Effect of Trophy Regulations and Reservoir Discharge on a Population of Stocked Brown Trout in a Large, Southeastern United States Tailwater

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Abstract: Reservoir tailwaters can be an important resource for developing quality trout fisheries, especially when managed with special regulations. The objective of this study was to evaluate the effectiveness of a 508-mm minimum-length limit and a 1 fish day^{-1} creel limit on increasing abundance and size of the brown trout (*Salmo trutta*) in the Cumberland River below Lake Cumberland, Kentucky. Annual stockings of catchable-sized brown trout remained relatively stable throughout the study at approximately 31,000 fish (503 fish km^{-1}). The purpose of the new regulations, which did not include gear or bait restrictions, was to increase the numbers of quality (381–507 mm total length [TL]) and trophy-size (≥508 mm TL) brown trout in the 121-km tailwater. A significant increase in brown trout electrofishing catch-per-unit-effort (CPUE) was observed across years for small (< 381 mm TL), quality, trophy-size, and all sizes combined brown trout. The trophy regulations resulted in an increase in CPUE of all sizes of brown trout, including trophy-size, in the tailwater without any observed negative density-dependent impacts to brown trout growth or condition. Creel surveys showed that the management objectives of doubling the brown trout size structure of ≥381 mm TL and ≥508 mm TL in the angler catch were more than exceeded. Annual reservoir discharge was positively related with warmer water temperatures and lower dissolved oxygen in the tailwater. There was a negative relationship between both brown trout growth and condition versus annual discharge from the reservoir.

Key words: *Salmo trutta*, tailwaters, special regulations, water quality

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A tailwater is that portion of a stream or river below a reservoir directly affected by the discharge of water through or over the dam (Parsons 1957). Tailwaters below most hypolimnetic-release reservoirs are characterized by relatively low turbidity, cold temperature, and more stable seasonal flow, as well as abundant food for trout (Walburg et al. 1981). Between the efforts of the Tennessee Valley Authority and the U. S. Army Corps of Engineers (ACOE), New Deal-era dam construction exploded in the southeastern United States in the middle of the 20th century (Miranda 1996). As a result, stocking and management of trout in altered habitats below high-head dams became commonplace (Axon 1974) and thriving trout populations now exist in many of these tailwaters. However, many of these populations must be maintained by stocking because extreme short-term flow fluctuations and unsuitable spawning habitat in some of these environments limits natural reproduction (Pender and Kwak 2002, Holbrook and Bettoli 2006).

Since the 1970s, as the concept of catch and release fishing became more popular, there has been greater demand for quality trout angling experiences (Fatora 1976, Hartzler 1988, Gigliotti and Peyton 1993). Tailwater trout fisheries are a resource that can satisfy this demand, sometimes in regions not normally conducive to coldwater fisheries. Further, the exceptional economic return from developing and maintaining high-quality tailwater trout fisheries throughout the United States (USFWS 2006), combined with the increasingly limited supply of hatchery sources, requires that existing hatchery production be optimized by researching and using various fisheries management strategies.

Rainbow trout (*Oncorhynchus mykiss*) are the most common trout species stocked in tailwaters because they are highly vulnerable to sportfishing and excel as a put-and-take species (Fatora 1976, Swink 1983, Hartzler 1988). To offset heavy angling pressure, rainbow trout are often stocked at high densities (Weiland and Hayward 1997). However, brown trout (*Salmo trutta*) are more difficult to catch (Behnke 1990, Weiland and Hayward 1997), exhibit faster growth (Weiland and Hayward 1997), and are regarded as more tolerant of warmer water temperatures (Jager et al. 1999, Galbreath et al. 2004), making the species ideally suited for put-grow-and-take fisheries where there is a potential to create a trophy fishery (Behnke 1990, Hudy 1990). Although low-density brown trout stockings in conjunction with rainbow trout can produce trophy brown trout fisheries, excessive fishing pressure and elevated harvest rates in brown trout can limit such potential (Hudy 1990). Fisheries managers can attempt to balance demands for increased recreational quality while mitigating for high harvest and pressure and making efficient use of hatchery production by implementing bait restrictions, restrictive size and creel limits, or some combination of these regulations. Special regulations alone cannot improve a river's natural capacity to support trout as each system is limited by its specific carrying capacity (Behnke 1990). Large rivers and tailwaters often have an abundance of slower flows and deeper water, favored by larger brown trout as the species undergoes a well-documented ontogenetic shift in habitat usage (Näslund et al. 1998, Klemetsen et al. 2003, Öhlund et al. 2008, Ayllón et al. 2010). If conditions for growth and survival are favorable but fishing mortality is high, then specialized harvest restrictions can be used to enhance trophy fishing potential (Noble and Jones 1993).

Fish population modeling has confirmed that limiting fishing mortality with high minimum-length limits (MLL) or slot limits can lead to decreased harvest and increases in abundance of the total population and of larger fish in the population if growth rates are maintained (e.g., Clark et al. 1980, 1981; Power and Power 1996; Nordwall et al. 2000). High MLLs or catch and release regulations have commonly been shown to be the best regulatory option to maximize abundance and induce favorable shifts in size structure in trout fisheries (Clark et al. 1980, 1981; Nordwall et al. 2000). Ultimately, success of fisheries regulations depends on angler acceptance and compliance (Fatora 1976, Anderson and Nehring 1984, Brousseau and Armstrong 1987, Pierce and Tomcko 1998). Some anglers place high value on harvesting fish, while others enjoy catching and releasing high numbers of fish or simply catching large fish. Fatora (1976) stated that the ultimate goal of trout management should be to provide quality fishing for the varied desires of the resource users and suggested that the trout resources in a given area should be managed to meet multiple goals. This concept can be accomplished in a single waterbody by applying different regulations on sympatric trout species to achieve "put-and-take" and "trophy" components in the same system.

The Kentucky Department of Fish and Wildlife Resources (KDFWR) manages a popular trout fishery in the Lake Cumberland tailwater. Brown trout were first introduced in 1982 while rainbow trout were first stocked in 1956; both are stocked annually as catchable-sized fish. Through 1996, both species on the Lake Cumberland tailwater were regulated with statewide regulations which consisted of an eight-trout aggregate daily creel limit of which three could be brown trout, and no size limit. However, recognizing the trophy trout potential and because of pressure from public interests, KDFWR implemented a special regulation zone in 1995 on the Lake Cumberland tailwater which consisted of a 305-mm to 508-mm protective slot length limit where anglers could harvest to up four trout less than 305 mm total length (TL) and one trout longer than 508 mm TL. Unanticipated local opposition to the special regulations zone prompted its elimination after two years (Kosa 1999). Creel survey data had indicated that there was substantial brown trout and rainbow trout catch and harvest that was concentrated in the uppermost reach of the tailwater nearest the dam. In 1997, trout regulations were standardized across the entire Kentucky portion of the Lake Cumberland tailwater to feature rainbow trout as a put-and-take component of the fishery (no size limit, 8-fish creel limit) and brown trout as a trophy component by regulating with a 508-mm MLL and a 1 fish daily creel limit. No gear or bait restrictions were enacted with these regulation changes. Specific management goals were to double the angler catch of brown trout ≥381 mm TL and ≥508 mm TL.

Typically, the water temperature of Lake Cumberland tailwater releases seasonally fluctuates between 6 and 15 C. However, consistent trends of higher water temperatures and lower dissolved oxygen have been observed in the tailwater during summer and autumn of years with abnormally high discharge. Elliot (1994) reported that while 15.6 C may not be stressful on brown trout at maximum ration, growth efficiency was reduced, and in combination with hypoxic conditions may be a limiting factor (Molony 2001).

There is a paucity of peer-reviewed, empirical research on the effects of restrictive minimum-size and creel limits on salmonid populations (Power and Power 1996). The goal of this study was to evaluate the effectiveness of the restrictive harvest regulation to increase brown trout numbers, especially the numbers of quality-size (381–507 mm TL) and trophy-size (≥508 mm TL) brown trout. Specific objectives were to (1) compare the relative abundance of several size groups of brown trout before and after trophy regulations were implemented, (2) document any potential density dependent effects by determining if there were any post-regulation changes in brown trout growth rates or condition, (3) conduct creel surveys to periodically document trout fishing pressure, catch, and harvest, and 4) examine relations among reservoir discharge, water temperature, and dissolved oxygen and assess their effects on brown trout CPUE, growth rates, and condition.

Methods

Study Site

The Lake Cumberland tailwater in Kentucky is a 121-km section of the Cumberland River extending from Wolf Creek Dam to the Kentucky-Tennessee state line and is located in the Highland Rim Province of southeastern Kentucky. The study area for this project encompasses the upper 61.6-km section beginning immediately below Wolf Creek Dam and ending at the Hwy 61 Bridge (Figure 1). Alkalinity ranges between 40 and 60 mg L^{-1} (U. S. Army Corps of Engineers, unpublished data) and river width varies from 60 to 120 m. Long pools (0.8–6.4 km) interspersed with riffles (0.2–1.1

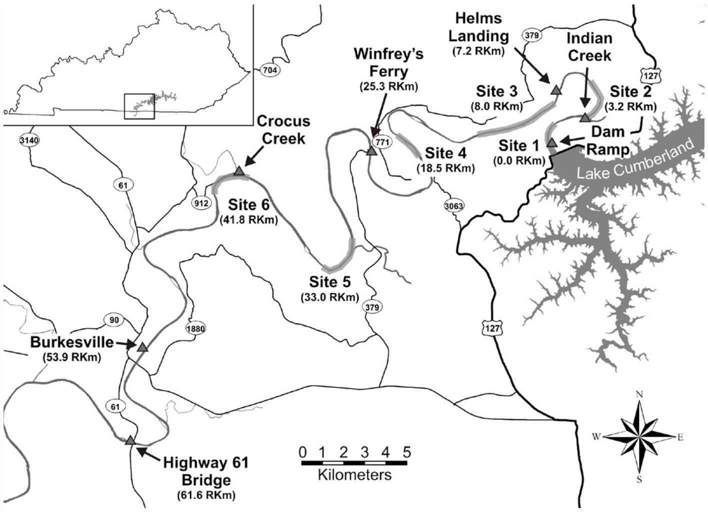

Figure 1. Map depicting the location of Lake Cumberland in south central Kentucky (inset) and the Cumberland River below Wolf Creek Dam. Solid triangles represent the trout stocking sites. The six standardized autumn sampling sites are shaded with Site 1 being the uppermost site. The approximate river kilometer below the dam (RKM) to upper end of each site is in parentheses.

km) characterize the river with the first 13 km of river below the dam having relatively swifter current and shallower water than further downstream (Hauser et al. 2004). Shoals associated with islands and small tributary streams, along with large woody debris along the banks, make up the primary in-stream habitat (Coopwood et al. 1987, Kosa 1999). Releases from the dam are variable and depend on hydropower demand. Water is drawn from 30.8 m below maximum power pool. Average daily discharge is 240 m^3 sec^{-1}, but typically fluctuates from 0.6 to 625 m^3 sec^{-1} within 3 h. Daily water-level fluctuations can range from 6 m in the upper reaches of the tailwater to 1.8 m at the lower end of the study area.

Stocking Protocols

All brown trout stocked in the Lake Cumberland tailwater were produced at the Wolf Creek National Fish Hatchery, located immediately below Wolf Creek dam. Catchable-size brown trout (mean, ~203 mm TL) were stocked in March or early April annually from 1995 to 2006. Annual stocking rates of brown trout remained relatively stable over this time period at approximately 31,000 fish (503 fish km^{-1}). In 1995, brown trout were stocked among six sites between the dam and Burkesville (Figure 1). Brown trout stocking at the dam site was moved 3.2-km downstream to the Indian Creek site in 1996, which was then also discontinued in 1997. Thus beginning in 1998, all brown trout stocking was eliminated within 3.2 km of the dam, an area of more intensive bait fishing pressure, and most of this allotment was stocked at a new stocking site (Highway 61 Bridge), which also served as the downstream boundary of the research area (Figure 1). Also, the annual number of stocked catchable-size rainbow trout was nearly doubled from 78,000 in 1995 to approximately 140,000 after 1997.

Stocked brown trout year classes were distinguished by batch marking with either uncoded wire tags or various fin clips in all years except 2003. For that particular cohort, the absence of a mark served to distinguish the fish from other cohorts. Prior to stocking, short-term (approximately one month) tag loss or fin clip efficacy, mean length, and weight were estimated from a random subsample of 100 fish from each cohort. Hale and Gray (1998) documented 99% retention rates of dorsal (20 days, $n = 100$) and caudal (22 days, $n = 300$) coded wire tags inserted into brown trout at Wolf Creek National Fish Hatchery. They observed that the 19- to 30-day loss of coded wire tags did not increase with number of days brown trout and rainbow trout spent in raceways prior to tag inspection. Through anecdotal field observations, fin regeneration of adipose fin clips was rare to non-existent. Pelvic and pectoral fin regeneration was slightly more common; however, anomalous fin characteristics of regenerated fins usually made marked fish obvious.

Trout Sampling

Trout were sampled annually in a single night in November from 1995–2006 using boat-mounted pulsed DC electrofishing gear (Smith-Root 5.0 GPP electrofishers) at each of five fixed sites over a 42-km reach within the study area (Figure 1). The ACOE provided a constant single-turbine release from the dam during our sampling activities to ensure that all five 3-person electrofishing crews experienced a stable flow, thereby reducing within and between year variations (Dauwalter et al. 2009). The study area (61.6 km) was limited to roughly the upper half of the available trout water (121 km) as this was deemed the amount of water that could practically be sampled with five crews in one evening with the manpower and special water release limitations at the time. Multiple 15-min transects were collected at fixed sites located on shoal areas (Figure 1, Sites 1–4 and Site 6): three transects per site in 1995 and four per site in 1996. Beginning in 1997, sampling effort was increased to five transects at each site and because of the discontinuation of brown trout stocking near the dam, sampling was discontinued at Site 1 and a new sampling site was established downstream (Site 5, Figure 1). Trout captured were measured to the nearest 2.5 mm TL and any marks were identified. From 2000 through 2006, trout were also weighed to the nearest 4.5 g. Relative weights (Wr) were calculated based on the standard weight equation for lotic brown trout as referenced in Anderson and Neumann (1996).

Site 4 (Figure 1, 18.5 river km below the dam) was chosen as a representative area to monitor changes in growth and condition of the marked brown trout cohort stocked earlier that spring and was sampled monthly from May to December 1997–2006. In each month, successive 15-min transects were made until a minimum of 30 brown trout were collected. All trout collected were measured, weighed, and checked for microwire tags and fin clips. The months of January through April were not sampled as growth is minimal in the winter, and the winter and spring months are typically months of high discharge from the dam that preclude effective sampling. Monthly sampling was not conducted in 1999 or 2003 for logistical reasons.

Trout Sampling Analyses

Brown trout collected in annual samples were separated into four length groups for analysis of catch-per-unit-effort (CPUE), which were: all sizes combined, less than 381 mm, 381–507 mm, and ≥508 mm and hereafter are referred to as CPUE-All, CPUE< 381, CPUE381 – 507, and CPUE ≥ 508. Annual CPUE (fish h^{-1}) was calculated for each length group to examine temporal changes in abundance. These data were also segregated into two time periods: pre-regulation change and post-regulation change. After adding 0.5 to remove zeros, CPUE data were $\log_{10}$-transformed to normalize the data. Comparisons of mean CPUE between periods for each size group were made using a repeated measures analysis of variance (ANOVA) using the MIXED procedure in SAS (SAS Institute 2008) with no weighting variable and the AR(1) covariance parameter (Neumann and Allen 2007). The AR(1) covariance structure has homogenous variances and correlations decline exponentially with distance in time (i.e., measurements in successive years are more related than those taken five years apart). Catch rates of larger sizes of brown trout (≥ 381 mm) would not be expected to increase immediately following the implementation of the more restrictive regulations, despite the reduced creel limit, because fish need time to grow into those size classes (Ross and Kosa 2001, Dauwalter et al. 2009). Based on known growth rates of the 1997 stocked cohort in the Lake Cumberland tailwater, the 1997 CPUE381 – 507 data and the 1997 and 1998 CPUE ≥ 508 data were considered transition years and omitted from the pre-regulation and post-regulation catch rate comparisons.

Several other population parameters were analyzed during the post-regulation period (1997–2006) to assess evidence of any density-dependent effects due to potential brown trout population increases. The first-year post-stocking (age-2) growth rate was estimated using the slope of the linear regression of cohort mean TL in monthly samples versus days post stocking. First-year post-stocking growth rates (slopes = mm day^{-1}) from 1997 to 2006 were compared using an ANCOVA (SAS Institute 2008). Monthly samples were not conducted in 1999 and 2003 so the data consisted only of cohort mean lengths at stocking and cohort mean lengths in the autumn electrofishing sample. The slope coefficient of the linear regression of cohort mean TL versus days post stocking was multiplied by 30 to convert first year daily growth rate to monthly growth rate (mm mo^{-1}). Annual growth increments of age-3 brown trout were calculated as the difference between individual age-3 fish length in autumn electrofishing samples and the cohort mean length the previous fall. Comparisons of cohort mean growth increments of age-3 brown trout (two years post-stocking) were made using a one-way ANOVA (SAS Institute 2008). The first year post-stocking growth rate (age-2) and age-3 growth increments were regressed against year with a linear model to determine if growth decreased through time. Similarly, to examine changes in relative weights, a one-way ANOVA was also used to compare differences among years in autumn relative weights of brown trout for the same four size groups as described above, with the exception that brown trout less than 203 mm were excluded to avoid the increased variability of weight measurements of small fish.

Creel Survey Data Collection and Analyses

Non-uniform probability roving creel surveys were conducted on the upper 61.6 km section of the Cumberland River in 1995, 2002, and 2006 to estimate fishing pressure, catch, and harvest of brown trout and rainbow trout. The creel surveys were conducted from March through November to encompass the bulk of the fishing pressure. Creel clerks surveyed 18 days per month including eight weekend days. The start time of each 6-hour survey period was randomized such that the earliest survey would begin at sunrise and the latest possible survey would end at sunset. Depending on the reach surveyed and the water release schedule, either: (1) instantaneous pressure counts were taken during the first and last half hour of the survey or (2) an instantaneous count and a progressive count was conducted. Creel clerks identified and measured all fish in angler's creels and recorded angler's estimates of number and length of fish released. The survey area was divided into four reaches ranging in size from 7.2 to 19.3 km and a single reach was covered on each survey day. Because of greatly different angler usage patterns, the area of the survey was stratified into two equal probability strata for data summary: the 7.2 km reach from the dam to Helm's Landing was the upper stratum and the remaining three reaches combined from Helm's Landing to Highway 61 bridge (54.4 km) were the lower stratum.

Creel survey data were expanded to annual estimates based on assigned probabilities using SAS. The combined regulatory and voluntary catch and release rate was defined as the proportion of the annual estimate of total catch that was not harvested (released).

Unexpanded length distributions of brown trout harvested or released were actual number of brown trout in the creel that were either measured by the creel clerk (harvested) or length of fish as reported by the angler (released).

Water Quality Analyses

Hourly discharge data as well as water temperature and dissolved oxygen data were provided by the Nashville District of the ACOE. An index of annual discharge was calculated by summing all the hourly data for each year from 1995 to 2006 and dividing by the number of days, resulting in the annual mean hourly discharge in cubic meters per second ($m^3\ sec^{-1}$). The grand mean annual hourly discharge from 1995 to 2006 was calculated and used to assign the years above the mean as "Wet" and the years below the mean as "Dry." The four size groupings of mean brown trout CPUE were compared between wet and dry years using the same repeated measures analysis of variance (ANOVA) procedures described above. Water temperatures exceeding 15.6 C and dissolved oxygen levels less than 4 mg L^{-1} are atypical for the Lake Cumberland tailwater and so these thresholds were chosen for analysis. Days of temperature greater than 15.6 C and days of dissolved oxygen less than 4 mg L^{-1} were extrapolated from ACOE water quality sampling in the immediate tailwater of Wolf Creek Dam. Linear regression was used to detect relationships between annual mean hourly discharge and (1) days of temperature greater than 15.6 C, (2) days of dissolved oxygen less than 4 mg L^{-1}, (3) first-year growth rate of stocked brown trout and (4) brown trout relative weight. All statistical tests used in this study were considered significant at $P < 0.10$.

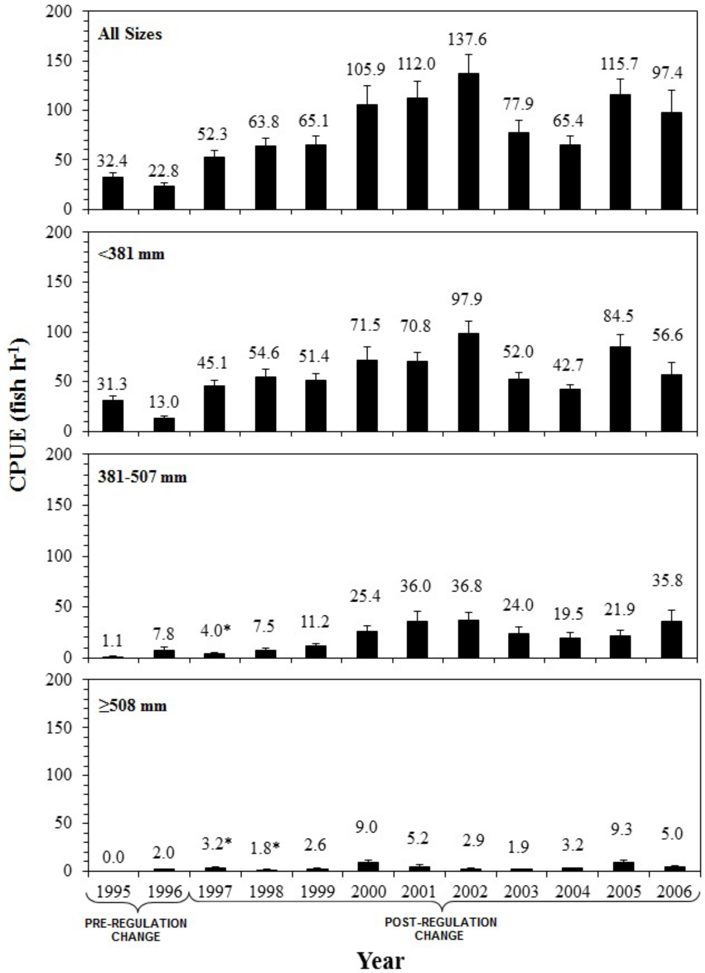

Figure 2. Autumn electrofishing mean relative abundance (fish h-1) of all sized, <381-mm, 381–507-mm, and ≥508-mm brown trout in the Lake Cumberland tailwater from 1995 to 2006. Error bars represent the standard error. Asterisks indicate data omitted from statistical analysis.

Results

Catch Per Unit Effort

Brown trout CPUE increased for all size classes after the regulation change (Figure 2). Mean CPUE-All increased from 27.3 fish h^{-1} (SE = 3.8) in pre-regulation years to 89.3 fish h$^-$1 (SE = 8.3) in post-regulation years ($F = 9.94$, df = 1, 10, $P = 0.01$). Likewise, mean CPUE < 381 increased from 21.7 fish h^{-1} (SE = 3.9) to 62.7 fish h^{-1} (SE = 4.8) over the same time period ($F = 11.61$; df = 1, 10; $P = 0.007$). Mean CPUE381-507 (± SE) and CPUE ≥ 508 similarly increased following regulation change (4.6 ± 2.2 fish h$^-$1 to 24.2 ± 4.0 fish h^{-1} and 1.0 ± 0.7 to 4.9 ± 0.9 fish h^{-1}, respectively, F range = 5.70 to 6.03, $P < 0.05$). Length distributions of autumn electrofishing mean CPUE from 1995 to 2006 steadily shifted towards larger fish after institution of the trophy regulations in 1997 (Figure 3).

Growth and Condition

Post-stocking growth rates of age-2 brown trout during their first year following stocking in the post-regulation period (1997–2006) varied significantly among years ($F = 6.36$; df = 7, 49; $P < 0.0001$). However, post-stocking growth rates of age-2 brown trout was unrelated to year ($r^2 < 0.01$, $P = 0.98$), indicating growth did not slow down through time. Monthly growth rates of age-2 brown trout during post-regulation years ranged from 8.9 mm mo^{-1} in 2003 to 17.8 mm mo^{-1} in 2000 and 2001 and averaged 13.5 mm mo^{-1}. The annual mean cohort growth increment of age-3 brown trout ranged from 75 to 122 mm across years and varied significantly among years ($F = 18.41$; df = 4, 472; $P < 0.0001$). Similar to growth of age-2 fish, mean annual growth rates of age-3 brown trout was unrelated to year ($r^2 < 0.01$, $P = 0.98$), indicating growth did not slow down through time.

The relative weight of all brown trout combined during the

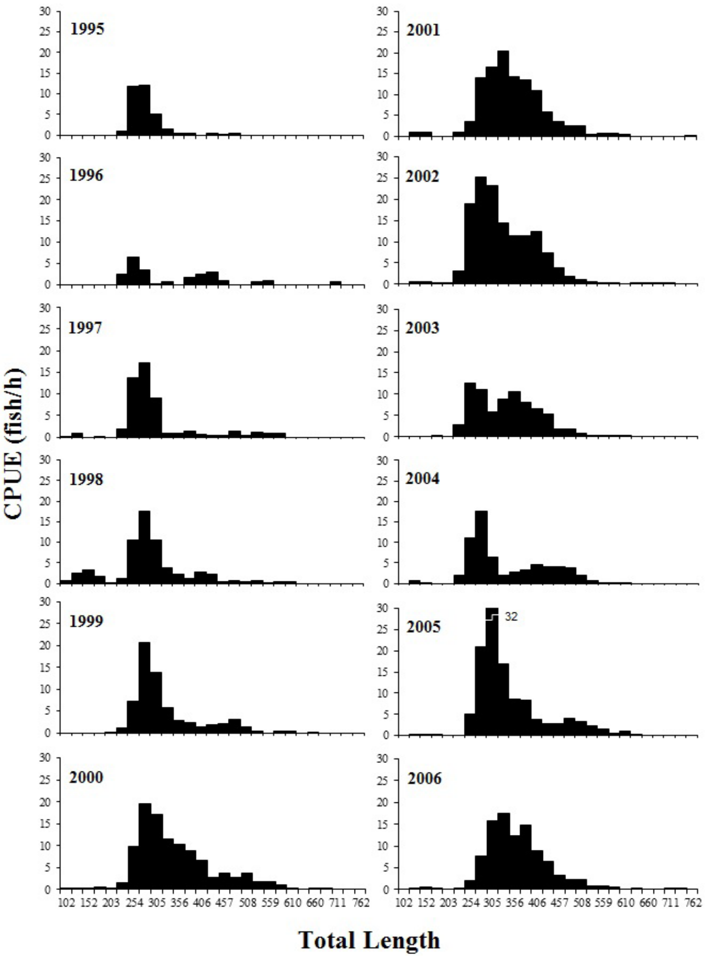

Figure 3. Brown trout autumn electrofishing mean CPUE by 25-mm length groups in the Lake Cumberland tailwater from 1995 to 2006. Trophy regulations were implemented in 1997.

post-regulation years of 2000–2006 ranged from 91 in 2003 to 107 in 2001 and averaged 100. Overall mean relative weight of brown trout varied significantly among years ($F = 104.12$; df = 6, 4,320; $P < 0.0001$), but similar to growth was unrelated to year ($r^2 = 0.09$, $P = 0.52$), indicating condition did not decline through time. When broken down by size group, condition also differed among years within the 203- to 380-mm TL ($F = 105.75$; df = 6, 2,876; $P < 0.0001$), 381-507-mm TL ($F = 26.1$; df = 6, 1,213; $P < 0.0001$) and the ≥ 508-mm groups ($F = 2.3$; df = 6, 217; $P = 0.04$). Mean brown trout relative weight was unrelated to year for any of the three size groups ($P \geq 0.32$), indicating condition did not decline through time. Overall mean relative weights of the < 381-mm, 381-507-mm, and ≥508-mm brown trout size groups between 2000 and 2006 increased with increasing size (98, 103, and 107, respectively), but brown trout exhibited above-average to excellent condition in all post-regulation years.

Creel Survey Results

Fishing pressure (angler-h) on the Cumberland tailwater trended upward after the implementation of the trophy regulations in 1997, rising from 4369 h km^{-1} in the pre-regulation creel survey (1995) to 8751 h km^{-1} and 6587 h km^{-1} in the post-regulation creel surveys conducted in 2002 and 2006, respectively (Table 1). Over this same period, brown trout catch rates nearly doubled from 0.11 fish h^{-1} in 1995 to 0.20 fish h^{-1} in 2002), before declining to 0.12 fish h^{-1} in 2006. However, number of brown trout caught by anglers remained high relative to 1995 (Table 1). Harvest of brown trout declined from an estimated 13,023 fish in 1995 to 380 fish and 2087 fish in 2002 and 2006, respectively (Table 1). Harvest rates declined by an order of magnitude from 0.048 fish h^{-1} in 1995, to less than 0.001 fish h^{-1} in 2002 and 0.005 fish h^{-1} in 2006. The combined regulatory and voluntary catch and release rate of brown trout increased from 55.4% of the total catch in 1995 to 99.4% and 95.7% in 2002 and 2006, respectively (Table 1), with voluntary release of legal-sized fish (≥508 mm) becoming more common (Figure 4).

Unexpanded length distributions of brown trout in the creel also showed that the proportion of large brown trout in the catch increased. In 1995, only 5.0% of the brown trout caught by anglers were ≥381 mm and 0.2% were ≥508 mm (Table 1, Figure 4). However, following implementation of the trophy regulations, angler catch of brown trout ≥ 381 mm increased to 23.9% and 29.2% of total brown trout catch in 2002 and 2006, respectively; whereas, angler catch of fish ≥ 508 mm increased from 0.2% in 1995 to 1.6% and 2.7% in 2002 and 2006, respectively.

Table 1. Results for daytime creel surveys on Lake Cumberland tailwater brown trout during 1995, 2002, and 2006. RKM denotes river km below Wolf Dam.

	1995	2002	2006
Fishing pressure (all species)			
Effort directed at trout (%)	91	96	94
Total (man-hours)	269,123	539,034	405,754
Man-hours RKM^{-1}	4369	8751	6587
Brown trout catch			
Number of fish caught	29,221	108,102	48,504
Fish hour^{-1}	0.11	0.20	0.12
Fish RKM^{-1}	474	1755	787
Brown trout harvest			
Number of fish harvested	13,023	663	2087
Fish hour^{-1}	0.048	0.001	0.005
Fish RKM^{-1}	211	11	34
Brown trout catch-and-release rate (%)	55.4%	99.4%	95.7%
Brown trout size structure (%)			
381 mm and greater	5.0	23.9	29.2
508 mm and greater	0.2	1.6	2.7

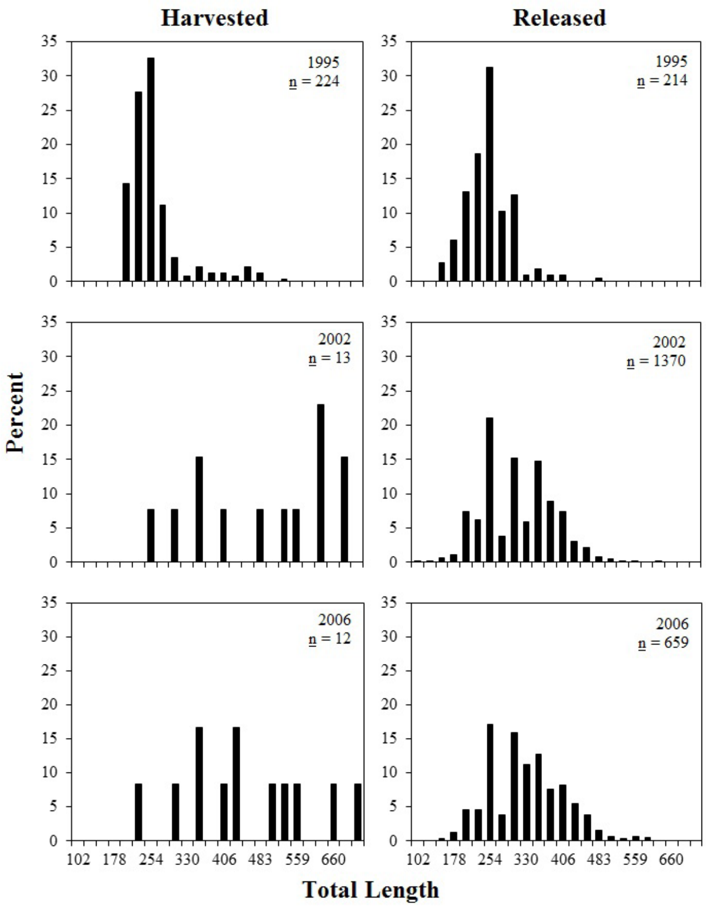

Figure 4. Length distributions of harvested and released brown trout in the Lake Cumberland tailwater creel surveys during 1995, 2002, and 2006. (Lengths for released fish were as reported by angler.)

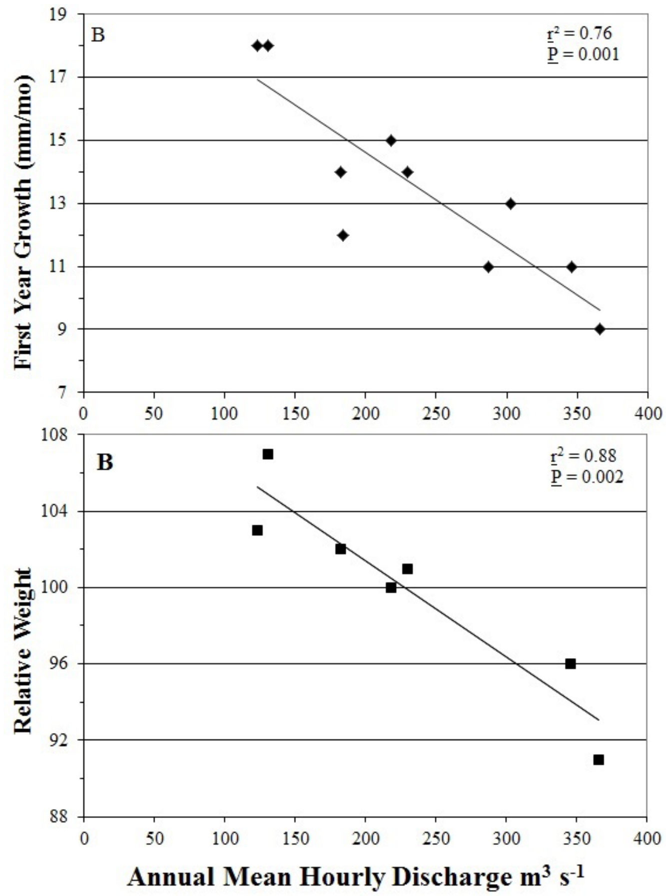

Figure 5. Catchable-size brown trout growth in the first year after stocking (panel A; 1997–2006) and mean relative weight in autumn sampling (panel B; 2000–2006) in the Lake Cumberland tailwater versus annual mean hourly discharge ($m^3 sec^{-1}$) from Wolf Creek Dam.

Effects of Dam Discharge

Above-normal precipitation in the Lake Cumberland drainage basin resulted in high discharge rates from Wolf Creek Dam in 1996, 1997, 1998, 2003, and 2004. The grand mean discharge over the 12 years was 240 m^3 sec^{-1}. In wet years, discharge rates ranged from 287 to 367 m^3 sec^{-1}, whereas, in dry years discharge ranged from 123 to 229 m^3 sec^{-1}. Both the number of days each year that tailwater water temperatures exceeded 15.6 C ($r^2 = 0.80$, $P < 0.0001$) and the number of days tailwater dissolved oxygen levels were 4 mg L^{-1} or less ($r^2 = 0.40$, $P = 0.03$) increased with annual mean hourly discharge rates. Water quality was most severely impacted in 2004, when water temperatures near the dam were as high as 18.8 C and dissolved oxygen levels were as low as 1.9 mg L^{-1}.

CPUE-All was greater ($F = 4.60$, df = 1, 10, $P = 0.06$) in dry years (mean ± SE = 95.0 ± 11.3 fish h^{-1}) than in wet years (56.5 ± 7.0 fish h^{-1}). CPUE< 381 was also greater ($F = 3.42$; df = 1, 10; $P = 0.09$) in dry years (66.2 ± 6.4 fish h^{-1}) than in wet years (41.5 ± 4.8 fish h^{-1}). However, brown trout CPUE381-507 ($F = 0.27$; df = 1, 10; $P = 0.61$) and CPUE≥508 ($F = 0.32$; df = 1, 10; $P = 0.59$) were similar between dry and wet years. First-year growth rate ($r^2 = 0.76$, $P = 0.001$) and relative weight of brown trout ($r^2 = 0.88$, $P = 0.002$) declined as annual mean hourly discharge increased (Figure 5).

Discussion

Prior to the implementation of the trophy size and creel limits for brown trout, few brown trout exceeded 381 mm in the Lake Cumberland tailwater due to high angler exploitation (Kosa 1999). High harvest rates of both brown and rainbow trout have previously been documented in other tailwater fisheries (e.g., Axon 1974, Aggus et al. 1977, Wiley and Dufek 1980, Hudy 1990, Bettoli et al. 1999). Lake Cumberland tailwater creel surveys documented that harvest of brown trout was greatly reduced by implementation of the trophy regulations even though fishing pressure increased.

The management objective of doubling the percent of brown trout angler catch ≥381 mm TL and ≥508 mm TL was easily exceeded, as fish ≥381 mm TL were increased 6-fold and ≥508 mm fish were increased nearly 14-fold. Brown trout electrofishing catch rates and improvements in the size structure in the angler catch were observed without any concomitant decreases in growth or condition.

In some cases, length limits have been judged unsuccessful, but this may be more a result of study limitations and high variability rather than failure of the length limit to alter fish populations. In an analytical review of 49 length limit evaluation studies, Wilde (1997) suggested that most were limited by (1) the duration of the evaluation, frequently less than 5 years of data combined for the pre- and post-treatment periods; and (2) the lack of creel survey data to document changes in angler catch and harvest rates. Allen and Pine (2000) demonstrated that recruitment variation exceeding 60%–70% over 5-year evaluation periods often masked detection of population effects of minimum-length limit (MLL) changes. They also documented that significant responses in the fish population are more difficult to detect when minor increases in MLLs are implemented, assuming stable growth and mortality rates.

In the current study, we avoided many of these limitations. We had the benefit of stable recruitment due to the fact that the population is entirely supported through stocking (i.e., negligible natural reproduction). Our study had limited years of pre-regulation electrofishing catch data but ample post-regulation data as well as pre- and post-regulation creel survey data. Though this study avoids most of the impediments for effective length limit evaluations suggested by Wilde (1997), it does not include replication and control areas. These would have been preferable; however, the Lake Cumberland tailwater is unique in Kentucky and special regulation sections were not an option for the tailwater, as these had been tried in the recent past and had proven very unpopular with landowners adjacent to the tailwater (Kosa 1999).

Effectiveness of MLLs can also be reduced by intraspecific (Power and Power 1996) and interspecific (Hearn 1987) density-dependent interactions after the implementation of restrictive regulations. Increasing numbers of fish below a high MLL can result in decreases in growth rate (Wiley et al. 1993, Weiland and Hayward 1997) and/or relative weight (Van Den Avyle 1993). Declines in growth can also allow natural mortality more time to act on the population, reducing the number of larger fish (Van Den Avyle 1993). Trout abundance, biomass, and survival all increased in a reach of a Wisconsin river regulated with a high MLL, but Hunt (1981) speculated that density-dependent decreases in growth limited the fishery from producing more trophy fish. Similar density-dependent impacts after implementation of restrictive regulations were also documented for trout populations in other studies (Hunt 1977).

Following implementation of the trophy regulations in the Lake Cumberland tailwater, brown trout density increased significantly, but growth or Wr did not change. The first year after stocking mean monthly growth rate (13.5 mm mo^{-1}) of brown trout in the Lake Cumberland tailwater was greater than those observed in a variety of Tennessee tailwaters (5.7–12.0; Bettoli and Besler 1996, Bettoli and Bohm 1997, Devlin and Bettoli 1999, Bettoli et al. 1999). Furthermore, growth rates of brown trout in their first three years after stocking did not slow with increasing electrofishing catch rates, indicating a lack of evidence that the trout populations in the Lake Cumberland tailwater had reached a level where density-dependent mechanisms were limiting. Stocking rates of brown trout (503 km^{-1}) and rainbow trout (2,272 km^{-1}) in the Lake Cumberland tailwater are well below those reported for other tailwaters; for example, stocking rates of brown trout and rainbow trout in Arkansas are as high as 1293 and 11,952 fish km^{-1}, respectively (J. Williams, Arkansas Game and Fish Commission, personal communication).

Water is released almost exclusively through the bottom of Wolf Creek Dam, so in years of greater precipitation, increased discharge severely depleted the winter-stored cold, oxygenated water in the hypolimnion of Lake Cumberland by autumn. Martin and Stroud (1973) observed that heavy spring-time inflows, consisting of high oxygen-demand water, resulted in more severe hypoxia in the hypolimnion of two Kentucky reservoirs later in the year. In spring 2003 and 2004, above average rainfall in the Lake Cumberland drainage basin led to high discharge. Discharge from Wolf Creek Dam in autumn of each of these two years was warmer and had lower DO than in previous years. Typically, hypoxic conditions are most severe in the upper portion of the Lake Cumberland tailwater as natural reaeration of the water occurs as water flows downstream (Hauser et al. 2004). Anglers reported that fishing success for both brown trout and rainbow trout of all sizes had greatly diminished during these two years, and we also observed a substantial decline in electrofishing catch rate of both species. In contrast, brown trout CPUE had progressively increased over the previous four years that had relatively lower flows. The electrofishing catch rate of brown trout improved when flows declined in 2005 and 2006, which implied that reduced CPUE during high-flow years may have been in part due to downstream movement of fish or decreased capture efficiency (Dauwalter et al. 2009) rather than increased mortality of trout. Declining angler catch rates with increasing hypoxia (linked to higher flows in the Lake Cumberland tailwater) has been documented for rainbow trout in several tailwaters (Weithman and Haas 1984, Klein 2003). During these two years it was suspected that a substantial portion of both trout populations had either moved downstream of our sampling sites into the nearly 60 km of trout water below the study area or into tributaries seeking higher DO levels. Elliott (2000) found that brown trout showed a preference for higher oxygen concentration as long as the water temperature remained below the incipient lethal value around 25 C. Research on both adult brown trout (Heggenes 1988) and rainbow trout (Gido et al. 2000) found that large spikes in discharge did not result in long-distance displacement of fish downstream. However, neither study documented hypoxic conditions associated with high flows, and we suspect trout movement in the Lake Cumberland tailwater may have been related more to the former than the latter.

In 2004, the ACOE began using sluice gate releases in the late summer and autumn to mitigate for hypolimnetic releases of water with low DO. This type of release sprays water into the air to effectively aerate the entire volume of water that is released from the dam. Improvements benefiting water quality in TVA tailwaters (Scott et al. 1996), such as pulsing of releases to limit long periods of zero discharge and the addition of hub baffles to turbines, were also instituted at Wolf Creek Dam in 2000. Given these changes in operation, the Lake Cumberland tailwater water quality improved and thus the potential for poor water quality impacting angler and electrofishing catch rates has lessened.

Results of this study demonstrated that trophy regulations can positively alter brown trout abundance and size structure without negatively affecting growth and condition. As Power and Power (1996) indicated, because of the nature of our study (i.e., evaluating population response to a simultaneous change in both the size limit and creel limit) it was not possible to unequivocally attribute the observed response in the Lake Cumberland tailwater brown trout population to either the size limit or the creel limit change. However, we believe that these were the two most likely factors effecting the observed changes. We further suggest that density-dependent limitations on growth and condition were not observed because increases in brown trout density, due to the implementation of the restrictive regulations, remained below carrying capacity of the tailwater. However, we also observed that poor water quality related to high precipitation in the reservoir drainage basin can possibly be a limiting factor. Bioenergetics studies of the Lake Cumberland tailwater could help identify the maximum biomass of brown trout the river can support and quantify the effect of temperature and dissolved oxygen levels on brown trout physiology (Elliott 1994).

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Literature Cited

Aggus, L. R., D. I. Morais, and R. F. Baker. 1977. Evaluation of the trout fishery in the tailwater of Bull Shoals Reservoir, Arkansas, 1971–73. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 31:565–573.

Allen, M. S. and W. E. Pine. 2000. Detecting fish population responses to a minimum length limit: effects of variable recruitment and duration of evaluation. North American Journal of Fisheries Management 20:672–682.

Anderson, R. M. and R. B. 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.

Axon, J. 1974. Review of coldwater fish management in tailwaters. Proceedings of the Annual Conference Southeastern Association of Game and Fish Commissioners 28:351–355.

Ayllón, D., A. Almodóvar, G. G. Nicola, and B. Elvira. 2010. Ontogenetic and spatial variations in brown trout habitat selection. Ecology of Freshwater Fish 19:420–432.

Behnke, R. J. 1990. Roots, origins, and management of *Salmo trutta*, our most versatile species of trout. Pages 1–2 *in* J.C. Borawa, editor. Brown trout workshop: biology and management. American Fisheries Society, Southern Division, Trout Committee, Asheville, North Carolina.

Bettoli, P. B. and D. A. Besler. 1996. An investigation of the trout fishery in the Elk River below Tims Ford Dam. Fisheries Report 96–22, Tennessee Wildlife Resources Agency, Nashville.

——— and L. A. Bohm. 1997. Clinch River trout investigations and creel survey. Tennessee Wildlife Resources Agency, Fisheries Report 97–39, Nashville.

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

Brousseau, C. S. and E. R. Armstrong. 1987. The role of size limits in walleye management. Fisheries 12(1):2–5.

Clark, R. D., Jr., G. R. Alexander, and H. Gowing. 1980. Mathematical description of trout-stream fisheries. Transactions of the American Fisheries Society 109:587–602.

———, ———, and ———. 1981. A history and evaluation of regulations for brook trout and brown trout in Michigan streams. North American Journal of Fisheries Management 1:1–14.

Coopwood, T. R., S. W. McGregor, T. S. Talley, and D. B. Winford. 1987. An investigation of the tailwater fishery below Wolf Creek Dam, Russell County, Kentucky to Celina, Tennessee. U.S. Fish and Wildlife Service, Ecological Services, Cookeville, Tennessee.

Dauwalter, D. C., F. J. Rahel, and K. G. Gerow. 2009. Temporal variation in trout populations: implications for monitoring and trend detection. Transactions of the American Fisheries Society 138:38–51.

Devlin, G. J. and P. B. Bettoli. 1999. Creel survey and population dynamics of salmonids stocked into the Caney Fork River below Center Hill Dam Fisheries Report 99-8. Tennessee Wildlife Resources Agency, Nashville.

Elliott, J. M. 1994. Quantitative ecology and the brown trout. Oxford University Press. Oxford, UK.

———. 2000. Pools as refugia for brown trout during two summer droughts: trout responses to thermal and oxygen stress. Journal of Fish Biology 56:938–948.

Fatora, J. R. 1976. Stream trout fishery management in the southeastern United States. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 30:280–284.

Galbreath, P. F., N. D. Adams, and T. H. Martin. 2004. Influence of heating rate on measurement of time to thermal maximum in trout. Aquaculture 241:587–599.

Gido, K. B., R. D. Larson, and L. A. Ahlm. 2000. Stream-channel position of adult rainbow trout downstream of Navajo Reservoir, New Mexico, following changes in reservoir release. North American Journal of Fisheries Management 20:250–258.

Gigliotti, L. M. and R. B. Peyton. 1993. Values and behaviors of trout anglers, and their attitudes toward fishery management, relative to membership in fishing organizations: a Michigan case study. North American Journal of Fisheries Management 13:492–501.

Hale, R. S. and J. H. Gray. 1998. Retention and detection of coded wire tags and elastomer tags in trout. North American Journal of Fisheries Management 18:197–201.

Hartzler, J. R. 1988. Catchable trout fisheries: the need for assessment. Fisheries 13(2):2–8.

Hauser, G. E., J. A. Parsly, and G. C. Chapman. 2004. Wolf Creek tailwater modeling for minimum flow evaluation. U. S. Army Engineers, Nashville, Tennessee, District.

Hearn, W. E. 1987. Interspecific competition and habitat segregation among stream-dwelling trout and salmon: a review. Fisheries 12(5):24–31.

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.

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

Hudy, M. 1990. Brown trout population structures in White River tailwaters currently managed under no special regulations. Pages 94–97 *in* J.C. Borawa, editor. Brown trout workshop: biology and management. American Fisheries Society, Southern Division, Trout Committee, Asheville, North Carolina.

Hunt, R. L. 1977. An unsuccessful use of catch-and-release regulations for a wild brook trout fishery. Pages 125–136 *in* R.A. Barnhart and T.D. Roelofs, editors. Catch-and release fishing as a management tool. Humboldt State University, Arcata, California.

———. 1981. A successful application of catch and release regulations on a Wisconsin trout stream. Technical Bulletin 119. Wisconsin Department of Natural Resources, Madison.

Jager, H. I., W. Van Winkle, and B. D. Holcomb. 1999. Would hydrologic climate changes in Sierra Nevada streams influence trout persistence? Transactions of the American Fisheries Society 128:222–240.

Klein, L. A. 2003. Investigation of the trout fishery in the Chattahoochee River below Buford Dam. Project Number F-66. Georgia Department of Natural Resources, Wildlife Resources Division, Social Circle.

Klemetsen, A., P.-A. Amundsen, J. B. Dempson, B. Jonsson, N. Jonsson, M. F. O'Connell, and E. Mortensen. 2003. Atlantic salmon *Salmo salar* L., brown trout *Salmo trutta* L. and arctic charr *Salvelinus alpinus* (L.): a review of aspects of their life histories. Ecology of Freshwater Fish 12:1–59.

Kosa, J. 1999. Evaluation of rainbow and brown trout stockings in the Lake Cumberland tailwater. Bulletin 102. Kentucky Department of Fish and Wildlife Resources, Frankfort.

Martin, R. G. and R. H. Stroud. 1973. Influence of reservoir discharge location on water quality, biology and sport fisheries of reservoirs and tailwaters, 1968–1971. Completion Report Contract Number DACW31-67-C-0083. U.S. Army Engineers Waterways Experiment Station, Vicksburg, Mississippi.

Miranda, L. E. 1996. Development of reservoir fisheries management paradigms in the twentieth century. Pages 3–11 *in* L. E. Miranda and D. R. DeVries, editors. Multidimensional approaches to reservoir fisheries management. American Fisheries Society Symposium 16. Bethesda, Maryland.

Molony, B. 2001. Environmental requirements and tolerances of rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*) with special reference to Western Australia: A review. Fisheries Research Report Number 130. Department of Fisheries, North Beach, Australia

Näslund, I., E. Degerman, and F. Nordwall. 1998. Brown trout (*Salmo trutta*) habitat use and life history in Swedish streams: possible effects of biotic interactions. Canadian Journal of Fisheries and Aquatic Sciences 55:1034–1042.

Neumann, R. M. and M. S. Allen. 2007. Size structure. Pages 375–421 *in* C. S. Guy and M. L. Brown, editors. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland.

Noble, R. L. and T. W. Jones. 1993. Managing fisheries with regulations. Pages 383–402 *in* C. C. Kohler and W. A. Hubert, editors. Inland fisheries management in North America. American Fisheries Society, Bethesda, Maryland.

Nordwall, F., P. Lundberg, and T. Eriksson. 2000. Comparing size-limit strategies for exploitation of a self-thinned stream fish population. Fisheries Management and Ecology 7:413–423.

Öhlund, G., F. Nordwall, E. Degerman, and T. Eriksson. 2008. Life history and large-scale habitat use of brown trout (*Salmo trutta*) and brook trout (*Salvelinus fontinalis*)—implications for species replacement patterns. Canadian Journal of Fisheries and Aquatic Sciences 65:633–644.

Parsons, J. W. 1957. The trout fishery of the tailwater below Dale Hollow Reservoir. Transactions of the American Fisheries Society 85:75–92.

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

Pierce, R. B. and C. M. Tomcko. 1998. Angler noncompliance with slot length limits for northern pike in five small Minnesota lakes. North American Journal of Fisheries Management 18:720–724.

Power, M. and G. Power. 1996. Comparing minimum-size and slot limits for brook trout management. North American Journal of Fisheries Management 16:49–62.

Ross, J. R. and J. T. Kosa. 2001. Response of brown trout in Lake Cumberland tailwater to a trophy regulation. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 55:23–37.

SAS Institute. 2008. SAS user's guide: statistics, version 9.1. SAS Institute, Inc. Cary, North Carolina.

Scott, E. M., Jr., 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. Tennessee Valley Authority, Norris.

Swink, W. D. 1983. Nonmigratory salmonids and tailwaters—A survey of stocking practices in the United States. Fisheries 8(3):5–9.

U. S. Fish and Wildlife Service (USFWS). 2006. Economic effects of rainbow trout production by the National Fish Hatchery System: science and efficiency at work for you. USFWS, Division of Fisheries and Aquatic Resource Conservation, Arlington, Viginia.

Van Den Avyle, M. J. 1993. Dynamics of exploited fish populations. Pages 105–135 *in* C. C. Kohler and W. A. Hubert, editors. Inland Fisheries Management in North America. American Fisheries Society, Bethesda, Maryland.

Walburg, C. H., J. F. Novotny, K. E. Jacobs, W. D. Swink, T. M. Campbell, J. Nestler, and G. E. Saul. 1981. Effects of reservoir releases on tailwater ecology: a literature review. Technical Report E-81-12. U.S. Army Engineers Waterways Experiment Station, Vicksburg, Mississippi.

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.

Wilde, G. R. 1997. Largemouth bass fishery response to length limits. Fisheries 22(6):14–23.

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.

———, R. A. Whaley, J. B. Satake, and M. Fowden. 1993. Assessment of stocking hatchery trout: a Wyoming perspective. North American Journal of Fisheries Management 13:160–170.