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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 one-fish-per-day creel limit on improving the size structure of the brown trout *Salmo trutta* population in the Cumberland River below Lake Cumberland, Kentucky. 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) and trophy-size (≥ 508 mm total length) brown trout in the 121 km tailwater. A significant increase in brown trout electrofishing catch per unit effort was observed across years for small (< 381 mm), quality, trophy-size trout, and all sizes combined. As brown trout electrofishing and angler catch rates increased over time, no corresponding decrease in growth or condition was observed. Reservoir discharge was positively correlated with warmer water temperatures and lower dissolved oxygen in the tailwater. Growth and condition of brown trout in the tailwater were inversely correlated with an index of discharge from the reservoir. The trophy regulations resulted in an increase in abundance and larger sizes of brown trout in the tailwater without any observed negative density-dependent impacts.

INTRODUCTION

A reservoir tailwater can be described as that portion of a stream or river below a dam that is directly affected by the discharge of water through or over that dam (Parsons 1957). Tailwaters below most deep-release reservoirs offer 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 last century. The stocking and management of trout in the altered habitats below high-head dams subsequently became commonplace (Axon 1975) 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 1970's, as the concept of catch and release fishing became more popular, there has been greater demand for quality trout angling experiences (Fatora 1978; Barnhart and Roelofs 1977, 1987; Harris and Bergersen 1985; 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 US (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 because they are highly vulnerable to sportfishing and serve well as a put-and-take species (Fatora 1978; Swink 1983; Hartzler 1988; Heidinger 1993). To offset heavy angling pressure, rainbow trout are often stocked at high densities (Weiland and Hayward 1997). However, brown trout 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; Boyd et al. 2010), 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; Heidinger 1993). Although low-density brown trout stockings in conjunction with rainbow trout can produce trophy brown trout fisheries (Hudy 1990), excessive fishing pressure and elevated harvest rates can limit such potential. Fisheries managers can attempt to balance the 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. However, Behnke (1990) observed that special regulations alone cannot improve a river's natural capacity to support trout as each system will have its own limits for trout growth, size, and age structure, but he also noted that brown trout in large rivers and tailwaters were an exception and can grow faster and live longer than fish in small and medium-size streams. This can also be explained by the fact that large rivers and tailwaters often have an abundance of slower flows and deeper water, favored by large brown trout as they undergo a well-documented ontogenetic shift in habitat usage (Näslund et al. 1998; Klemetsen et al. 2003; Öhlund et al. 2008; Ayllon et al. 2010). If conditions for growth and survival are favorable, but not realized due to high fishing mortality, then specialized harvest restrictions can be used to enhance trophy fishing potential (Noble and Jones 1993).

Minimum length limits requiring the release of all fish below a specified limit, have been suggested for fish populations exhibiting high rates of angler exploitation and low rates of recruitment and natural mortality, with good growth potential (Anderson 1980, Novinger 1984).

Fish population modeling has confirmed that limiting fishing mortality through either high minimum size limits 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; Jensen 1981; Zagar and Orth 1986; Power and Power 1996; Nordwall et al. 2000). Clark et al. (1980) conducted population simulations with Michigan stream brown trout regulated with two minimum size limits and a slot limit. The higher minimum size limit resulted in the greatest abundance of trophy-size fish. In simulation modeling comparing various minimum size limits and catch and release on brook and brown trout, Clark et al. (1981) found that the catch of large trout increased with increasing minimum size limits and was maximum under catch and release regulations. Nordwall et al. (2000) also found when comparing various size limit management strategies in situations with moderate to high exploitation, that a high minimum length limit was superior to all other strategies in terms of maximizing post-harvest abundance and inducing favorable shifts in size structure.

However, the success of fisheries regulations ultimately depends on angler acceptance (Fatora 1978; 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 (1978) 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 differently to accommodate all angler desires. This concept can also be applied to a single body of water by applying different regulations on two or more cohabitating trout species that would result in a “put-and-take” and “trophy” component in the same system.

The Kentucky Department of Fish and Wildlife Resources (KDFWR) manages a popular brown and rainbow trout fishery in the Lake Cumberland tailwater. Brown trout were first introduced in 1982 while rainbow trout were first stocked in 1956. For years, both species were regulated together using no length limits and a combined eight trout daily creel limit of which three could be brown trout (Kosa 1999). In 1997, a 508 mm minimum total length (TL) and a one-fish-per-day creel limit was implemented on brown trout in an attempt to develop a trophy fishery. No bait or gear restrictions were enacted. Rainbow trout regulations remained as above until 2004, when regulations were changed to a 5-fish creel limit and 381-507 mm protective slot limit of which only one fish could be over 508 mm.

There is a paucity of peer-reviewed 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 restrictive harvest regulations (508 mm minimum length limit and one-fish-per-day creel limit) which were enacted to increase the numbers of quality-size (381-507 mm) and trophy-size (≥508 mm) brown trout. The specific objectives were to (1) compare the relative abundance of several size groups of brown trout before and after trophy regulations were implemented, (2) determine if there were any changes in brown trout growth rates or condition, (3) compare several abiotic variables with brown trout growth rates and condition, and (4) monitor the cohabitating rainbow trout population.

STUDY SITE

The Lake Cumberland tailwater in Kentucky is a 121 km section of the Cumberland River which extends from the Wolf Creek Dam to the Kentucky-Tennessee state line. It is located in the Highland Rim Province of southeastern Kentucky and is managed as a coldwater fishery. The study area for this project encompasses the upper 61.6 km section beginning immediately below Wolf Creek Dam (Figure 1). Average daily discharge from the dam, released from 30.8 m below maximum power pool, is 240 m^3/s, but can fluctuate from 0.6 to 425 m^3/s within 3 h. Daily discharge fluctuations and durations of minimum flows are variable and depend on hydropower demands. 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. River width varies from 60 to 120 m. Long pools (0.8-6.4 km) interspersed with riffles (0.2-1.1 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).

METHODS

All brown and rainbow trout stocked in the Lake Cumberland tailwater were produced at the Wolf Creek National Fish Hatchery, which is located immediately below Wolf Creek dam. Catchable-size brown trout that averaged about 203 mm total length (TL) were stocked in March or early April of each year from 1995 to 2006 (Table 1). Annual stocking rates of brown trout remained relatively stable at approximately 30,000 fish (487 fish per km), but beginning in 1996, brown trout stockings within 3.2 km of the dam, an area of more intensive bait fishing pressure, were discontinued and this allotment were distributed among stocking sites further downstream. Catchable-size rainbow trout that averaged about 229 mm TL were also stocked monthly from April through December from 1995 to 2006 (Table 1). Rainbow trout stocking rates were lower during 1995 and 1996, but increased to approximately 145,000 fish annually (2,354 per km) thereafter.

For growth rate determinations, stocked year classes were distinguished by batch marking with either uncoded wire tags or various fin clips. Prior to stocking, short-term (approximately one month) tag loss, mean length, weight, and fin clip efficacy were estimated from a random subsample of fish from each cohort. Hale and Gray (1998) documented 99% retention rates of dorsal and caudal wire tags inserted into brown trout in prior work at Wolf Creek National Fish Hatchery. Through anecdotal field observations, fin regeneration of adipose fin clips was rare to non-existent. Pelvic and pectoral fin regeneration was more common; however, anomalous fin characteristics of regenerated fins usually made marked fish obvious.

Trout were sampled at night in November of each year from 1995-2006 using boat-mounted pulsed DC electrofishing gear at each of five fixed sites (Figure 1). Prior to sampling, a request was made to the ACOE to provide a constant single hydropower turbine release from Wolf Creek Dam to ensure that all crews experienced a stable flow, thereby reducing sampling variation (Dauwalter et al. 2009). Multiple timed samples (15-min) were collected at each site and consisted of three runs per site in 1995 and four runs per site in 1996 at Sites 1, 2, 3, 4 and 6.

From 1997-2006, because of the discontinuation of brown trout stocking near the dam, sampling was discontinued at Site 1 and this effort was shifted to the area designated as Site 5 (Figure 1). Beginning in 1997, sampling effort was increased to five runs at each site. Trout captured were measured to the nearest 2.5 mm TL and any marks were identified. From 2000 through 2006, trout were weighed to the nearest 4.5 g. The sampling data was not only used to calculate catch-per-unit-effort (CPUE, fish/h), but also to collect growth and relative weight (W_r) information. Relative weight was calculated based on the standard weight equation for lotic brown trout as referenced in Anderson and Neumann (1996).

Site 4 was sampled monthly from May to December of 1997-2006, excluding 1998 and 2003, to monitor monthly changes in growth and condition of brown trout. In each sampling event, successive 15-minute runs were made until a minimum of 30 brown trout were collected which had been stocked earlier during that sampling year. All trout collected were measured, weighed, and checked for microwire tags and fin clips.

The CPUE of each of four size groups of brown trout collected in autumn nocturnal samples were analyzed across years to determine if changes in abundance occurred as a result of the trophy regulations. The CPUE groupings were: all sizes combined, less than 381 mm, 381-507 mm, and greater than or equal to 308 mm and hereafter referred to as CPUE-All, CPUE<381, CPUE381-507, and CPUE≥508. Each CPUE group was regressed against year to test for significant increasing trends. However, 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 as Ross and Kosa (2001) noted in preliminary reporting on a portion of this data (see also Dauwalter et al. 2009). Based on known growth rates of the 1997 stocked cohort in the Lake Cumberland tailwater, the CPUE data from the year prior to when a change would be expected served as the origins for the linear regressions of CPUE on year and included years through 2006. The origins are 1996 for CPUE-All and CPUE<381; 1997 for CPUE381-507; and 1998 for CPUE≥508.

Relative abundance data were also segregated into two time periods: pre-regulation change and post-regulation change. After adding 0.5 to remove zeros, the CPUE data were log-transformed and tested for normality using the Shapiro-Wilk test statistic from the UNIVARIATE procedure with the NORMAL option in the Statistical Analysis System (SAS). Because of the time dependent nature of the data, comparisons of mean CPUE between periods for each size group were made using a repeated measures analysis of variance (ANOVA). Specifically, the MIXED procedure in SAS was used 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). For reasons noted above, 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. Selected rainbow trout data is also provided since it has long been understood that competitive interactions among cohabiting salmonid species can result in the displacement of one species (Hearn 1987).

Several other population parameters were analyzed to determine if there were any density dependent effects due to brown trout population increases. First year growth rates (i.e., the slopes of the cohort mean TL versus days post stocking regression line each year) were compared using an ANCOVA. Further testing with linear regression was used to determine if there was a significant relationship between first year growth rate and year. First year monthly growth rates were calculated by multiplying the slope of the regression by 30. Comparisons of cohort mean growth increments of age-3 and 4 brown trout (years two and three post-stocking) were made using a one-way ANOVA. 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.

The relationships among several abiotic variables and brown trout growth and condition were examined. Scatterplots revealed consistent trends of higher temperatures and lower dissolved oxygen in the tailwater during summer and autumn of years with high discharge. Water temperatures exceeding 15.6° C and dissolved oxygen levels less than 4 mg/l are atypical for the Lake Cumberland tailwater. These thresholds were chosen for analysis. While 15.6° C may not be stressful on brown trout at maximum ration, growth efficiency is reduced (Elliott 1994), and in combination with hypoxic conditions may be a limiting factor (Elliott 1994; Molony 2001). 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, (3) first-year growth rate of stocked brown trout and (4) brown trout relative weight. Hourly discharge data were provided by the ACOE, Nashville District. An index of annual discharge was calculated by summing all the hourly data for each year and dividing by the number of days, resulting in the annual mean hourly discharge in cubic meters per second (m^3/s). Days of temperature greater than 15.6° C and days of dissolved oxygen less than 4 mg/l were extrapolated from ACOE water quality sampling in the immediate tailwater of Wolf Creek Dam. An alpha level of 0.1 was used for all statistical tests, with the exception of tests for normality ($\alpha = 0.05$).

Roving creel surveys were conducted on the upper 61.6 km section of the Cumberland River in 1995, 2002 and 2006. The creels were conducted from March through November and creel clerks surveyed 18 days per month, including eight weekend days. The study 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 usage patterns, the area of study was stratified into two 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.

RESULTS

Autumn nocturnal electrofishing CPUE

The log-transformed brown trout electrofishing CPUE data of each of the four analysis groups (CPUE-All, CPUE<381, CPUE381-507, and CPUE≥508) satisfied the assumptions for normality ($P > 0.05$) for both periods (pre- and post-regulation) with one exception. The pre-regulation period CPUE≥508 did not satisfy the normality assumption ($P < 0.05$) because there were so few brown trout of this size collected prior to 1997 resulting in many zero samples.

Length frequency histograms of autumn electrofishing CPUE from 1995 to 2006 show an increasing trend in relative abundance of brown trout in the Cumberland tailwater after institution of the trophy regulations in 1997 (Figure 2). From the last pre-regulation year (1996) to 2006, CPUE-All showed a significantly increasing trend (slope = 6.3; $r^2 = 0.11$; $P = 0.01$) (Figure 3). CPUE-All was significantly greater ($F = 9.94$; df = 1, 10; $P = 0.01$) in post-regulation years (mean ± SE = 89.3 ± 8.3 fish/h) than in pre-regulation years (27.3 ± 3.8 fish/h) (Figure 4).

The brown trout electrofishing CPUE<381 showed a significantly increasing trend from 1996 to 2006 (slope = 3.3; $r^2 = 0.09$; $P = 0.03$) (Figure 3). CPUE<381 was significantly greater ($F = 11.61$; df = 1, 10; $P = 0.007$) in post-regulation years (62.7 ± 4.8 fish/h) than in pre-regulation years (21.7 ± 3.9 fish/h) (Figure 4).

There was a significant increasing trend in CPUE381-507 from 1997 to 2006 (slope = 2.6; $r^2 = 0.08$; $P = 0.04$) (Figure 3). The brown trout electrofishing CPUE381-507 was significantly greater ($F = 5.70$; df = 1, 9; $P = 0.04$) in the post-regulation years (24.2 ± 4.0 fish/h) than in the pre-regulation years (4.6 ± 2.2 fish/h) (Figure 5).

There was not a significant increasing trend in CPUE≥508 from 1998 to 2006 (slope = 0.3; $r^2 = 0.02$; $P = 0.34$) (Figure 3). However, the brown trout electrofishing CPUE≥508 was significantly greater ($F = 6.03$; df = 1, 8; $P = 0.04$) in the post-regulation years (4.9 ± 0.9 fish/h) than in the pre-regulation years (1.0 ± 0.7 fish/h) (Figure 5).

Wolf creek dam discharge correlations

Above normal rainfall amounts in the Lake Cumberland drainage basin resulted in abnormally high discharge rates in 1996, 1997, 1998, 2003 and 2004 as indexed by the annual mean hourly discharge (Figure 6). The mean discharge over the 12 years was 240 m^3/s. In wet years, annual mean hourly discharge rates ranged from 287 to 367 m^3/s and in dry years discharge ranged from 123 to 229 m^3/s. Annual mean hourly discharge rates were positively correlated to both the number of days each year that tailwater water temperatures exceeded 15.6° C ($r = 0.90$; $P < 0.0001$) and the number of days tailwater dissolved oxygen levels were 4 mg/l or less ($r = 0.65$; $P = 0.02$). During these combined periods, water temperatures near the dam were as high as 18.8 ºC and dissolved oxygen levels were as low as 1.9 mg/l, with oxygen saturation ranging from 20-50%. Post-stocking growth rates of age-2 brown trout during their first year following stocking varied significantly by year ($F = 6.36$; df = 7, 49; $P < 0.0001$), but did not slow down over the course of the study ($r^2 < 0.0001$; $F = 0.0005$; df = 1, 8; $P = 0.98$). Rather, first year growth rate of the stocked brown trout (Figure 7) was negatively correlated with annual mean hourly discharge ($r = -0.90$; $P < 0.001$). Monthly growth rates of age-2 brown trout in the tailwater ranged from 8.9 mm/month in 2003 to 17.8 mm/month in 2000 and 2001 and during the post-regulation years averaged 13.5 mm/month. The annual mean cohort growth increment of age-3 brown trout ranged from 76 to 122 mm for the available years of 1998-2000, 2005 and 2006 and varied significantly among years ($F = 18.41$; df = 4, 472; $P < 0.0001$), however there was not a trend of growth slowing over time. The annual growth increments of age-4 brown trout ranged from 61 to 79 mm per year in the available years of 1999-2001 and 2006 and did not vary ($F = 2.01$; df = 3, 472; $P < 0.1140$).

The mean relative weight of all sizes of brown trout combined in autumn sampling varied significantly among years from 2000 to 2006 ($F = 104.12$; df = 6, 4,320; $P < 0.0001$) (Table 2). There was not a trend of declining condition over time, but rather relative weights of brown trout collected in annual autumn sampling (Figure 7) were also negatively correlated with annual mean hourly discharge (r = -0.95; P = 0.001). When broken down by size group, condition was also significantly different in the 203 to 380 mm group ($F = 105.75$; df = 6, 2,876; $P < 0.0001$), 381-507 mm group ($F = 26.1$; df = 6, 1,213; $P < 0.0001$) and ≥ 508 mm group ($F = 2.3$; df = 6, 217; $P = 0.04$) (Table 2). The condition exhibited by 381 mm and greater brown trout was average to excellent in post-regulation years and no group exhibited a trend of declining condition across years.

Autumn electrofishing length frequency histograms (Figure 2) show decreased catch rates of brown trout in some wet years (1996, 2003, and 2004) but not others (1997, 1998). The rainbow trout population also exhibited declines in some years of high discharge (Figure 8). The most severe declines in both populations were observed in 2003 and 2004, the years when discharge rates were greatest, after both populations had slowly expanded during the four preceding years of relatively lower flows. The electrofishing catch rates of both trout populations improved in 2005 and 2006, also years of below average discharge.

Creel survey results

The angler harvest of brown trout on the Cumberland tailwater declined after the implementation of the trophy regulations in 1997 from an estimated 13,023 fish in a pre-regulation creel survey (1995), to 380 and 2,087 fish in the post-regulation creel surveys conducted in 2002 and 2006 (Table 3). Concurrently, fishing pressure trended upward, rising from 4,369 man-hours/kilometer (mh/km) in 1995 to 8,751 mh/km in 2002 and 6,587 mh/km in 2006 (Table 3). Harvest rates (fish/hour) declined by an order of magnitude from 0.048 fish/hour in 1995, to less than 0.001 fish/hour in 2002 and 0.005 fish/hour in 2006. Over this same period, brown trout catch rates nearly doubled from 0.11 fish/hour (1995) to 0.20 fish/hour (2002), before falling back to 0.12 fish/hour in 2006. The combined regulatory and voluntary catch and release rate of brown trout increased from 55% of the total catch in 1995 to over 99.6% and 95.7% in 2002 and 2006 (Table 3) with voluntary release of legal-sized fish becoming more common (Table 4).

Unexpanded length distributions of brown trout creeled also showed that the proportion of large brown trout in the catch also increased. Only 5.0% of the brown trout caught by anglers were 381 mm or longer and 0.2% were 508 mm or longer in 1995 (Tables 3 and 4). However, following implementation of the trophy regulations, angler catch of 381 mm or longer brown trout increased to 23.9% and 29.2% of total catch in 2002 and 2006, while the angler catch of 508 mm or longer fish increased by an order of magnitude in the two post-regulation creel surveys (1.6% and 2.7%).

Both rainbow trout harvest and catch increased from 1995 to 2002 but the catch-and-release rate also increased (Table 3). This can be attributed to an increase in voluntary release of legal-sized fish (Table 5). After the rainbow trout regulations were changed (2004), rainbow trout harvest (0.30 fish/hour) declined but catch rate (0.63 fish/hour) and the catch and release rate (53.2%) continued increasing in 2006. The proportion of large rainbow trout in the angler catch also increased through time (Tables 3 and 5).

DISCUSSION

Prior to the implementation of the trophy size and creel limits for brown trout, there were few brown trout exceeding 381 mm present in the Lake Cumberland tailwater, due to high angler exploitation. High harvest rates of both brown and rainbow trout have previously been documented in other tailwater fisheries (e.g. Axon 1975; Aggus et al. 1979; Wiley and Dufek 1980; Hudy 1990; Bettoli et al. 1999). Lake Cumberland tailwater creel surveys documented that the harvest of brown trout was greatly curtailed by the implementation of the trophy regulations even though fishing pressure increased. The voluntary release of legal-sized fish has been shown to be an important factor in reducing fishing mortality (Clark 1983; Fayram 2003; Allen et al. 2008). However, the very restrictive size and creel limits implemented on the Lake Cumberland tailwater minimizes the effect as just a small fraction of the brown trout population are available to legal harvest. Both electrofishing and angler catch rates for all sizes of brown trout, including trophy sizes (≥508 mm) were substantially increased 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) found that minimum length limits (excluding 305-mm) on largemouth bass failed to increase population size and the proportion of larger fish, but did increase angler catch rates. However, Wilde (1997) suggested that most studies 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) used a simulation model to demonstrate how recruitment variability and the evaluation duration may hinder fisheries manager’s ability to detect fish population response to a minimum length limit on white crappie *Pomoxis annularis* and largemouth bass. Recruitment variation exceeding 60-70% with 5-year evaluation periods often masked detection of population effects of minimum length limit changes. Allen and Pine (2000) also documented that significant responses in the fish population are more difficult to detect when minor increases in minimum length limits are implemented, assuming stable growth and mortality rates. In a study of various length limits on northern pike, Pierce (2010) found that a 762 mm minimum size limit was successful at increasing the percentage of the population greater than 508 mm and 610 mm, but did not translate into increased percentage of fish 762 mm and longer. However, Pierce (2010) noted that low sample sizes (gill net-years) may have precluded observing any changes in relative abundance resulting from the minimum length limits.

In the current study, we avoid 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 has limited years of pre-regulation electrofishing catch data but we have ample post-regulation data and we have 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 adjacent landowners.

Another factor that has the potential to derail the effectiveness of minimum size limits is intraspecific (Power and Power 1996) and interspecific (Hearn 1987) density-dependent negative effects on the population after the implementation of restrictive regulations, which is common in salmonids. Increasing numbers of brown trout in the Lake Cumberland tailwater as a result of the trophy regulations had the potential to result in decreases in growth rate (Wiley et at. 1993; Weiland and Hayward 1997; Van Den Avyle 1993) and/or relative weight (Van Den Avyle 1993). A decrease in growth rate would result in a longer time to reach quality size (381 mm) and allow the forces of natural mortality more time to act on fish, which would limit the potential for increasing the number and sizes of fish (Van Den Avyle 1993). For instance, Hunt (1981) compared trout population response to a high minimum size limit/one fish creel limit versus a control reach under less restrictive regulations in a Wisconsin river. Abundance, biomass, and survival all increased in the trophy reach, but Hunt (1981) speculated that density-dependent decreases in growth limited the fishery from “stockpiling” more trophy fish. Negative density-dependent impacts after implementation of restrictive regulations were also seen in wild brook and brown trout populations in a Michigan river (Shetter and Alexander 1966) and in brook trout populations in Lawrence Creek, Wisconsin (Hunt 1977).

Following implementation of the trophy regulations in the Lake Cumberland tailwater, the brown trout density increased significantly, but there were no decreasing trends in growth rate or relative weight. The first year monthly growth rate averaging 13.5 mm/month for brown trout in the Lake Cumberland tailwater is greater than first year brown trout growth rates observed in some Tennessee tailwaters such as the Elk River, TN (5.7 mm/month, Bettoli and Besler 1996), Clinch River, TN (12 mm/month, Bettoli and Bohm 1997), Caney Fork River, TN (8 mm/month, Devlin and Bettoli 1999), and South Fork of Holston River, TN (11 mm/month, Bettoli et al. 1999). Growth rates of brown trout in their first three years after stocking did not slow with increasing population density, indicating that the trout populations in the Lake Cumberland tailwater had not reached a level where density-dependent mechanisms were limiting. Stocking rates of brown trout (487/km) and rainbow trout (2,354/km) in the Lake Cumberland tailwater are well below those reported for Arkansas tailwaters where stocking rates are as high as 1,293 brown trout per km and 11,952 rainbow trout per km (J. Williams, Arkansas Game and Fish Commission, personal communication). Lake Cumberland tailwater stocking rates are more comparable with those in Tennessee tailwaters where brown trout are stocked at 311 to 796 fish per km and rainbow trout are stocked at rates ranging from 1,513 to 2,467 per km (Bettoli 1999; Bettoli and Besler 1996; Bettoli et al. 1999; Devlin and Bettoli 1999).

When regulations are enacted to protect fish from harvest, escalated hooking mortality can be a concern (Carline et al. 1991; Schill 1996; Pollock and Pine 2007). Hooking mortality rates for nonanadromous trout species caught on artificial lures and flies has averaged around 4-5% (Taylor and White 1992; Schill and Scarpella 1997; Schisler and Bergersen 1996). In a literature review of hooking mortality, Wydoski (1977) reported that hooking mortality of salmonids caught on baited hooks was as high as 61% and averaged 25%. In a meta-analysis of hooking mortality of nonanadromous trout species caught on bait, Taylor and White (1992) concluded the average hooking mortality was around 31%. However, brown trout are less susceptible to hooking mortality, caught with bait or lures, than other salmonids (Taylor and White 1992; Boyd et al. 2010) and DuBois and Kuklinski (2004) reported a hooking mortality of 3% for brown trout caught with an active baitfishing technique. Greater angling pressure, as is often the case in trophy fisheries, can also lead to increased hooking mortality (Risley and Zydlewski 2010). However, Carline et al (1991) and Schill (1996) observed that allowing bait-fishing may be compatible with special regulations on trout fisheries depending on the management goals and especially where bait fishing is not predominant. The KDFWR did not enact any bait or gear restrictions in association with the trophy regulations on the Lake Cumberland tailwater. Behnke (1987) advocated against imposing unnecessary restrictions on anglers in order to maintain a broad base of support for special regulations. Lake Cumberland tailwater creel survey results from 1995 showed the upper 7.2 km reach had greater fishing pressure and anglers in that area fished with bait and harvested fish at a higher rate than anglers further downstream. To reduce unnecessary consumptive fishing pressure and minimize encounters with bait fishing anglers, brown trout stockings were altered in the years leading up to the implementation of the trophy regulations. Eliminating the upper two stocking sites and redistributing the fish to stocking sites in the lower reaches of the tailwater represented a shift in stocking location of approximately one third of the total number of brown trout stocked. It is possible that this change in stocking regime played a role in the observed increases in numbers of brown trout; however, potentially saving a small proportion of stocked brown trout from potentially slightly higher hooking mortality would seem to be a very minor contributor.

Cause and effect relationships are best evaluated with studies designed for that purpose (Hanson 1986). However, these types of relationships may go unnoticed until revealed during the course of other research. As is the case with the relationship between Wolf Creek Dam discharge and both water temperature and dissolved oxygen (DO) levels in the tailwater. 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 the spring of 2003 and 2004, above average rainfall in the Lake Cumberland drainage basin led to high discharge. Discharge from Wolf Creek Dam in the 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). During 2003 and 2004, anglers reported that fishing success for both brown and rainbow trout of all sizes had greatly diminished. Declining angler catch rates with increasing hypoxia has been documented for rainbow trout in several tailwaters (Weithman and Haas 1984; Klein 2003). A substantial decline in electrofishing catch rate of both species in the Lake Cumberland tailwater was observed in autumn 2003. Electrofishing catch rates in autumn 2004 remained low for both brown and rainbow trout. During these two years, it was suspected that a substantial portion of both trout populations had either moved downstream of our sampling sites or into tributaries seeking more preferred DO levels. Trout moving into either area would have mostly gone unnoticed by anglers as these areas have much lower fishing pressure. Elliott (2000) found that brown trout would show a preference for higher oxygen concentration as long as the water temperature remained below the incipient lethal value around 25º C. Research on both adult brown trout (Heggenes 1988) and rainbow trout (Gido et al. 2000) has shown that large spikes in discharge do not result in long-distance displacement of fish downstream. Other unknown factors may be responsible for the reduced angler and electrofishing catch rates in the Lake Cumberland tailwater. However, after water quality conditions improved in 2005, electrofishing catch rates of large (381 mm and greater) brown and rainbow trout improved immediately, indicating that these fish must have been present in 2003 and 2004 but were not sampled. Although the two trout populations were regulated differently, the fact that there were similar declines in electrofishing and angler's catch rates of each trout species in the Lake Cumberland tailwater followed by a rebound, further support the explanation that the observed declines were related to environmental factors. The less-than-ideal environmental conditions associated with increased levels of dam discharge in some years were also negatively correlated with both brown trout growth rate and condition. Theoretically, if it were not for the reductions in growth and condition during 2003 and 2004, the brown trout population in the Lake Cumberland tailwater may have shown an even stronger positive response to the trophy regulations.

Beginning 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. Effective 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 may improve and have the potential of supporting a greater stocking rate of brown trout and a greater potential for increased numbers of quality (381-507 mm) and trophy size (≥508 mm) fish without negatively affecting growth or condition, assuming the threshold has not been reached where other density dependent factors (e.g., prey abundance) will affect fish health and growth.

The results of the current research have shown 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 is 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. Rigorous evaluations, as outlined by Wilde (1997) and Allen and Pine (2000), of singly imposed regulations are still needed. We suggest that density-dependent limitations on growth and condition were not observed because increases in brown trout density, subsequent 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 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).

The brown trout is especially well-suited for use in the development of trophy trout fisheries in similar modified river habitats because of its rapid growth to large sizes, ability to tolerate warmer water and lower susceptibility to angling increases long-term survival. This research demonstrates that a high minimum size limit and very restrictive creel limit can result in an increase in quality and trophy sizes of brown trout. The concept of severely limiting harvest to provide a trophy fishery for one trout species, while managing an additional salmonid species for a more harvest-oriented fishery is unique. This strategy of partitioning the trout fishery caters to the desires of various resource users and should allow for wider angler acceptance of restrictive limits. While acknowledging that regulation complexity can be of concern, we recommend fisheries managers consider the use of similar variable salmonid management strategies where two or more species cohabitate.

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Table 1. Catchable-size brown and rainbow trout annual stocking numbers and locations in the Lake Cumberland tailwater from 1995 to 2006.

Stocking site	River kilometer	Year											
		1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
		Brown Trout											
Dam	0.0	2,984	0	0	0	0	0	0	0	0	0	0	0
Indian Creek	3.2	3,152	6,000	0	0	0	0	0	0	0	0	0	0
Helm's Landing	7.2	7,506	7,000	3,000	6,500	7,407	3,006	3,050	3,000	3,000	3,000	3,500	3,000
Winfrey's Ferry	25.3	6,959	7,000	9,000	8,985	7,407	9,018	8,930	9,000	9,000	9,000	9,000	9,000
Crocus Creek	41.4	5,053	5,000	9,000	6,150	5,752	9,018	8,930	9,300	9,000	9,000	9,000	9,000
Burkesville Ramp	53.9	4,506	5,000	9,000	6,345	5,752	5,010	5,010	5,300	5,000	5,000	5,000	5,000
Hwy. 61 Ramp	61.6	0	0	5,000	1,237	5,752	4,008	4,030	4,100	4,000	4,000	4,000	6,700
Total		30,160	30,000	35,000	29,217	32,070	30,060	29,950	30,700	30,000	30,000	30,500	32,700
		Rainbow Trout											
Dam	0.0				73,700	50,050	66,300	72,000	72,000	69,000	63,000	68,300	71,000
Helm's Landing	7.2	70,990	78,841	104,500	12,000	10,500	16,500	17,000	17,500	17,500	20,500	17,500	18,500
Winfrey's Ferry	25.3				12,000	9,000	16,500	17,000	12,500	21,500	20,500	17,500	18,500
Crocus Creek	41.4				14,000	9,000	14,000	14,500	18,000	16,000	19,000	16,000	16,000
Burkesville Ramp	53.9	7,160	22,250	40,250	12,000	29,500	14,000	14,500	17,500	14,000	14,000	14,000	14,000
Hwy. 61 Ramp	61.6				8,000	6,000	8,500	8,000	8,000	8,000	8,000	8,000	8,000
Total		78,150	101,091	144,750	131,700	114,050	135,800	143,000	145,500	146,000	145,000	141,300	146,000

Table 2. Mean relative weights (Wr) of various sizes of brown trout in the Lake Cumberland tailwater from 2000 to 2006. Different letters within columns indicate significant differences among years at an α level of 0.10.

Year	All Sizes	8.0-14.9 in	15.0-19.9 in	≥ 20.0 in
2000	103 v	102 w	107 v,w	103 z
2001	107 u	105 v	109 v	109 y,z
2002	100 x	98 x	101 y	115 y
2003	91 z	88 z	96 z	104 y,z
2004	96 y	91 y	105 w,x	103 y,z
2005	101 w,x	100 w,x	102 x,y	105 z
2006	102 v,w	101 w	102 x,y	106 y,z

Table 3. Comparison of statistics derived from daytime creel surveys on Lake Cumberland tailwater during 1995, 2002, and 2006.

	1995		2002		2006	
	Brown Trout	Rainbow Trout	Brown Trout	Rainbow Trout	Brown Trout	Rainbow Trout
Harvest						
Number of fish harvested	13,023	48,029	663	184,745	2,087	120,364
Fish/hour	0.048	0.18	0.001	0.34	0.005	0.30
Fish/rkm	211	780	11	2,999	34	1,954
Catch						
Number of fish caught	29,221	63,651	108,102	310,331	48,504	257,137
Fish/hour	0.11	0.24	0.20	0.58	0.12	0.63
Fish/rkm	474	1,033	1,755	5,038	787	4,174
Fishing pressure (all species)						
Effort directed at trout (%)	91		96		94	
Total (man-hours)	269,123		539,034		405,754	
Man hours/rkm	4,369		8,751		6,587	
Catch-and-release rate (%)	55.4%	24.5%	99.4%	40.5%	95.7%	53.2%
Size structure (%)						
381 mm and greater	5.0	2.7	23.9	8.7	29.2	12.7
508 mm and greater	0.2	0.3	1.6	0.4	2.7	0.7

Table 4. Length distribution comparisons of both 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)

		25 mm class																							
Year		102	127	152	178	203	229	254	279	305	330	356	381	406	432	457	483	508	533	559	584	610	660	762	838	Total
1995	Harvested					32	62	73	25	8	2	5	3	3	2	5	3		1							224
	Released			6	13	28	40	67	22	27	2	4	2	2			1									214
	Total			6	13	60	102	140	47	35	4	9	5	5	2	5	4		1							438
2002	Harvested							1		1		2		1			1		1	1		3		2		13
	Released	1	1	9	15	101	86	288	53	209	82	203	123	101	42	29	12	8	2	4		1				1370
	Total	1	1	9	15	101	86	289	53	210	82	205	123	102	42	29	13	8	3	5		4		2		1383
2006	Harvested						1			1		2		1	2			1	1	1			1		1	12
	Released			2	8	30	30	113	25	105	74	84	50	54	36	25	10	4	2	4	3					659
	Total			2	8	30	31	113	25	106	74	86	50	55	38	25	10	5	3	5	3		1		1	671

Table 5. Length distribution comparisons of both harvested and released rainbow trout in the Lake Cumberland tailwater creel surveys during 1995, 2002, and 2006. (Lengths for released fish were as reported by angler)

Year		25 mm Class																							
		76	102	127	152	178	203	229	254	279	305	330	356	381	406	432	457	483	508	533	559	584	610	660	Total
1995	Harvested				1	1	76	311	373	221	137	45	26	15	9	4		2	3	1					1225
	Released				2	10	47	31	93	76	52	16	12		4	3	1								347
	Total				3	11	123	342	466	297	189	61	38	15	13	7	1	2	3	1					1572
2002	Harvested				5	18	135	363	802	852	722	296	295	138	84	68	35	16	7	2	1				3839
	Released	3	1	8	68	53	266	230	575	161	547	115	227	50	73	28	28	3	9	1	5	1	1		2453
	Total	3	1	8	73	71	401	593	1377	1013	1269	411	522	188	157	96	63	19	16	3	6	1	1		6292
2006	Harvested						26	149	454	553	596	304	160	25	8	3	5	3	4	2	1				2293
	Released			4	22	20	97	101	371	142	448	151	180	150	135	64	91	37	15	5		2		1	2036
	Total			4	22	20	123	250	825	695	1044	455	340	175	143	67	96	40	19	7	1	2		1	4329

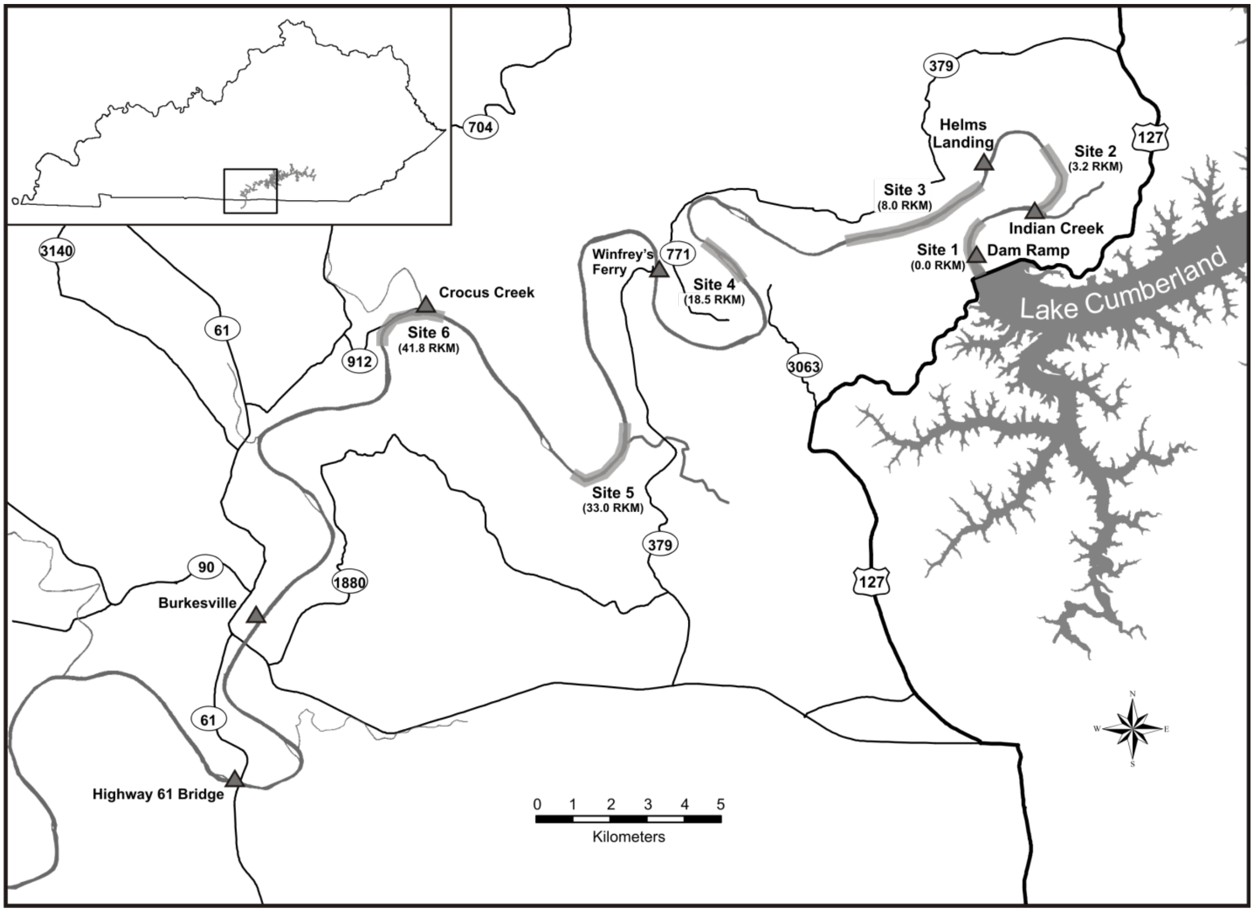

Figure 1. Map depicting the location of Lake Cumberland in south central Kentucky (inset) and the Cumberland River below Wolf Creek Dam. Solid triangles represent the trout stocking sites. The six standardized autumn sampling sites are shaded with Site 1 being the uppermost site. The approximate river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

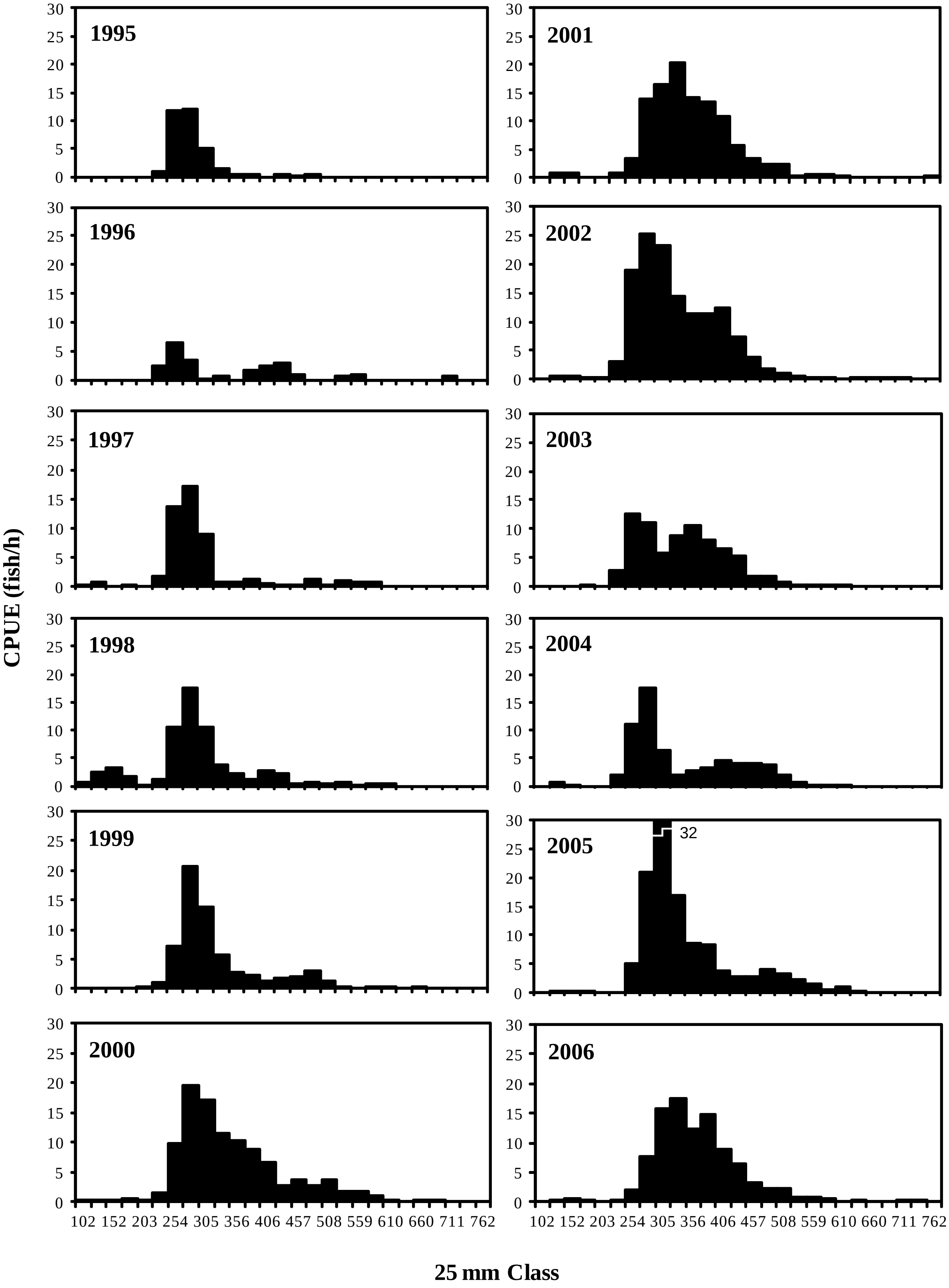

Figure 2. Autumn electrofishing mean relative abundance of brown trout by 25-mm class in the Lake Cumberland tailwater from 1995 to 2006. The trophy regulations were implemented in 1997.

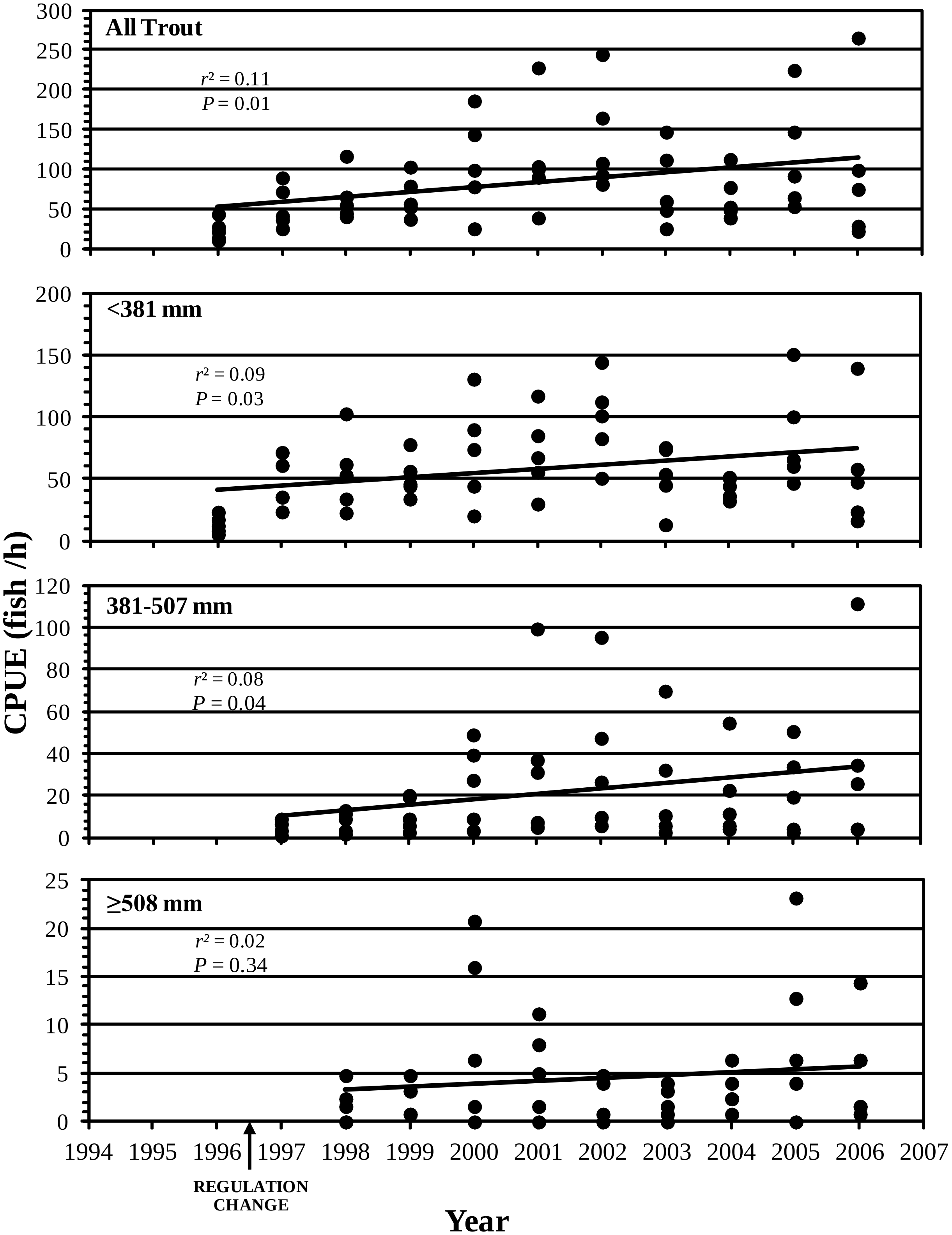

Figure 3. Trends in autumn electrofishing catch per unit effort (CPUE) of brown trout in the Lake Cumberland tailwater. Note y-axis scale changes. (All Trout and <381 mm: 1996-2006; 381-507 mm: 1997-2006; ≥508 mm: 1998-2006.)

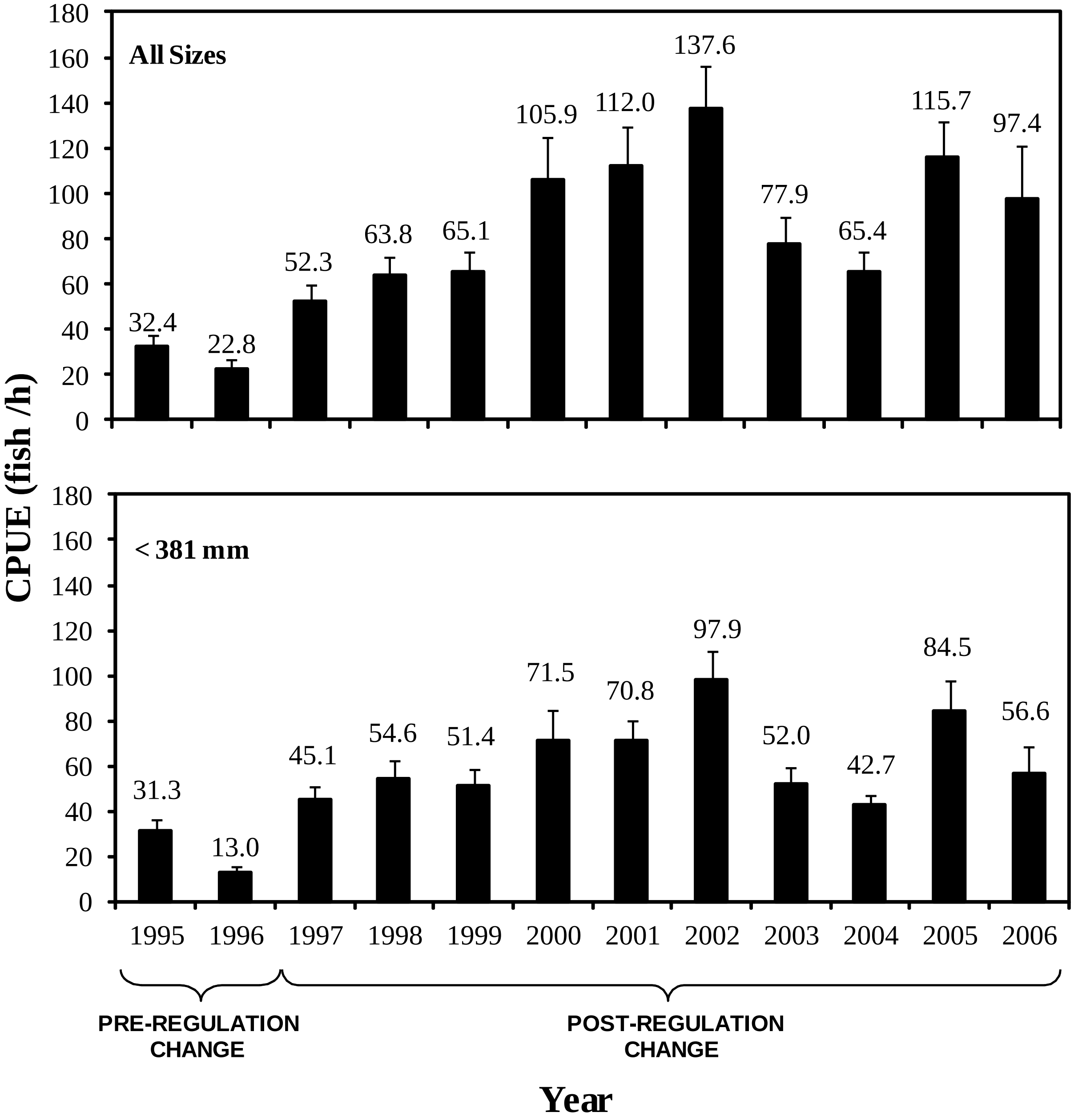

Figure 4. Autumn electrofishing mean relative abundance (fish/h) of all sizes of brown trout and <381 mm brown trout in the Lake Cumberland tailwater from 1995 to 2006. Error bars represent the standard error.

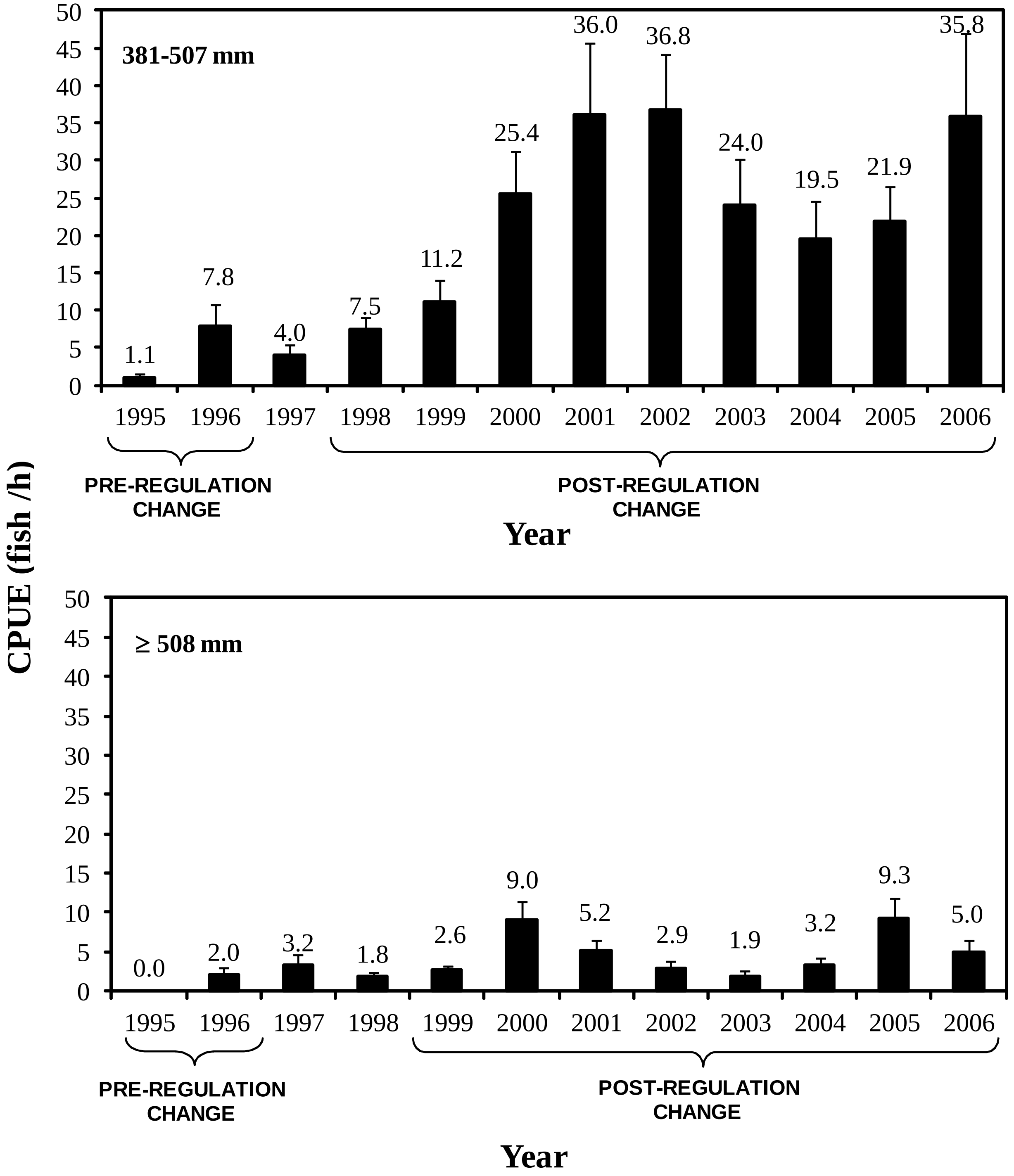

Figure 5. Autumn electrofishing mean relative abundance (fish/h) of 381-507 mm and ≥508 mm brown trout in the Lake Cumberland tailwater from 1995 to 2006. Error bars represent the standard error.

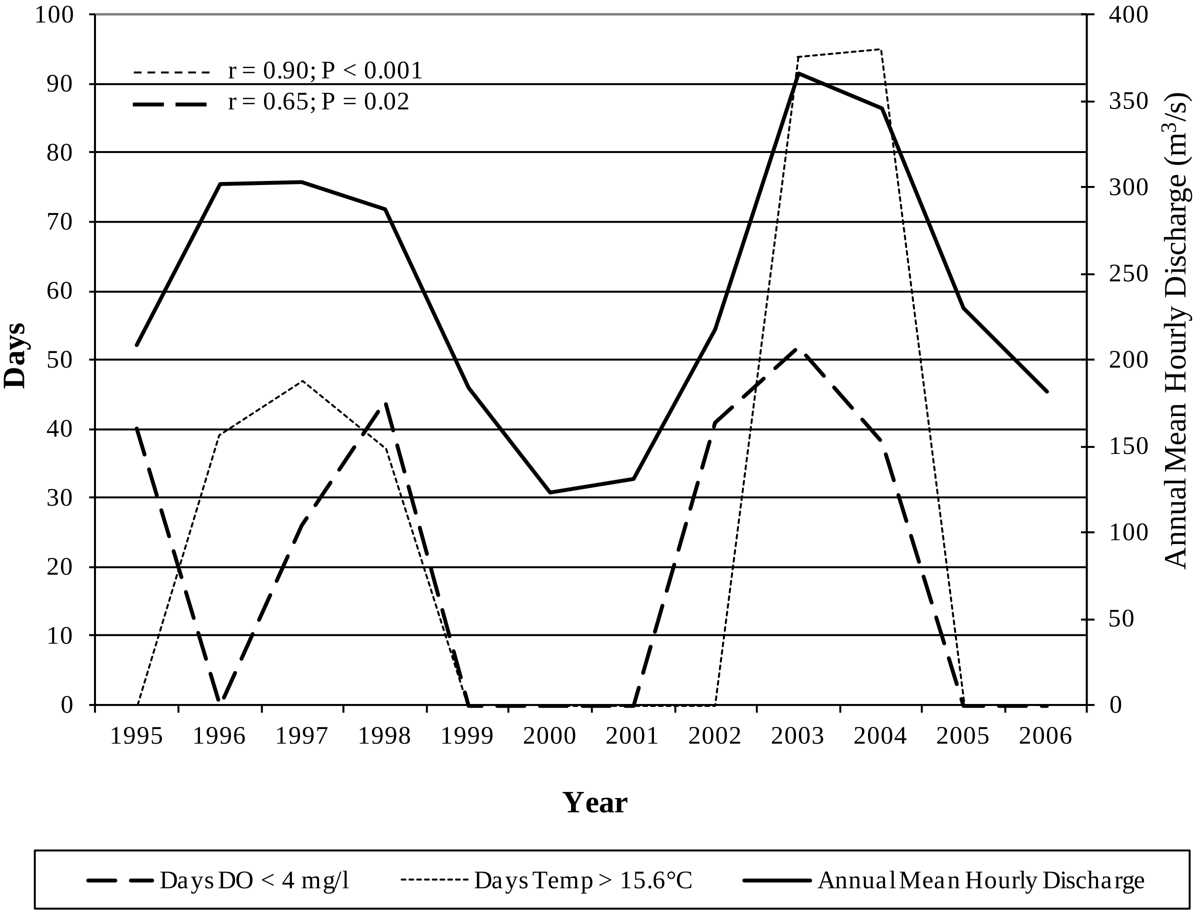

Figure 6. Number of days each year of dissolved oxygen (DO) levels below 4 mg/l and water temperature above 15.6º C measured in the Lake Cumberland tailwater near Wolf Creek Dam and relationship with annual mean hourly discharge from Wolf Creek Dam from 1995-2006.

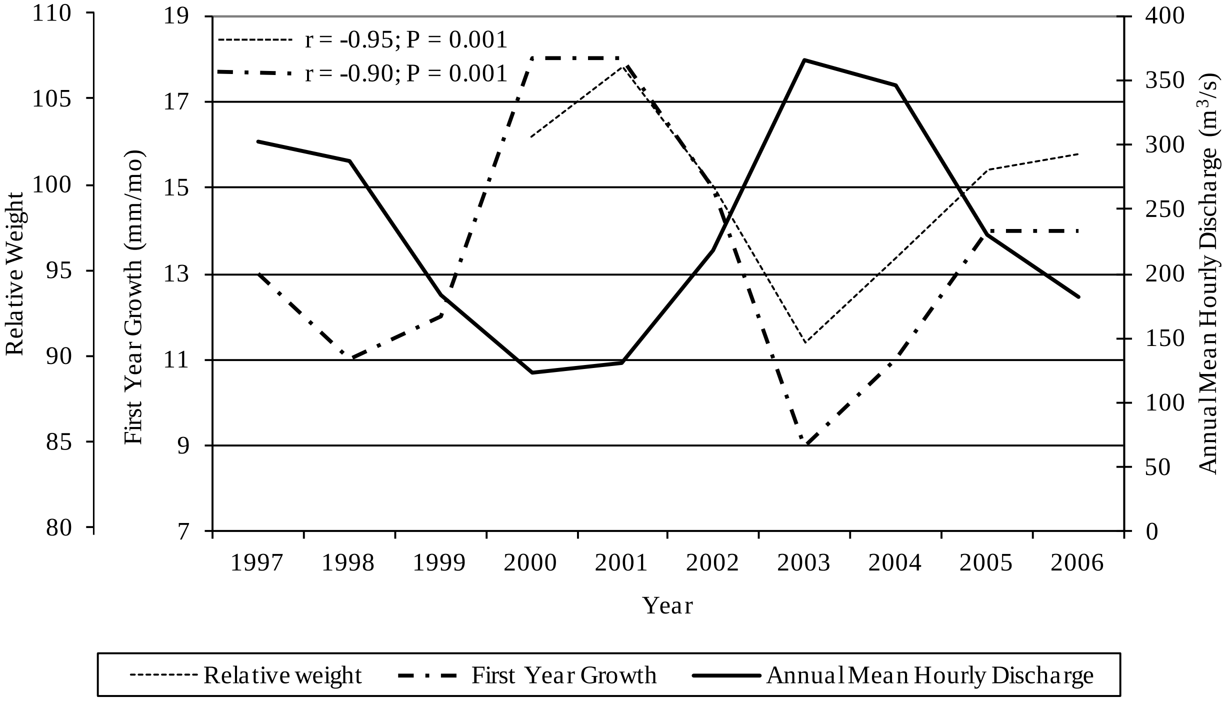

Figure 7. Brown trout mean relative weight collected in autumn sampling and catchable-size brown trout first year growth after stocking in the Lake Cumberland tailwater and their correlation with annual mean hourly discharge from Wolf Creek Dam from 2000-2006.

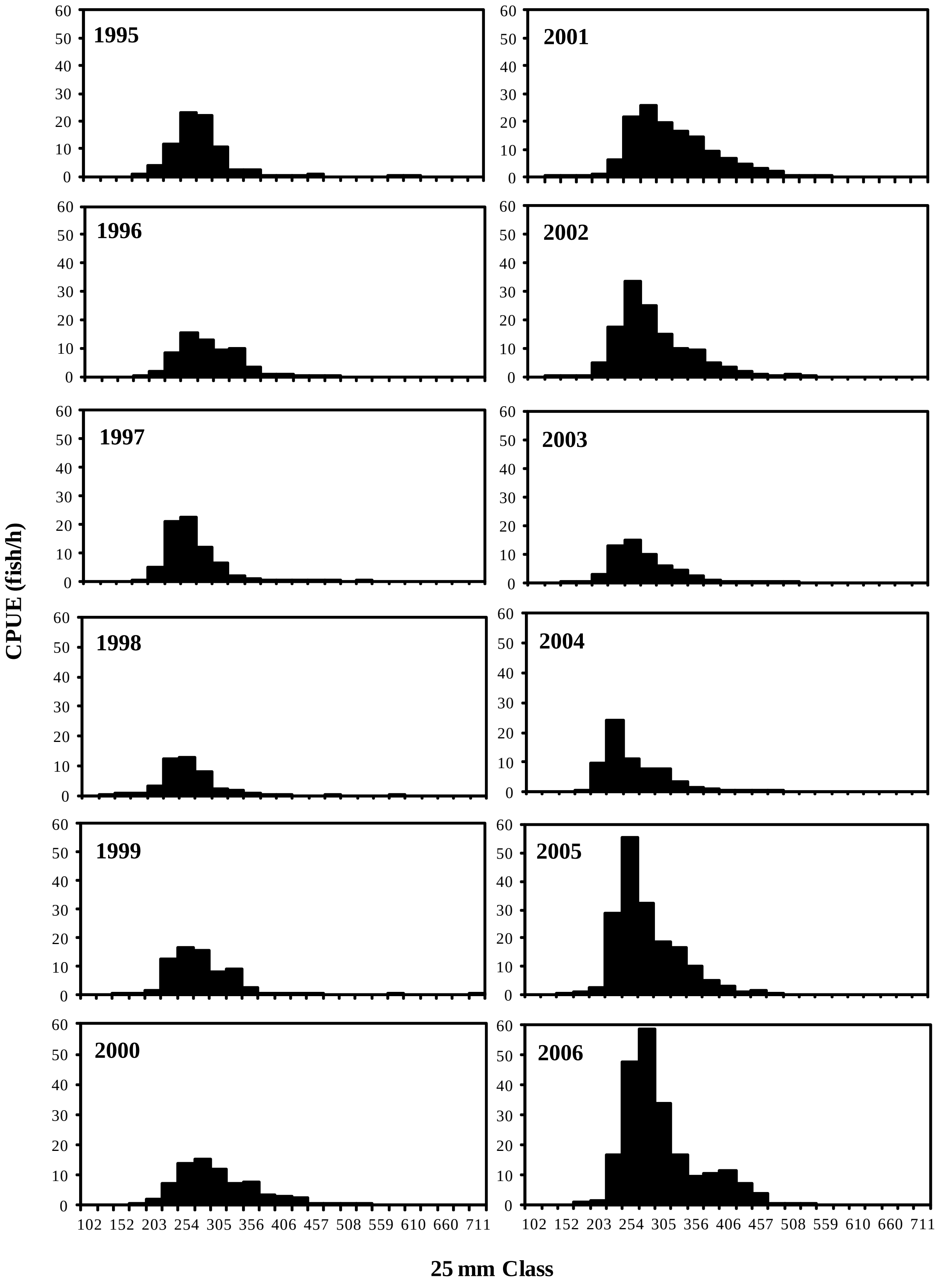

Figure 8. Autumn electrofishing mean relative abundance of rainbow trout by 25-mm class in the Lake Cumberland tailwater from 1995 to 2006. In 2004, the creel limit was reduced to 5 fish and a 381-508 mm protective slot limit was implemented with only one fish over 508 mm.