterans, and amphipods (Tables 2 and 3).

Watauga River. - The mean size of 215 brown trout examined for food habits was 212 mm total length. Minimum and maximum total lengths were 144 mm and 286 mm, respectively. Similar to fish in the South Fork of the Holston River, few (2%) brown trout in the Watauga River had empty stomachs and five of the nine classes of prey taxa contributed at least 10% to the total number of organisms eaten. However, the types of prey consumed in the Watauga River differed. Specifically, terrestrial organisms were a much more important group of prey items in the Watauga River than in the South Fork of the Holston River. In some months, terrestrial prey represented more than half of all organisms consumed (Table 3; Figure 17). Other prey groups (Diptera pupae, Ephemeroptera, Gastropoda, Trichoptera) were important in two or three seasons and isopods were consumed frequently in the winter.

The number of food items per stomach was highest (mean = 73.5) in June 2003 when trout preyed heavily on terrestrial organisms, diptera pupae, and ephemeropterans (Tables 2 and 3). During all other seasons, the number of food items per stomach never exceeded 40 and was usually lower than any other river except the Hiwassee River. The amount of digestible biomass consumed varied significantly over time and was highest in October 2003 when trout consumed high numbers of terrestrial organisms, diptera pupae, and trichopterans ($P < 0.05$).

Overwinter Population and Biomass Estimates

Microtagged brown trout (N = 19,765) were stocked in the Caney Fork River on 4-5 April 2003 and sampled 10-11 April 2003. Tagged trout were collected at all stations; thus, overwinter population estimates pertained to the entire reach (135 ha) managed for trout. The census sample (n = 170 brown trout longer than 120 mm TL) yielded 75 tagged brown trout; thus, the population estimate was 25,035 brown trout or 184 trout/ha (Table 4). The estimate was reasonably precise; 95% confidence limits were 17,301 and 32,770. The mean weight of brown trout in the census sample was 219 g and the estimated biomass was 41 kg/ha. The density and biomass of brown trout in the Caney Fork River in 2003 was the lowest of any of the five rivers examined in this study.

On 8-9 April 2003, microtagged brown trout (n = 19,540) were stocked in the Clinch River and sampled 16-18 April 2003. Few brown trout of any year class were collected below the last stocking site; therefore, overwinter population estimates for brown trout pertained to the upper 12 km of the tailrace. Of the 202 brown trout collected, 94 fish were tagged; therefore, an estimated 22,450 brown trout (95% CI: 16,111 – 28,784) or 161 trout/ha were in the tailwater before stocking began in 2003 (Table 4). The mean weight of brown trout in the census sample was 214 g; thus, brown trout biomass was 34 kg/ha, the second lowest of any of the five rivers.

On 18 and 21 March 2003, adipose fin-clipped brown trout (n = 21,757) were stocked in the Hiwassee River above Reliance, TN, and the river was sampled on 26 March 2003. The census sample yielded 28 brown trout, of which 19 were marked (Table 4). The estimated number of brown trout overwintering in the Hiwassee River was 10,306 fish, or about 69 fish/ha; however, the census sample and number of fish recaptured were small and the sample variance was high. Thus, the 95% confidence intervals for the population estimate ranged from less than 2,000 to more than 18,000 brown trout. The mean weight of brown trout was 355 g; thus, the estimated biomass of brown trout was only 24 kg/ha. That biomass estimate was the lowest of any of the five rivers and the 95% confidence interval was relatively large (5-44 kg/ha).

The South Fork of the Holston River was stocked with microtagged brown trout on 22-23 April 2003 and sampled 1 May 2003. The overwinter population estimate for brown trout pertained to the entire 22 km of the river managed for trout. Of the 300 brown trout captured, 61 fish were tagged; thus, an estimated 68,119 brown trout (774 trout/ha) resided in the river before stocking began in 2003 (Table 4). That estimate was reasonably precise (95% CI: 48,576 – 87,662). Brown trout averaged 268 g; thus, the biomass estimate for brown trout was 207 kg/ha. The South Fork of the Holston River had the highest density and biomass of brown trout of all other rivers.

On 16-17 April 2003, microtagged brown trout (n = 16,068) were stocked in the Watauga River and sampled 24 April 2003. The overwinter population estimate for brown trout pertained to the entire 26 km managed for trout. The census sample (n = 314) had 73 tagged brown trout, which yielded a population estimate of 53,046 (95% CI: 38,873 – 67,220), or about 394 trout/ha were in the river before stocking began in 2003 (Table 4). The mean weight of brown trout in the census sample was 215 g; thus, brown trout biomass was 85 kg/ha.

Thermal Environment and Incidence of Low Dissolved Oxygen Concentrations

Caney Fork River. - Water temperatures above 20 °C were observed on 16 d in late July and August 2003. The maximum water temperature recorded was 22 °C on 11 July 2003, the same date the river experienced the largest daily fluctuation in water temperature (7.7 °C). Daily fluctuations exceeding 5 °C were common between June and August 2003. The reservoir overturned in mid-November 2003 and water temperatures declined to 6 ºC on 22 February 2004 (Figure 18). Mean interval water temperatures between fish sampling events ranged from 7.7 to 16.8 °C (Table 2). Low (1.7 – 5.6 mg/L) dissolved oxygen concentrations were the norm between July and early October 2003 (Appendix Table A2).

Clinch River. - The highest water temperature (22.3 °C) and maximum fluctuation (12.7 °C) occurred on 22 June 2003 (Figure 19). Water temperatures exceeded 20 °C on only five other days. After Norris Reservoir overturned in early November 2003, minimum and maximum water temperatures varied less than 3.2 °C through the end of February. Mean interval water temperatures between fish sampling events in the Clinch River were similar and ranged from 7.1 to 16.6 °C (Table 2). Low (4.3-5.6 mg/L) dissolved oxygen concentrations were observed in early October 2003.

Hiwassee River. - Maximum water temperatures exceeded 20 °C on 78 d between 1 August and 31 October 2003 (Figure 20). Water temperatures never fell below 20 °C on 31 of those 78 days. The maximum water temperature (23.9 °C) occurred on 12 September 2003. In addition to elevated water temperatures, daily water temperature fluctuations exceeding 5 °C were common from late March to April 2003 and exceeded 9.5 °C on 23 March 2003. Mean interval water temperatures in the Hiwassee River were higher on average than in all other rivers and ranged from 11 to 21 °C (Table 2). Dissolved oxygen concentrations never dropped below 7.0 mg/L.

South Fork of the Holston River. – Water temperatures never exceeded 20 °C between 8 May 2003 and 27 March 2004; the highest water temperature (19.7 °C) was measured on 6 September 2003 (Figure 21). There were only 11 d in which water temperatures exceeded 17 °C and these events occurred sporadically. Although water temperatures rarely exceeded 19 °C, daily fluctuations of 5 °C or more occurred on 69 d and were most common from May to August 2003 and in March 2004. Mean interval water temperatures recorded between sampling ranged from 6.4 to 14.9 °C (Table 2). Dissolved oxygen concentrations never dropped below 6.0 mg/L.

Watauga River. – Similar to the South Fork of the Holston River, maximum water temperatures in the Watauga River never exceeded 20 °C. The warmest water (19.8 °C) occurred in early September 2003 (Figure 22). Water temperatures greater than 17 °C were observed on only 24 d, mostly in late summer. Daily water temperature fluctuations exceeding 5 °C were frequent (n = 139 d) and the temperature fluctuated more than 8°C on 39% of those days. The largest fluctuations in daily water temperature (~ 11 °C) occurred 30 June and 20 July 2003. Mean interval water temperature between sampling events ranged from 6.7 to 13.4 °C (Table 2). Dissolved oxygen concentrations never dropped below 7.0 mg/L.

Influence of Diet and Temperature on Growth and Condition

Correlations among the three measures of well-being (i.e., specific growth in length and weight, relative weight) were positive and all were significant ($P < 0.001$; $r \geq 0.54$). Specific growth in weight and mean relative weights were significantly correlated to mean interval water temperatures ($P < 0.04$; $r \geq 0.35$); however, specific growth in length was not correlated to water temperature ($P = 0.09$; $r = 0.28$). The mean weight of digestible biomass in trout stomachs was not correlated to any of the measures of well-being ($P \geq 0.26$; $r < 0.20$); however, the amount of digestible biomass in trout stomachs was positively correlated with water temperature ($P = 0.008$; $r = 0.45$).

DISCUSSION

Survival

The fate of stocked salmonids often depends on the amount of fishing pressure a river experiences. Trout angling in Tennessee tailwaters is highly valued by many user groups and fishing pressure can be intense (Hutt 2003; Williams 2003), but brown trout are often more difficult to catch than other salmonids and those that are caught are usually released (Anderson and Nehring 1984; Bettoli 1999; Luisi and Bettoli 2001). Delayed hooking mortality associated with catch-and-release fishing is usually low for trout and rarely influences total mortality (Wydoski et al. 1976). In addition, fishing pressure in tailwaters is usually low in years of above-average rainfall and discharge (Hanson 1977; Bettoli and Bohm 1997; Devlin 1998) and 2003 was one of the wettest years in the past decade in Tennessee (Appendix Table A3). Therefore, the influence of fishing mortality on survival of stocked brown trout in this study was deemed negligible.

Mortality rates varied more than 2-fold in this study and the poorest survival occurred in the Caney Fork River, which was the river with the poorest habitat, highest discharge, and lowest DO concentrations. Habitat varies among Tennessee tailwaters and is frequently used to describe trends in mortality (Bettoli et al. 1999; Devlin and Bettoli 1999; Luisi and Bettoli 2001). Contrary to the abundant boulder and cobble habitat found in eastern Tennessee rivers, few foraging and resting sites were available for trout in the Caney Fork River and 200-d survival rates were always low (26-34%; Devlin and Bettoli 1999; present study). Bachman (1984) studied the foraging behavior of stocked brown trout in Spruce Creek, Pennsylvania, and documented poor survival in areas where suitable microhabitats were scarce. Hunt (1969) modified stream habitat in areas where few resting and feeding areas were available, which subsequently increased trout survival. Coarse substrate and woody debris provide low water velocity habitats and brown trout seek these areas during periods of high discharge (Heggenes 1988). Average daily discharge during the past ten years was much higher in the Caney Fork River than all other rivers except the Clinch River (Appendix Table A3). A combination of poor habitat and high discharge probably caused high mortality of brown trout in the Caney Fork River.

Hypoxic conditions in the Caney Fork River (and to a lesser extent, the Clinch River) were common during late summer and early fall of 2003 (Appendix Table A2). Although low DO concentrations may cause direct mortality, suffocation is rare where oxygen deficiencies routinely occur because fish can acclimate to hypoxia (Kramer 1987). For instance, trout in the Chattahoochee River below Buford Dam, Georgia, acclimated to and survived DO concentrations near 1.0 mg/L (Grizzle 1981). Similarly, brown trout in the Caney Fork River were collected in habitats with DO concentrations as low as 1.7 mg/L. Although hypoxic conditions probably did not cause direct mortality, trout fitness was undoubtedly reduced.

When trout are exposed to extended periods of hypoxia, their immunity against bacterial pathogens is reduced, which can reduce survival (Grizzle 1981). In tailwaters below Lake Taneycomo, Missouri, and Norris Reservoir, Tennessee, the abundance of rainbow trout and large brown declined after a period of hypoxia (Weithman and Haas 1984; Bettoli and Bohm 1997). In this study, brown trout catch rates decreased 38% from August to December 2003. Devlin and Bettoli (1999) also observed a 73% decrease in stocked brown trout abundance during an extended period of hypoxia in the Caney Fork River. These results support the finding that brown trout survival in the Caney Fork River was compromised by low DO.

Striped bass *Morone saxatilis* predation may also have contributed to poor survival of stocked brown trout in the Caney Fork River. Congregations of striped bass were observed in the Caney Fork River in the late summer during this and previous studies (Devlin and Bettoli 1999). It is not uncommon for trout to be preyed upon by striped bass. Trout stocked below Tenkiller Dam, Oklahoma, and Hoover Dam, Arizona-Nevada, were the predominate prey of striped bass, which resulted in low creel returns (Deppert and Mense 1980; Walters et al. 1997). Devlin and Bettoli (1999) reported 13 trout in the stomach of one striped bass in the Caney Fork River. Although striped bass predation is recognized, few studies have attempted to estimate population-level effects of striped bass on stocked trout in Tennessee rivers.

Intermediate rates of 200-d survival (43-55%) in this study occurred in rivers with high water temperatures and high stocking rates. The upper incipient lethal temperature for rainbow trout acclimated to water temperatures of 10 ºC and 16 ºC was 25.6-27.0 ºC (Hokanson et al. 1977; Luisi and Bettoli 2001); however, the upper incipient lethal temperature for brown trout acclimated at temperatures between 12 and 23ºC was much lower (23 ºC; Cherry et al. 1977). Brown trout in this study were exposed to water temperatures above 23 ºC on one date in the Hiwassee River. Poor trout survival has been related to extended periods of high water temperatures (> 20 ºC; Johnstone and Rahel 2003). Water temperatures in the Hiwassee River historically exceed 20 ºC in summer and early fall and survival rates are usually low (13-55%; Luisi and Bettoli 2001; present study).

Stocking rates of fingerling (~ 100 mm TL) and catchable trout (both species combined) have doubled in the Clinch River from a quarter of a million per year between 1990-2001 to over half a million per year in 2002 and 2003. The current stocking rate is the highest of any Tennessee river (Habera et al. 2002; TWRA 2002) and the number of trout stocked may influence brown trout survival. In the Chattahoochee River below Buford Dam, Georgia, higher stocking rates in the absence of increased pressure and harvest led to lower survival and a 75% decline in abundance (Klein 2003). In the Clinch River, only 43% of stocked brown trout survived 200-d in 2003; however, 69% survived 200-d in 1995 when stocking rates were nearly 50% lower and harvest rates were much higher. The inverse relationship between survival and stocking rates has been observed elsewhere (Bachman 1984; Cada et al. 1987; Filbert and Hawkins 1995).

Stream-residing trout are often food limited and the effect of increased stocking rates is generally negative (Cada et al. 1987; Bettoli and Besler 1996; Klein 2003). The Watauga River has a long history of poor benthic production (Phitzer 1962; Bivens et al. 1997) and survival of stocked trout has been low (1-46% over 200 d; Bettoli 1999; present study). When compared to the South Fork of the Holston River, the abundance of benthic organisms in the Watauga River was 15 to 65% lower (Bivens et al. 1997), but stocking rates were higher (Frank Fiss, TWRA, personal communication). Even in productive tailwaters, high stocking rates reduce the prey base available to trout (Weiland and Hayward 1997). Bachman (1984) reported that every stream has an upper size limit of trout it can support based on invertebrate drift rates, regardless of the density of stocked trout. Historically, benthic production in the Watauga River was lowest during the winter (Phitzer 1962) and in the present study, trout prey consumption was also the lowest in winter. High stocking rates in the absence of adequate benthic productivity undoubtedly contribute to high natural mortality of brown trout in the Watauga River.

Survival rates of brown trout stocked into the South Fork of the Holston River in 2003 were the highest ever recorded for any tailwater in Tennessee. Few regulated rivers in Tennessee provide environments that allow good trout survival (Bettoli and Besler 1996; Devlin and Bettoli 1999), but the South Fork of the Holston River is one exception (Bettoli et al. 1999; present study). High survival rates can be attributed to cool water temperatures that rarely exceed 20 ºC, adequate DO concentrations year round (> 6 mg/L), good instream habitat, low predator densities, and good benthic productivity (Bettoli et al. 1999; Bivens et al. 1997; present study).

Growth

Growth in this study was calculated using the difference in a cohort's mean weight (or length) between consecutive dates; however, this method may be biased due to size-dependent trout movement and mortality, or from differences in growth of fish among river reaches. Stocked brown trout were larger in the upper reach of the Watauga River and growth rates in late fall and winter reflected the reach where the most fish were caught. This confounding effect was not observed on the other rivers; therefore, inferences on brown trout growth (and condition) in the Watauga River during the fall and winter were eliminated from the following discussion.

Stocked brown trout in all rivers consumed few prey in the first few weeks, but growth was not uniformly poor. Brown trout grew well in the Hiwassee, Watauga, and South Fork of the Holston Rivers, but grew poorly in the Caney Fork and Clinch Rivers. Others have observed poor foraging and growth of recently-stocked brown trout (Bachman 1984; Bettoli and Besler 1996).

After brown trout habituated to natural conditions, their growth in Tennessee tailwaters was influenced by a combination of water temperature and food availability. The effect of water temperature on trout growth has been frequently assessed (Pentelow 1940; Elliott 1975a; Spigarelli et al. 1982). Several investigators developed models to predict brown trout growth when fed to satiation at constant water temperatures (Elliott1975a; Elliott et al. 1995; Jensen and Berg 1995). In general, growth was maximized between 13 and 15 ºC and brown trout usually grew at water temperatures between 3.5-19.5 ºC. However, feeding to satiation may be infrequent in natural populations of stream-dwelling salmonids (Ellis and Gowing 1957; Cada et al. 1987; McKinney and Speas 2001). Field studies have shown that trout growth often reflects food availability (Lobon-Cervia and Ricon 1998; Railsback and Rose 1999; Nicola and Almodovar 2004). Dam releases adversely affect macroinvertebrate production, diversity, and density (Cushman 1985; Trotzky and Gregory 1974); thus, growth of trout in Tennessee tailwaters was expected to be less than what Elliot (1975a) observed for captive brown trout. However, growth in Tennessee tailwaters occasionally exceeded growth rates observed in laboratory settings. A generalized explanation of brown trout growth in Tennessee tailwaters is as follows: Brown trout in Tennessee tailwaters grew fast in the spring and summer, slow in early or late fall, and fast during the winter. A similar pattern was noted for brown trout in unregulated Spanish streams (Noicola and Almodovar 2004), California streams (Railsback and Rose 1999) and English streams (Mann et al. 1989), as well as in a laboratory setting (Jensen and Berg 1995). Previous studies of Tennessee tailwaters also noted seasonal differences in brown trout growth and concluded they were related to fluctuations in invertebrate production or physico-chemical constraints (Bettoli 1999; Devlin and Bettoli 1999; Luisi and Bettoli 2001).

Throughout the spring and summer, water temperatures in Tennessee tailwaters were conducive for good trout growth (i.e., 5 to 15 ºC; Railsback and Rose 1999); therefore, growth in each river was related mostly to the amount and type of prey items consumed. The magnitude of insect emergence and input from terrestrial or reservoir sources often influences trout growth (Cunjak and Power 1987). In the tailwater below Hartwell Dam, Georgia, drifting invertebrates that originated from the reservoir made up most of the drift in July (Matter et al. 1983). In some regulated rivers, entrained Cladocera are consumed but do not contribute substantially to the diet of trout or influence growth rates (Cushing 1963; Odenkirk and Estes 1991; Simpkins and Hubert 2000). Conversely, in this study brown trout in the Clinch and Caney Fork Rivers were frequently engorged with Cladocera from June to July and growth rates were excellent.

Likewise, rainbow trout stocked into two Utah reservoirs grew the fastest when cladocerans contributed substantially to the diet (Tabor et al. 1996).

An influx of food organisms from reservoir releases is not required for good trout growth to occur in Tennessee tailwaters. Rivers that experience regular periodic water level fluctuations may attain reasonably high production from macroinvertebrates that have adapted to these flow variations (Hudson and Nichols 1986). In the Hiwassee, Watauga, and South Fork of the Holston Rivers, aquatic invertebrates were consumed frequently from late spring to early summer and fish grew well.

If temperatures were elevated in the fall, brown trout grew slowly or lost weight, regardless of prey consumption rates. Depressed growth at high water temperatures has been observed in Tennessee rivers (e.g., Bettoli et al. 1999; Luisi and Bettoli 2001); however, this is the first study to identify temperature as the proximate cause of slow growth by brown trout in these same rivers. The amount of energy required to meet metabolic needs increases with temperature and at some point, little or none of the energy consumed is available for growth (Cada et al. 1987). Even when ample food resources are present, salmonid growth becomes depressed at temperatures somewhere between 19.5 and 23 °C (Brett et al. 1969; Elliot 1975a). Temperatures rarely reached these extremes in most Tennessee tailwaters, but growth was always slow at the highest water temperatures, regardless of how much food was available or consumed. These results suggest that even in rivers that rarely attained water temperatures acutely stressful to trout, modest increases in temperatures decreased trout growth.

Dissolved oxygen concentrations are also an important factor affecting growth of fishes. According to Davison et al. (1959), yearling coho salmon appetite decreased at low DO concentrations (2 mg/L), which resulted in substantial weight loss. Similarly, Todd and Bly (2000) and Cunjak and Power (1987) observed reduced prey consumption by trout and poor growth during hypoxic periods. Brown trout in the Caney Fork River experienced hypoxic water releases in the fall of 2003 and growth was slow. Devlin and Bettoli (1999) also noted slow growth of stocked brown trout in the Caney Fork River during fall when DO concentrations fell below 2 mg/L. Although TVA modified its hydroelectric facilities to improve reservoir releases (Scott et al. 1996), DO concentrations below Center Hill Dam (USACE facility) consistently fall below Tennessee state standards (6 mg/L; TDEC 2000) in late summer and fall and impair trout growth (Devlin and Bettoli 1999; present study). Dissolved oxygen concentrations also dropped below 6.0 mg/L in the Clinch River in the fall, which has been observed in previous studies (Bohm 1997), and growth (in weight) was also depressed.

Growth of brown trout increased in winter as water temperatures decreased, DO concentrations increased, and the abundance of entrained prey fish increased. Stocked brown trout often become more piscivorous as they increase in size (Weiland and Hayward 1997), provided that prey fish are available. The entrainment of clupeids, particularly threadfin shad, often occurs in reservoirs that cool below 10 °C (Griffith and Tomljanovich 1975); these entrained fish provide important winter forage for trout in many tailwaters (Weiland and Hayward 1997; Todd and Bly 2000). Brown trout in the Caney Fork, Clinch, and Hiwassee Rivers regularly consumed clupeids in the winter of 2003-2004 and growth increased 3 to 6 fold. Parson (1955) and Odenkirk and Estes (1991) also observed threadfin shad in the diet of trout in the Caney Fork River, but they did not assess changes in growth.

In the South Fork of the Holston River, brown trout consumed similar amounts of aquatic and terrestrial invertebrates in fall and winter and growth increased as water temperatures decreased. Cada et al. (1987) also observed faster growth in winter in five Appalachian streams. Brown trout in the South Fork of the Holston River never appeared to be food limited and water temperatures were always in the range where growth is usually good; therefore, declining water temperatures from fall to winter appeared responsible for the increased growth.

Filbert and Hawkins (1995) noted that the number of foraging sites and population density influenced trout growth. Artificially high fish densities resulting from an intensive stocking program can limit the amount of foraging habitat, increase intraspecific competition, and reduce growth (Bachman 1984; Weiland and Hayward 1997). The number of adult and fingerling trout stocked in 2003 into the five rivers in this study ranged from 66,500 to more than 250,000 fish per river. The potential for competition exists where natural reproduction occurs, trout survival rates are high, or both (e.g., Clinch River, South Fork of the Holston River). Trout stocked at densities of 1,400 fish/ha degraded the food base and experienced poor growth in the White River below Lake Taneycomo, Missouri (Weiland and Hayward 1997). Simpkins and Hubert (2000) suggested negative effects occur at even lower stocking rates and densities. Tennessee rivers in 2003 were stocked at rates of 1,467 to 3,895 adult and fingerling trout/ha. These stocking densities may be too high, particularly in rivers with limited riffle habitat and instream structures suitable for foraging (e.g., Caney Fork River).

Condition

The mean body condition of stocked brown trout in Tennessee tailwaters declined or remained the same the first two weeks post-stocking. Decreased post-stocking condition of trout in regulated rivers is not uncommon (Bettoli and Besler 1996; Bettoli 1999; Devlin and Bettoli 1999). Rivers that were stocked with brown trout in the best condition ($W_r > 100$; Caney Fork and Hiwassee Rivers) decreased in condition the most. Acute decreases in condition may be caused by the inability of the system to support overweight hatchery fish or hatchery fish expending too much energy habituating to a new environment (Ersbak and Haase 1983; Bachman 1984).

Condition indices are linked to prey availability and water quality and reflect the vigor of the animal (Liao et al. 1995; Anderson and Neumann 1996). Despite the initial decrease in brown trout condition, body condition throughout the spring and summer was good (mean $W_r \geq 92$) in most rivers. In rivers where fish were in the highest condition they consumed, on average, the most prey items. Brown trout in the Caney Fork and Clinch Rivers preyed heavily on entrained food items (i.e., Cladocera) in late spring and early summer and were especially plump. Odenkirk and Estes (1991) also observed robust rainbow trout in the Caney Fork River when Cladocera were preyed on heavily.

Todd and Bly (2000) investigated the effect of low (< 6 mg/L) DO concentrations on the health and condition of brown trout in the Norfolk River below Norfolk Dam, Arizona. During the summer and fall, fish health was poor in the reach near the dam due to hypoxic releases, but recovered further downstream. No differences were detected in trout condition among reaches of the Caney Fork and Clinch Rivers, both of which experienced hypoxic conditions in the fall. This was expected because the entire study area in each river was affected, to some extent, by low DO concentrations and few (if any) DO refuges were available to trout.

Prey availability was probably the single most important factor influencing the condition of brown trout in the Hiwassee and Watauga Rivers. They consumed few prey items in summer, fall, and winter and trout condition was poor. Instream productivity in the Hiwassee and Watauga Rivers is low (Phitzer 1962; USACE 1997; Bivens et al. 1997) and reduces the potential for these systems to support a high-density trout population.

By late winter, the condition of trout in the Caney Fork, Clinch, and Hiwassee Rivers increased 9-17%. Increased trout condition during this period is attributed, in part, to increased piscivory. Over 40% of brown trout collected during winter in the Caney Fork, Clinch, and Hiwassee Rivers consumed clupeids. Odenkirk and Estes (1991) found that stocked rainbow trout in the Caney Fork River frequently consumed threadfin shad in winter and condition of those fish was also high.

Prey Utilization

Cada et al. (1987) observed that the number of prey items consumed by trout was directly related to the number of food items in the drift. The number of food organisms per trout stomach in this study varied greatly (1.7 to 1,747 organisms per stomach). In the Caney Fork, Clinch, and Watauga Rivers, prey consumption was highest in late spring and early summer, decreased throughout the late summer and fall, and increased in the winter. Conversely, stomachs of brown trout in the South Fork of the Holston River always contained high numbers of prey. The relative paucity of food items in brown trout stomachs in the Hiwassee and Watauga Rivers suggested that trout in these systems were frequently food limited. Prey consumption rates were seldom above 30 items/fish and on numerous occasions, trout stomachs contained less than 20 prey items. These consumption rates were comparable to food-limited trout streams in eastern Tennessee (2.4-19.7 organisms per brown trout; Cada et al. 1987) and western North Carolina (7.7-12.5 organisms per brown trout; Tebo and Hassler 1963), but much less than the rates reported for a Michigan stream (58 organisms per trout stomach; Ellis and Gowing 1957).

A poor food base may also be characterized by a lack of nutritional food items. In the Elk River, Tennessee, benthic production and trout prey consumption were low and most trout ate organisms with low nutritional value such as gastropods and dipterans (Bettoli and Besler 1996). Similarly, in Causey Reservoir, Utah, rainbow trout consumed large quantities of mollusks when other food items were unavailable (Tabor et al. 1996). In this study, gastropods and trichopterans with silk cases were commonly consumed by stocked brown trout in the Watauga River and Hiwassee River and represented a large proportion of the dry weight biomass of the stomach contents each month. The remains of mollusk shells and trichopteran cases were usually intact in the large intestine, indicating that these items were difficult to digest and provided little nutritional value.

Overwintering Population and Biomass Estimates

Fish in lotic ecosystems are influenced by food, physical habitat, discharge patterns, biotic interactions, water quality, and temperature (Orth 1987). In this study, biomass of brown trout was lowest in the rivers with the poorest habitat and highest discharges. As with most large tailwaters, discharge patterns in the Caney Fork and Clinch Rivers increased daily by as much as 80-fold, sometimes within a few hours. Habitat that provides a hydraulic refuge in these two systems was limited (particularly in the Caney Fork River) and stocking large numbers of trout exacerbates the problem. Similar relations between trout biomass and amount of instream cover were noted in the Green River, Fontenelle Dam, Wyoming (Wiley and Dufek 1980) and the White River, below Beaver Dam, Arkansas (Quinn and Kwak 2000).

Modde et al. (1991) suggested that a combination of deep pools and swift water shoals provided trout with efficient foraging areas and hydraulic refuges during high discharge, which increased trout biomass. In the Watauga, Hiwassee, and South Fork of the Holston Rivers, these habitats were readily available to brown trout and river discharges were much lower than in the Caney Fork and Clinch Rivers (Appendix Table A3); consequently, the biomass of brown trout was higher.

Brown trout biomass was also lower in rivers with low alkalinity. Alkalinity in the Hiwassee and Watauga Rivers (9-43 mg/L $CaCO_3$) was much lower than the alkalinity of the South Fork of the Holston River (94-110 mg/L $CaCO_3$; Luisi and Bettoli 2001), where the biomass estimate was 144% to 762% higher. Low trout standing crops were associated with low alkalinity in headwater streams of the Copper Lake watershed, Newfoundland (Clarke and Scruton 1999), and streams of northern Colorado (Scarnecchia and Bergersen 1987) and northern Minnesota (Waters et al. 1990). Alkalinity does not directly affect trout biomass, but acts indirectly by influencing primary productivity, macroinvertebrate densities. Macroinvertebrate density is positively correlated to increased alkalinity (Koetsier et al. 1996; Miserendino and Pizzolon 2003).

The overwintering population and biomass estimates of brown trout in 2003 were higher than in previous years (Bettoli and Bohm 1997; Bettoli et al. 1999; Bettoli 1999; Luisi and Bettoli 2001). Higher biomass and density might be attributed, in part, to higher stocking rates in recent years. The number of catchable brown trout stocked in the five Tennessee rivers examined in this study increased from 2 to 70% since 2000.

Natural recruitment may also influence trout biomass and population size. Brown trout reproduce in the Watauga and South Fork of the Holston Rivers (Banks and Bettoli 2000) and the standing crop is always high in these systems (Bettoli 1999; Bettoli et al. 1999; present study). A similar relation between trout recruitment and cohort size was observed in a Spanish stream (Lobon-Cervia 2003).

CONCLUSIONS

The results from this study confirm the findings of previous studies regarding factors limiting brown trout populations in Tennessee tailwaters. High temperature, low DO, poor habitat, and a depauperate food base were collectively or individually responsible for limiting the survival and growth of stocked brown trout in four of the rivers. The South Fork of the Holston River was the only system in which none of these environmental factors were limiting and stocked brown trout foraged, grew, and survived well. Brown trout in the Caney Fork River would clearly benefit if DO conditions in late summer and fall met the Tennessee standard of 6 mg/L. Brown trout in the Caney Fork River would also benefit if a minimum flow regulation were enacted. Unlike other limiting factors, the lack of minimum flows and hypoxic discharges can be manipulated and engineering solutions are possible. In contrast, chemical properties such as low alkalinity in the Watauga and Hiwassee Rivers constrain primary and secondary productivity and cannot be manipulated. Stocking density in those two systems is probably the most important factor influencing the survival and growth of stocked trout; however, little research has been conducted to determine appropriate stocking rates in unproductive rivers. The doubling of the number of trout (both species and all sizes) stocked into the Clinch River each year beginning in 2002 has been treated as an experiment (F. Fiss, TWRA, personal communication). Our findings suggest that the carrying capacity of the Clinch River is being approached, or perhaps exceeded. Stocked brown trout experienced much lower 200-d survival rates in 2003 (43%) than in 1996 (70%), yet both years were “wet” years of above average discharges and no appreciable harvest of stocked brown trout occurs in any year. Determining stocking rates suitable for productive and unproductive rivers that allow specific management objectives to be met should be a research priority.

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REFERENCES

Allen, K. R. 1985. Comparison of the growth rate of brown trout in a New Zealand stream with experimental fish in Britian. Journal of Animal Ecology 54:487-495.

Anderson, R. and R. Nehring. 1984. Effects of a catch-and-release regulation on a wild trout population in Colorado and its acceptance by anglers. North American Journal of Fisheries Management 4:257-265.

Anderson, R. O., and R. M. Neumann. 1996. Length, weight, and associated structural indices. Pages 447-482 *in* B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

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.

Banks, S. M., and P. W. Bettoli. 2000. Reproductive potential of brown trout in Tennessee tailwaters. Fisheries Report No. 00-19. Tennessee Wildlife Resource Agency, Nashville, Tennessee.

Besler, D. A. 1996. Fate of salmonids stocked into the Tims Ford tailwater, Tennessee. M. S. Thesis. Tennessee Technological University, Cookeville.

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 Resource Agency, Nashville, Tennessee.

Bettoli, P. W. and D. A. Besler. 1996. An investigation of the trout fishery in the Elk River below Tims Ford Dam. Fisheries Report No. 96-22. Tennessee Wildlife Resource Agency, Nashville, Tennessee.

Bettoli, P. W. and L. Bohm. 1997. Interim report and summary of project activities: Clinch river trout investigations and creel survey. Fisheries Report 97-39. Tennessee Wildlife Resource 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 99-3, Tennessee Wildlife Resource Agency, Nashville.

Bivens, R. D., B. D. Carter, and C. E. Williams. 1997. Trout Fisheries Report Region IV 1997. Fisheries Report 98-3. Tennessee Wildlife Resources Agency, Nashville, Tennessee.

Bohm, L. A. 1997. Spatial and temporal variation in habitat and prey use by trophy rainbow trout and brown trout in the Clinch River below Norris Dam, Tennessee. M.S. Thesis. Tennessee Technological University, Cookeville, Tennessee.

Brett, J. R., J. E. Shelbourn, and C. T. Shoop. 1969. Growth rate and body composition of fingerling sockeye salmon, *Oncorhynchus nerka*, in relation to temperature and ration size. Journal of the Fisheries Research Board of Canada 26:2363-2394.

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.

Cherry, D. S., K. L. Dickson, J. Carns, Jr., and J. R. Stauffer. 1977. Preferred, avoided, and lethal temperatures of fish during rising temperature conditions. Journal of the Fisheries Research Board of Canada 34:239-246.

Clarke, K. D., and D. A. Scruton. 1999. Brook trout production in the streams of a low fertility Newfoundland watershed. Transactions of the American Fisheries Society 128:1222-1229.

Coutant, C. C. 1973. Effect of thermal shock on vulnerability of juvenile salmonids to predation. Journal of the Fisheries Research Board of Canada 30:965-973.

Cunjak, R. A., and G. Power. 1987. The feeding and energetics of stream-resident trout in winter. Journal of Fish Biology 31:493-511.

Cushing, C. E. 1963. Filter feeding insect distribution and planktonic food in the Montreal River. Transactions of the American Fisheries Society 92:216-219.

Cushman, R. M. 1985. Review of ecological effects of rapidly varying flows downstream from hydroelectric facilities. North American Journal of Fisheries Management 5:330-339.

Davison, R. C., W. P. Breese, C. E. Warren, and P. Doudoroff. 1959. Stream pollution: experiments on the dissolved oxygen requirements of cold-water fishes. Sewage and Industrial Waste 31:949-966.

Department of Environmental Conservation. 2000. State of Tennessee water quality standards, general water quality criteria. Chapter 1200-4-3.

Deppert, D. L. and J. B. Mense. 1980. The effect of striped bass predation on an Oklahoma trout fishery. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 33:384-392.

Devlin, G. J. Jr. 1998. Population dynamics of salmonids stocked into the Caney Fork River below Center Hill Dam, Tennessee. M. S. Thesis. Tennessee Technological University, Cookeville.

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 Resource Agency, Nashville, Tennessee.

Elliott, J. M. 1973. The food of brown and rainbow trout in relation to the abundance of drifting invertebrates in a mountain stream. Oecologia 12:329-347.

Elliott, J. M. 1975a. The growth rate of brown trout fed on maximum rations. Journal of Animal Ecology 44:805-821.

Elliott, J. M. 1975b. The growth rate of brown trout (*Salmo trutta* L.) fed on reduced rations. Journal of Animal Ecology 44:823-842.

Elliott, J. M., M. A. Hurley, and R. J. Fryer. 1995. A new, improved growth model for brown trout, *Salmo trutta*. Functional Ecology 9:290-298.

Ellis, R. J., and H. Gowing. 1957. Relationship between food supply and condition of wild brown trout in a Michigan stream. Limnology and Oceanography 2:299-308.

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.

Filbert, R. B., and C. P. Hawkins. 1995. Variation in condition of rainbow trout in relation to food, temperature, and individual length in the Green River, Utah. Transactions of the American Fisheries Society 124:824-835.

Gatz, A. J., Jr., J. M. Loar, and G. F. Cada. 1986. Effects of repeated electroshocking on instantaneous growth of trout. North American Journal of Fisheries Management 6:176-182.

Griffith, J. S. and D. A. Tomljanovich. 1975. Susceptibility of threadfin shad to impingement. Proceedings Annual Conference Southeastern Association of Game and Fish Commissioners 29:223-234.

Grizzle, J. M. 1981. Effects of hypolimnetic discharge on fish health below a reservoir. Transactions of the American Fisheries Society 110:29-43.

Habera, J. W., R. D. Bivens, B. D. Carter and C. E. Williams. 2002. Region IV trout fisheries report 2002. Fisheries Report 03-03. Tennessee Wildlife Resources Agency, Nashville, Tennessee.

Hanson, W. D. 1977. Tailwater fisheries of Lake of the Ozarks and Pomme De Terre Lake, Missouri. Proceedings Annual Conference Southeastern Association of Fish and Wildlife Agencies 31:505-513.

Heggenes, J. 1988. Effects of short-term flow fluctuations on displacement of, and habitat use by, brown trout in a small stream. Transactions of the American Fisheries Society 117:336-344.

Hokanson, K. E., C. F. Kleiner, and T. W. Thorslund. 1977. Effects of constant temperatures and diel temperature flucuations on specific growth and mortality rates and yield of juvenile rainbow trout. Journal of the Fisheries Research Board of Canada 34:639-648.

Hudson, P. L., and S. J. Nichols. 1986. Benthic community of the Savannah River below a peaking hydropower station. Journal of the Elisha Mitchell Scientific Society 102:107-121.

Hunt, R. L. 1969. Effects of habitat alteration on production, standing crops and yield of brook trout in Lawrence Creek, Wisconsin. Pages 281-312 *in* T. G. Northcote, editor, Symposium on salmon and trout in streams. H. R. MacMillan Lectures in Fisheries, Vancouver, Canada.

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.

Jensen, J. W., and T. Berg. 1995. The annual growth rate cycle of brown trout. Progressive Fish-Culturist 57:231-237.

Johnstone, H. C. and F. J. Rahel. 2003. Assessing temperature tolerance of bonneville cutthroat trout based on constant and cycling thermal regimes. Transactions of the American Fisheries Society 132:92-99.

Kanehl, P. D. 1989. Growth and movement of stocked trout in the Center Hill Lake tailwater, Tennessee. M. S. Thesis. Tennessee Technological University, Cookeville.

Klein, L. 2003. Investigation of the trout fishery in the Chattahoochee River below Buford Dam. Georgia Department of Natural Resources, Wildlife Resources Division, Social Circle, Georgia.

Koetsier, P., G. W. Minshall, and C. T. Robinson. Benthos and macroinvertebrate drift in six streams differing in alkalinity. Hydrobiologia 317:41-49.

Kramer, D. L. 1987. Dissolved oxygen and fish behavior. Environmental Biology of Fishes 18:81-92.

Liao, H., C. L. Pierce, D. H. Wahl, J. B. Rasmussen, and W. C. Leggett. 1995. Relative weight (*Wr*) as a field assessment tool: relationships with growth, prey biomass, and environmental conditions. Transactions of the American Fisheries Society 124:387-400.

Lobon-Cervia, J. 2003. Spatiotemporal dynamics of brown trout production in a Cantabrian stream: Effects of density and habitat quality. Transactions of the American Fisheries Society 132:621-637.

Lobon-Cervia, J., and P. A. Rincon. 1998. Field assessment of the influence of temperature on growth rate in a brown trout population. Transactions of the American Fisheries Society 127:718-728.

Luisi, M. P., and P. W. Bettoli. 2001. An investigation of the trout fishery in the Hiwassee River. Fisheries Report No. 01-13. Tennessee Wildlife Resource Agency, Nashville, Tennessee.

Mann, R. H. K., J. H. Blackburn, and W. R. C. Beaumont. 1989. The ecology of brown trout *Salmo trutta* in English chalk streams. Freshwater Biology 21:57-70.

Matter, W. J., P. L. Hudson, and G. E. Saul. 1983. Invertebrate drift and particulate organic material transport in the Savannah River below Lake Hartwell during a peak power generation cycle. Pages 357-370 *in* T. D. Fontaine, and S. M. Bartell, editors. Dynamics of lotic ecosystems. Ann Arbor Science Publishers, Ann Arbor.

McKinney, T. and D. W. Speas. 2001. Observations of size-related asymmetries in diet and energy intake of rainbow trout in a regulated river. Environmental Biology of Fishes 61:435-444.

McMichael, G. A. 1993. Examination of electrofishing injury and short-term mortality in hatchery rainbow trout. North American Journal of Fisheries Management 13:229-233.

Merritt, R. W. and K. W. Cummins, editors. 1996. An introduction to the aquatic insects of North America, 3rd edition. Kendall-Hunt Publishing Company, Dubuque, Iowa.

Milewski, C. L. and M. L. Brown. 1994. Proposed standard weight (*Ws*) equation and length-categorization standards for stream-dwelling brown trout (*Salmo trutta*). Journal of Freshwater Ecology 9:111-116.

Miserendino, M. L. and L. A. Pizzolon. 2003. Distribution of macroinvertebrate assemblages in the Azul-Quemquemtreu river basin, Patagona, Argentina. New Zealand Journal of Marine and Freshwater Research 37:525-539.

Modde, T., D. A. Young and D. Archer. 1991. Evaluation of factors influencing population characteristics and habitat utilization of trout in the Flaming Gorge tailwater 1987-1989. Utah Division of Wildlife Resources, Publication 91-10, Salt Lake City.

Moss, D. D. 1967. Handbook of Tennessee reservoirs. Department of Biology. Tennessee Technological University, Cookeville.

Moyle, P. B. and J. J. Jr. Cech. 2000. Fishes: An introduction to ichthyology. 4th edition. Prentice Hall, Upper Saddle River, NJ.

Nicola, G. G. and A. Almodovar. 2004. Growth pattern of stream-dwelling brown trout under contrasting thermal conditions. Transactions of the American Fisheries Society 133:66-78.

Odenkirk, J. S. 1987. Food habits of rainbow trout and seasonal abundance of aquatic macroinvertebrates in the Center Hill tailwater. M. S. Thesis. Tennessee Technological University, Cookeville.

Odenkirk, J. S. and R. D. Estes. 1991. Food habits of rainbow trout in a Tennessee tailwater. Proceeding of the Annual Conference Southeast Association Fish and Wildlife Agencies 45:451-459.

Orth, D. J. 1987. Ecological considerations in the development and application of instream flow-habitat models. Regulated Rivers-Research and Management 1:171-181.

Parsons, J. W. 1955. The trout fishery of the tailwater below Dale Hollow reservoir. Transactions of the American Fisheries Society 85:75-92.

Parsons, J. W. and C. C. Crossman. 1956. An example of state and federal cooperation in establishing water control for fisheries management purposes. Proceedings Annual Conference Southeastern Association of Game and Fish Commissioners 9:108-110.

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.

Pentelow, F. 1939. The relation between growth and food consumption in the brown trout. Journal of Experimental Biology 16:446-473.

Pfitzer, D. W. 1962. Investigations of waters below large storage reservoirs in Tennessee. Final Report F-1-R. Tennessee Wildlife Resource Agency, Nashville, Tennessee.

Quinn, J. W. and T. J. Kwak. 2000. Use of rehabilitated habitat by brown trout and rainbow trout in an Ozark tailwater river. North American Journal of Fisheries Management 20:737-751.

Railsback, S. F. and K. A. Rose. 1999. Bioenergetics modeling of stream trout growth: temperature and food consumption effects. Transaction of the American Fisheries Society 128:241-256.

Ramachandran, N. 1986. Operational management of thermal regimes of Center Hill, Dale Hollow, and Wolf Creek tailwaters. M. S. Thesis. Tennessee Technological University, Cookeville.

SAS Institute. 2001. SAS/STAT user’s guide. Version 8.0 SAS Institute, Cary, North Carolina.

Scarnecchia, D. L., and E. P. Bergersen. 1987. Trout production and standing crop in Colorado's small streams, as related to environmental features. North American Journal of Fisheries Management 7:315-330.

Scott, Jr., E. M., K. D. Gardner, D. S. Baxter, and B. L. Yeager. 1996. Biological and water quality responses in tributary tailwaters to dissolved oxygen and minimum flow improvements, implementation of the reservoir releases improvements program / lake improvement plan. Water Management Services. Tennessee Valley Authority, Norris.

Simpkins, D. G., and W. A. Hubert. 2000. Drifting invertebrates, stomach contents, and body conditions of juvenile rainbow trout from fall through winter in a Wyoming tailwater. Transactions of the American Fisheries Society 129:1187-1195.

Spigareli, S. A., M. M. Thommes, and W. Prepejchal. 1982. Feeding, growth, and fat deposition by brown trout in constant and fluctuating temperatures. Transactions of the American Fisheries Society 111:199-209.

Swift, D. R. 1961. The annual growth-rate cycle in brown trout and its cause. Journal of Experimental Biology 38:595-604.

Tabor, R., C. Luecke, and W. Wurtsbaugh. 1996. Effects of daphnia availability on growth and food consumption of rainbow trout in two Utah reservoirs. North American Journal of Fisheries Management 16:591-599.

Tebo, L. B., Jr., and W. W. Hassler. 1963. Food of brook, brown, and rainbow trout from streams in western North Carolina. Journal of the Elisha Mitchell Scientific Society 79:44-53.

Tennessee Valley Authority. 1983. Experimental Clinch River flow re-regulation weir. Office of Natural Resources and Economic Development, Division of Air and Water Resources. TVA/ONR/WR-83/5. Knoxville, Tennessee

Tennessee Wildlife Resources Agency (TWRA). 2002. Management plan for the Norris tailwater trout fishery 2002-2006. Tennessee Wildlife Resources Agency, Nashville, Tennessee.

Thompson, K. G., E. P. Bergersen, R. B. Nehring, and D. C. Bowden. 1997. Long-term effects of electrofishing on growth and body condition of brown trout and rainbow trout. North American Journal of Fisheries Management 17:154-159.

Tippets, W. E. and P. B. Moyle. 1978. Epibenthic feeding by rainbow trout (*Salmo gairdneri*) in the McCloud River, California. Journal of Animal Ecology 47:549-559.

Todd, C. S. and T. R. Bly. 2000. Health and condition of trout in the Norfork tailwater, Arkansas, following hypoxic periods. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 54:157-166.

Trotzky, H. M., and R. W. Gregory. 1974. The effects of water flow manipulation below a hydroelectric power dam on the bottom fauna of the Upper Kennebee River, Maine. Transactions of the American Fisheries Society 2:318-324.

U. S. Army Corp of Engineers. 1996. Operational assessment of Center Hill Lake. Department of the Army, Nashville District Corp of Engineers, Water Management Office, Nashville, Tennessee.

U. S. Army Corp of Engineers. 1997. Macroinvertebrate survey in the Caney Fork River drainage. Department of the Army, Nashville District Corp of Engineers, Water Management Office, Nashville, Tennessee.

Walters, J. P., T. D. Fresques, and S. D. Bryan. 1997. Comparison of creel returns from rainbow trout stocked at two sizes. North American Journal of Fisheries Management 17:474-476.

Waters, T. F., M. T. Doherty, and C. C. Krueger. 1990. Annual production and production: biomass ratios for three species of stream trout in Lake Superior tributaries. Transactions of the American Fisheries Society 119:470-474.

Weiland, M. A., and R. S. Hayward. 1997. Cause for the decline of large rainbow trout in a tailwater fishery: too much putting or too much taking? Transactions of the American Fisheries Society 126:758-773.

Weithman, A. S. and M. A. Haas. 1984. Effects of dissolved-oxygen depletion on the rainbow trout fishery in Lake Taneycomo, Missouri. Transactions of the American Fisheries Society 113:109-124.

Wiley, R. W. and D. J. Dufek. 1980. Standing crop of trout in the Fontenelle Tailwater of the Green River. Transactions of the American Fisheries Society 109:168-175.

Williams, J. S. 2003. Net value of trout fishing opportunities in Tennessee tailwaters. M.S. Thesis. Tennessee Technological University, Cookeville.

Wrona, F. J., J. M. Culp, and R. W. Davies. 1982. Macroinvertebrate subsampling: a simplified apparatus and approach. Canadian Journal of Fisheries and Aquatic Science 39:1051-1054.

Wydoski, R. S., Wedemeyer, G. A., and Nelson, N. C. 1976. Physiological response to hooking stress in hatchery and wild rainbow trout (*Salmo gairdneri*). Transactions of the American Fisheries Society 105:601-606.

Yeager, B. L., W. M. Seawell, C. M. Alexander, D. M. Hill and R. Wallus. 1987. Effects of aeration and minimum low enhancement on the biota of Norris Tailwater. Tennessee Valley Authority, Office of Natural Resources and Economic Development, Division of Services and Field Operations. Knoxville, Tennessee.

Table 1. Number, tag location, and tag or mark retention for brown trout stocked into five Tennessee rivers. Fish in the Hiwassee River received an adipose fin-clip. Subsamples of at least 140 fish were taken to determine mean total lengths, weights, and relative weights (W_r). Standard errors are given in parentheses. Means in a column with the same letter were not statistically different (P = 0.05).

River	Date Stocked	Total Length (mm)	Weight (g)	W_r	Number Tagged or Marked	Tag or Mark Retention (%)	Effective Number Stocked
Caney Fork	3-4 April 2003	179 (1.5)^{a}	69 (1.8)^{a}	104^{a}	20,005	98.8	19,765
Clinch	8-9 April 2003	178 (1.6)^{ab}	64 (1.9)^{ab}	97^{b}	20,000	97.7	19,540
Hiwassee	18-21 March 2003	172 (1.5)^{b}	62 (1.7)^{bc}	105^{a}	22,201	98.0	21,757
South Fork Holston	22-23 April 2003	182 (1.3)^{a}	69 (1.6)^{a}	99^{b}	18,054	96.3	17,386
Watauga River	16-17 April 2003	172 (1.6)^{b}	56 (1.6)^{c}	95^{c}	16,843	95.4	16,068

Table 2. Number of fin-clipped or microtagged fish collected (N), mean total lengths (TL) and weights (WT), instantaneous growth rates (%-d^{-1}), mean relative weights (W_r), mean digestible stomach biomass (g) and number of organisms per stomach for brown trout stocked into five Tennessee rivers. Standard errors (SE) for all means are in parentheses. Means for each river with the same letter were not significantly different (P = 0.05). N/A = data not available.

				%-d^{-1}					
Date	N	Mean TL (mm)	Mean WT (g)	Length	Weight	Mean Digestible Stomach Biomass	Organisms per Trout	Mean Interval Temperature (°C)	Wr
				Caney Fork River					
4/10-11/03	75	175 (2.0)^{a}	61 (2.3)^{a}	-0.33	-1.80	0.009 (0.005)^{a}	1.7 (0.4)^{a}	8.8 (0.067)	101 (0.89)^{a}
6/10/03	95	217 (2.3)^{b}	111 (3.9)^{b}	0.35	0.99	0.304 (0.010)^{a}	49.9 (14.1)^{ab}	12.4 (0.051)	96 (0.86)^{ab}
7/9/03	22	230 (3.2)^{bc}	131 (5.9)^{b}	0.21	0.56	0.238 (0.003)^{a}	192.9 (43.5)^{c}	15.7 (0.038)	97 (1.44)^{ab}
8/8/03	29	233 (3.4)^{bc}	136 (6.2)^{b}	0.05	0.12	0.223 (0.047)^{a}	146.8 (29.3)^{bc}	15.9 (0.028)	96 (1.45)^{ab}
10/3/03	32	239 (2.7)^{c}	137 (4.7)^{b}	0.04	0.02	0.086 (0.024)^{a}	35.3 (10.4)^{a}	16.8 (0.022)	92 (1.37)^{b}
12/15/03	18	264 (5.2)^{d}	196 (15.1)^{c}	0.14	0.49	0.301 (0.066)^{a}	49.2 (13.9)^{ab}	15.8 (0.026)	94 (2.51)^{ab}
1/26-2/3/04	7	303 (7.2)^{e}	281 (24.2)^{d}	0.30	0.78	1.968 (1.01)^{b}	44.0 (12.9)^{ab}	10.1 (0.031)	92 (2.90)^{b}
3/19/04	7	320 (8.9)^{e}	366 (31.5)^{e}	0.11	0.54	1.643 (1.42)^{b}	62.1 (22.5)^{ab}	7.7 (0.014)	102 (3.71)^{a}
				Clinch River					
4/16-18/03	95	170 (2.2)^{a}	54 (2.4)^{a}	-0.45	-1.91	0.023 (0.006)^{a}	12.8 (2.9)^{a}	7.2 (0.050)	93 (0.90)^{a}
6/5/03	25	208 (3.8)^{b}	113 (6.5)^{b}	0.40	1.51	0.178 (0.018)^{ab}	1746.6 (177.3)^{b}	10.2 (0.050)	113 (1.54)^{b}
7/8/03	46	229 (2.3)^{c}	138 (3.8)^{bc}	0.30	0.59	0.059 (0.014)^{a}	230.4 (50.8)^{a}	11.8 (0.064)	104 (1.18)^{c}
8/10/03	122	245 (1.9)^{d}	158 (3.7)^{cd}	0.20	0.41	0.191 (0.055)^{ab}	49.4 (19.3)^{a}	12.4 (0.017)	97 (1.11)^{ac}
10/6/03	29	258 (4.3)^{de}	183 (8.8)^{cd}	0.09	0.26	0.212 (0.034)^{ab}	108.4 (17.7)^{a}	15.7 (0.023)	97 (1.47)^{a}
12/17/03	41	259 (3.1)^{de}	156 (5.8)^{d}	0.01	-0.22	0.097 (0.018)^{a}	23.2 (3.2)^{a}	16.6 (0.031)	82 (1.34)^{d}
1/18/04	40	266 (3.8)^{d}	174 (8.6)^{d}	0.09	0.34	0.449 (0.096)^{c}	78.4 (19)^{a}	9.1 (0.023)	83 (1.54)^{d}
4/1/04	21	305 (5.3)^{e}	305 (19.6)^{e}	0.19	0.76	0.343 (0.076)^{bc}	38.1 (12.6)^{a}	7.1 (0.022)	97 (1.89)^{a}
				Hiwassee River					
3/26/03	19	181 (4.8)^{a}	65 (5.8)^{a}	0.71	0.78	0.056 (0.011)^{a}	45.1 (14.2)^{a}	11.1 (0.202)	95 (1.34)^{a}
6/2/03	24	196 (3.2)^{ab}	80 (4.2)^{a}	0.12	0.30	0.120 (0.020)^{a}	12.6 (1.9)^{b}	13.3 (0.042)	95 (1.10)^{ab}

Table 2. continued.

				%-d^{-1}					
Date	N	Mean TL (mm)	Mean WT (g)	Length	Weight	Mean Digestible Stomach Biomass	Organisms per Trout	Mean Interval Temperature (°C)	Wr
7/3/03	23	199 (3.9)^{ab}	84 (5.2)^{a}	0.04	0.15	0.067 (0.012)^{a}	12.7 (3.7)^{b}	16 (0.034)	94 (0.99)^{ab}
8/1/03	16	206 (4.6)^{b}	91 (6.6)^{ab}	0.12	0.28	0.090 (0.026)^{a}	15.8 (1.9)^{ab}	17.6 (0.022)	92 (1.53)^{abc}
9/11/03	6	210 (9.0)^{bc}	80 (9.1)^{ab}	0.04	-0.29	0.029 (0.014)^{a}	12.2 (4.7)^{b}	19.8 (0.020)	78 (2.34)^{d}
9/29/03	25	210 (2.7)^{bc}	88 (3.5)^{a}	0.03	-0.05	0.049 (0.012)^{a}	16.1 (2.9)^{ab}	21.2 (0.016)	87 (1.48)^{bc}
11/26/03	9	208 (5.9)^{b}	77 (5.5)^{a}	-0.02	-0.24	0.159 (0.064)^{a}	10.0 (2.1)^{b}	18.6 (0.033)	78 (2.94)^{d}
1/6/04	17	229 (4.3)^{c}	113 (6.7)^{b}	0.21	0.59	0.470 (0.133)^{b}	12.7 (3.2)^{b}	11.0 (0.055)	85 (2.61)^{dc}
South Fork of the Holston River									
5/1/03	61	189 (2.9)^{a}	78 (4.1)^{a}	0.43	1.41	0.059 (0.008)^{a}	15.2 (1.9)^{a}	N/A	99 (1.37)^{a}
6/3/03	66	193 (2.5)^{ab}	81 (3.4)^{a}	0.05	0.11	0.123 (0.013)^{a}	34.8 (3.3)^{ab}	7.8 (0.050)	99 (1.08)^{a}
7/3/03	59	204 (2.4)^{b}	96 (4.1)^{ab}	0.19	0.59	0.199 (0.030)^{a}	44.9 (4.5)^{ab}	8.3 (0.049)	100 (1.50)^{ab}
8/5/03	56	220 (2.9)^{c}	125 (5.8)^{b}	0.22	0.77	0.230 (0.030)^{a}	82.8 (21.0)^{abc}	10.3 (0.037)	103 (1.74)^{ab}
9/30/03	48	255 (2.8)^{c}	191 (6.9)^{c}	0.26	0.77	0.297 (0.037)^{a}	104.4 (25.2)^{bc}	13.8 (0.028)	104 (1.60)^{ab}
12/2/03	55	256 (4.1)^{cd}	201 (10.3)^{c}	0.01	0.08	0.427 (0.054)^{a}	143.3 (27.7)^{cd}	14.9 (0.029)	105 (1.22)^{b}
1/7/03	34	269 (3.1)^{d}	220 (7.9)^{c}	0.14	0.24	0.237 (0.032)^{a}	75.8 (11.8)^{abc}	9.4 (0.033)	102 (1.20)^{ab}
3/10/03	51	291 (4.2)^{e}	277 (12.3)^{d}	0.12	0.37	1.313 (0.302)^{b}	192.2 (33.5)^{d}	6.4 (0.024)	100 (1.23)^{ab}
Watauga River									
4/24/03	73	173 (2.1)^{a}	57 (2.7)^{a}	0.07	0.24	0.068 (0.026)^{a}	7.1 (1.5)^{a}	N/A	95 (1.31)^{abc}
6/4/03	49	193 (2.9)^{b}	80 (3.7)^{ab}	0.26	0.82	0.234 (0.033)^{a}	73.5 (14.0)^{b}	10.9 (0.069)	99 (1.15)^{ab}
7/3/03	43	199 (3.0)^{b}	85 (4.3)^{ac}	0.12	0.22	0.189 (0.024)^{a}	26.8 (4.9)^{a}	11.0 (0.069)	95 (1.13)^{bc}
8/4-19/03	75	215 (2.3)^{c}	105 (3.8)^{c}	0.20	0.54	0.387 (0.075)^{ab}	25.6 (5.2)^{a}	12.2 (0.054)	94 (1.14)^{bc}
9/30/03	58	216 (2.2)^{c}	107 (5.0)^{c}	0.01	0.03	0.621 (0.114)^{b}	37.7 (4.1)^{a}	13.4 (0.047)	93 (1.72)^{bcd}
12/3/03	14	236 (5.7)^{d}	151 (11.7)^{d}	0.14	0.54	0.223 (0.048)^{a}	10.8 (2.7)^{a}	13.1 (0.030)	103 (2.07)^{a}
1/6-7/03	33	222 (3.8)^{c}	107 (6.1)^{c}	-0.19	-1.01	0.344 (0.057)^{ab}	19.1 (5.7)^{a}	8.6 (0.044)	87 (1.38)^{d}
3/17/03	19	244 (4.2)^{d}	145 (8.5)^{d}	0.14	0.42	0.372 (0.093)^{ab}	19.5 (5.7)^{a}	6.7 (0.034)	89 (1.49)^{cd}

Table 3. Percent by number (%N) and frequency of occurrence (%O) of major food organisms found in stomachs of 1,040 brown trout collected in five Tennessee rivers, April 2003 to March 2004.

		Percent	Month															
Prey	Total	of Total	April		June		July		August		October		December		January		March	
Item	Number	Number	%N	%O	%N	%O	%N	%O	%N	%O	%N	%O	%N	%O	%N	%O	%N	%O
Caney Fork River																		
Number trout examined	198		57		30		22		26		31		18		7		7	
Percent Empty (number)	15 (30)		49 (28)		0		0		0		3 (1)		6 (1)		0		0	
Terrestrial[1]	1062	9	7	11	13	87	9	95	<1	85	12	65	2	33	1	29	41	71
Diptera pupae	273	2	5	5	<1	10	1	58	<1	62	14	52	<1	6	0	0	0	0
Cladocera	8209	66	65	23	70	50	82	82	90	96	0	0	0	0	0	0	49	57
Ephemeroptera	20	<1	4	7	0	0	<1	5	0	0	0	0	2	6	0	0	0	0
Trichoptera	47	<1	0	0	0	0	<1	9	<1	8	0	0	5	6	0	0	<1	14
Isopoda	2061	17	11	8	15	53	<1	27	1	58	69	65	88	72	68	43	7	71
Amphipoda	31	<1	2	2	1	17	<1	9	<1	19	<1	3	<1	6	2	43	1	29
Gastropoda	598	5	2	2	2	23	8	36	3	46	5	39	3	22	18	29	1	14
Fish	40	<1	1	2	0	0	0	0	0	0	0	0	<1	6	12	43	0	0
Other[2]	36	<1	3	5	<1	10	<1	23	<1	27	<1	3	0	0	0	0	<1	14
Clinch River																		
Number trout examined	239		34		25		30		37		29		34		29		21	
Percent Empty (number)	2 (5)		12 (4)		4 (1)		0		0		0		0		0		0	
Terrestrial[1]	2120	4	39	68	<1	60	3	73	33	68	10	55	5	53	29	76	9	52
Diptera pupae	6708	11	56	68	1	76	3	87	40	81	84	97	64	91	65	83	75	81
Cladocera	49813	83	0	0	99	96	94	83	0	0	0	0	0	0	0	0	0	0
Ephemeroptera	56	<1	0	0	<1	4	<1	7	0	0	0	0	<1	6	<1	3	6	62
Trichoptera	43	<1	0	0	0	0	<1	3	<1	3	0	0	1	18	1	24	1	19
Isopoda	242	<1	1	6	0	0	<1	30	1	24	1	34	10	50	2	48	7	52
Amphipoda	122	<1	0	0	0	0	<1	3	4	14	1	31	1	24	1	24	1	10
Gastropoda	719	1	0	0	0	0	0	0	22	16	5	59	18	56	1	28	0	0
Fish	31	<1	0	0	0	0	0	0	0	0	<1	7	<1	3	1	21	1	43
Other[2]	62	<1	4	32	0	0	<1	3	1	11	<1	14	<1	3	<1	13	0	0

Table 3. continued.

		Percent	Month															
Prey	Total	of Total	April		June		July		August		October		December		January		March	
Item	Number	Number	%N	%O	%N	%O	%N	%O	%N	%O	%N	%O	%N	%O	%N	%O	%N	%O
Hiwassee River																		
Number trout examined	133		19		24		23		16		25		9		17			
Percent Empty (number)	2 (2)		5 (1)		0		0		0		4 (1)		0		0			
Terrestrial[1]	836	35	<1	16	59	92	26	96	58	94	94	92	23	67	19	71		
Diptera pupae	908	38	85	89	16	50	23	65	1	19	1	8	18	56	20	24		
Cladocera	29	1	0	0	0	0	10	22	0	0	<1	4	0	0	0	0		
Ephemeroptera	103	4	4	32	19	58	2	22	0	0	0	0	1	11	5	12		
Trichoptera	270	11	8	79	3	21	6	30	21	81	3	24	26	89	39	71		
Isopoda	23	1	0	0	<1	4	7	48	0	0	<1	4	1	11	0	0		
Amphipoda	3	<1	0	0	1	4	<1	4	0	0	0	0	0	0	0	0		
Gastropoda	155	6	<1	5	3	25	27	30	5	25	1	8	30	56	12	59		
Fish	10	<1	0	0	1	8	0	0	0	0	0	0	1	11	3	41		
Other[2]	75	3	2	16	1	13	4	35	15	69	<1	8	0	0	1	6		
South Fork of the Holston River																		
Number trout examined	255		32		30		30		30		36		33		34		30	
Percent Empty (number)	<1 (1)		0		0		0		0		0		3 (1)		0		0	
Terrestrial[1]	840	4	13	50	20	80	3	63	4	80	10	64	<1	36	<1	25	<1	43
Diptera pupae	3641	16	36	75	29	90	18	87	43	87	39	67	3	30	3	35	3	43
Cladocera	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ephemeroptera	3428	15	31	84	27	87	36	97	11	80	5	42	1	9	3	41	34	80
Trichoptera	599	3	2	25	8	63	<1	10	0	0	<1	11	<1	6	1	21	8	63
Isopoda	6298	28	10	47	8	80	21	93	14	90	13	89	65	94	52	97	11	90
Amphipoda	5157	23	5	34	7	50	7	70	21	63	9	42	21	61	27	62	42	57
Gastropoda	2183	10	1	3	9	40	13	67	7	57	24	92	9	82	12	73	2	53
Fish	13	<1	0	0	0	0	0	0	<1	1	0	0	<1	3	<1	6	<1	3
Other[2]	32	<1	2	28	<1	3	<1	3	0	0	0	0	0	0	1	9	0	0
Watauga River																		
Number trout examined	215		19		30		25		34		41		14		33		19	
Percent Empty (number)	2 (5)		5 (1)		0		0		0		0		14 (2)		3 (1)		5 (1)	

Table 3. continued.

Prey Item	Total Number	Percent of Total Number	Month															
			April		June		July		August		October		December		January		March	
			%N	%O	%N	%O	%N	%O	%N	%O	%N	%O	%N	%O	%N	%O	%N	%O
Terrestrial[1]	2303	35	16	47	55	93	17	88	53	88	22	88	5	36	9	55	42	79
Diptera pupae	1168	18	34	63	7	63	51	88	10	56	34	76	0	0	<1	6	5	42
Cladocera	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ephemeroptera	999	15	14	26	37	97	13	76	1	15	3	37	0	0	5	18	4	42
Trichoptera	714	11	6	16	2	47	3	32	3	53	22	56	39	50	30	79	6	26
Isopoda	342	5	9	32	1	33	2	36	6	50	2	34	0	0	24	21	20	47
Amphipoda	57	1	2	16	<1	3	2	24	1	12	<1	7	3	29	3	21	1	11
Gastropoda	940	14	22	37	1	27	11	72	26	65	16	46	52	50	26	55	29	68
Fish	4	<1	0	0	0	0	0	0	<1	3	<1	7	0	0	0	0	0	0
Other[2]	48	1	5	26	<1	7	1	16	1	18	<1	2	2	2	3	21	0	0

[1] includes adult winged insects, adult Coleoptera, Araneae, Chilopoda, Diplopoda, Formicidae, Orthoptera, Hemiptera, Lepidoptera, Oligochaeta, Dermaptera, Coccinellidae, and Amphibia.

[2] includes larval Coleoptera, Decapoda, Pleocoptera, Hydracarnia, Megaloptera, Odonata, eggs, and bait.

Table 4. Change-in-ratio population and biomass estimates of brown trout (≥ 120 mm, TL) for five Tennessee rivers during the spring of 2003. Confidence intervals (95%) are given in parentheses.

River	Number of Marked Fish Stocked	Size of Census Sample	Number of Recaptures	Number of Unmarked Fish	CIR Population Estimate	Variance	Hectares	Number/ Hectare	Mean Wt (g)	Biomass (kg/ha)
Caney Fork	19,765	170	75	95	25,035 (17,301-32,770)	1.5×10^7	135	185 (129-243)	219	41 (28-53)
Clinch	19,540	202	94	108	22,450 (16,117-28,784)	1.0×10^7	139	161 (116-207)	214	34 (25-44)
Hiwassee	21,757	28	19	9	10,306 (1,965-18,647)	1.7×10^7	149	69 (13-125)	355	24 (5-44)
South Holston	17,386	300	61	239	68,119 (48,576-87,662)	9.5×10^7	88	774 (552-996)	268	207 (148-267)
Watauga	16,068	314	73	241	53,046 (38,873-67,220)	5.0×10^7	135	393 (289-499)	215	85 (62-107)

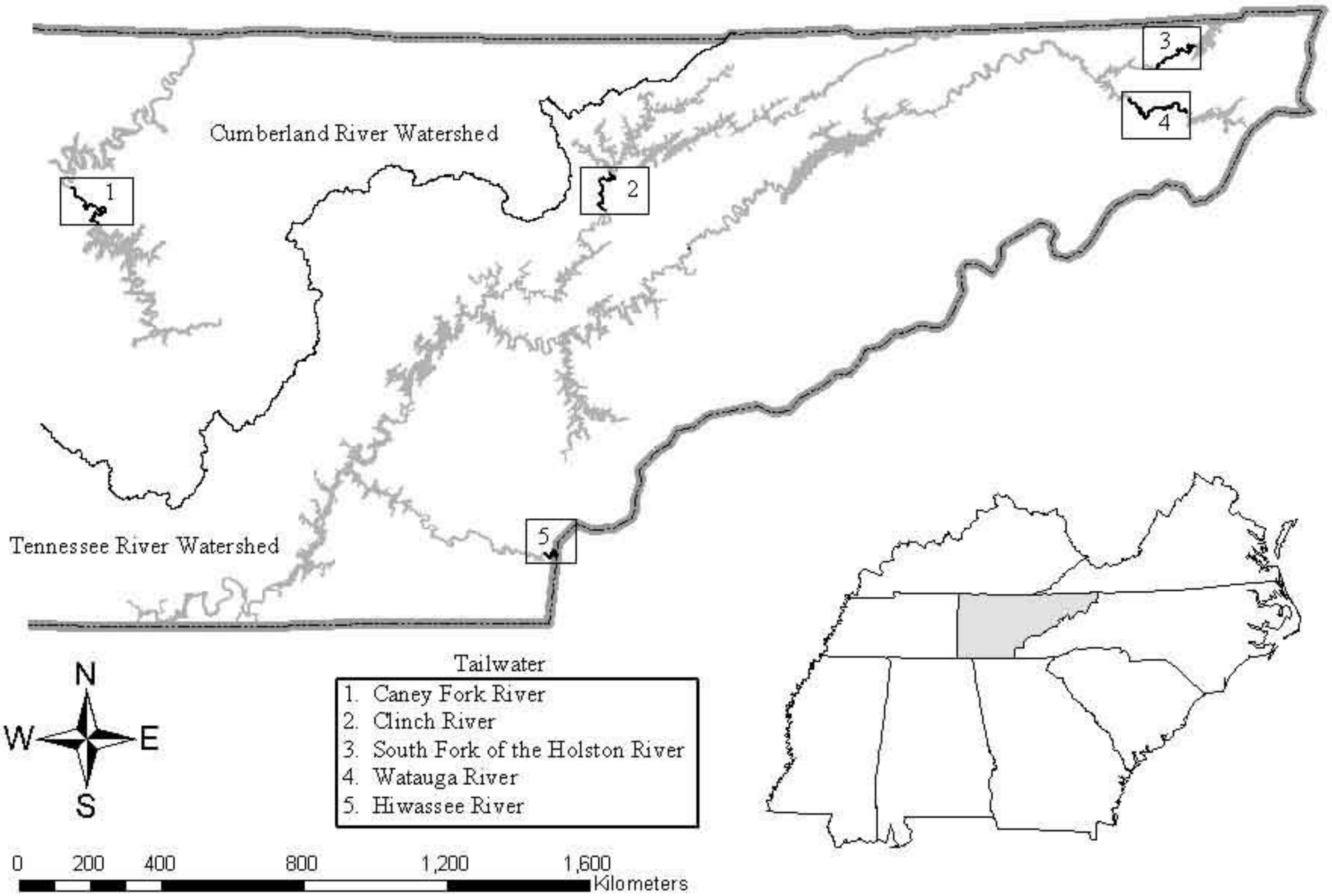

Figure 1. Location of study sites in the Cumberland and Tennessee River watersheds.

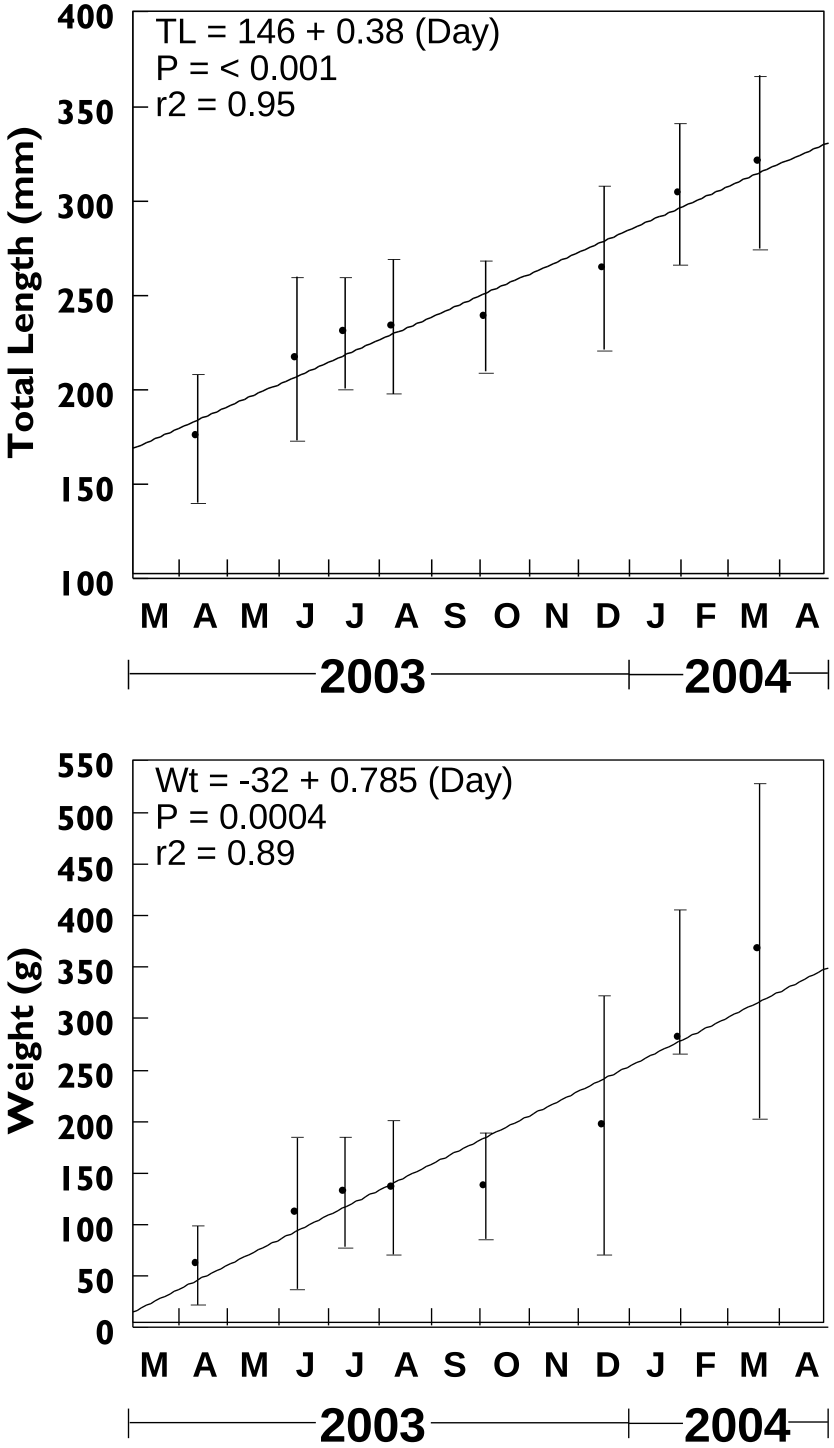

Figure 2. Mean total lengths and weights of microtagged brown trout stocked into the Caney Fork River in April 2003. Vertical bars represent 95% confidence intervals. The linear relationship between calendar day and mean length (TL) and weight (Wt) is depicted.

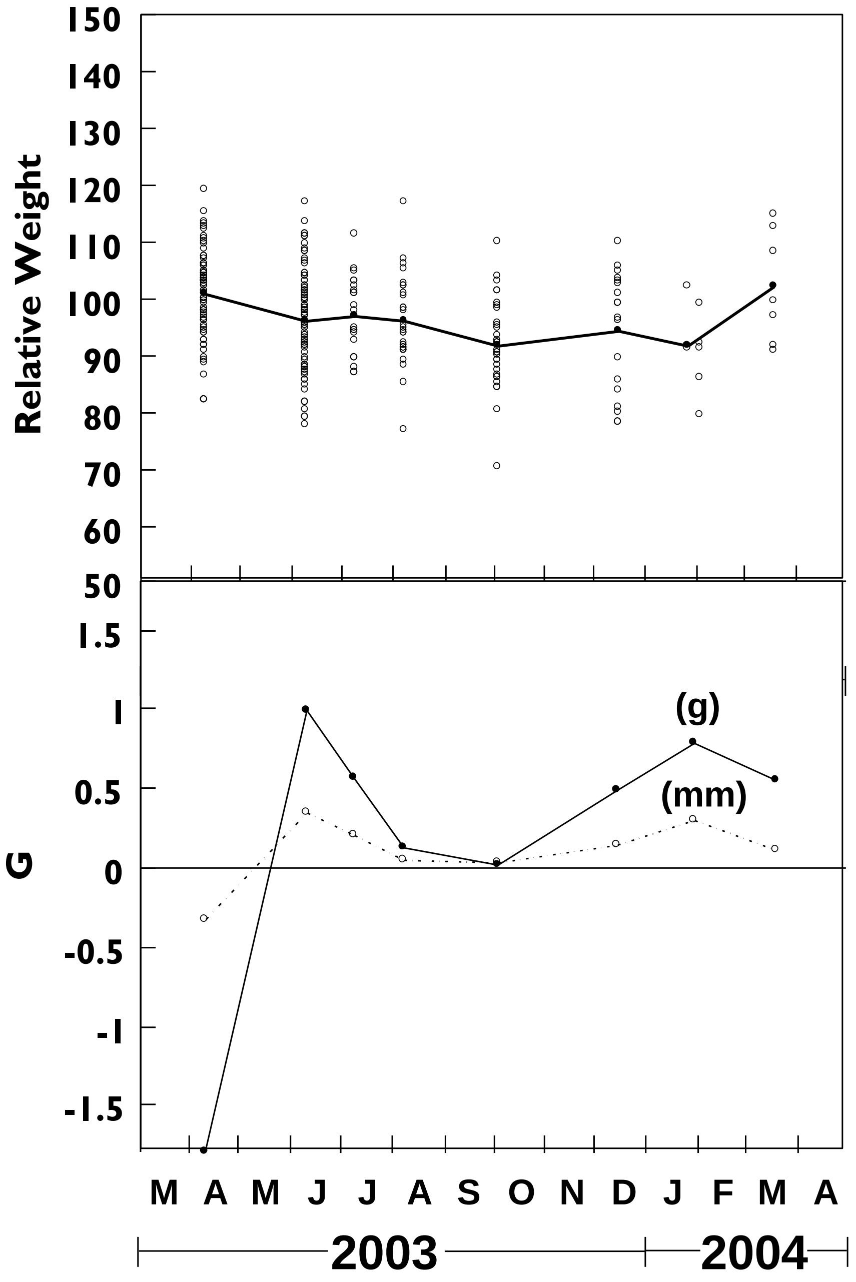

Figure 3. Instantaneous rates of growth in weight and length (G, % per day) and relative weights of microtagged brown trout collected in the Caney Fork River from April 2003 to March 2004. Solid line and filled circles represents mean relative weights for each sampling period.

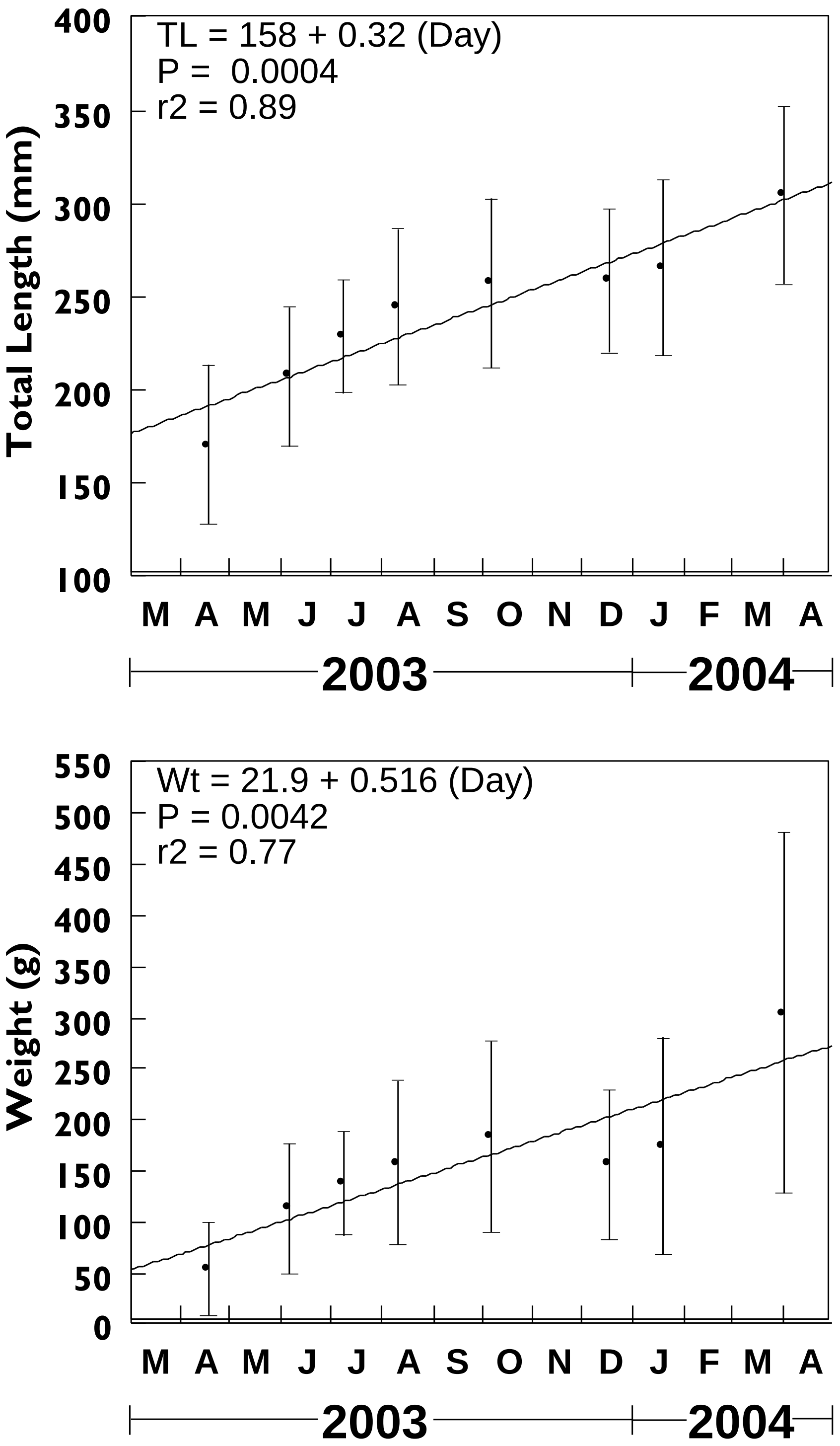

Figure 4. Mean total lengths and weights of microtagged brown trout stocked into the Clinch River in April 2003. Vertical bars represent 95% confidence intervals. The linear relationship between calendar day and mean length (TL) and weight (Wt) is depicted.

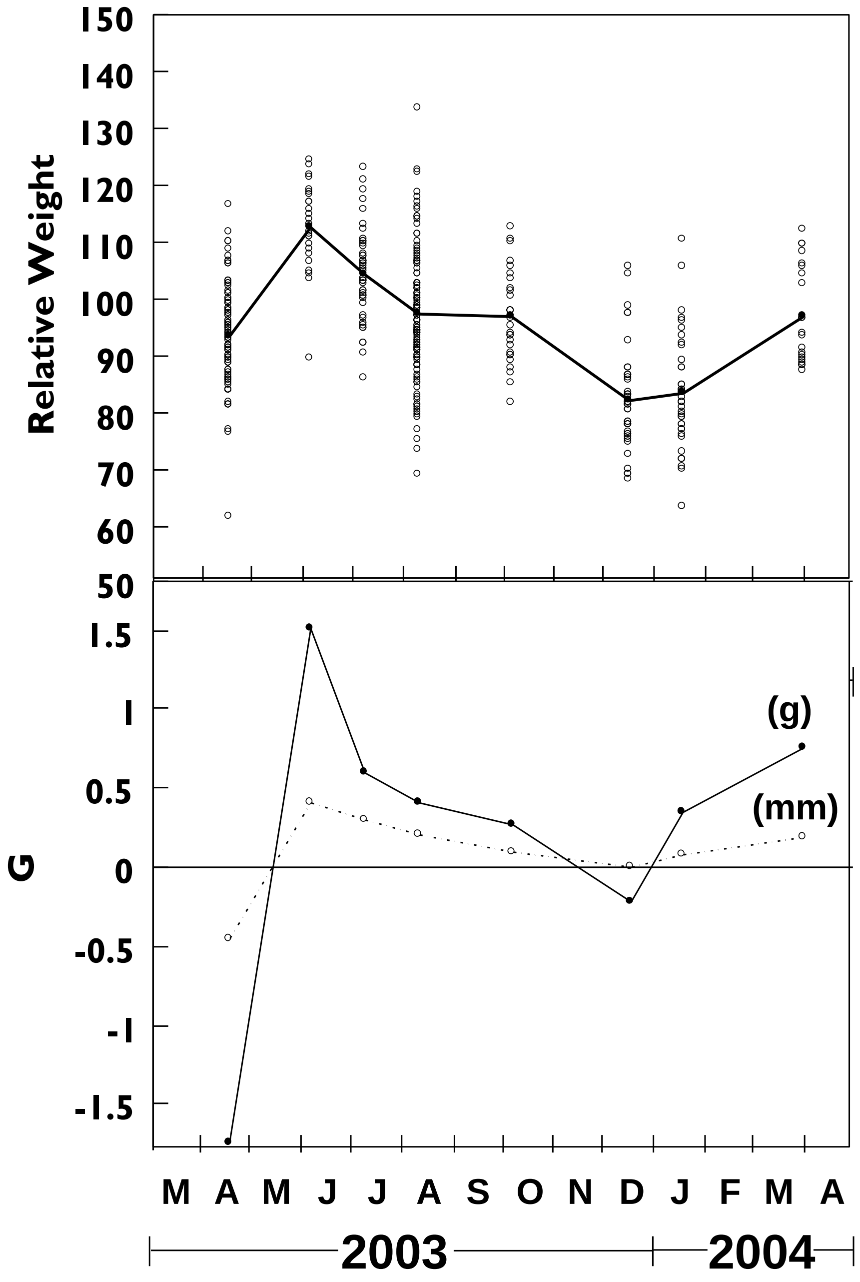

Figure 5. Instantaneous rates of growth in weight and length (G, % per day) and relative weights of microtagged brown trout collected in the Clinch River from April 2003 to April 2004. Solid line and filled circles represents mean relative weights for each sampling period.

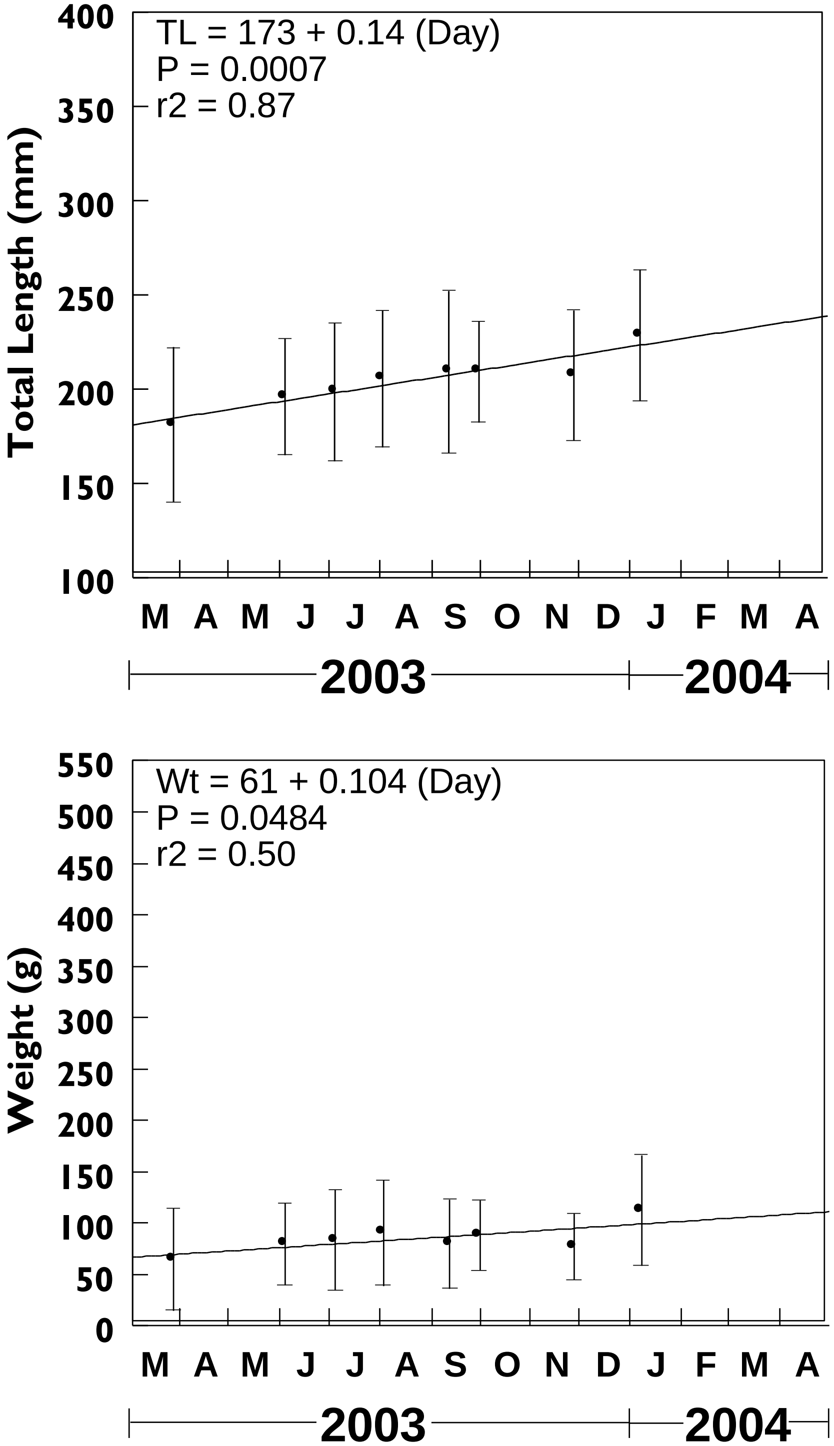

Figure 6. Mean total lengths and weights of adipose fin clipped brown trout stocked into the Hiwassee River in March 2003. Vertical bars represent 95% confidence intervals. The linear relationship between calendar day and mean length (TL) and weight (Wt) is depicted.

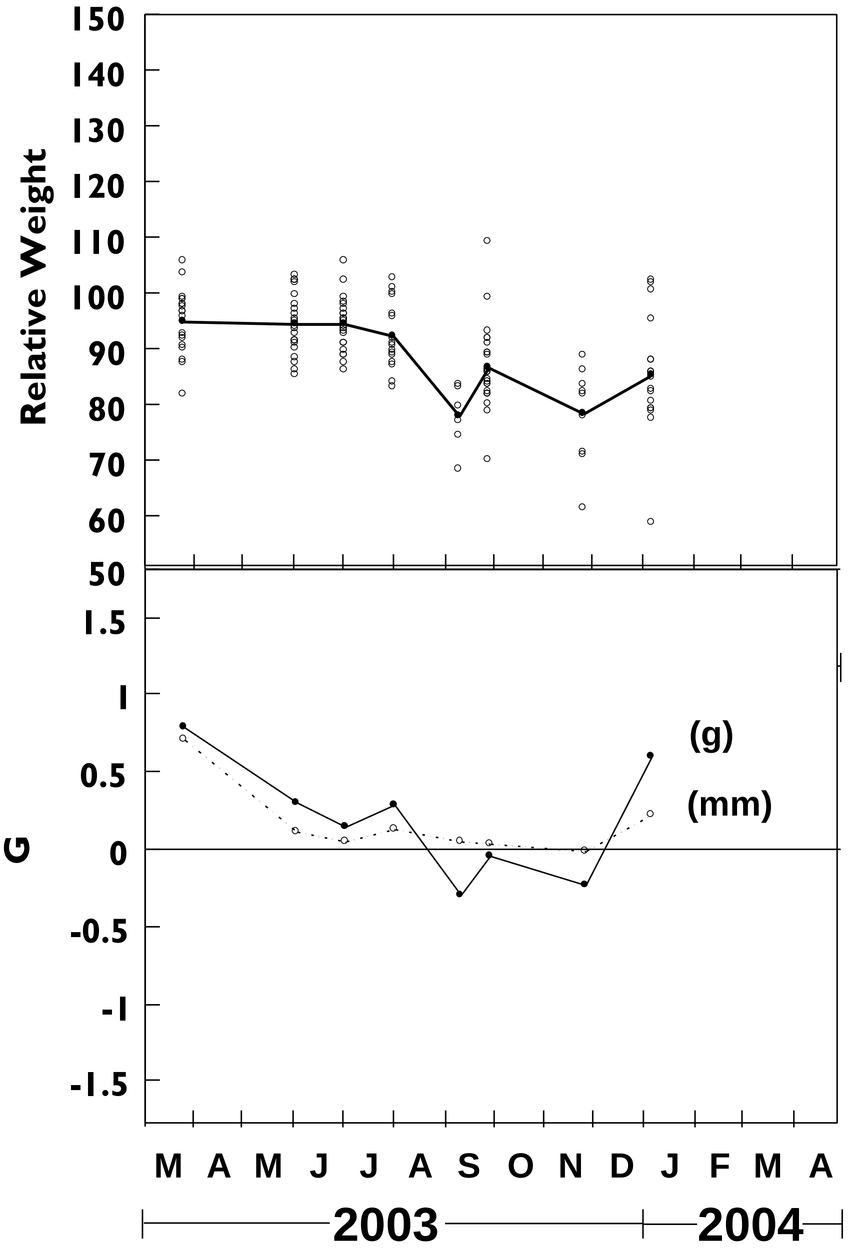

Figure 7. Instantaneous rates of growth in weight and length (G, % per day) and relative weights of fin clipped brown trout collected in the Hiwassee River from April 2003 to January 2004. Solid line and filled circles represents mean relative weights for each sampling period.

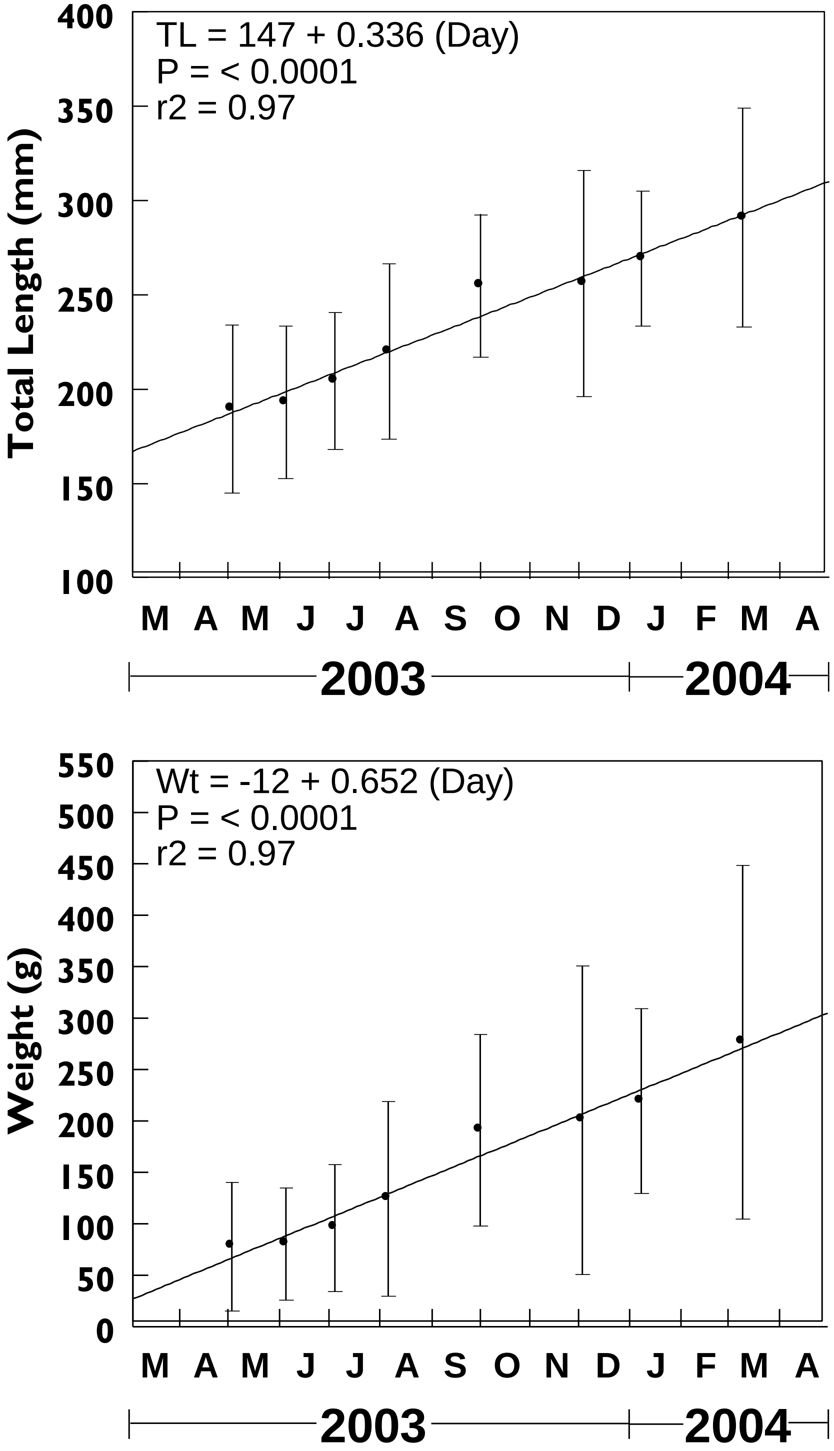

Figure 8. Mean total lengths and weights of microtagged brown trout stocked into the South Fork of the Holston River in April 2003. Vertical bars represent 95% confidence intervals. The linear relationship between calendar day and mean length (TL) and weight (Wt) is depicted.

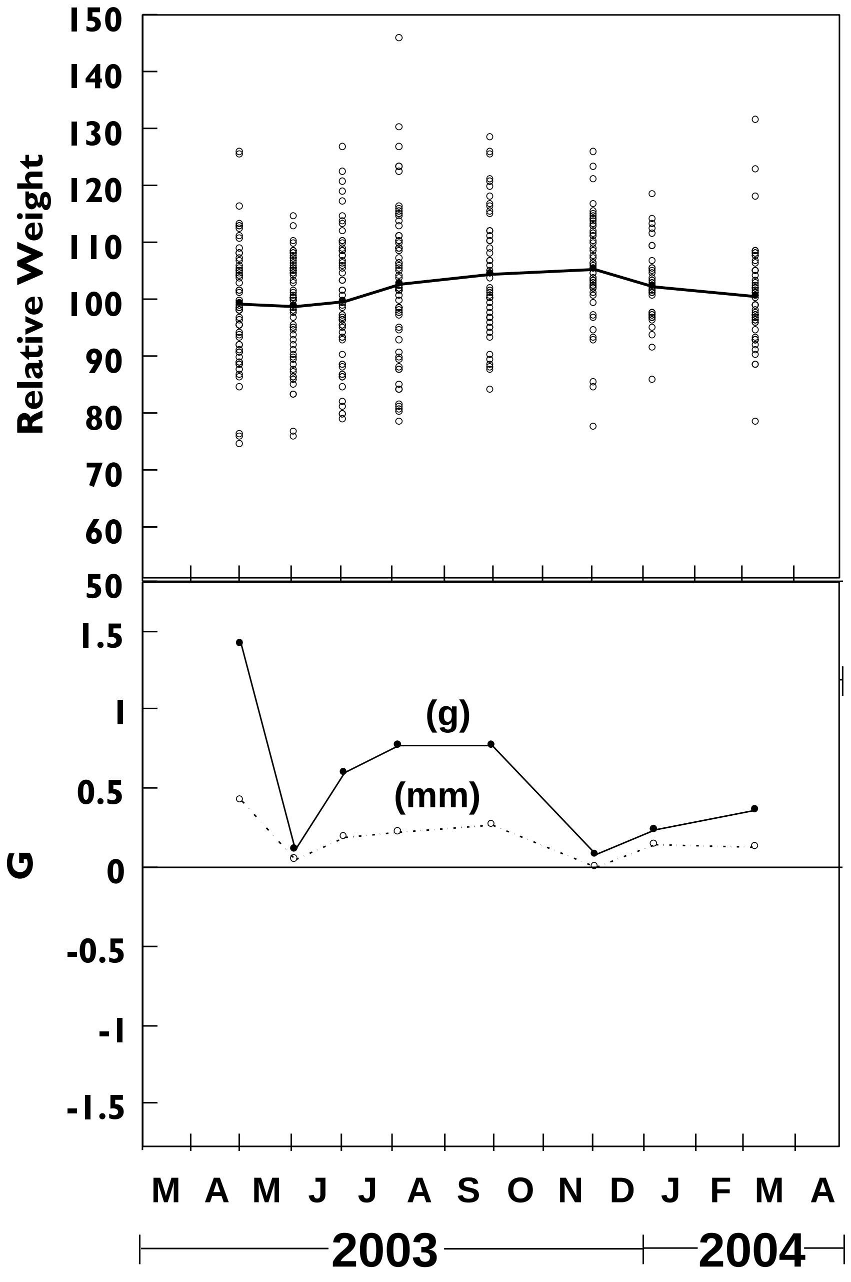

Figure 9. Instantaneous rates of growth in weight and length (G, % per day) and relative weights of microtagged brown trout collected in the South Fork of the Holston River from April 2003 to March 2004. Solid line and filled circles represents mean relative weights for each sampling period.

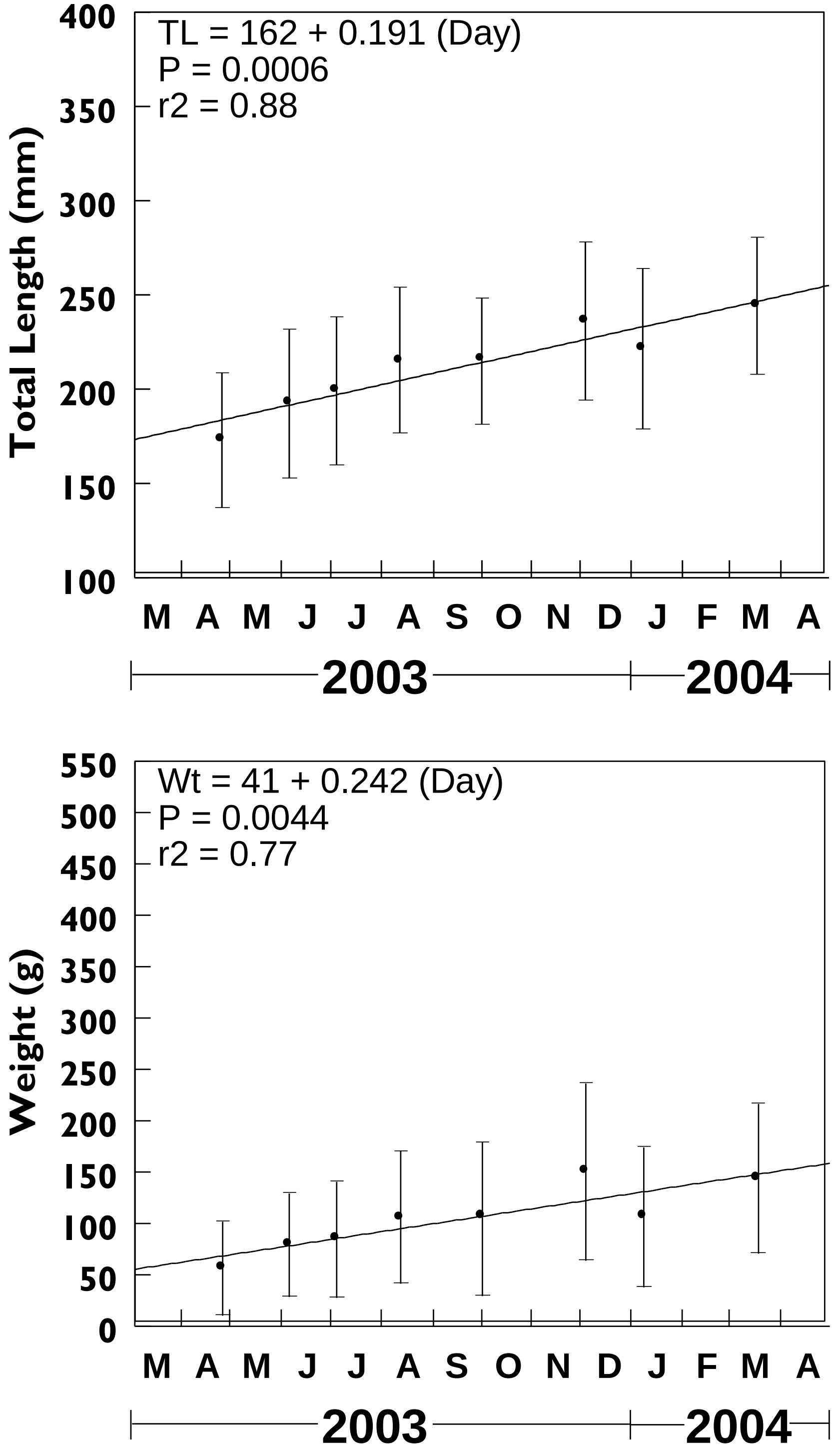

Figure 10. Mean total lengths and weights of microtagged brown trout stocked into the Watauga River in April 2003. Vertical bars represent 95% confidence intervals. The linear relationship between calendar day and mean length (TL) and weight (Wt) is depicted.

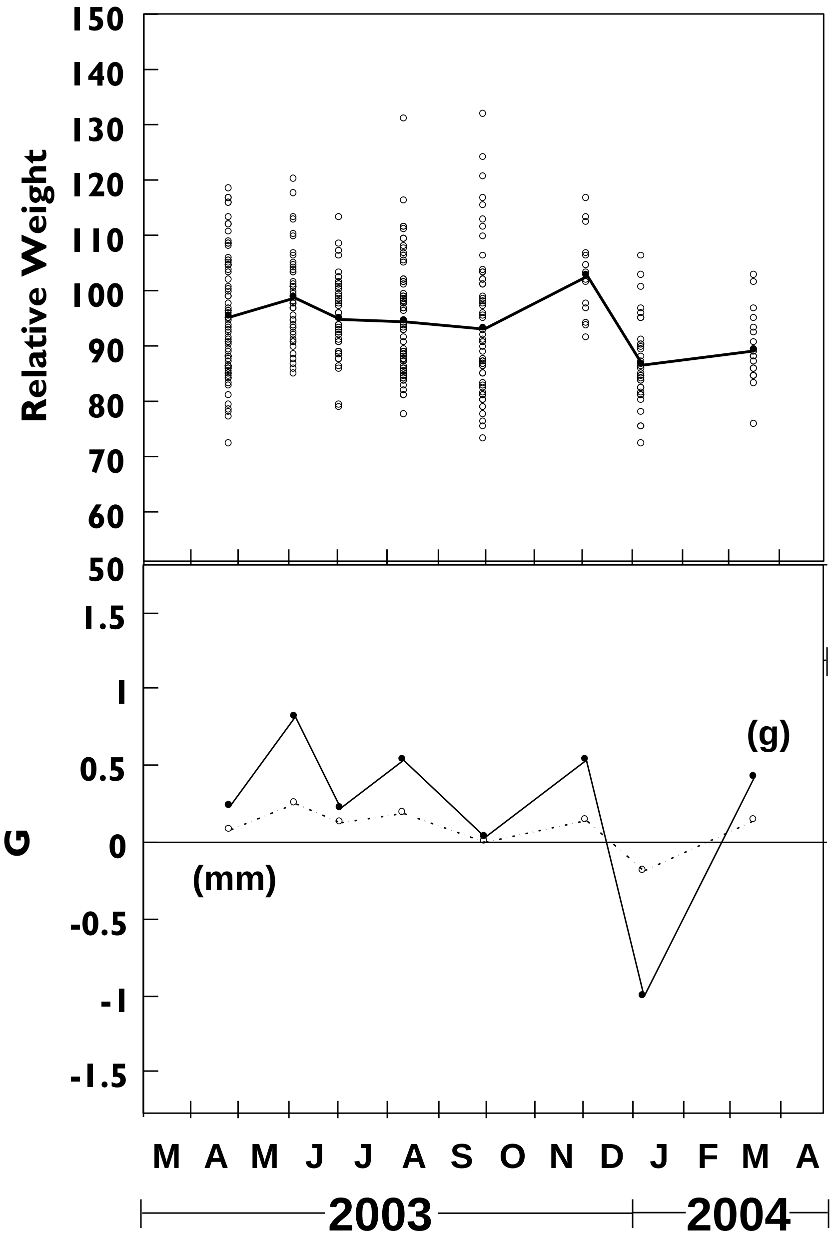

Figure 11. Instantaneous rates of growth in weight and length (G, % per day) and relative weights of microtagged brown trout collected in the Watauga River from April 2003 to March 2004. Solid line and filled circles represents mean relative weights for each sampling period.

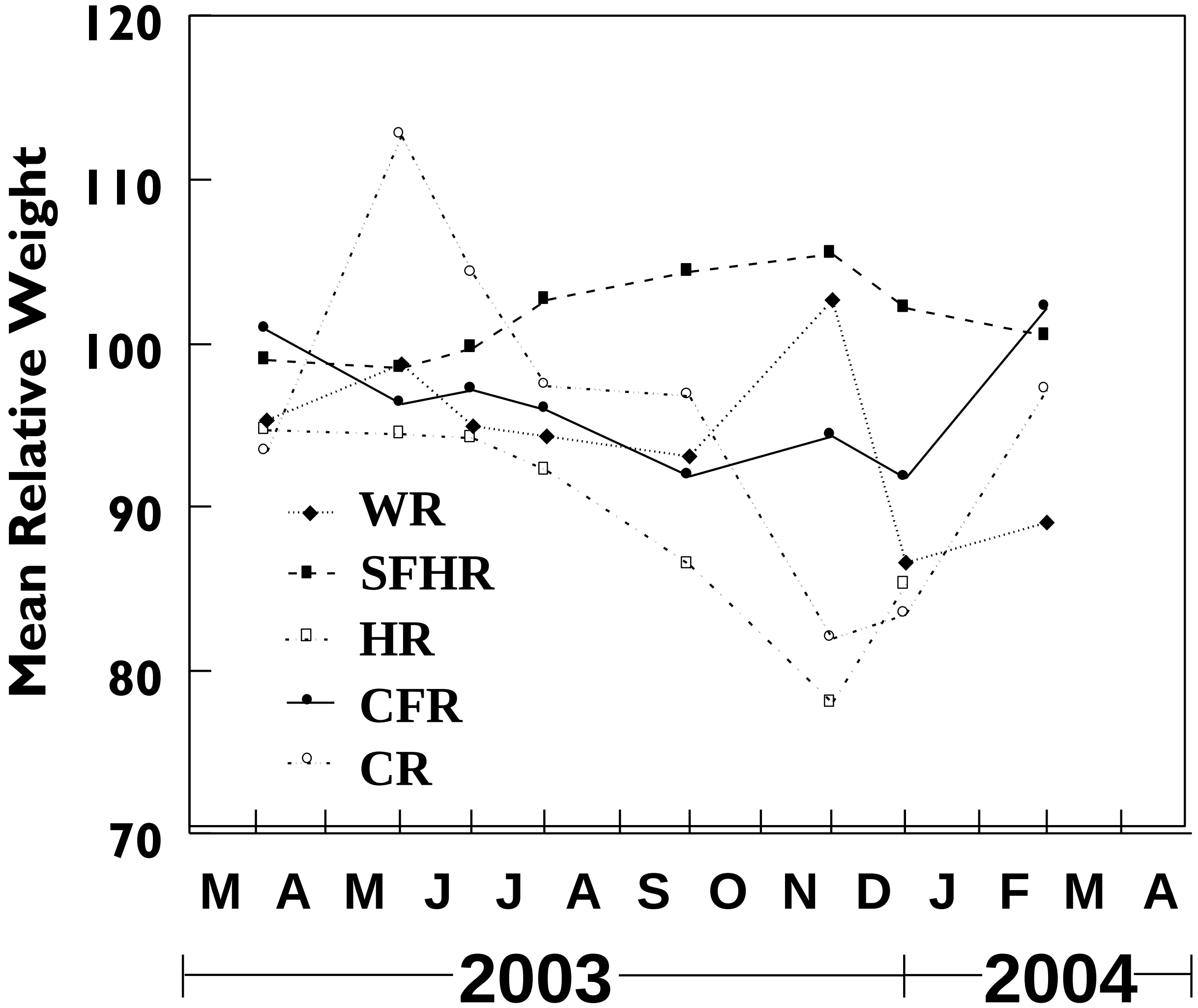

Figure 12. Mean relative weights for brown trout stocked into five tailwaters. WR = Watauga River; SFHR = South Fork of the Holston River; HR = Hiwassee River; CFR = Caney Fork River; CR = Clinch River.

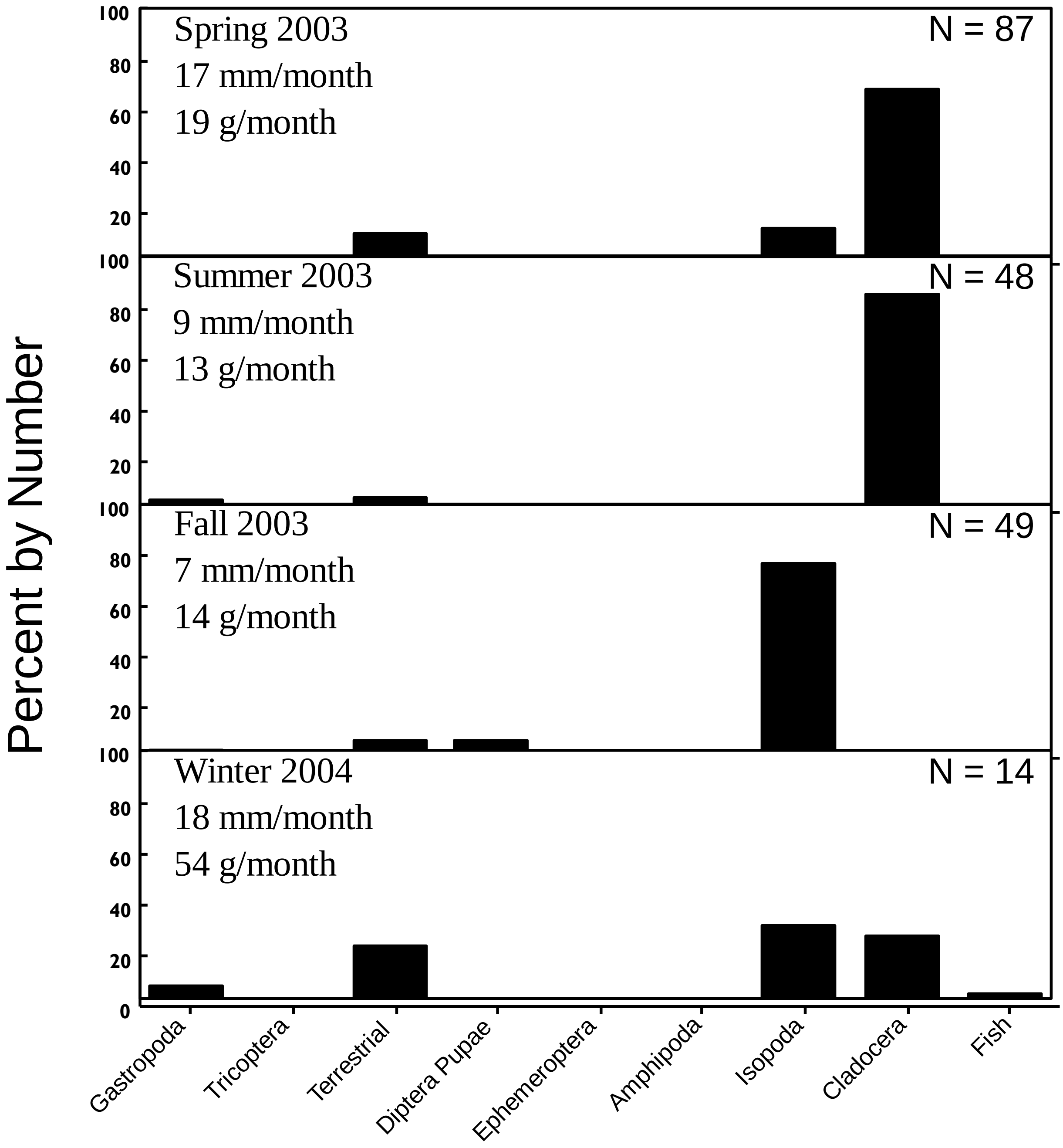

Figure 13. Percent by number of major prey taxa consumed, mean growth rates, and number of microtagged brown trout examined each season in the Caney Fork River.

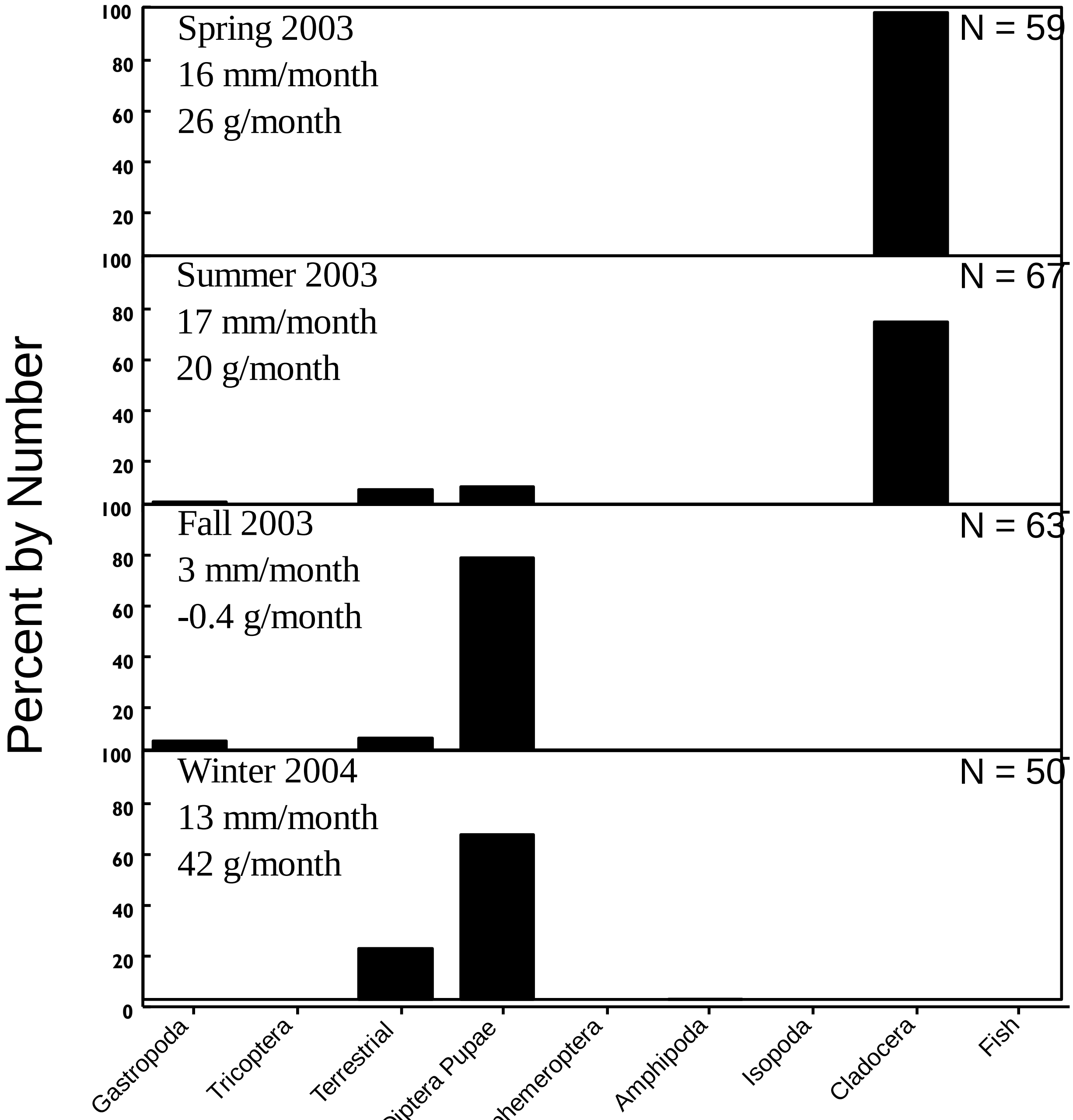

Figure 14. Percent by number of major prey taxa consumed, mean growth rates, and number of microtagged brown trout examined each season in the Clinch River.

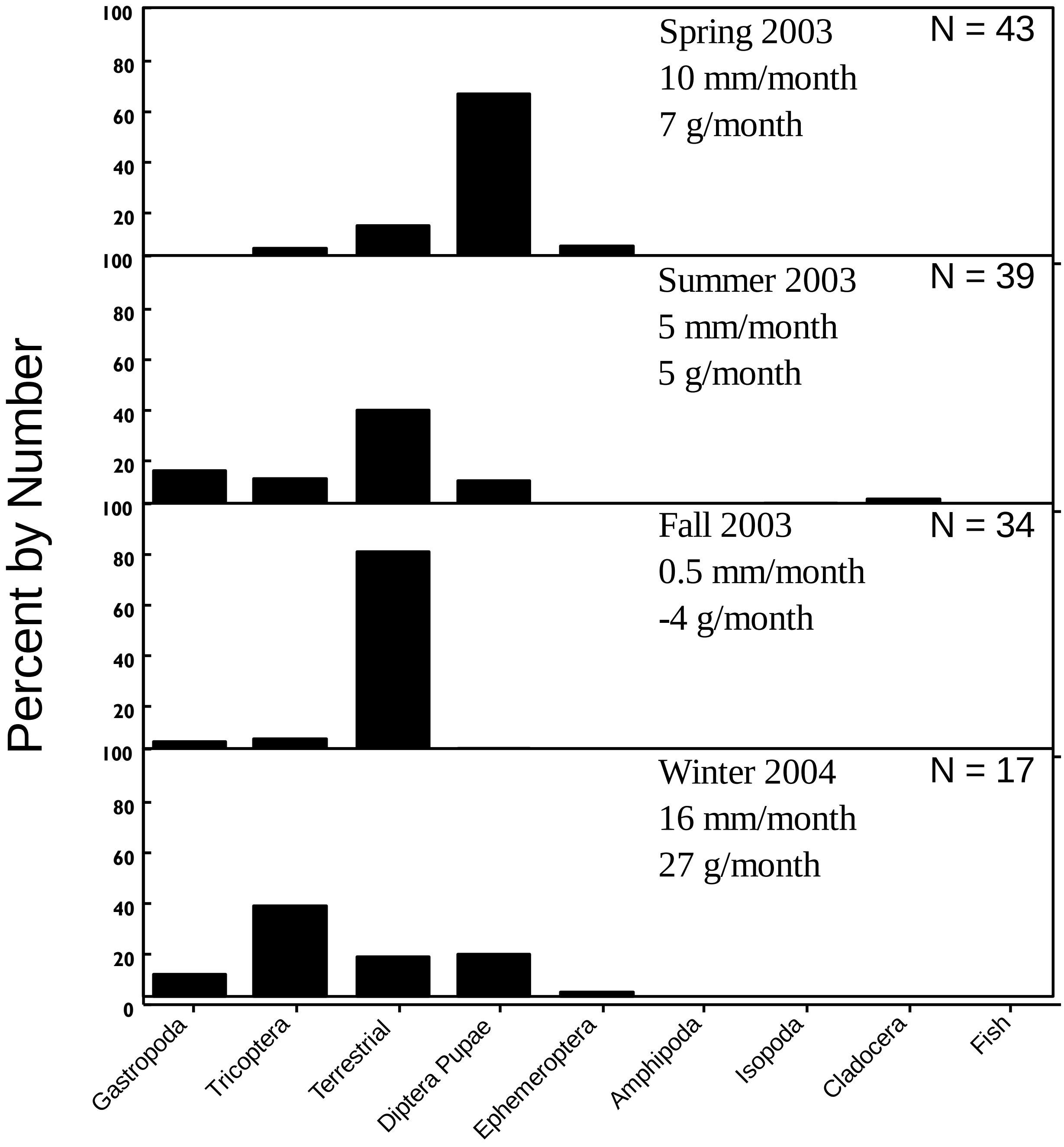

Figure 15. Percent by number of major prey taxa consumed, mean growth rates, and number of adipose fin-clipped brown trout examined each season in the Hiwassee River.

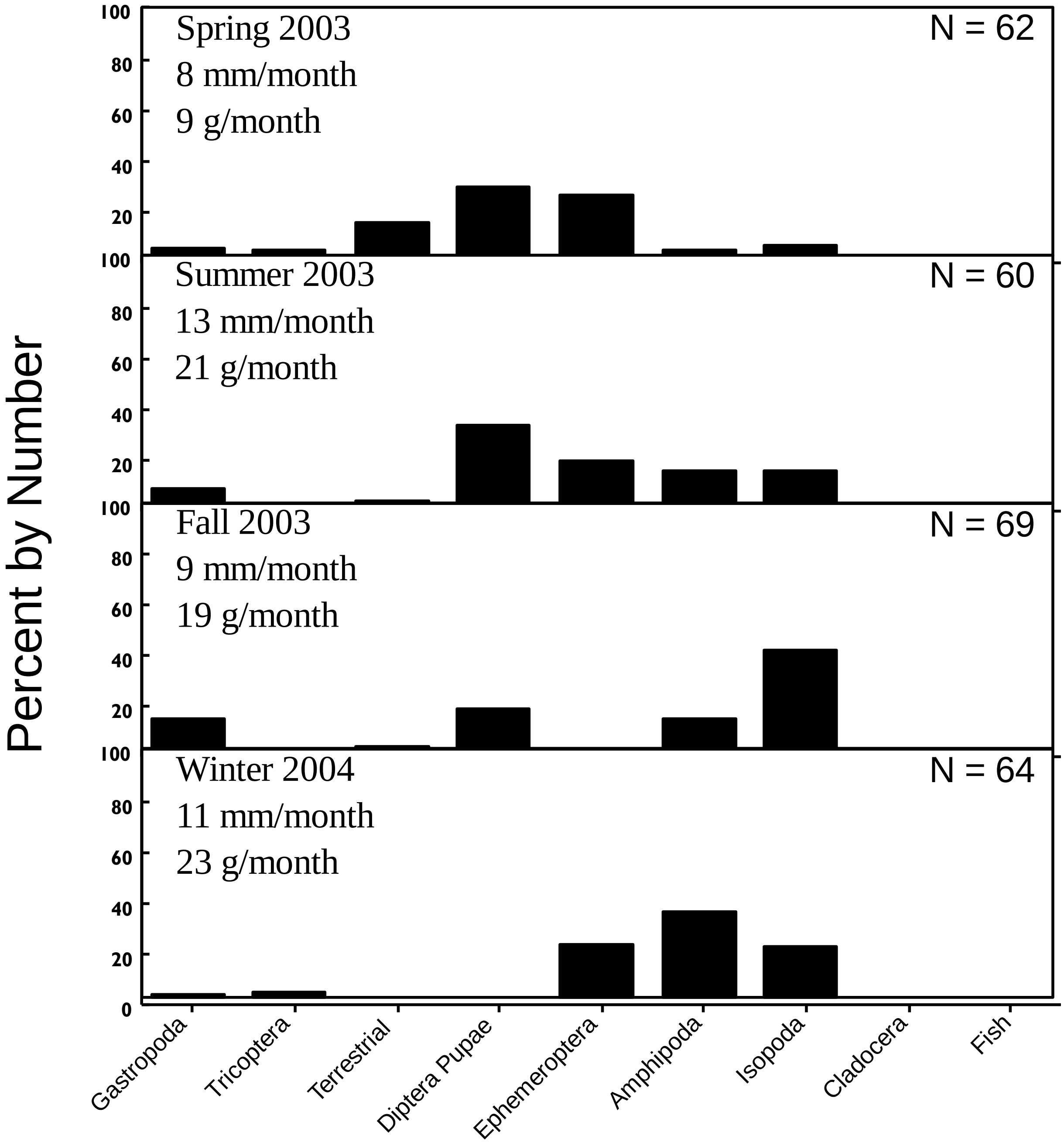

Figure 16. Percent by number of major prey taxa consumed, mean growth rates, and number of microtagged brown trout examined each season in the South Fork of the Holston River.

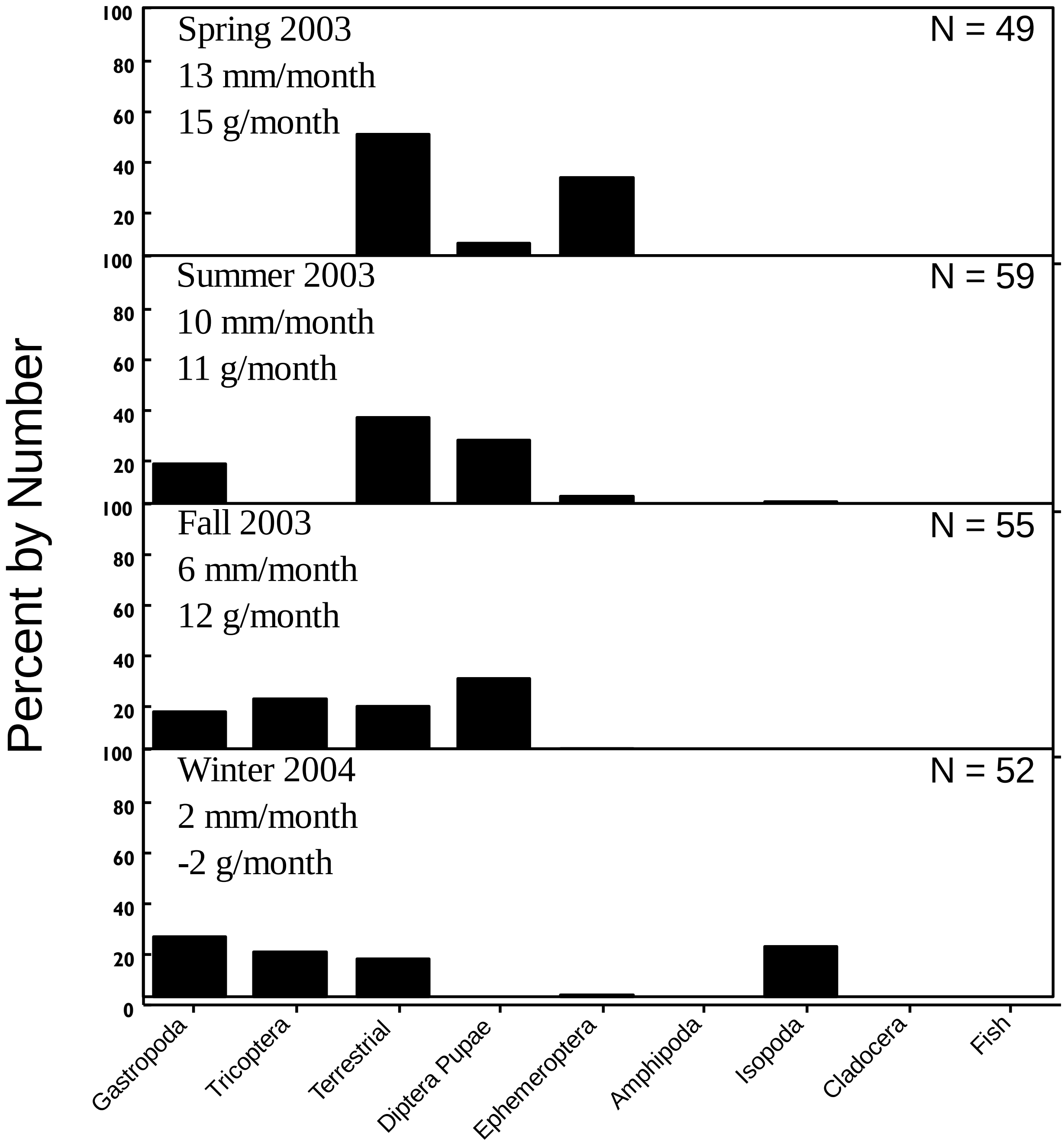

Figure 17. Percent by number of major prey taxa consumed, mean growth rates, and number of microtagged brown trout examined each season in the Watauga River.

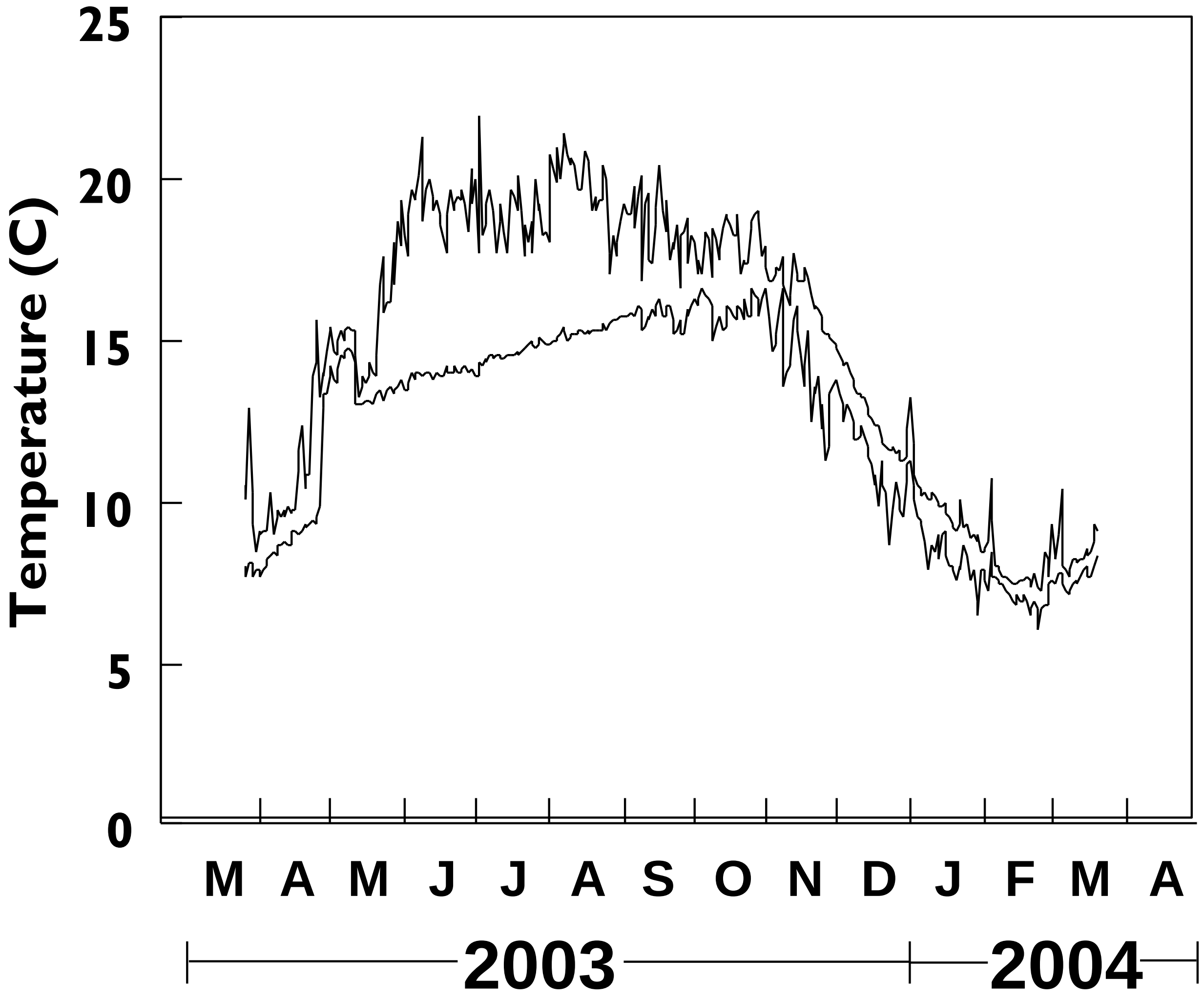

Figure 18. Maximum and minimum daily temperatures (°C) recorded by temperature loggers in the Caney Fork River from March 2003 to March 2004. One logger was placed 5 km downstream of Center Hill Dam; a second logger was at the Betty's Island access site (about 18 km downstream of the dam). A third logger at the Stonewall Bridge (about 28 km downstream from the dam) recorded temperatures between 1 June 2003 and 12 September 2003.

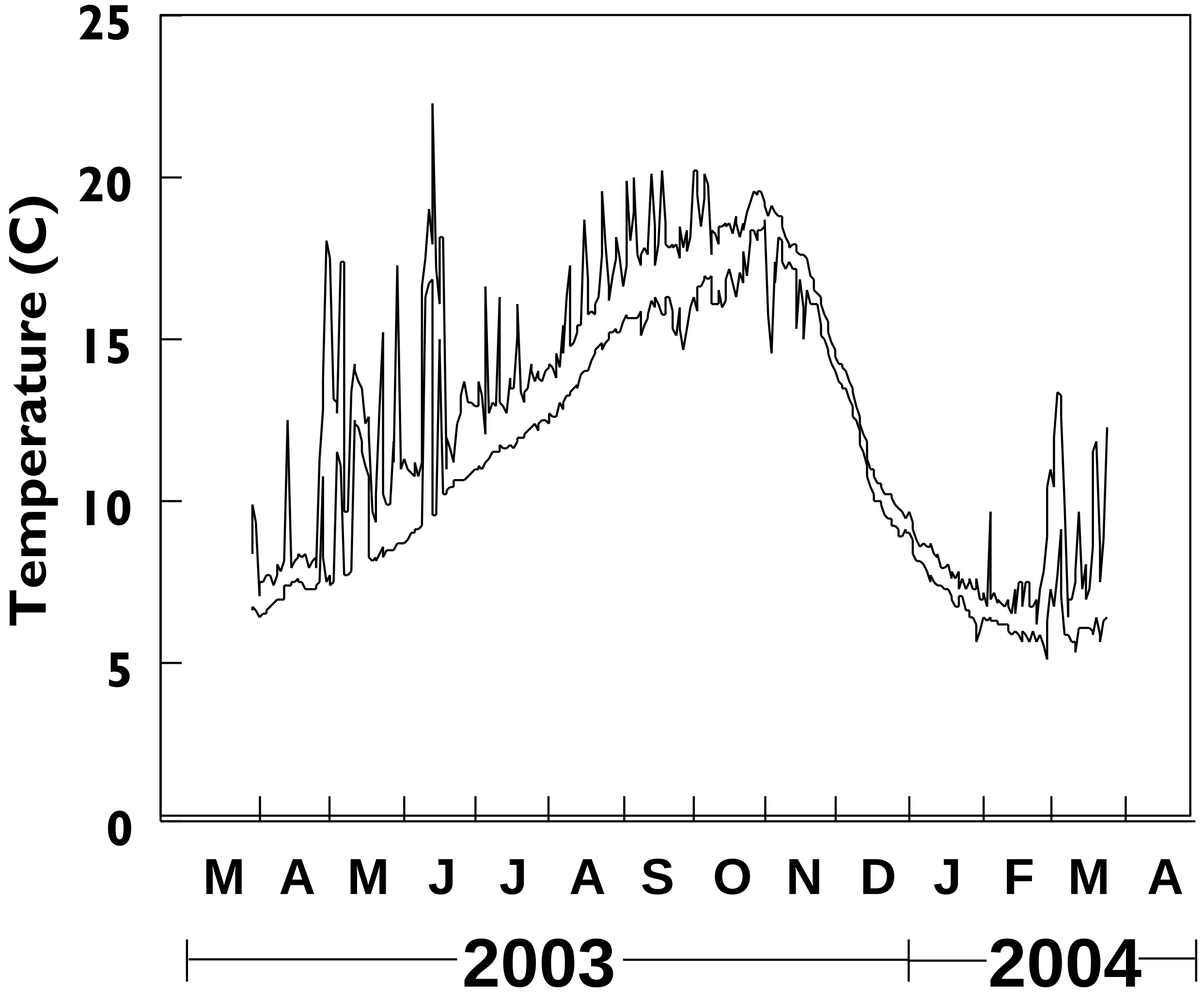

Figure 19. Maximum and minimum daily temperatures (°C) recorded by temperature loggers in the Clinch River from April 2003 to March 2004. One temperature logger was in the reach between the weir dam and Miller Island; the second logger was approximately 16 km downstream from Norris Dam.

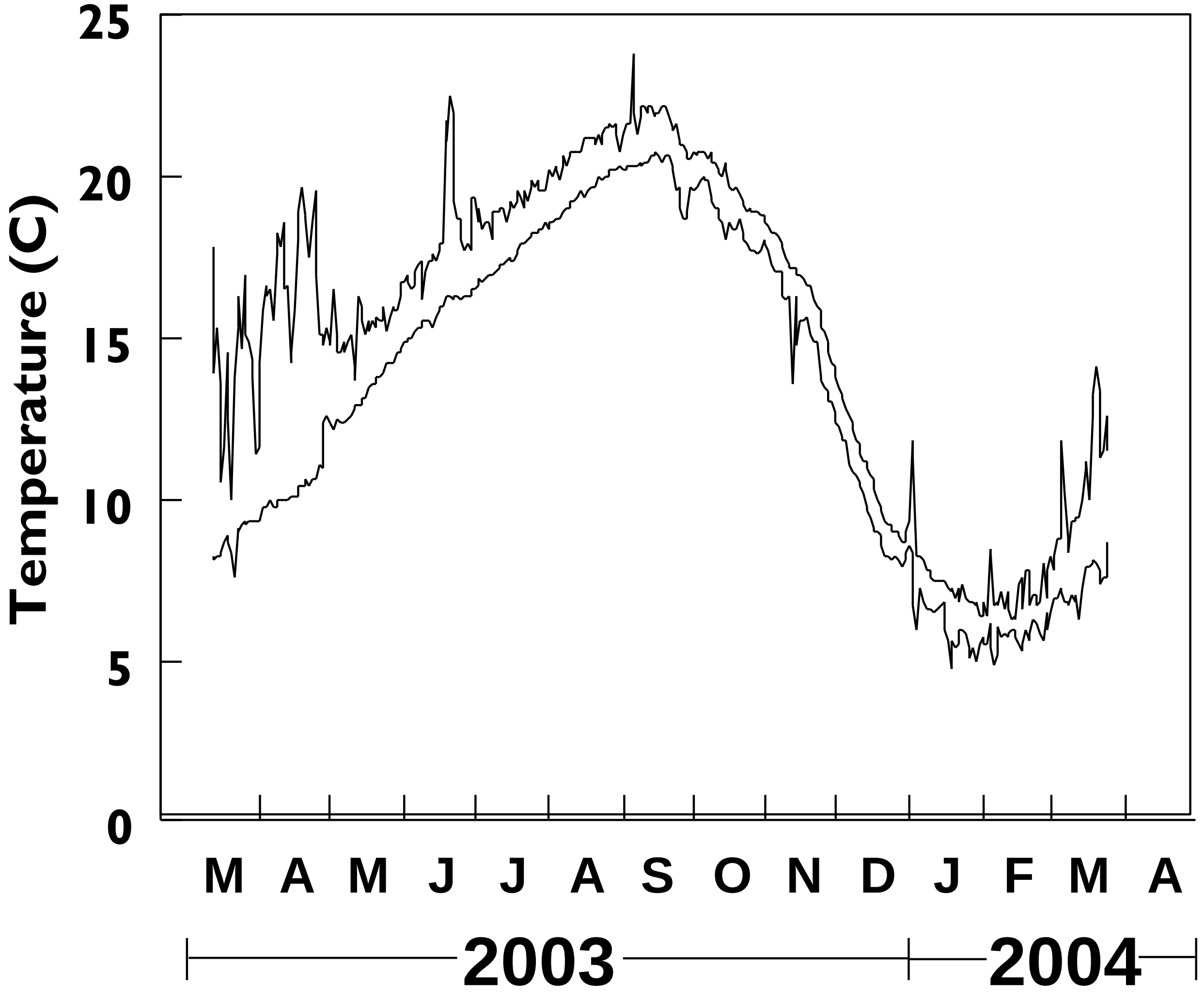

Figure 20. Maximum and minimum daily temperatures (°C) recorded by temperature loggers in the Hiwassee River from March 2003 to March 2004. One logger was immediately downstream of the Appalachia Powerhouse; the second logger was near the Big Bend parking lot access area (~ 4 km downstream of the powerhouse).

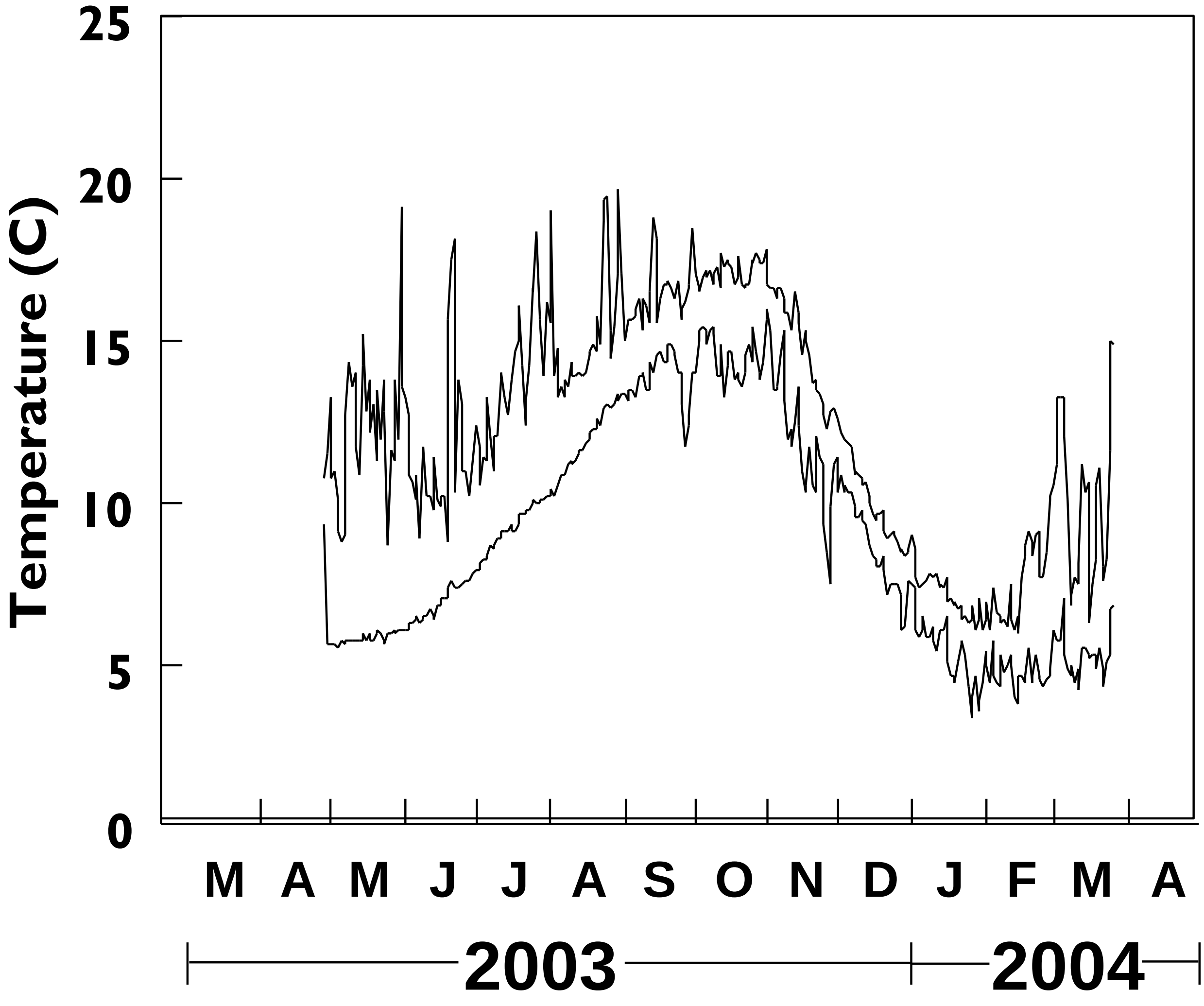

Figure 21. Maximum and minimum daily temperatures (°C) recorded by temperature loggers in the South Fork of the Holston River from April 2003 to March 2004. Loggers were placed just below the Bristol Weir (~ 2 km downstream of South Holston Dam), at the Highway 44 Bridge (~ 8 km downstream of the dam), and at the Webb Bridge (~17 km downstream of the dam).

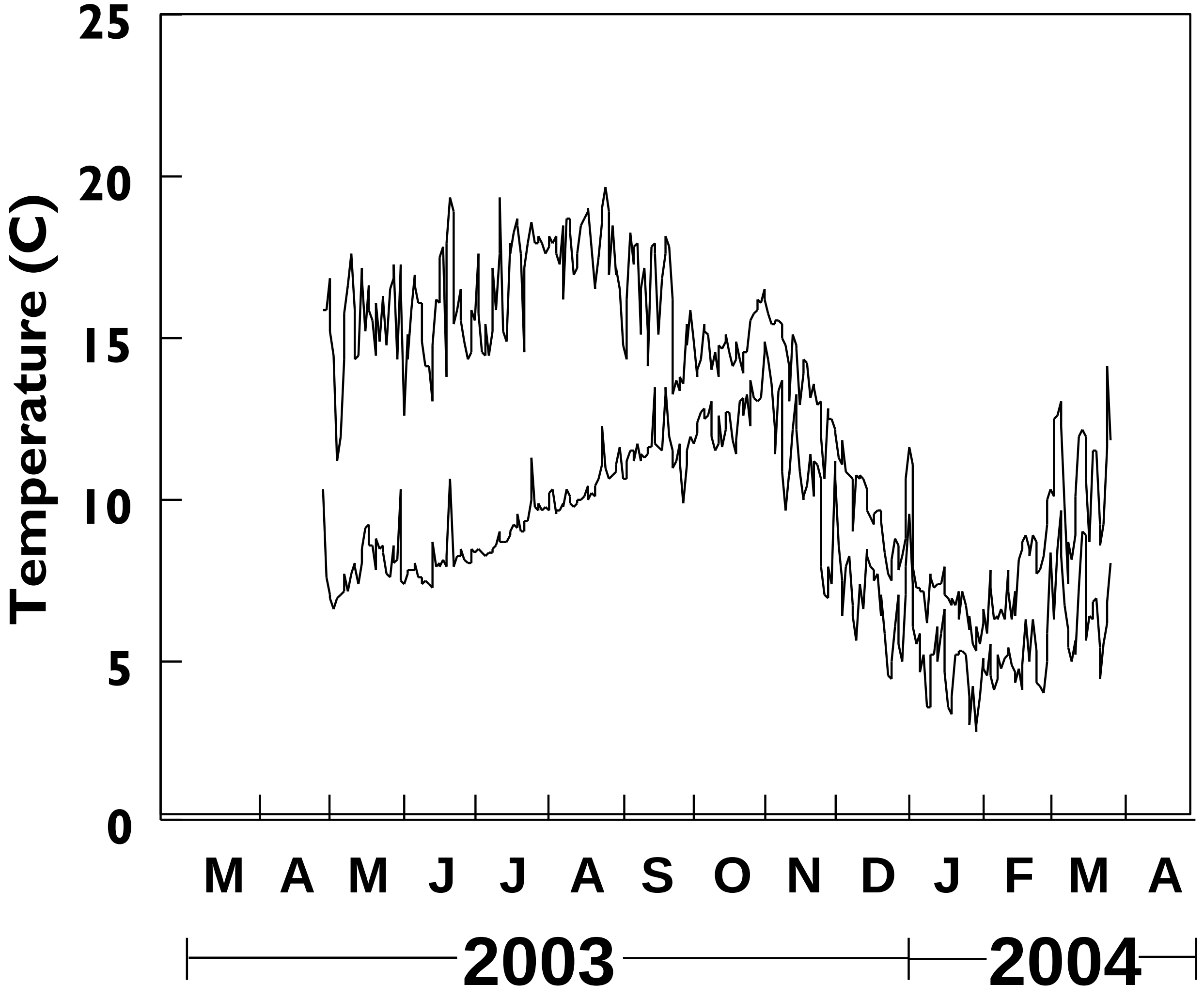

Figure 22. Maximum and minimum daily temperatures (°C) recorded by temperature loggers in the Watauga River from April 2003 to March 2004. One logger was at the PSG/Hunter Bridge (~ 7 km downstream of Wilbur Dam); a second logger was near the Blevin’s Bend ramp (~19 km downstream of Wilbur Dam).

APPENDIX

Table A1. Prey item classification system used in analysis of stomach contents

Species name	Classification
Amphipoda	Amphipoda
Daphnidae	Cladocera
Leptodora	Cladocera
Brachycera	Diptera
Chironimidae	Diptera
Nematocera	Diptera
Simulidae	Diptera
Tipulidae	Diptera
Ephemeroptera	Ephemeroptera
Catostomidae	Fish
Clupeidae	Fish
Salmonidae	Fish
Isopoda	Isopoda
Bivalvia	Mollusca
Gastropoda	Mollusca
Bait	Other
Decapoda	Other
Eggs	Other
Hydracarnia	Other
Larval Coleoptera	Other
Megaloptera	Other
Odonata	Other
Plecoptera	Other
Adult Coleoptera	Terresterial
Adult winged insects	Terresterial
Araneae	Terresterial
Chilopoda	Terresterial
Coccinellidae	Terresterial
Dermaptera	Terresterial
Diplopoda	Terresterial
Formicidae	Terresterial
Hemiptera	Terresterial
Lepidoptera	Terresterial
Oligochaeta	Terresterial
Orthoptera	Terresterial
Trichoptera	Trichoptera

Table A2. Temperatures (ºC) and dissolved oxygen concentrations (mg/L) in grab samples from five rivers from 26 March 2003 to 1 April 2004.

River	Date	Reach	Temperature (ºC)	Dissolved Oxygen (mg/L)
Caney Fork	10 April 2003	Upper	8.0	10.2
		Lower	12.8	9.3
	10 June 2003	Upper	13.3	7.0
		Lower	14.7	6.5
	9 July 2003	Upper	14.3	5.6
	8 August 2003	Upper	16.4	4.7
		Lower	15.4	4.7
	4 September 2003	Upper	16.8	3.9
	20 September 2003	Upper	16.7	2.5
		Lower	17.6	7.6
	3 October 2003	Upper	15.9	1.7
		Lower	16.0	2.5
	15 December 2003	Upper	13.1	6.8
	26 January 2004	Upper	8.8	9.5
	19 March 2004	Upper	8.3	11.8
Clinch	16 April 2003	Upper	8.5	9.5
	5 June 2003	Upper	8.6	7.9
	8 July 2003	Upper	11.1	8.3
	10 August 2003	Upper	15.4	7.8
		Lower	13.0	8.6
	6 October 2003	Upper	17.2	4.3
		Lower	17.3	5.6
	17 December 2003	Upper	11.4	8.6
		Lower	11.3	8.5
	18 January 2004	Upper	7.4	10.2
		Lower	7.6	9.8
	1 April 2004	Lower	8.5	11.5
Hiwassee	26 March 2003	Upper	11.8	10.9
	2 June 2003	Upper	15.0	9.2
		Lower	16.9	9.5
	3 July 2003	Upper	18.3	8.7
	1 August 2003	Upper	19.2	7.3

Table A2. continued.

River	Date	Reach	Temperature (ºC)	Dissolved Oxygen (mg/L)
	29 September 2003	Upper	20.7	8.0
	6 January 2004	Upper	8.5	10.7
South Fork Holston	3 June 2003	Lower	10.1	10.4
	3 July 2003	Upper	12.8	9.2
	5 August 2003	Upper	12.9	8.0
		Lower	13.6	12.0
	30 September 2003	Upper	17.3	8.5
		Lower	17.1	10.4
	2 December 2003	Upper	11.5	6.3
		Lower	12.3	8.1
	7 January 2004	Upper	7.2	11.1
		Lower	7.1	11.6
	10 March 2004	Upper	5.8	11.1
		Lower	6.6	11.6
Watauga	24 April 2003	Upper	7.3	12.2
		Lower	9.0	12.0
	4 June 2003	Upper	8.9	11.6
		Lower	10.7	10.8
	3 July 2003	Upper	12.5	10.7
	4 August 2003	Upper	13.5	10.1
	19 August 2003	Lower	17.6	11.0
	30 September 2003	Upper	11.4	8.5
		Lower	11.3	10.6
	3 December 2003	Upper	10.6	7.3
		Lower	11.0	8.3
	6 January 2004	Upper	6.4	10.8
	7 January 2004	Lower	7.0	11.2

Table A3. Average annual daily discharge (m^3/s) for Tennessee tailwaters from 1993 to 2003.

	Annual Average Daily Discharge (m^3/s)										
River	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Caney Fork	84.4	170.3	76.3	88.2	128.1	128.3	85.0	72.0	71.7	104.7	143.6
Clinch	116.9	143.6	96.1	152.1	128.4	120.8	72.8	53.7	68.4	104.8	144.7
Hiwassee	51.8	70.4	59.4	67.5	70.2	60.8	46.3	30.9	33.4	44.1	67.7
South Fork Holston	8.9	33.7	24.3	32.4	28.2	31.8	15.5	15.2	18.8	21.1	44.6
Watauga	21.1	24.8	26.0	24.0	21.4	25.3	13.5	12.4	13.7	14.3	28.3

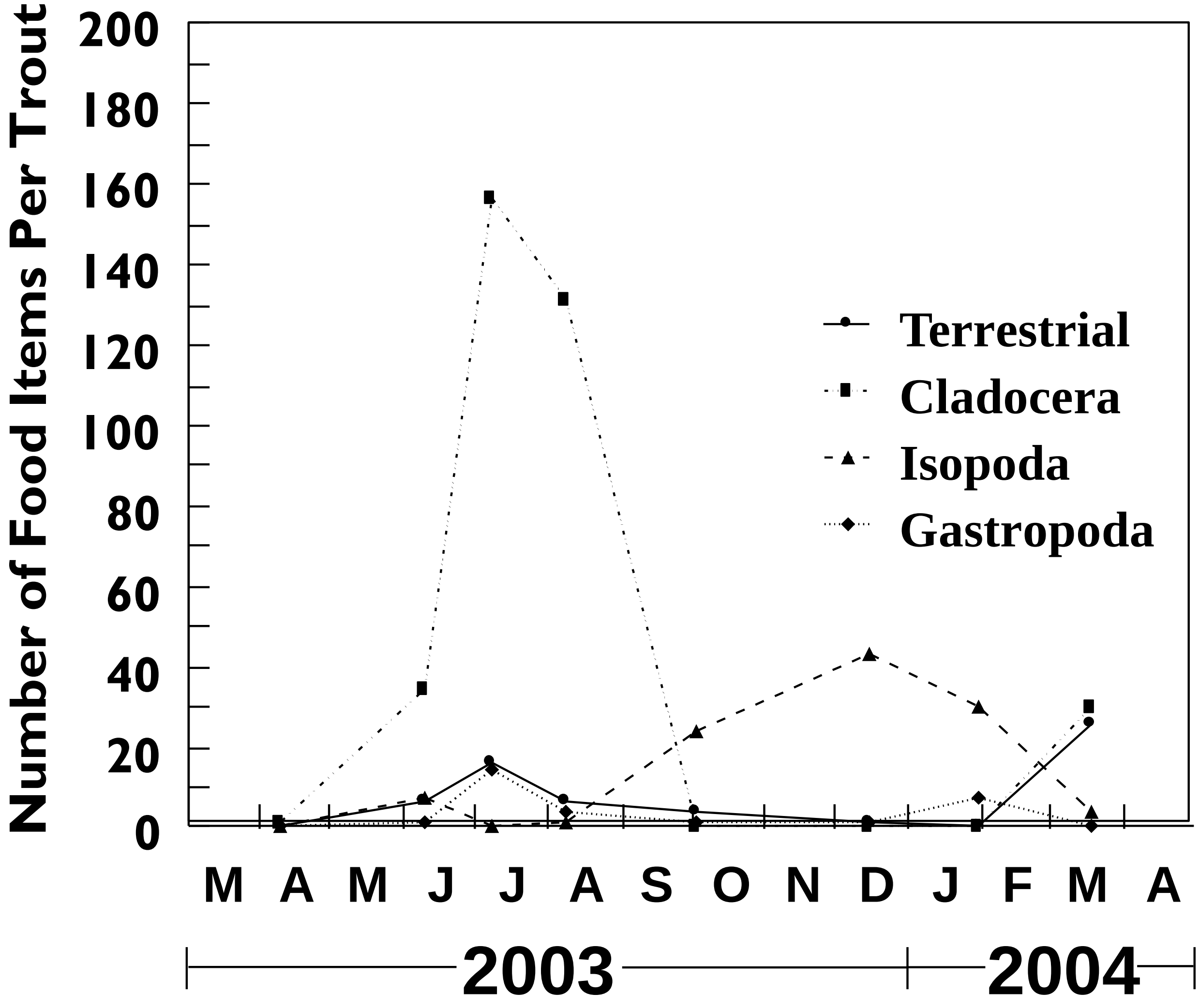

Figure A1. Consumption of major taxa by brown trout stocked into the Caney Fork River.

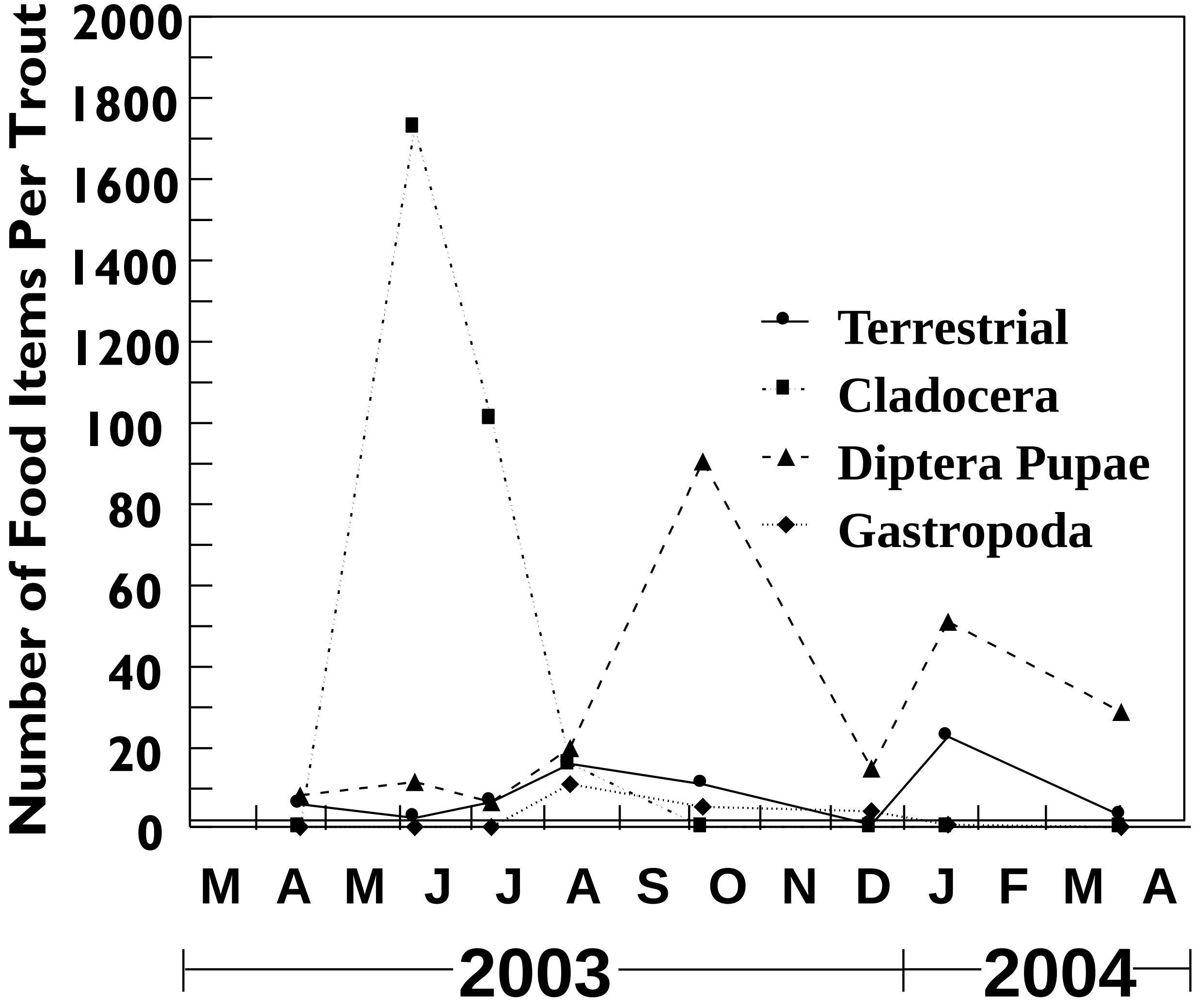

Figure A2. Consumption of major taxa by brown trout stocked into the Clinch River.

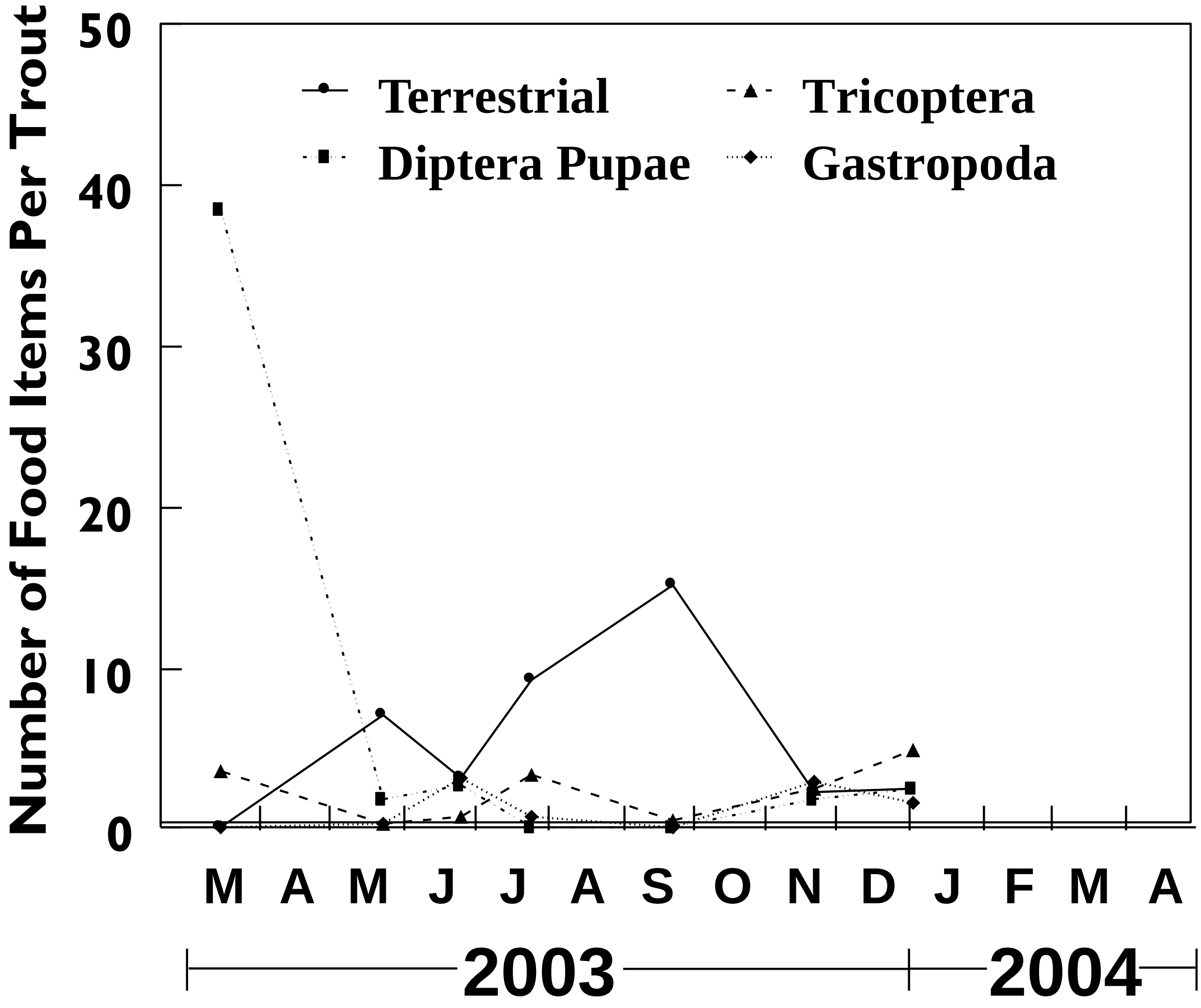

Figure A3. Consumption of major taxa by brown trout stocked into the Hiwassee River.

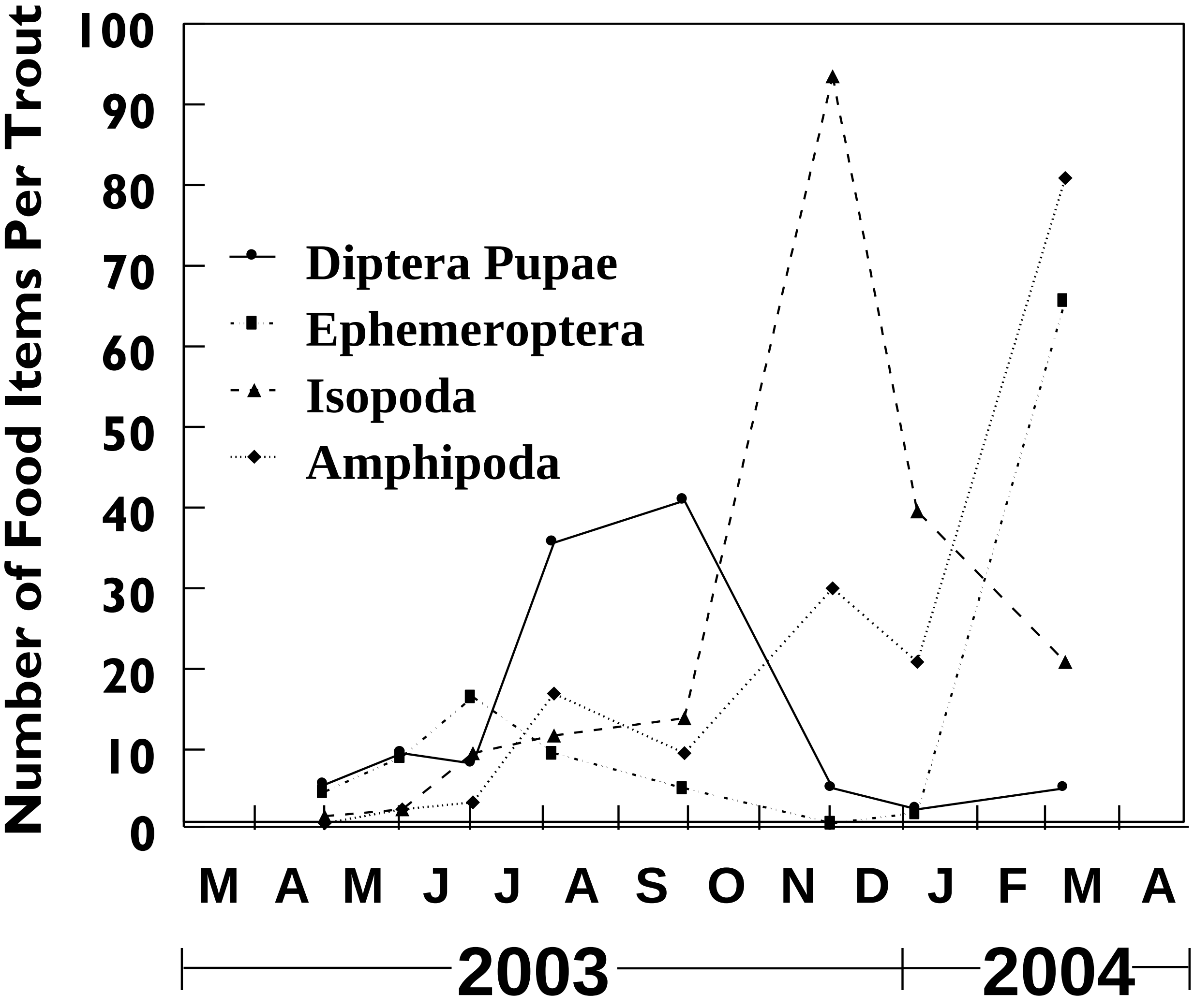

Figure A4. Consumption of major taxa by brown trout stocked into the South Fork of the Holston River.

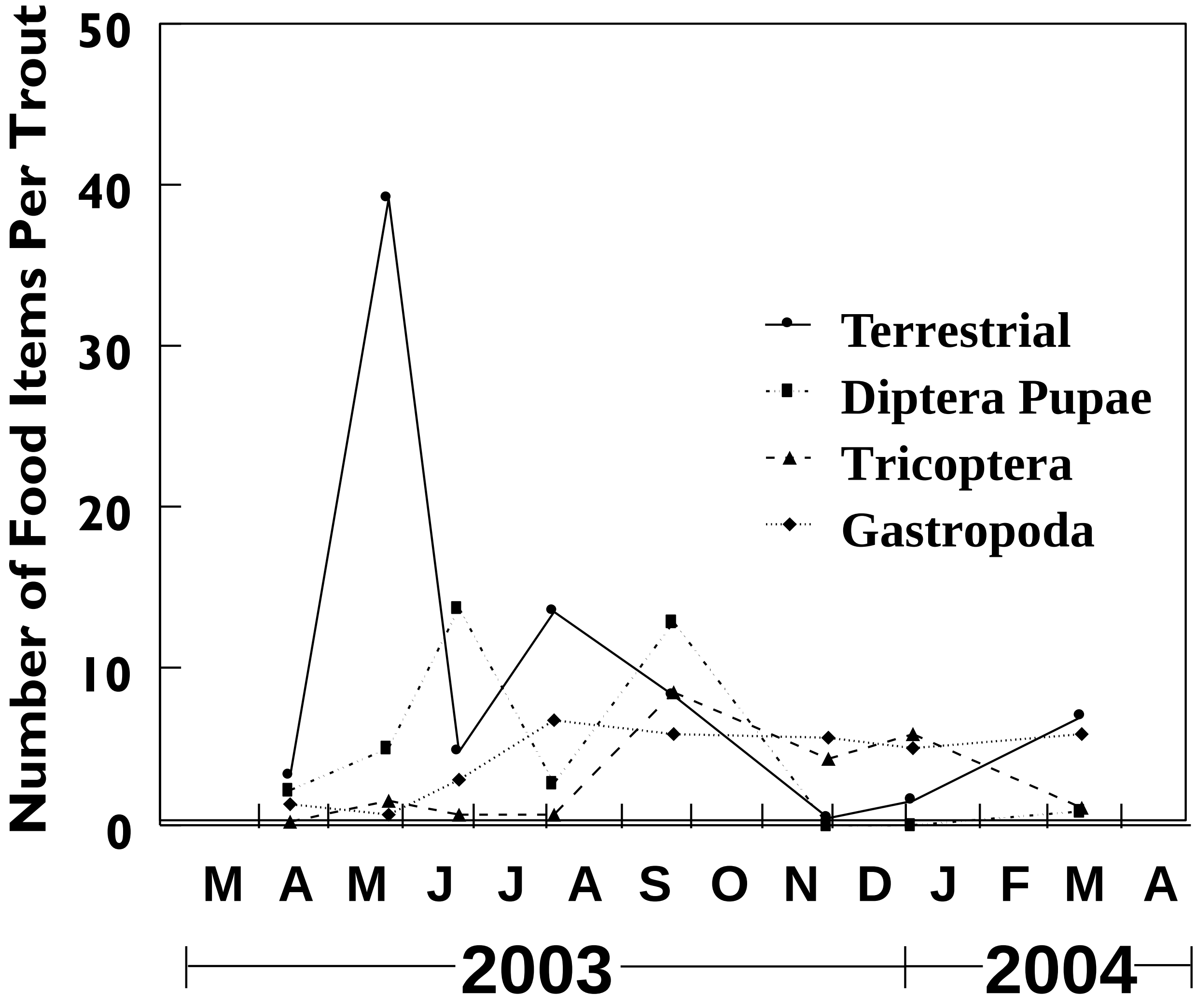

Figure A5. Consumption of major taxa by brown trout stocked into the Watauga River.