Fisheries Report 09-04

Growth, Diet, and Sampling of Rainbow Trout in Three Tennessee Reservoirs

A Final Report Submitted To

Tennessee Wildlife Resources Agency

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ABSTRACT

Marked and unmarked rainbow trout *Oncorhynchus mykiss* were stocked inshore and offshore into three Tennessee reservoirs (Dale Hollow, Watauga, South Holston) in December 2006-January 2007 and December 2007-January 2008. We subsequently assessed spatial variation in electrofishing catch rates of rainbow trout in the winters of 2007 and 2008. Electrofishing sites were stratified by location (embayment versus main channel) and reach (lower versus upper reservoir). Catch rates in all reservoirs were generally higher in embayments than along the main channel and embayment catch rates decreased with distance from the dam in Dale Hollow Lake and Watauga Lake. Large (4.9 x 91 m) experimental gill nets (n = 8) were fished midwater in each reservoir in July 2007. Catches in gill nets were low, averaging only 0.4 to 2.1 trout per net night. Walleyes *Sander vitreous* were the most common bycatch; 1.6 - 4.5 walleyes were caught per net night in each reservoir. Embayment electrofishing sampling produced 3X – 24X more trout per person-hour of effort than gillnetting in the three reservoirs. Stocked rainbow trout exhibited fast growth (32 - 48 mm per month) in all reservoirs between March and August 2007. Alewives *Alosa pseudoharengus* dominated the clupeid catch in gillnets in Dale Hollow Lake and were the only clupeid species collected in Watauga Lake; whereas, more threadfin shad *Dorosoma petenense* than alewives were caught in gillnets in South Holston Lake. Regardless of the clupeid forage base present in each reservoir, rainbow trout switched to piscivory at about 250 mm total length (TL) and fed almost exclusively on alewives in all three reservoirs. If rainbow trout were stocked at larger sizes each winter (> 250 mm TL), they would likely begin feeding on alewives immediately and grow faster earlier in the year, which would likely improve survival and returns to the creel.

INTRODUCTION

Tennessee’s reservoirs provide many excellent coldwater sportfishing opportunities. In 2004, Tennessee ranked third in the U.S. in total number of salmonids stocked by federal fish hatcheries to provide recreational angling opportunities (Caudill 2005). In 2005, the Tennessee Wildlife Resources Agency (TWRA) stocked 2.3 million rainbow trout *Oncorhynchus mykiss*, brown trout *Salmo trutta*, and lake trout *Salvelinus namaycush* produced by Dale Hollow National Fish Hatchery and four TWRA hatcheries (Fiss and Habera 2006).

Effective management of fishes produced in hatcheries and stocked in reservoirs depends on knowledge of fish habitat use and behavior. It is commonplace for researchers to describe variation in fish habitat use and behavior over time and space (Sammons and Bettoli 2002; Rhea et al. 2005). Salmonid distributions in lakes and reservoirs in the western United States have been shown to vary both spatially and temporally (Nowak and Quinn 2002), and rainbow trout are most commonly observed in littoral areas when temperatures in the epilimnion do not exceed their thermal preferences (Wurtsbaugh et al. 1975; Warner and Quinn 1995; Baldwin et al. 2000). As water temperature climbs above 21 ^{o}C, rainbow trout move to cooler areas deeper in the water column (Horak and Tanner 1964). Most of the lakes and reservoirs in the western United States that support salmonids do not support the complex two-story fisheries that are common in reservoirs in the southeastern United States. It is unclear whether complex predator communities in southeastern U.S. reservoirs influence rainbow trout distributions, especially soon after stocking when rainbow trout are most vulnerable to predation (Baldwin et al. 2003). Whereas much information exists on rainbow trout stocked in Tennessee’s tailwaters (e.g., Devlin and Bettoli 2001; Bettinger and Bettoli 2002), little is known about the fate of rainbow trout stocked in reservoirs.

The paucity of information on the biology of rainbow trout in reservoirs is largely due to the difficulty of sampling a coldwater species in a system that thermally stratifies. Many coolwater and warmwater reservoir fish species (e.g., walleye *Sander vitreus* and black basses *Micropterus* spp.) are sampled routinely using gillnets or electrofishing gear in the littoral zone. However, catch rates of rainbow trout in gillnets are often low (Kerr and Lasenby 2000) and electrofishing does not effectively sample depths that rainbow trout inhabit much of the year. Other researchers have found it difficult to collect large, statistically robust samples of rainbow trout (e.g., Atkinson 1932; Jones and Hoyer 1982), signaling the necessity for continued development of reliable sampling techniques for assessing coldwater populations (Wydoski 1986).

Electrofishing rainbow trout during periods of reservoir stratification is not feasible because rainbow trout inhabit deep waters and are not vulnerable to electric fields. However, when a reservoir is not stratified, rainbow trout may be much closer to the surface. Weiland and Hayward (1997) electrofished at night and captured up to 500 rainbow trout / h in Lake Tanneycomo, a shallow run-of-river reservoir in Missouri. Barwick et al. (2004) reported marginal success electrofishing rainbow trout during winter in Jocassee Reservoir, North Carolina.

Rainbow trout in small reservoirs can be sampled effectively with gillnets when rainbow trout move inshore to spawn in tributary creeks (Barwick et al. 2004). In the absence of spawning runs, researchers have attempted to catch trout using pelagic gillnets. Hubert and Chamberlain (1996) reported that sampling with horizontal experimental gillnets in Wyoming systems (<1 ha to 17,010 ha) yielded catch rates of less than 0.1 fish/h to 5.8 fish/h. In Lake Jocassee, South Carolina, gillnetting produced an average catch of 0.26 rainbow trout/ net night (Barwick and Geddings 1986). On Laurel River Lake, Kentucky, vertical gillnets fished for 120 net-nights in two consecutive years captured a mere 7 and 18 rainbow trout, respectively (Jones 1982). Babey and Berry (1989) assessed the performance of three strains of rainbow trout using sinking gillnets in the littoral zone of a Utah reservoir, but this method may be impractical in Tennessee reservoirs where large bycatches of prized sportfish species such as walleye and smallmouth bass *M. dolomieu* are possible.

The objectives of this study were to: (1) assess spatial and temporal variation in electrofishing catches of rainbow trout in three Tennessee reservoirs, (2) compare electrofishing and gillnet catches of rainbow trout to determine the best method for collecting trout while minimizing bycatch, and (3) examine rainbow trout growth, their diet, and forage fish abundance.

STUDY AREAS

Dale Hollow Lake is a 11,215 ha impoundment on the Obey River in north central Tennessee and southern Kentucky. The United States Army Corps of Engineers constructed the dam and reservoir in 1943 for flood control, electric power, and recreation. Dale Hollow Lake is monomictic and stratifies between late March and November (Figure 1). At full pool, Dale Hollow Lake has a shoreline length of 1000 km and is 92 km long. Full pool is at 202 m above mean sea level (m msl) and the reservoir has an average depth of 16.7 m and a maximum depth of 42 m. Schultz (1992) classified Dale Hollow as an oligo-mesotrophic lake based on secchi disk depth, total phosphorus and chlorophyll-*a* concentrations, and hypolimnetic dissolved oxygen concentrations. As a two-story reservoir, it supports a warmwater fishery for largemouth bass *M. salmoides*, a coolwater fishery for smallmouth bass and walleye, and a coldwater fishery for rainbow trout and brown trout. The primary forage fishes are alewives *Alosa pseudoharengus* and threadfin shad *Dorosoma petenense* (Reeser 1995).

South Holston Lake is a 3,068 ha impoundment on the South Fork of the Holston River in northeast Tennessee and southwest Virginia. At full pool, South Holston Lake has a shoreline length of 293 km and is 38.6 km long. Full pool is at 527 m msl and the average and maximum depths are 10 m and 75 m, respectively. South Holston Lake is monomictic and is stratified from late spring to late autumn. The Tennessee Wildlife Resources Agency classified South Holston Lake as mesotrophic with a trophic index of 44.7 (Carlson 1977); chlorophyll-a concentrations average 4.2 mg/L (Hammonds and Peterson 2005a). As a two-story reservoir, it supports a warmwater fishery for largemouth bass, a coolwater fishery for smallmouth bass and walleye, and a coldwater fishery for rainbow trout, brown trout, and lake trout. The primary forage fishes are alewives, gizzard shad *D. cepedianum*, and threadfin shad.

Watauga Lake is a 2,602 ha impoundment on the Watauga River in northeast Tennessee. The Tennessee Valley Authority constructed the dam and reservoir in 1948 for flood control and hydropower generation. At full pool, Watauga Lake has a shoreline length of 169 km and is 26.2 km long (Hammonds and Peterson 2005b). It has an average depth of 7 m, a maximum depth of 95 m, and is the highest reservoir in the Tennessee River system at more than 597 m msl. Watauga Lake is monomictic and is stratified from late spring to late autumn. The Tennessee Wildlife Resources Agency classified Watauga Reservoir as mesotrophic with a trophic index of 44.3; chlorophyll-a concentrations averaged 4.0 mg/L (Hammonds and Peterson 2005b). As a two-story reservoir, it supports a warmwater fishery for largemouth bass and spotted bass, a coolwater fishery for smallmouth bass and walleye, and a coldwater fishery for rainbow, brown, and lake trout. The primary forage fish species is the alewife.

METHODS

Spatial and Temporal Variation in Electrofishing Catches

Nighttime electrofishing on each reservoir was conducted in March 2007 and January-February 2008 when surface water temperatures were between 6 and 12 ^{o}C. A 4.9 m aluminum boat was outfitted with a 4500-W generator, a Smith-Root DC electrofishing unit, and boom mounted steel cable anodes. The crew consisted of a driver and two netters. Fifteen shoreline sites on each reservoir were electrofished for 10 min each. The 15 sites were stratified by location (5 main channel and 10 embayment sites) because anecdotal reports suggested catch rates in embayments would be higher than catch rates along main channels. Each reservoir was also stratified by reach (i.e., lower and upper). Five embayment sites were chosen randomly from each reach. Each channel site was selected by generating a random distance (km) from the dam within the lower or upper reach. Three channel sites were electrofished in lower reaches and two channel sites were electrofished in upper reaches.

Nearly all of the rainbow trout stocked into the three reservoirs in this study were stocked in December 2006 - January 2007 and December 2007 - January 2008 (Table 1),; a small number of rainbow trout were stocked into South Holston lake in march 2007. The trout stocked into each reservoir each year were adipose fin-clipped, microtagged, or left untagged (depending on whether they were stocked inshore or offshore) as part of a concurrent study that examined survival as a function of stocking location (Bergthold 2008). Mean total length of rainbow trout at stocking differed by no more than 18 mm among reservoirs and stocking events. ArcGIS software was used to measure the shortest distance (km) from each stocking site to the dam in each reservoir. The shortest distance from each electrofishing sample site to the dam was also measured.

Analysis of covariance was used to detect differences in embayment and main channel electrofishing catches of rainbow trout in each study reservoir; data were pooled over both years for this analysis. Log_{10}(catch+1) was the dependent variable, location (embayment or main channel) was the independent variable, and distance from the dam was the covariate. Adjusted mean catches at embayment and main channel sites were compared only if the relation between catches and distance from the dam (i.e., the slopes) were similar (F-test; $P > 0.05$).

Gear Comparison

Nighttime electrofishing samples were collected in March 2007 per the previous description. Experimental horizontal gillnets (4.9 m X 91 m; n = 8 net nights) were fished midwater in July 2007 when each reservoir was stratified. Gillnets were set before dusk (1445 – 1815 hours) and retrieved the following morning (0700 – 1030 hours); soak time averaged 16.7 h (SE = 0.22). An electric pot puller was used to retrieve nets and anchors. Each gillnet was constructed with four equal-length panels of 38, 51, 64, and 76 mm monofilament bar mesh and fished at offshore locations in and below the thermocline. The top of the net fished from 8 to 10 m deep ($\bar{Z}$ = 8.6 m, SE = 0.20). Gillnets were fished in the lower reach of each reservoir to avoid uplake reaches where hypolimnetic dissolved oxygen concentrations were below 5 ppm.

The person-hours required to collect each electrofishing and gillnet sample were recorded and included all time dedicated to gear deployment, retrieval, and fish processing. Fish processing was the time necessary to remove fish from the net and record total length and weight. Bycatch species and frequency in the catch were also recorded. Crew size for the gillnet sampling was three people.

Sampling precision was evaluated as the coefficient of variation (CV_x = SD/mean) among replicate samples for each gear type (Van Den Avyle et al. 1995). Two measures of gear efficiency were calculated. Gear efficiency for each reservoir and gear was first calculated as the number of replicate samples (N_{ij}) needed to estimate median catch per unit effort (CPUE) within 25% of the true median at P = 0.05. The average number of person-hours of labor expended per replicate was multiplied by N_{ij} to obtain the number of person-hours of effort (L_{ij}) required to estimate the median CPUE within 25% (at P = 0.05), per the methods of Van Den Avyle (1995):

$$N_{ij} = \left(Z^2 s_{ij}^2\right) / \left[\log_e\left(RE + 1\right)\right]^2$$

where

Z = 1.96; the ordinate of the normal curve at the 95% confidence level;

s_{ij}^2 = variance of transformed data $\log_e$(CPUE + 1);

RE = 0.25, the target relative error about the median CPUE;

i = reservoir;

j = sample gear.

The second measure of gear sampling efficiency was the catch of trout per person-hour of effort. This metric was calculated by dividing the catch per replicate by the person-hours necessary to complete one replicate. Ideally, one of the gears would generate large *and* precise mean catches per unit of effort.

In addition to the trout collected in winter electrofishing and summer gillnet samples, we also staged "Trout Derby" fishing tournaments once at each reservoir in June 2007 to obtain a sample of trout in early summer. Anglers at each derby allowed us to weigh and measure the rainbow trout they caught and remove the stomachs of trout.

Growth

We estimated growth of rainbow trout between March and August 2007. Instantaneous growth rates (G, %-d^{-1}) were calculated as:

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

where $\overline{W_1}$ equals the initial mean weight (g), $\overline{W_2}$ equals the final mean weight, and Δt is the interval in days. Rate of growth in length (TL, mm) was calculated by substituting mean length for mean weight.

Interval growth rates of rainbow trout between March, June, and August 2007 were calculated by regressing TL against sampling date at each reservoir. A one-way ANOVA was used to test for differences in mean TL at stocking among study reservoirs. Analysis-of-covariance (ANCOVA) was then used to detect differences among growth rates of rainbow trout in the three study reservoirs, where day of year was the covariable and TL was the dependent variable. Adjusted mean lengths with 95% joint confidence intervals were then calculated and compared among reservoirs.

Clupeid Sampling

Relative amounts of pelagic forage fish available to rainbow trout in each reservoir were estimated using inshore gillnet catches. Horizontal sinking gillnets (1.8 m X 18.3 m; n = 30 net nights) with equal-length panels of 10, 12, 16, and 18 mm bar-mesh were fished on each reservoir. Samples were taken in April and May 2007 when surface water temperatures were between 9 and 24 ^{o}C. Nets were set along shorelines with shallow slopes and gravel substrate. Gillnets were set in tandem perpendicular to shore at 5 stations in the littoral zone and fished overnight for three nights in each reservoir. The mesh size nearest the shore was alternated in each tandem set. An ANOVA model compared $\log_{10}$(catch+1) rates among reservoirs. Interval growth rates (mm per month) by rainbow trout were subsequently tested for correlation with mean clupeid CPUE.

Ration Weights

Up to 75 rainbow trout from each study reservoir ($\leq$ 25 from each of three sampling seasons) were sacrificed in 2007 for diet analysis when catches allowed. Stomachs were extracted and preserved in 10% formalin. In the laboratory, stomach contents were extracted, patted dry, and wet weighed. Invertebrates were identified taxonomically to order and counted. Fish remains were separated from the other stomach contents, wet weighed, identified to species (when possible), and counted.

Proportion of empty stomachs was calculated for each sampling event in each study reservoirs. One-way ANOVA models were used to explain variation in rainbow trout total length, mean ration weight (g), number of prey per rainbow trout stomach, mean ration weight of fish, and mean number of prey fish per rainbow trout within and among reservoirs for each sampling event.

RESULTS

Spatial and Temporal Variation in Electrofishing Catch Rates

Dale Hollow Lake - Twenty-three rainbow trout were electrofished in 2007 (Table 2) and 4.3% of those fish were holdovers (Figure 2). Rainbow trout were stocked up to 17 km from the dam, but few fish were recaptured further than 5 km from the dam. Catch rates at embayment electrofishing sites in 2007 were correlated with catch rates at those same embayment sites in 2008 (n = 10; R = 0.84; P = 0.002). Half as many rainbow trout were stocked in 2008 as 2007, but twice as many rainbow trout were collected in 2008 than in 2007. Variation in the catch of rainbow trout over both years with increasing distance from the dam was not similar for embayment and main channel sites (i.e., the slopes differed: F = 10.02; df = 1, 28; P = 0.0037). On average, one fewer rainbow trout was caught at embayment sites for every 0.9 km moved upstream from the dam (F = 27.06; df = 1, 18; P < 0.0001). Catches of rainbow trout at main channel sites (both years combined) in Dale Hollow Lake were low ($\bar{x} =$ 0.25; SE = 0.18) and did not vary with distance from the dam (P = 0.70).

South Holston Lake - Fifty-one rainbow trout were electrofished in 2007 (Table 2; Figure 3) and no holdover fish were observed. Twenty-nine rainbow trout were collected in the February 2008 and one fish was a holdover stocked in a previous year. Rainbow trout were stocked up to 6 km from South Holston dam and were collected up to 12 km from the dam. Embayment electrofishing catch rates were lower in 2007 than in 2008 and catches at each site were correlated between years (n = 10; R = 0.69; P = 0.03). After catch data were truncated to exclude catches further than 10 km from the dam, the slopes of the regression lines relating $\log_{10}$ (catch + 1) to distance from the dam were similar (F = 0.17; df = 1, 18; P = 0.69). Adjusted mean catch of rainbow trout (both years combined) was 128% higher at embayment sites than at channel sites (ANCOVA; F = 3.76; df = 1, 19; P = 0.07).

Watauga Lake - One hundred ninety-five rainbow trout were electrofished in 2007 and holdover rainbow trout represented 2.1% of the catch (Figure 4). One hundred forty rainbow trout, two of which were holdovers, were collected in 2008. Rainbow trout were stocked up to 11 km from the dam and few fish were recaptured farther upriver. No correlation existed between catch rates at each embayment site in 2007 and 2008 (n = 10; R = 0.32; P = 0.37). Embayment and main channel catches in both years declined at similar rates with distance from the dam (F = 0.10; df = 1, 26; P = 0.93). Catches declined at a rate of ~1 fish per 0.5 km distance from the dam (t = -6.60; df = 1; P = 0.0001). Catches were not similar between embayment and main channel sites (ANCOVA; F = 10.67; df = 1, 27; P = 0.003). The adjusted mean catch of rainbow trout in the embayment locations was 237% more than the adjusted mean catch at main channel sites.

Gear Comparison

The precision of mean catch estimates (i.e., CV_x's) generated by the three sampling schemes (i.e., embayment electrofishing; main channel electrofishing; gillnetting) overlapped broadly (Table 3). The effort (person-hours) required to estimate median CPUE within 25% of the true median at P = 0.05 (i.e., L_{ij}) was similar for gillnetting and embayment electrofishing in South Holston Lake, but gillnetting was 4 times more efficient than embayment electrofishing in Dale Hollow Lake and 2 times more efficient in Watauga Lake. Despite being more efficient (as measured by L_{ij}), gillnetting produced mean catches per person-hour that were only 8 - 38 % of mean embayment electrofishing catches in the three study lakes. Gillnetting also yielded an average bycatch of approximately two large walleye (mean TL $\geq$ 544 mm) for every rainbow trout at all three study reservoirs (pooled data).

Growth

Rainbow trout grew at different rates between March and August 2007 in Dale Hollow Lake (48 mm/month), South Holston Lake (38 mm/month), and Watauga Lake (32 mm/month; F = 6.15; df = 2, 397; P = 0.002). Rainbow trout grew fastest in Dale Hollow Lake and South Holston Lake and fish in both of those reservoirs grew faster than fish in Watauga Lake (Bonferroni test; P = 0.05).

Instantaneous growth in length from stocking to mid March 2007 (~ 90 d) was slow ($\leq$ 0.2 %-d^{-1}) on all three study reservoirs (Figure 5). By June 2007, instantaneous growth rates increased to 0.3 - 0.5 %-d^{-1}. Growth through July 2007 slowed in Dale Hollow Lake and South Holston Lake (0.07 and 0.18 %-d^{-1}, respectively); whereas, growth in Watauga Lake increased from 0.3 to 0.5 %-d^{-1}. Instantaneous growth in weight followed a similar pattern over time in all three reservoirs (Figure 6).

Clupeid Sampling

Catches of clupeids in the three study reservoirs were composed almost exclusively of alewives and threadfin shad, although the relative contribution of each species differed markedly. Combined clupeid catch varied more than 20-fold among reservoirs (ANOVA; F = 25.24; df = 2, 86; P < 0.0001; Figure 7) and was higher in Dale Hollow Lake ($\bar{x} = 86$; SE = 18.9) and South Holston Lake ($\bar{x} = 81$; SE = 20.2) than in Watauga Lake ($\bar{x} = 2$; SE = 0.9). Alewife catches varied nearly 20-fold among reservoirs (F = 21.03; df = 2, 86; P < 0.0001) and were highest in Dale Hollow Lake ($\bar{x} = 75$; SE = 17.8), followed by South Holston Lake ($\bar{x} = 14$; SE = 5.5) and Watauga Lake ($\bar{x} = 2$; SE = 0.9).

Threadfin shad catches also differed widely among reservoirs (ANOVA; F = 22.35; df = 2, 86; P < 0.0001). None were collected in Watauga Lake and mean catches in Dale Hollow Lake ($\bar{x} = 11.3$; SE = 5.5) and South Holston Lake ($\bar{x} = 67$; SE = 17.8) varied six-fold (F = 18.45; df = 1, 2; P $\leq$ 0.0001). .

Growth rates (mm/month) of rainbow trout were not statistically correlated (df = 1; R = 0.98; P = 0.14) with mean alewife CPUE because of low sample size and too few degrees of freedom. Nevertheless, the data suggested that rainbow trout grew fastest where alewives were most abundant.

Ration Weights

Significant variation in composition and weight of stomach contents of rainbow trout was detected among reservoirs, primarily in March 2007 (Table 4). The mean total length of rainbow trout in March 2007 was higher in South Holston Lake than in Dale Hollow Lake and Watauga Lake (ANOVA; F = 7.58; df =2, 74; P = 0.001), and rainbow trout in South Holston Lake fed heavily on clupeids. No clupeids were found in the stomachs of rainbow trout in March 2007 in Watauga Lake (Table 6); thus, mean ration weight was lower in Watauga Lake than in Dale Hollow Lake and South Holston Lake (ANOVA; F = 10.78; df = 2, 74; P < 0.0001; Table 4). Diptera were the most common invertebrate prey and were a large percentage of the rainbow trout diet during March 2007 in Dale Hollow Lake and Watauga Lake.

Although mean lengths of rainbow trout collected for diet analysis in June 2007 varied among reservoirs (ANOVA; F = 25.00; df = 2, 53; P < 0.0001), no differences in mean ration weight, organisms per rainbow trout, or mean ration weight of fish prey were detected (ANOVA; F ≤ 1.66; df = 2, 53; P ≥ 0.20). However, rainbow trout in Watauga Lake consumed more fish prey than in the other two study reservoirs during June (ANOVA; F = 8.07; df = 2, 53; P = 0.0009).

No differences in rainbow trout lengths or ration weights could be detected in July 2007 (P ≥ 0.14). Mean ration weight of fish increased over time in Dale Hollow Lake and South Holston Lake (Figure 8). In Watauga Lake, mean ration weight of fish was highest in June, and was higher in July than in March.

DISCUSSION

Spatial and Temporal Variation in Electrofishing Catches

We found no reports in the literature that rainbow trout choose embayment habitats over main channel habitats during winter. Rainbow trout in reservoirs in the western U.S. inhabit littoral areas during winter, spring, and fall (Warner and Quinn 1995; Baldwin et al. 2000; Yule 2000; Rhea et al. 2005), but descriptions of littoral habitat selected by rainbow trout in western reservoirs made no mention of “main channel versus embayment habitat use”. Barwick et al. (2004) electrofished rainbow trout from Jocassee Reservoir, South Carolina, but made no mention of the habitat where rainbow trout were collected. Complex habitats can serve as refuge from predation (Lynch and Johnson 1989) or as productive foraging areas (Werner et al. 1983; Beauchamp et al. 1994). Embayment sites may have more complex habitat where rainbow trout can seek shelter from predation and more invertebrate prey from allochthonous inputs from run-off and stream inflows. Rainbow trout in New Zealand’s Lake Coleridge moved toward the mouths of inflowing streams prior to migrating upstream to spawn (James and Kelso 1995), but such inflows are not common or persistent in the embayments of the three Tennessee study reservoirs.

Examples of rainbow trout catches varying with distance from the dam could not be located in the literature, but uplake-downlake trends in catch rates do occur with alewives and gizzard shad (Tisa and Ney 1991; Michaletz and Gale 1999). Low catch rates in the upper reaches of Watauga Lake and South Holston Lake may have resulted from fewer uplake stocking locations. However, rainbow trout were stocked in Dale Hollow Lake nearly 10 km uplake of electrofishing sites where few trout were collected. Rainbow trout stocked in lotic environments tend to move downstream initially (Cresswell 1981; Bettinger and Bettoli 2002), but no documentation of this behavior in lentic systems was found.

Gear Comparison

Electrofishing along shorelines of embayments was superior to gillnetting as a method for collecting rainbow trout, but rainbow trout can only be electrofished when the reservoir is not stratified. If it were necessary to collect rainbow trout after stratification, gillnetting would be a possible option; however, it would be difficult (and expensive) to collect large numbers of fish with average catches of only 0.4 - 2.1 rainbow trout per net-night in the three study reservoirs.

The gillnet design used for this study was not a standard gillnet design; therefore, the catches of rainbow trout in gillnets could not be directly compared with other studies. However, general trends can be discussed. In Laurel River Lake, Kentucky, vertical gillnets fished for 120 net-nights in two consecutive years captured a mere 7 and 18 rainbow trout (Jones 1982). The mean catch of rainbow trout per net-night in gillnets (surface sets; 52 m X 2.4 m) set in limnetic areas in late summer in Lake Desmet, Wyoming was 1.4 (SE = 0.3;Rhea et al. 2005). However, mean catch of rainbow trout in the Coal Creek of Seminoe Reservoir, Wyoming, was 5.1 fish per net-night (Rhea et al. 2005).

When gillnets are set in western U. S. reservoirs, catches of rainbow trout are typically greater inshore than offshore (Horak and Tanner 1964; Rhea et al. 2005). Rainbow trout were sampled with gillnets in the littoral zone in Jocassee Reservoir, South Carolina, but walleye were not common in that system (Barwick and Geddings 1986). Across all three Tennessee reservoirs, two walleyes were captured for every rainbow trout caught in gillnets in the present study. Bycatch of large walleye in offshore gillnets and the subsequent mortality of those walleye would likely be perceived negatively by anglers. The combination of high bycatch and low CPUE of rainbow trout rendered gillnetting an impractical method for sampling rainbow trout in the three Tennessee reservoirs we examined. In contrast, embayment electrofishing prior to thermal stratification, which has been used in other southeastern and midwestern U.S. reservoirs (Barwick 1985; Weiland and Hayward 1997; Barwick et al. 2004), is a promising tool for managers seeking to monitor rainbow trout populations in Tennessee reservoirs. Low water clarity can decrease the efficiency of electrofishing (Reynolds 1996) and on several occasions in the present study, electrofishing was conducted following rain events when turbidity was high. Decreased visibility due to high turbidity was especially apparent in embayments where runoff transported sediments into the reservoir. Future research should attempt to account for variation in electrofishing catches of trout due to turbidity.

Growth and Condition

Rainbow trout grew much faster in Tennessee reservoirs than in Tennessee tailwaters. Rainbow trout stocked as fingerlings and catchables (> 200 mm TL) grew only 5-14 mm/month in the Watauga River (Bettoli 1999) compared to 32 mm/month in Watauga Lake. Similarly, catchable rainbow trout stocked into the South Fork of the Holston River grew 9-16 mm/month (Bettoli et al. 1999) compared to 38 mm/month for the same size fish stocked into South Holston Lake. The growth of rainbow trout stocked into Dale Hollow Lake (48 mm/month) was the fastest growth we are aware of for any Tennessee population of rainbow trout.

Fish growth is regulated by temperature and food intake (Railsback and Rose 1999) and the faster growth in spring and early summer of rainbow trout in Dale Hollow Lake and South Holston Lake (compared to Watauga Lake) can be attributed to both factors. In March 2007, surface water temperatures averaged 1-2 ^{o}C higher in Dale Hollow Lake and South Holston Lake than in Watauga Lake. Alewives move inshore to spawn when water temperatures reach 9 ^{o}C (Irwin and Bettoli 1995) and the higher temperatures may have triggered slightly earlier spawning runs of alewives in Dale Hollow Lake and South Holston Lake and provided ample, readily-accessible prey. Alewives were also much more abundant in Dale Hollow Lake and South Holston Lake than in Watauga Lake.

The date that rainbow trout were stocked may have also had an affect on subsequent growth rates. Rainbow trout were stocked up to a month later in Watauga Lake than in Dale Hollow Lake and South Holston Lake in 2007. Other researchers have observed poor foraging by recently stocked salmonids (O'Grady 1983; Bachman 1984) and the low ration weights of rainbow trout in Watauga Lake during March 2007 may have reflected their later stocking date. Rainbow trout in this study and others (Beauchamp 1990) shifted to piscivory at approximately 250 mm TL. Thus, rainbow trout that were stocked later would be expected to shift to piscivory later (as observed in this study) and to grow slower initially.

The amount of habitat available to rainbow trout in southeast U.S. reservoirs decreases as the summer progresses (Barwick et al. 2004) and zones of hypoxia were detected during the summer of 2007 in all three Tennessee reservoirs, but especially Dale Hollow Lake and South Holston Lake. A temperature-dissolved oxygen squeeze offers an explanation of why the instantaneous growth rate of rainbow trout slowed in Dale Hollow Lake and South Holston Lake but increased in Watauga Lake from June to July 2007. Even though 2007 was a relatively good year in terms of water quality and trout habitat in Dale Hollow Lake and South Holston Lake, fish were still restricted to increasingly scarce habitat in summer and it is likely that growth was negatively affected.

Clupeid Abundance

Forage fish abundance can vary greatly from year to year in Tennessee reservoirs (e.g., Sammons et al. 1999) and the trends observed in this study may not hold true every year. Yearly monitoring of clupeid abundance would be necessary to determine the relation between clupeid abundance and growth of rainbow trout. Low sample size (n = 3) prevented the declaration of a statistical correlation between mean CPUE of alewives and the growth rate of rainbow trout. However, the growth rate was highest where the most alewives were sampled (Dale Hollow) and lowest where the fewest alewives were sampled (Watauga).

Ration Weights

Rainbow trout less than 250 mm TL fed almost exclusively on invertebrates in all three study reservoirs. Larger rainbow trout preyed heavily upon alewives and instantaneous growth rates increased after the switch to piscivory. Similarly, Beauchamp (1990) observed that rainbow trout in Lake Washington, Washington, switched to piscivory at about 250 mm TL. If rainbow trout were stocked at larger sizes (> 250 mm TL), they might be capable of feeding on alewives immediately (and growing faster) soon after they are stocked, which would likely improve survival and returns to the creel.

The diet of rainbow trout consisted primarily of alewives even where more threadfin shad were collected (i.e., South Holston Lake). Alewives have a cooler thermal ecology than threadfin shad and are found deeper in the water column during stratification (Irwin and Bettoli 1995). Rainbow trout likely selected alewives as prey simply because alewives were more available at the depths that rainbow trout inhabited when the reservoirs was stratified.

MANAGEMENT IMPLICATIONS

Whereas reservoir fishery managers have developed and refined efficient sampling schemes for warmwater and coolwater fish species over many decades, sampling programs for salmonids in reservoirs are uncommon and poorly documented. Although more work is needed, winter electrofishing along fixed transects in embayments is probably the best sampling technique currently available to biologists seeking to monitor trout populations in southern U.S. reservoirs.

In the absence of a severe temperature-dissolved oxygen squeeze, rainbow trout in Tennessee reservoirs grow extremely fast when they become piscivorous. All of the cohorts of rainbow trout that were stocked in this study averaged less than 250 mm TL, which is the size at which rainbow trout begin to switch to piscivory; thus, stocking slightly larger trout would probably result in faster-growing trout that will be less vulnerable to predation, which should improve angler return rates and simultaneously boost the abundance of larger fish.

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Table 1. Mean total length (TL) and standard error (SE), mark or microtag location, number stocked, and stocking location of rainbow trout stocked from December 2006 to January 2008 in three Tennessee reservoirs. Subsamples of approximately 300 fish were taken to determine mean total length and tag retention. Retention for cohorts without a mark or tag was the proportion of rainbow trout missing the adipose fin. N/A = mean total length was estimated from hatchery records and was not obtained by subsampling; thus, there was no SE.

Reservoir	Date Stocked	TL (mm)	SE	Mark or Tag	Number Stocked	Stocking Location
Dale Hollow	12/05/06	229	1.4	Adipose Clip	30,044	Offshore
Dale Hollow	12/07/06	237	1.2	None	46,446	Inshore
Dale Hollow	12/27/07	224	N/A	None	35,718	Inshore
South Holston	12/12/06	228	1.7	Adipose Clip	19,132	Offshore
South Holston	12/21/06	246	N/A	None	5,000	Offshore
South Holston	12/21/06 - 01/17/07	232	1.8	None	8,559	Inshore
South Holston	03/26/07	245	3.8	Dorsal Tag	2,858	Inshore
South Holston	12/11/07	240	1.3	None	15,208	Inshore
South Holston	12/21/07	231	1.5	Adipose Clip	18,254	Offshore
Watauga	12/28/06 - 01/25/07	241	1.5	None	27,148	Inshore
Watauga	01/18/07	235	1.4	Adipose Clip	23,950	Offshore
Watauga	12/18/07 - 01/08/08	238	1.3	None	18,488	Inshore
Watauga	12/17/07	246	1.6	Adipose Clip	18,212	Offshore

Table 2. Catch of rainbow trout (N), mean catch per unit effort (CPUE), mean total length (mm), mean surface water temperature (^{o}C), and mean pedal or soak time (min) during 2007 and 2008 sampling events on three Tennessee reservoirs. Standard errors are in parentheses.

Date	Sampling Method and Location	Number of Replicate Samples	N	CPUE	Mean Total Length (mm)	Mean Temperature (^{o}C)	Mean Pedal or Soak Time (min)
				Dale Hollow Lake			
03/05/07	Electrofishing / Channel	6	0	0 (0)	N/A	7.0	10
03/05/07	Electrofishing / Embayment	10	23	2.3 (1.4)	270 (11)	8.1	10
06/01/07	Trout Derby	N/A	8	N/A	456 (14)	27.0	-
07/31/07	Gillnetting	8	3	0.4 (0.2)	480 (14)	29.7	1080
01/28/08 - 02/13/08	Electrofishing / Channel	6	3	0.5 (0.3)	257 (14)	7.2	10
01/28/08 - 02/13/08	Electrofishing / Embayment	10	47	4.7 (2.9)	259 (3)	6.9	10

Table 2. continued.

Date	Sampling Method and Location	Number of Replicate Samples	N	CPUE	Mean Total Length (mm)	Mean Surface Temp (^{o}C)	Mean Pedal or Soak Time (min)
				South Holston Lake			
8 - 15 March 2007	Electrofishing / Channel	5	10	2 (0.7)	253 (8)	7.0	10
8 - 15 March 2007	Electrofishing / Embayment	10	41	4.1 (1.2)	270 (6)	8.3	10
2 June 2007	Trout Derby	N/A	85	N/A	395 (4)	26.0	-
25 - 26 July 2007	Gillnetting	8	17	2.1 (1.0)	435 (11)	25.3	965
31 January 2008	Electrofishing / Channel	5	13	2.2 (1.2)	258 (19)	7.0	10
31 January 2008	Electrofishing / Embayment	10	16	1.7 (0.4)	245 (4)	7.2	10
				Watauga Lake			
7 March 2007	Electrofishing / Channel	5	33	6.6 (4.6)	254 (7)	5.8 (0.1)	10
7 March 2007	Electrofishing / Embayment	10	162	16.2 (5.5)	255 (3)	6.8 (0.3)	10
16 June 2007	Trout Derby	N/A	26	N/A	371 (16)	22.9 (N/A)	-
23 - 24 July 2007	Gillnetting	8	10	1.25 (0.5)	454 (28)	25 (0.1)	957
30 January 2008	Electrofishing / Channel	5	32	6.4 (3.7)	247 (10)	5.9 (0.2)	10
30 January 2008	Electrofishing / Embayment	10	108	10.8 (2.3)	250 (4)	6.1 (0.1)	10

Table 3. Mean catch per unit effort (CPUE), precision (CV_X), efficiency (L_{ij}), and mean catch per person-hour for embayment electrofishing, channel electrofishing, and gillnetting samples in three Tennessee reservoirs during 2007. Standard errors are in parentheses.

Reservoir	Number of samples	CPUE		N_{ij}[1]	L_{ij}[2]	Catch Per Person-Hour
		Mean	CV_x			
Electrofishing / Embayment (fish / 10 min)						
Dale Hollow	10	2.3 (1.4)	1.9	75	141	1.2 (0.7)
South Holston	10	4.1 (1.2)	0.9	58	112	2.1 (0.6)
Watauga	10	16.2 (5.5)	1.1	155	261	9.6 (3.3)
Electrofishing / Channel (fish / 10 min)						
Dale Hollow	6	0.0 (0.0)	.	.	.	0.0 (0.0)
South Holston	5	2.0 (0.7)	0.8	31	60	1.0 (0.4)
Watauga	5	6.6 (4.6)	1.6	88	148	3.9 (2.8)
Gillnetting (fish/net night)						
Dale Hollow	8	0.4 (0.2)	1.4	10	30	0.1 (0.1)
South Holston	8	2.1 (1.0)	1.4	44	121	0.8 (0.4)
Watauga	8	1.3 (0.5)	1.0	28	89	0.4 (0.1)

[1] The number of replicate samples required to estimate the median CPUE within 25% at P = 0.05.
[2] The number of person-hours of effort required to estimate the median CPUE within 25% at P = 0.05.

Table 4. Mean total length (TL), mean ration weight (g), mean number of prey consumed, mean weight of fish (g), and mean number of fish consumed by rainbow trout sampled in three Tennessee reservoirs in 2007. Standard errors are in parentheses. Means in a column for each month with the same letter were not significantly different (P = 0.05).

Reservoir	N	Mean TL (mm)	Mean Ration Weight (g)	Number of Prey per Stomach	Mean Weight of Fish prey (g)	Mean Number of Fish per Stomach
			March			
Dale Hollow	21	252 (3.5)	6.1 (1.0)	38 (26.4)	2.0 (0.8)	2 (0.8)
South Holston	31	267 (4.7)	5.8 (1.0)	6 (1.6)	4.2 (0.9)	5 (0.9)
Watauga	25	244 (4.1)	1.0 (0.2)	4 (2.4)	0 (0)	0 (0)
			June			
Dale Hollow	10	451 (16.7)	8.3 (3.5)	1 (0.5)	6.3 (3.4)	1 (0.5)
South Holston	25	407 (7.9)	11.8 (1.7)	3 (0.7)	10.3 (1.6)	2 (0.2)
Watauga	21	342 (9.1)	12.7 (2.1)	3 (0.5)	12.0 (2.0)	4 (0.5)
			July			
Dale Hollow	5	467 (14.6)	10.5 (5.7)	2 (1.3)	8.1 (5.7)	1.8 (1.1)
South Holston	17	429 (11.4)	13.9 (3.3)	3 (0.4)	13.6 (3.1)	3 (0.4)
Watauga	10	416 (15.9)	5.5 (1.5)	3 (0.4)	5.4 (1.4)	3 (0.4)

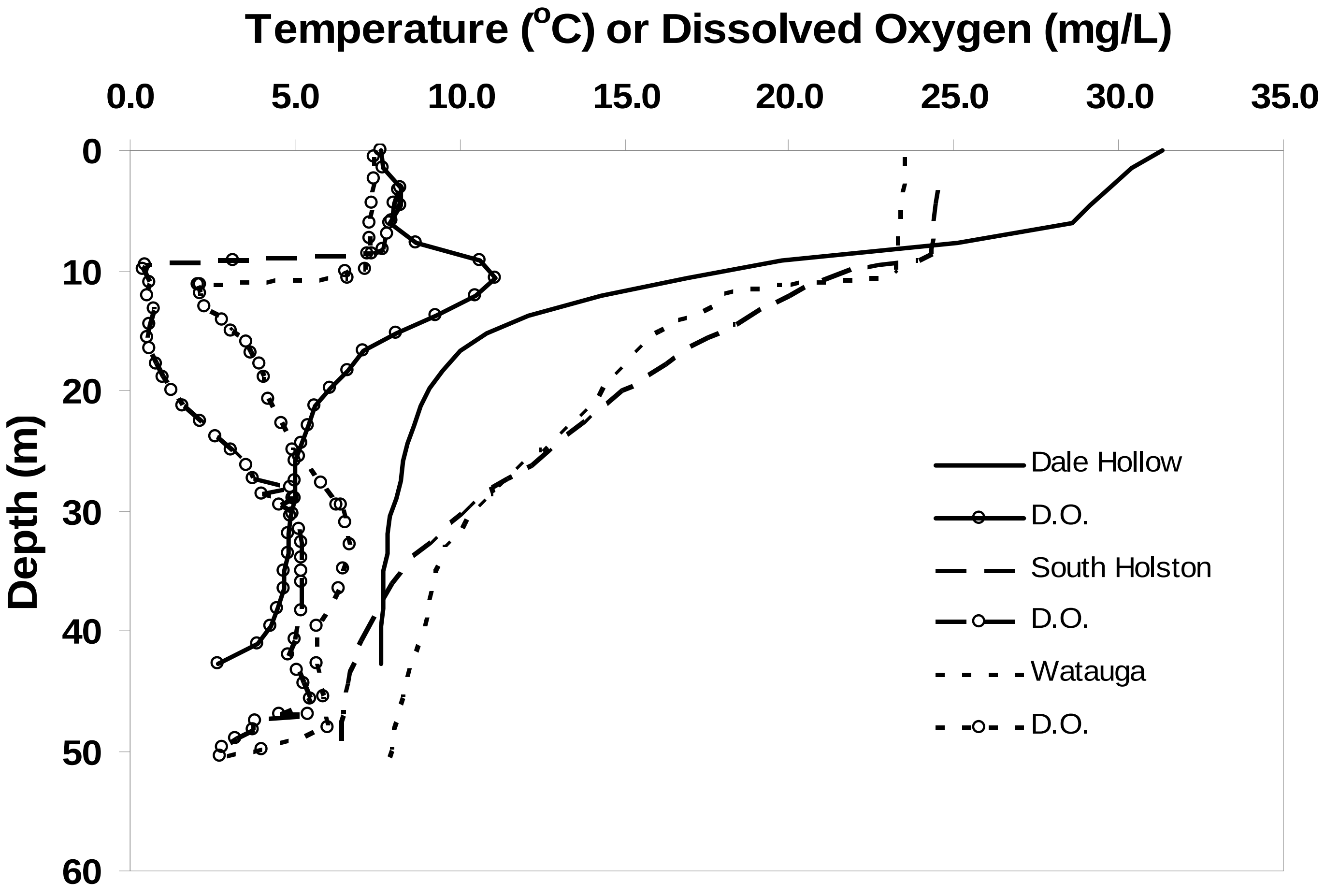

Figure 1. Temperature and dissolved oxygen profiles collected from South Holston Lake and Watauga Lake in September 2007 and from Dale Hollow Lake in July 2007. Samples were collected in reservoir forebays.

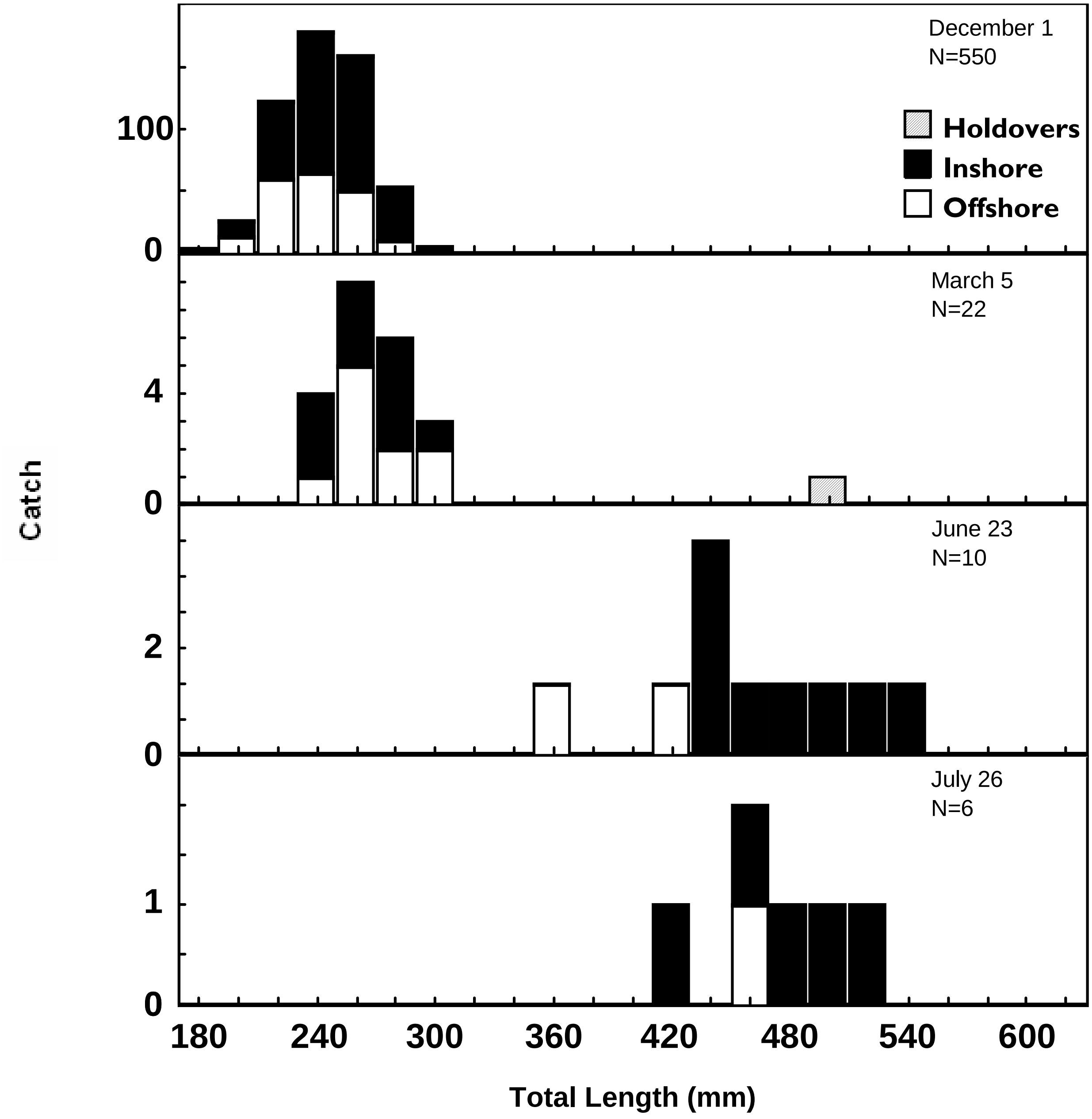

Figure 2. Length frequencies of rainbow trout in subsamples taken in December 2006 before stocking and in electrofishing (March), rainbow trout derby (June), and gillnetting (July) samples in 2007 in Dale Hollow Lake. Holdover trout stocked in previous years and trout stocked offshore and inshore are depicted separately.

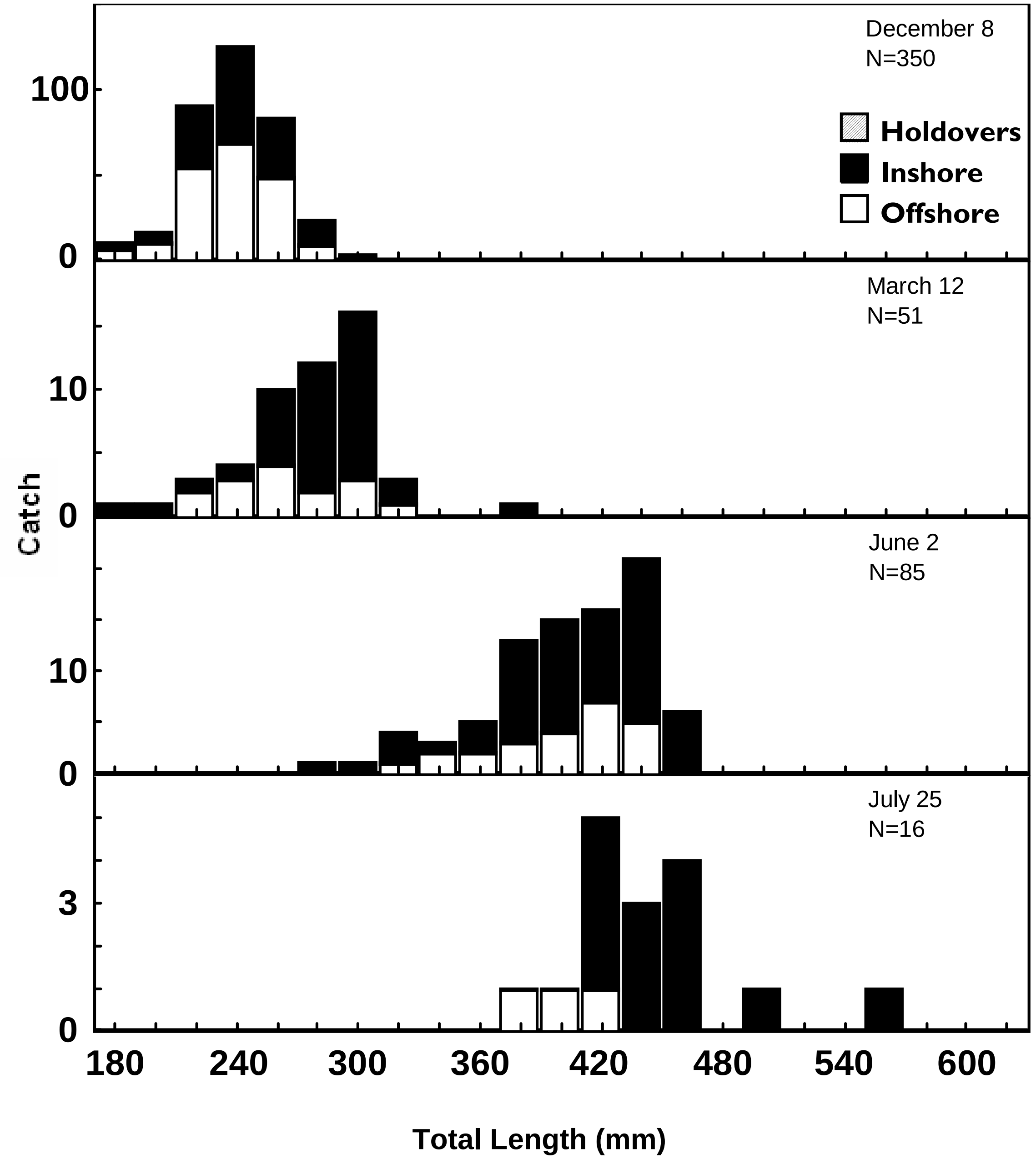

Figure 3. Length frequencies of rainbow trout in subsamples taken in December 2006 before stocking and in electrofishing (March), rainbow trout derby (June), and gillnetting (July) samples in 2007 in South Holston Lake.

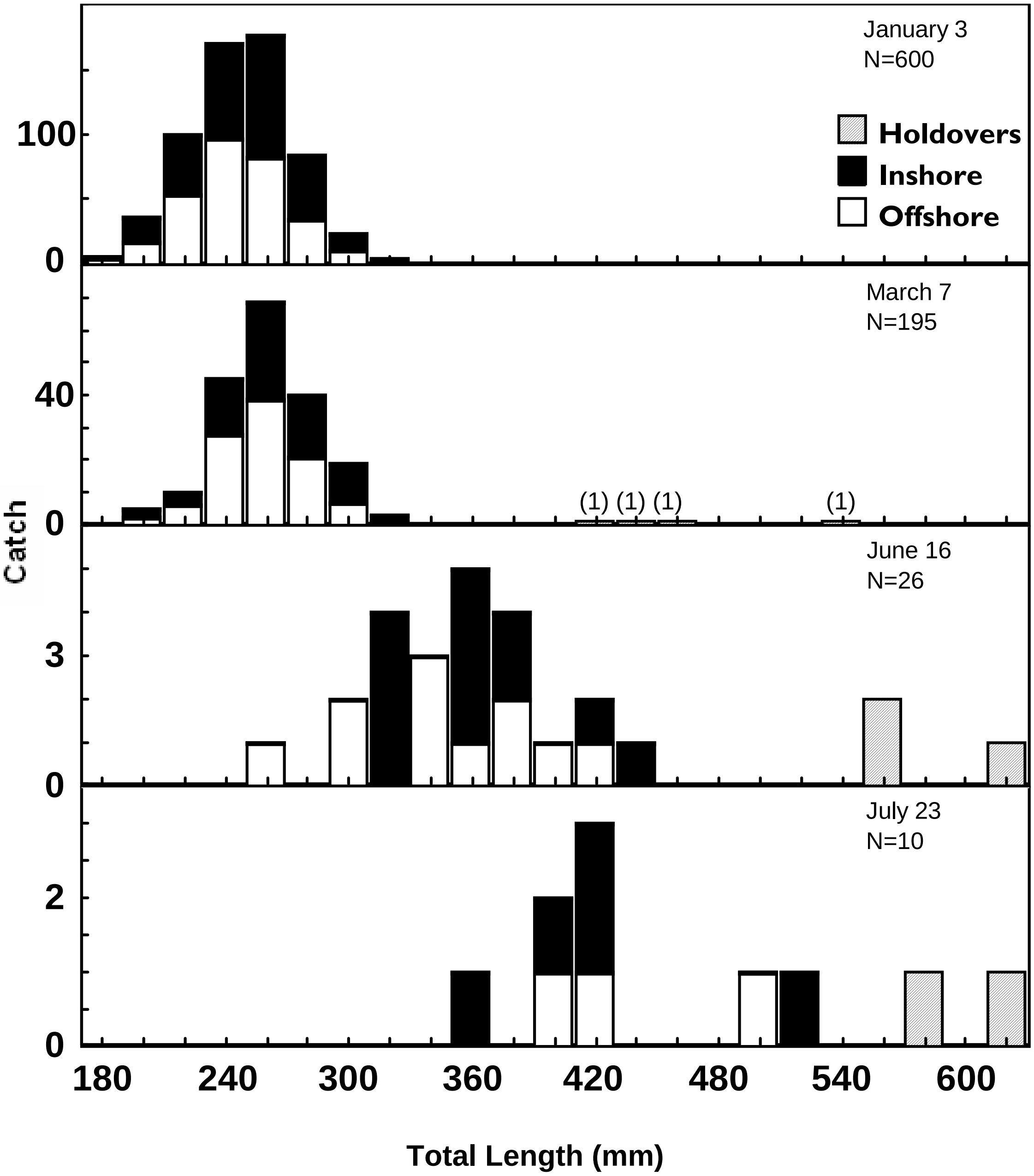

Figure 4. Length frequencies of rainbow trout in subsamples taken in January 2007 before stocking and in electrofishing (March), rainbow trout derby (June), and gillnetting (July) samples in 2007 in Watauga Lake. Number of holdover fish collected in parentheses.

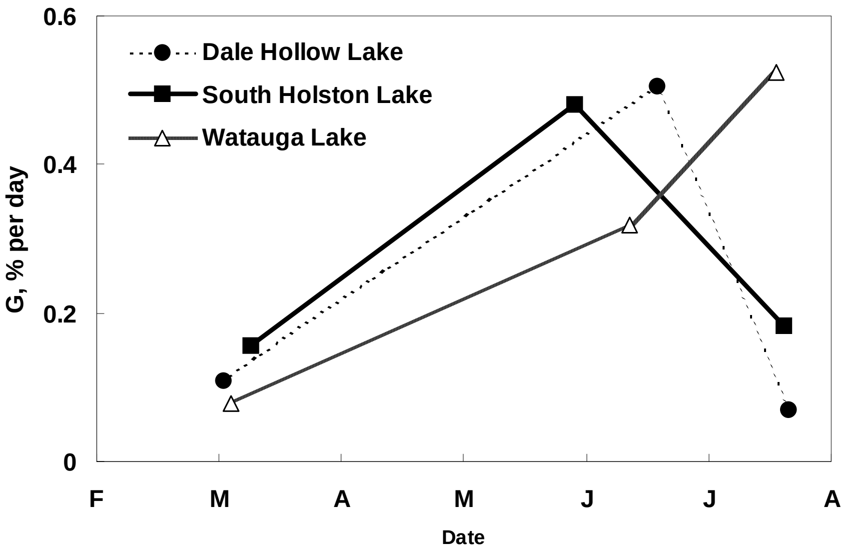

Figure 5. Instantaneous growth (G) in length of rainbow trout in three Tennessee reservoirs in 2007.

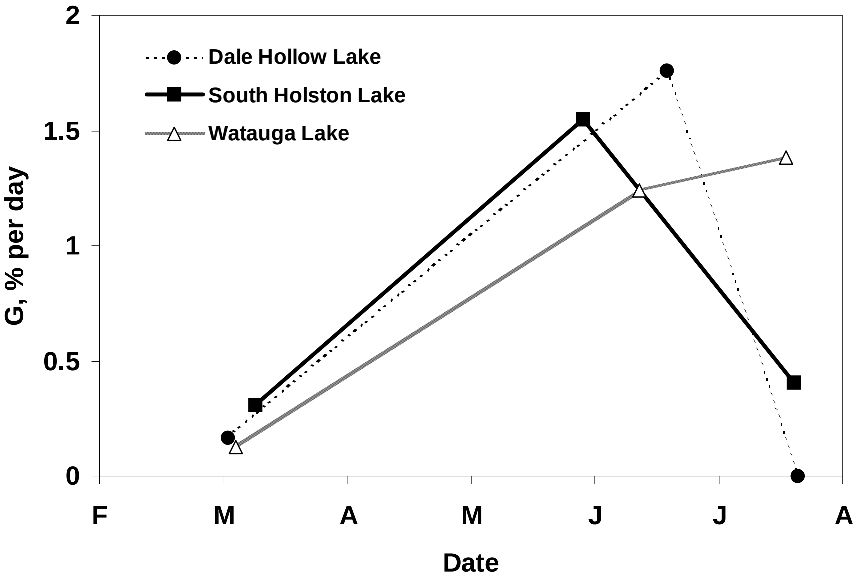

Figure 6. Instantaneous growth (G) in weight of rainbow trout in three Tennessee reservoirs in 2007.

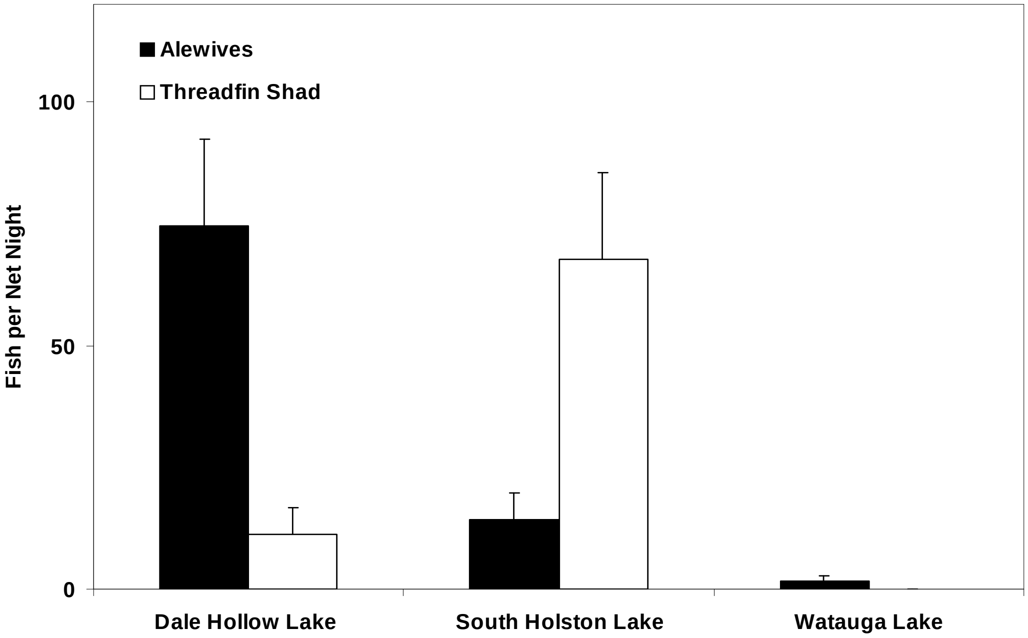

Figure 7. Mean CPUE of clupeids collected in gillnets (n = 30 per reservoir) in March 2007 in three Tennessee reservoirs. Bars represent one standard error.

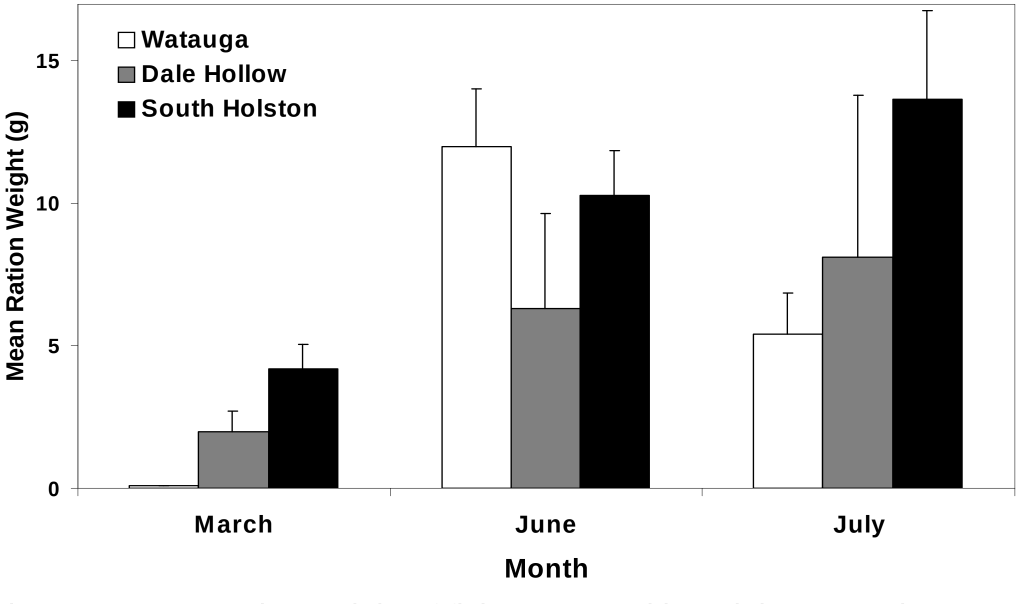

Figure 8. Mean ration weight of fish consumed by rainbow trout in Dale Hollow Lake, South Holston Lake, and Watauga Lake in 2007 during March electrofishing, June trout derbies, and July gillnetting. Bars represent one standard error.