Seasonal Fluctuations in Growth and Condition of Trout in a Southeastern Tailwater

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Abstract: Growth and condition of rainbow trout and brown trout in the Caney Fork River below Center Hill Dam in middle Tennessee were investigated for 1 year. Rainbow trout stocked in that spring grew faster (13 mm and 20 g/month) than rainbow trout stocked in June and August 1997. Brown trout grew slower in summer and fall (8 mm and 10 g/month) in summer and fall and faster (17 mm and 61 g/month) in winter. Adjusted mean weight of brown trout dropped from 141 g in May 1997 to 113 g in October 1997. Rainbow trout stocked in summer 1997 lost 14% of their body weight by fall 1997. Condition of both species improved in late fall with a corresponding improvement in tailwater dissolved oxygen concentration.

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Increasing use of tailwater trout fisheries in Tennessee, along with increases in the number of fish stocked annually, has prompted the need to investigate population characteristics of these valuable resources. The Tennessee Wildlife Resources Agency (TWRA) has stocked rainbow trout *(Oncorhynchus mykiss)* into the Caney Fork River below Center Hill Dam since the early 1950s (Parsons and Crossman 1956). Currently, TWRA maintains an extensive put-and-take fishery in 26 km of the tailwater that includes both rainbow trout and brown trout *(Salmo trutta),* annually stocking about 106,000 catchable (>200 mm) rainbow trout and 17,500 catchable brown trout. The number of trout stocked equates to about 920 trout per hectare per year. In 1997, the river received approximately 65,991 hours of angling pressure between March and October (Devlin and Bettoli 1999).

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Despite the success of this fishery, trout caught during the summer-fall period are typically in poor condition. Bettoli and Xenakis (1996) reported that the operation of Center Hill Dam results in severe fluctuations in tailwater flows, water temperatures, and dissolved oxygen (DO) concentrations. They also reported that tailwater DO concentrations during fall 1995 frequently dropped below levels which are lethal to salmonids (2.5 mg/liter; Dendy and Stroud 1949, Weithman and Haas 1984). Large fluctuations in flow and water temperature and poor water quality associated with hypolimnetic releases can stress fish, hamper growth, and increase mortality (Hokanson et al. 1977, Grizzle 1981, Cushman 1985). Salmonids subjected to low DO levels can experience renal ion loss, decreased food consumption, and low food conversion rates (Herrmann et al. 1962, Hunn 1969).

Condition indices reflect fish health, prey availability, and environmental conditions (Liao et al. 1995). Cada et al. (1987) observed that poor condition of trout was related to an inadequate food base in soft-water streams. The condition of rainbow trout was related to invertebrate drift and stream water temperature in the tailwater below Flaming Gorge Dam (Green River), Utah (Filbert and Hawkins 1995). Monitoring fish condition over time may be useful in assessing environmental stressors and determining when aquatic systems are most limited. The objective of this study was to estimate annual growth rates of trout stocked in 1997 and assess seasonal variations in condition.

Methods

Study area

Center Hill Dam is located on the Caney Fork River at river kilometer 43 in central Tennessee. Center Hill Reservoir was constructed by the U.S. Army Corps of Engineers (USACE) in 1948 for the purpose of flood control and hydroelectric power generation (USACE 1996). Discharge capacity for each of the facility's 3 turbines is normally 100 m^3/sec; a total maximum discharge through all 3 turbines is about 350 m^3/sec (USACE 1996). During periods of peak generation, water levels in the tailwater rise by more than 3 m. Seepage from the reservoir maintains a baseflow of 2.55 cms (90 cfs) during periods of no generation (B. Sneed, pers. commun., USACE). Regional power demands and rainfall determine the level of discharge and the fluctuations in downstream water levels. Center Hill Reservoir is thermally stratified from May to October (USACE 1996). Hypolimnetic water remains cool (7–12 C) throughout the summer, but typically becomes anoxic during September and October (Gordon and Morris 1979).

Trout Marking and Sampling

All trout stocked into the Caney Fork River in 1997 were cultured at the Dale Hollow National Fish Hatchery (DHNFH) in Celina, Tennessee. Microtagged cohorts ($\geq$7,000 each) of catchable rainbow trout were stocked in March, June and August 1997. These cohorts represented subsamples of the approximately 106,000 rainbow trout stocked in 1997. All catchable brown trout stocked in 1997 (16,529) were microtagged and stocked between 24 April and 15 May (weighted mean stocking date=3 May). All stockings occurred in a 26-km reach below the dam at 4 locations traditionally used by the TWRA. Trout were tagged with uncoded wire microtags (Northwest Mar. Tech., Inc., Shaw Island, Washington). Each cohort was tagged in a different anatomical location and the adipose fin of all tagged fish was clipped for ease of identification in the field. Random subsamples of trout (≥100) were measured (total length, mm), weighed (g), and checked for tag retention at DHNFH within a week of stocking.

Ten electrofishing surveys were conducted between April 1997 and April 1998 to sample stocked trout. Thirteen fixed stations were sampled in a 26-km reach below Center Hill Dam, except in April–May 1997 and April 1998 when 12 and 20 stations were sampled, respectively. One station was added after May 1997 to increase sample size and additional stations were added in April 1998 to obtain a population estimate. To ensure that the entire tailwater was adequately sampled, the river was divided into 3 reaches (8- to 10-km) and 3 to 5 500-m transects were randomly chosen from within each reach (Devlin and Bettoli 1999).

All electrofishing occurred at night using a 5.5-m jonboat outfitted with DC eclectrofishing gear consisting of a 4,500W generator and a Smith-Root Model GPP 2.5 electrofishing unit. Sampling occurred during periods of partial generation (i.e., 1 turbine discharging 75–115 m^3/sec), and 10 minutes of effort was expended at each station. Samples were collected at about monthly intervals between April 1997 and November 1997, and again in April 1998. At the end of each sample, fish were measured (mm), weighed (g), checked for tags using a detection wand, and returned to the river.

Data Analysis

Growth rates (length and weight) of microtagged trout were calculated by regressing mean lengths and weights against days post-stocking using SAS (SAS Inst. 1989). Mean total lengths and weights were calculated for each cohort in each sample when three or more fish were caught. Growth was declared significant if the slope of the regression line differed from zero ($P \leq 0.10$) and differences in growth among cohorts were tested using analysis-of-covariance. The specific rates of increase (%/day^{-1}) in length and weight of tagged brown trout were calculated using the following equation (Jensen and Berg 1995):

$$G=100(\log_e W2-\log_e W1)/t;$$

where $W1$=initial mean weight (g) and $W2$=the final mean weight over t days. Rates of growth in length (TL, mm) were calculated using the same equation and substituting lengths for weights. The specific growth rates of tagged rainbow trout were not analyzed due to small sample sizes.

Adjusted mean weights were calculated and compared using analysis-of-covariance of $\log_{10}$- transformed total lengths and weights to assess changes in condition of microtagged trout over time. The mean weight for each cohort on each sample date was adjusted to fit the overall mean total length for the cohort during the duration of the study. Adjusted mean weights were only calculated for cohorts when three or more fish were caught during a sampling event. The least-squares procedure in SAS was used to test for differences in adjusted mean weights among sample periods after slopes were determined to be similar ($P>0.10$). Simple linear regression was used to test for relationships between environmental variables (DO, water temperature, and tailwater discharge) and adjusted mean weight for brown trout. Relationships were declared significant if the slope of the regression line differed from zero ($P\leq0.05$).

Results

Mean daily discharge in 1997 (128 m^3/sec) was higher than the annual mean (108 m^3/sec) from 1951 to 1995 (USACE 1996). Discharges ranged from 2.55 to 382 m^3/sec and monthly means were higher earlier in the year (Table 1). The level of dissolved oxygen in Center Hill Dam discharges was high in the winter and spring of 1997, but was depressed in the late summer and fall (Fig. 1). Dissolved oxygen concentrations measured during periods of generation ranged from 0.9 to 10.8 mg/liter; they fell below 6.0 mg/liter by 18 June 1997 and remained low through November. Water temperatures during periods of generation ranged from 9–19 C, the coolest temperatures occurred in April 1997 and the warmest in November 1997, following the fall turnover of Center Hill Reservoir.

More brown trout were observed in electrofishing surveys due to a higher rate of survival (34% at 200 days post-stocking) than for the 3 rainbow trout cohorts (7%–14% at 200 days post-stocking; Devlin and Bettoli 1999). Thus, the number of fish used in growth and condition analyses differed greatly between species (Table 2).

Rainbow trout stocked early in the spring of 1997 grew faster than later-stocked rainbow trout. Rainbow trout stocked in March grew 13 mm per month ($P=0.02$;

Table 1. Mean monthly discharges (m^3/sec) from Center Hill Dam, 1997.

Month	Mean Discharge (m^3/sec)
Jan	224
Feb	165
Mar	287
Apr	83
May	119
Jun	270
Jul	104
Aug	44
Sep	50
Oct	69
Nov	58
Dec	65

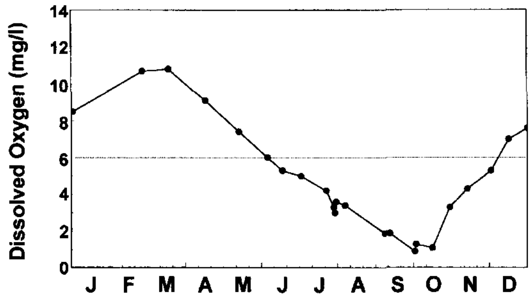

Figure 1. Dissolved oxygen concentration in discharges from Center Hill Dam during 1997. All measurements were taken during periods of generation approximately 500 m below Center Hill Dam. Horizontal line (6.0 mg/liter) represents the state standard minimum DO concentration for a cold-water fishery (USACE 1996).

r^2=0.87) and 20 g per month (P=0.08; r^2=0.70) over 132 days (Table 2). Rainbow trout stocked 5 June 1997 and 21 August 1997 did not exhibit significant growth during their first 100-day post-stocking (i. e., slopes of linear and log linear regressions did not differ from zero at P=0.10; Table 2). The 4 tagged rainbow trout collected in April 1998 exhibited substantial increases in length and weight compared to the size of each cohort in November 1997 samples (Table 2).

Brown trout stocked in May 1997 grew significantly slower in length and weight than rainbow trout stocked in March 1997 (F-test of slopes; P=0.0001). Monthly growth of brown trout averaged 8 mm (P=0.0001; r^2=0.94) and 10 g (P=0.0001; r^2=0.92) over 185 days (Table 2). Brown trout tripled in weight between November 1997 and April 1998 and grew an average of 17 mm and 61 g per month over winter.

Specific growth rates *(G)* in weight (g) of brown trout ranged from −0.11%/day to 0.98%/day; fastest growth occurred in spring and late fall of 1997 and during winter 1997–98 (Fig. 2). Slowest growth occurred during July and September–October 1997. Specific growth rates *(G)* in total length (mm) did not fluctuate as much as growth in weight and were usually lower during the summer and fall (Fig. 2).

The condition of all microtagged trout stocked in May or later declined between the time of stocking and October. Condition of March-stocked rainbow trout varied over the first 82 days in the river (Fig. 3). Adjusted mean weight increased 8% between April and May (P=0.0992), then decreased 7% between May and June (P=0.0876). No significant differences (P>0.19) were detected among adjusted mean weights of this cohort between June and late July (Fig. 3). Rainbow trout stocked in June and August exhibited significant (P≤0.10) declines in adjusted mean weights during the first 83- and 49-day post-stocking, respectively (Fig. 3). Rainbow trout stocked in June lost 15% of their weight after 48 days in the tailwater and the August cohort lost 14% of their weight within 7 weeks of being stocked. Between October and November (75 days post-stocking), adjusted mean weights of August-stocked rainbow trout increased 16% and did not differ from their adjusted mean weight when stocked (P=0.9471; Fig. 3).

Table 2. Mean total lengths (mm) and weights (g), and standard deviations for each microtagged cohort of trout stocked into the Caney Fork River. Sample sizes are in parentheses.

					Mean Total Lengths									
Cohort	Tag Location	Stocking Date		Stocking	1–2 Apr 1997	15–17 May 1997	3–4 Jun 1997	2–3 Jul 1997	23–24 Jul 1997	27–29 Aug 1997	15–16 Sep 1997	9 Oct 1997	4–5 Nov 1997	5–7 Apr 1998
Rainbow	Caudal	13 Mar 97	Mean	227	239	269	264	288	284			310	281	335
			SD	17	14	18	20	10	22				9	
					(23)	(10)	(13)	(10)	(6)	(0)	(0)	(1)	(2)	(1)
Rainbow	Dorsal	5 Jun 97	Mean	241				240	267	259	266		296	418
			SD	14				17	14	9				
								(8)	(5)	(4)	(1)	(0)	(1)	(1)
Rainbow	R. cheek and Pelvi	21 Aug 97	Mean	214						225	226	225	233	360
			SD	20						12	13	25	17	11
										(23)	(19)	(5)	(5)	(2)
Brown	Caudal and Pelvic	3 May 97	Mean	196		199	217	223	226	236	239	245	252	339
			SD	16		15	17	17	16	19	15	19	22	26
						(31)	(82)	(68)	(91)	(38)	(83)	(68)	(25)	(22)
Rainbow	Caudal	13 Mar 97	Mean	131	154	213	187	240	221			259	231	434
			SD	28	22	33	45	28	53				16	
					(22)	(10)	(13)	(10)	(6)	(0)	(0)	(1)	(2)	(1)
Rainbow	Dorsal	5 Jun 97	Mean	136				141	167	161	153		283	904
			SD	27				36	21	35				
								(8)	(5)	(4)	(1)	(0)	(1)	(1)
Rainbow	R. cheek and Pelvic	21Aug 97	Mean	114						120	116	106	135	554
			SD	33						23	25	31	24	32
										(22)	(19)	(5)	(5)	(2)
Brown	Caudal and Pelvic	3 May 97	Mean	91		91	107	117	115	132	133	134	156	463
			SD	25		22	26	25	27	36	28	31	42	126
						(30)	(82)	(68)	(91)	(38)	(83)	(68)	(25)	(22)

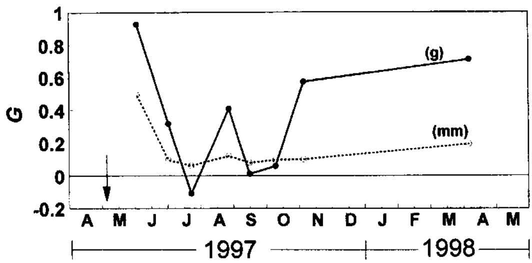

Figure 2. Specific growth rate in weight (solid line) and length (dotted line) (*G*, % per day) of microtagged brown trout stocked in the Caney Fork River 3 May 1997 (arrow).

Condition of microtagged brown trout dropped sharply after mid-May 1997 and continued to decline until October 1997. Five significantly different ranges of adjusted mean weights were observed over 11 months (Fig. 3) and adjusted mean weights ranged between 113 g (Oct 1997) and 149 g (Apr 1998). At 13 days post-stocking, condition was relatively good (141 g). Adjusted mean weight decreased 20% between May and October (159 days post-stocking), but subsequently increased 32% between October 1997 and April 1998.

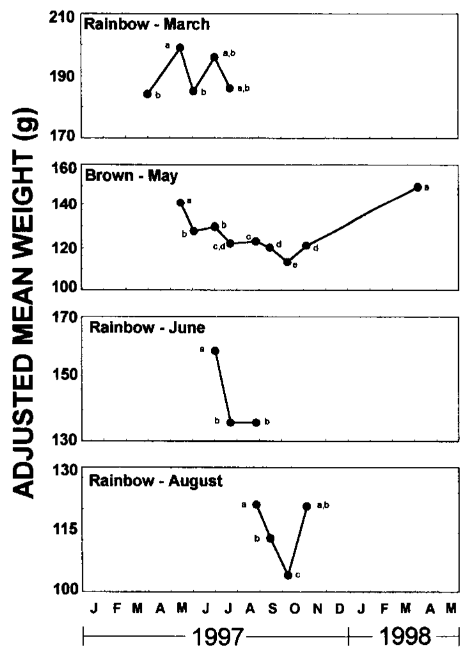

Figure 3. Adjusted mean weights plotted against days post-stocking for microtagged cohorts of trout stocked into the Caney Fork River in 1997. Points with the same letter are not significantly different ($P = 0.10$).

The condition of brown trout was positively related to DO (r^2=0.93, P=0.0001). Adjusted mean weight increased 4 g with every mg/liter increase in DO. Condition of brown trout was also negatively related to water temperature (r^2=0.87, P=0.0001). Average daily discharge between sampling periods did not affect brown trout condition (P>0.10). Tailwater DO and temperature were highly correlated (r^2=0.91); therefore, a multiple regression model was not used to determine which variable was more important to condition.

Discussion

Growth and condition of rainbow trout and brown trout varied depending on the time of year stocked, as well as the level of dissolved oxygen in water released from Center Hill Dam. March-stocked rainbow trout grew faster over 130 days in the tailwater than those stocked in early and late summer, despite enduring higher flows and lower water temperatures. The same cohort grew slightly faster in length than spring-planted rainbow trout in 2 east Tennessee tailwaters where habitat and flow regime were more preferable to salmonids (Bettoli and Bohm 1997, Owens 1998). Rainbow trout stocked in early and late summer 1997 did not exhibit significant growth in the Caney Fork River, but did in other Tennessee tailwaters (Besler 1996, Bettoli and Bohm 1997, Owens 1998). Higher growth rates of rainbow trout were observed in the Caney Fork River during all seasons during a drought year (1986), when flows, water temperatures, and DO concentrations were more stable (Kanehl 1989).

Brown trout grew slowly between May and November 1997 in the Caney Fork River compared to brown trout stocked in east Tennessee tailwaters (Bettoli and Bohm 1997, Owens 1998). Overwinter growth in weight was excellent, producing fish averaging >460 g at the start of the next fishing season (i.e., 1 April 1998). Specific growth rates of brown trout were higher during late spring and winter, whereas stocked brown trout observed over the same period in the South Fork of the Holston River had higher specific growth rates during the summer (Owens 1998).

All tagged trout stocked into the Caney Fork River in 1997 experienced significant post-stocking declines in condition. Post-stocking declines in condition have been observed in other tailwaters and small streams (Reimers 1963, Bachman 1984, Besler 1996). When stocked into a tailwater, trout may spend large amounts of energy and time avoiding predators and acclimatizing to fluctuating flows and water temperatures and suboptimal environmental conditions. A positive relationship existed between brown trout condition and DO concentration. Likewise, faster growth of both species corresponded to higher DO levels. Despite the apparent effect of water temperatures on brown trout condition, adjusted mean weights were lowest when water temperatures were in the range considered optimal for growth (15–18 C; Elliott 1975, Jensen and Berg 1995). Declines in the condition of rainbow trout and brown trout were also observed in the Clinch River, Tennessee, during periods of low (≤4.0 mg/liter) tailwater DO (Bettoli and Bohm 1997). Thus, results from this study suggest that hypoxic water discharged from the upstream reservoir constrained trout growth and condition in the Caney Fork River.

Previous studies of the Caney Fork River indicated that rainbow trout grew throughout the year and that seasonal availability of prey may have caused increases in condition, but did not cause significant declines (Kanehl 1989, Layzer et al. 1989, Odenkirk and Estes 1991). In 1986, the predominant prey items of rainbow trout in the Caney Fork River were *Lirceus* sp. and *Chironomidae* in the late spring and fall, *Daphnia* sp. and terrestial insects in the summer, and threadfin shad *Dorosoma petenense* in the winter and early spring (Odenkirk and Estes 1991). Although the quantity and variety of prey items were not consistent over time in 1986 and 1987, our data suggest that the pattern of decreasing condition observed in 1997 was not entirely related to the seasonal variation in prey. In 1997, DO concentrations of water discharged from Center Hill Dam were below 4.0 mg/liter from late July through October. Therefore, growth and condition of trout in the Caney Fork River were compromised during the summer and fall due to daily hypoxic stress.

Conclusion

The results from this study suggest that seasonal declines in DO negatively affected brown trout condition in the Caney Fork River. Unlike tailwaters in east Tennessee, where growth is sometimes slower in the winter due to low flood resources and colder water temperatures, the Caney Fork River provided a more favorable environment for salmonids in the winter and spring. Therefore, managers should consider seasonal differences in water quality in the future when determining stocking rates and schedules for the Caney Fork River and other tailwaters where water quality fluctuates seasonally.

Literature Cited

Bachman, R. A. 1984. Foraging behavior of free-ranging wild and hatchery brown trout in a stream. Trans. Am. Fish. Soc. 113:1–32.

Besler, D. A. 1996. Fate of salmonids stocked into the Tims Ford Tailwater, Tennessee. M. S. Thesis, Tenn. Tech Univ., Cookeville. 63pp.

Bettoli, P. W. and L. A. Bohm. 1997. Clinch River trout investigations and creel survey. Period: September 1995–June 1997. Tenn. Coop. Fish. Res. Unit, Tenn. Tech. Univ., Cookeville. Interim Rep. and Summary Proj. Activities Submitted to Tenn. Wildl. Resour. Agency, Nashville. 41 pp.

——— and S. M. Xenakis. 1996. An investigation of the trout fishery in the Caney Fork River below Center Hill Dam. Tenn. Coop. Fish. Res. Unit, Tenn. Tech. Univ., Cookeville. Final Rep. Submitted to Tenn. Wildl. Resour. Agency, Nashville. 38pp.

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. Trans. Am. Fish. Soc. 116: 692–702.

Cushman, R. 1985. Review of ecological effects of rapidly varying flows downstream from hydroelectric facilities. North Am. J. Fish. Manage. 5: 330–339.

Dendy, J. S. and R. H. Stroud. 1949. The dominating influences of Fontana Reservoir on temperatures and dissolved oxygen in the Little Tennessee River and its impoundments. Tenn. Acad. Sci. 24: 41–51.

Devlin, III, G. J. and P. W. Bettoli. 1999. Creel survey and population dynamics of salmonids stocked into the Caney Fork River below Center Hill Dam. Tenn. Coop. Fish. Res. Unit, Tenn. Tech. Univ., Cookeville. Final Rep. Submitted to Tenn. Wildl. Resour. Agency, Nashville. 85pp.

Elliott, J. M. 1975. The growth rate of brown trout *(Salmo trutta L.)* fed on maximum rations. J. Anim. Ecol. 44:805–821.

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. Trans. Am. Fish. Soc. 124: 824–835.

Gordon, J. A. and J. W. Morris. 1979. Dissolved oxygen depletion mechanisms operating in the metalimnion of a deep impoundment. Internatl. Symp. Environ. Effects of Hydraulic Eng. Works, 12–14 Sep 1978. Univ. Tenn., Knoxville. 11pp.

Grizzle, J. M. 1981. Effects of hypolimnetic discharge on fish health below a reservoir. Trans. Am. Fish. Soc. 110: 29–43.

Herrmann, R. B., C. E. Warren, and P. Doudoroff. 1962. Influence of oxygen concentration on the growth of juvenile coho salmon. Trans. Am. Fish. Soc. 91: 155–167.

Hokanson, K. E. F., C. F. Kleiner, and T. W. Thorslund. 1977. Effects of constant temperatures and diel temperature fluctuations on specific growth and mortality rates and yield of juvenile rainbow trout, *Salmo gairdneri.* J. Fish. Res. Bd. Can. 34: 639–648.

Hunn, J. B. 1969. Chemical composition of rainbow trout urine following acute hypoxic stress. Trans. Am. Fish. Soc. 98: 20–22.

Jensen, J. W. and T. Berg. 1995. The annual growth rate of brown trout. Prog.-Fish. Cult. 57: 231–237.

Kanehl, P. D. 1989. Growth and movement of stocked trout in the Center Hill Lake Tailwater, Tennessee. M.S. Thesis, Tenn. Tech. Univ., Cookeville. 82pp.

Layzer, J. B., T. J. Nehus, W. Pennington, J. Gore, J. M. Nestler. 1989. Seasonal variation in the composition of the drift below a peaking hydroelectric project. Regulated Rivers: Resour. Manage. 3: 29–34.

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. Trans. Am. Fish. Soc. 124:387–400.

Odenkirk, J. S. and R. D. Estes. 1991. Food habits of rainbow trout in a Tennessee tailwater. Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies. 45:452–459.

Owens, S. J. 1998. Characteristics of growth of rainbow trout and brown trout in the South Fork of the Holston River, Tennessee. M.S. Thesis, Tenn. Tech. Univ., Cookeville. 103pp.

Parsons, J. W. and C. C. Crossman. 1956. An example of state and federal cooperation in establishing water control for fisheries management purposes. Proc. Annu. Conf. Southeast. Assoc. Game and Fish Comm. 9:108–110.

Reimers, N. 1963. Body condition, water temperature, and over-winter survival of hatchery-reared trout in Convict Creek, California. Trans. Am. Fish. Soc. 92:39–46.

SAS Institute. 1989. SAS/STAT user's guide, vers. 6, 4th ed. SAS Inst., Inc., Cary, N.C.

U. S. Army Corps of Engineers. 1996. Operational assessment of Center Hill Lake. Dep. Army, Nashville Dist. Corp Eng., Water Manage. Office, Tenn. 15pp.

Weithman, S. T. and M. A. Haas. 1984. Effects of dissolved-oxygen depletion on the rainbow trout fishery in Lake Taneycomo, Missouri. Trans. Am. Fish. Soc. 113: 108–124.