Trout Growth and Mortality Following Water Quality and Flow Improvements on the Lower Saluda River in South Carolina

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Abstract: The lower Saluda River (LSR) supports a coldwater, put-grow-and-take trout fishery due to hypolimnetic releases from the Saluda Hydroelectric Project. The LSR has historically been noted for low flows (5.1 m^3 sec^{-1}) transitioning abruptly to peaking flows up to 509.7 m^3 sec^{-1} with seasonally hypoxic water. Recent relicensing resulted in changes in the Saluda Hydroelectric Project operation that were intended to improve habitat conditions downstream. In a multi-year study, a combination of tagging and boat electrofishing was used to evaluate mortality, growth, and angler catch and exploitation rates of catchable rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*) stocked into the LSR. Each year electrofishing catch rates and angler tag returns of December-stocked catchable-sized trout peaked in December shortly after stocking and declined rapidly in subsequent months. More than half of the angler tag returns were reported from the uppermost reach of the river that contained most of the angler access. Mean annual mortality of stocked rainbow trout and brown trout was high (>95%), but harvest rates were low (<9%) for both species, indicating natural or post-stocking mortality was more influential than fishing mortality. Mean annual angler catch rates were poor, with only 13% of stocked rainbow trout and 4% of brown trout caught by anglers. Despite the poor survival of stocked trout, quality trout habitat was demonstrated by the presence of large rainbow trout (2.6 kg) and brown trout (3.1 kg), excellent (>17 mm mo^{-1}) growth rates for both species, and the presence of small rainbow trout that were assumed to be wild. Because of these findings, several changes were made to the management of the fishery. A modification to the five-fish creel limit, whereby only one trout over 40.64 cm can be harvested as one of the five, was made to reduce exploitation of holdover fish. A 4-km catch-and-release-only zone was also established to serve as a nursery for young-of-the-year fish and provide additional protection for the holdover population.

Key words: tagging, electrofishing, flows, natural reproduction, tailrace

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The Lower Saluda River (LSR), a State Scenic River in South Carolina, supports a coldwater put-grow-and-take trout fishery due to hypolimnetic releases from the Saluda Hydroelectric Project at Lake Murray Dam. The river supports a highly valued urban fishery with opportunities for catching a variety of recreational species including rainbow trout (*Oncorhynchus mykiss*), brown trout (*Salmo trutta*), largemouth bass (*Micropterus salmoides*) and smallmouth bass (*Micropterus dolomieu*), striped bass (*Morone saxatilis*), and panfish (Fishery Information Management Systems 1997). A trout stocking program began in 1959 with 170- to 200-mm rainbow trout stocked from April through June. In the mid-1980s, sub-adult brown trout stocking was initiated during fall. Since then the South Carolina Department of Natural Resources (SCDNR) has stocked approximately 15,000 rainbow and 13,000 brown trout each year; however, sampling conducted during the early 2000s found that very few trout carried over into subsequent years and natural reproduction was negligible (Bales et al. 2005). It was speculated that the high mortality had been caused by poor water quality, predation, and angler harvest.

The Saluda Hydroelectric Project on the Saluda River historically operates at very low flows (5.1 m^3 sec^{-1}) that can abruptly transition to peak flows up to 100-fold higher—typically daily—during periods of high energy demand especially during summer (Figure 1). Fluctuating flows coupled with hypolimnetic releases of poor-quality water can reduce growth, increase mortality, and adversely affect natural reproduction of trout (Cushman 1985, Banks and Bettoli 2000, Holbrook and Bettoli 2006). During very low flows, temperatures exceeding 25° C occurred in the most downstream locations of the lower Saluda River (McKellar and Stecker 1988) and may have adversely impacted trout growth and survival over the years. Rainbow trout growth and survival decrease at temperatures more than 22° C (Bear et al. 2007, Hartman and Porto 2014). The upper incipient lethal temperature for rainbow trout is around 26° C (Hokanson et al. 1977, Kaya 1978, Bear et al. 2007) and that of brown trout around 25° C (Elliott 1981).

Dissolved oxygen (DO) in the river below the hydroelectric project was below 5 ppm 77%–97% of the time from August to November and was as low as 1 ppm during high-flow events in summer and fall (McKellar and Stecker 1988). To rectify the low DO discharge, South Carolina Electric and Gas Corporation (SCE&G) installed turbine vents in 1999 and hub baffles in 2005 to increase oxygen saturation in the discharge.

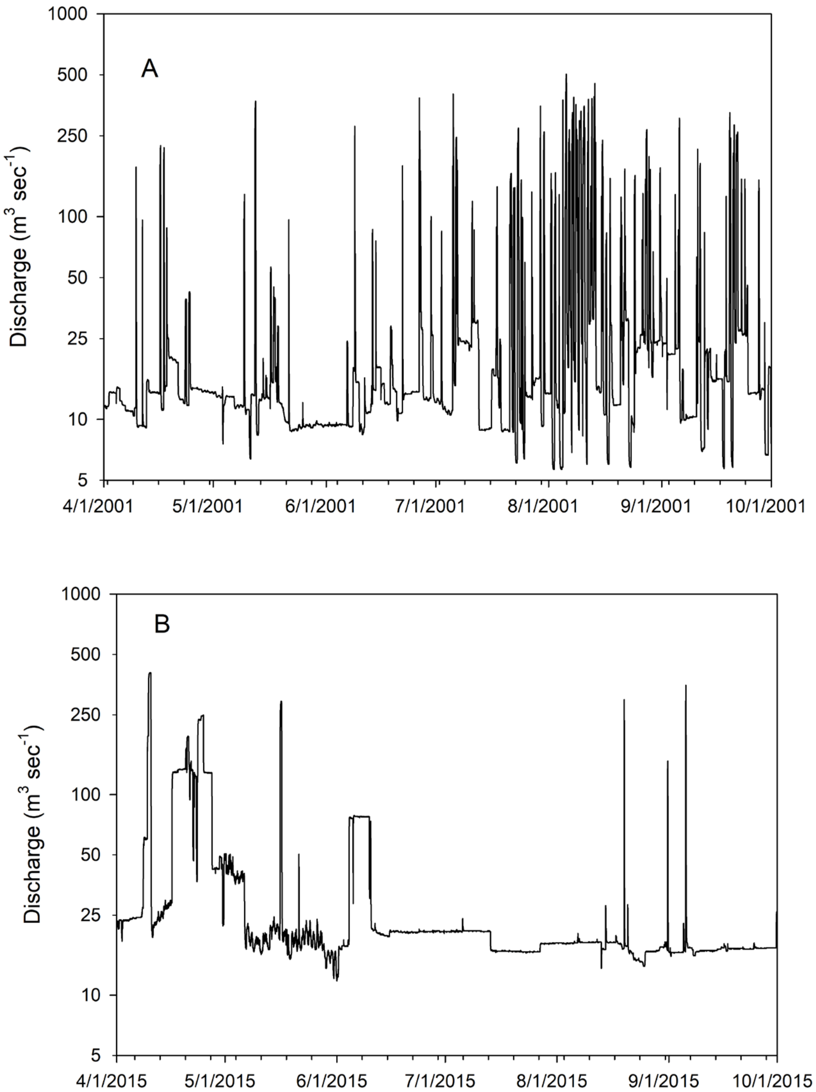

Figure 1. Discharge (m^3 sec^{-1}) in the Lower Saluda River below Lake Murray Dam (U.S. Geological Survey gage #2168504) showing flow characteristics in the Lower Saluda River before (Panel A) and after (Panel B) a new flow program was initiated with the filing of a settlement agreement in 2009.

The recent relicensing of the Saluda Hydroelectric Project (FERC NO. 516; Federal Energy Regulatory Commission 2010) resulted in dramatic changes in the operation of the facility. The power plant is no longer an energy peaking provider, but operates in a reserve capacity, meaning that generation at or near full capacity will only occur during flooding events or when there is a sudden outage in the power grid. A flow program for the Saluda Hydroelectric Project was initiated with the filing of a settlement agreement in 2009 that established minimum environmental flows. Minimum environmental flows were implemented based on an instream flow incremental methodology study using trout as one of the primary target species (Kleinschmidt Associates 2008). The recommended and adopted minimum flows were 28.3 m^3 sec^{-1} during the months of April and May and 19.8 m^3 sec^{-1} from June to March (SCE&G 2009). Prior to the initiation of this flow program, the licensed minimum flow was equivalent to dam leakage (5.1 m^3 sec^{-1}; Figure 1). The new flow program will ensure that the amount of useable habitat for trout would increase and be maintained (Kleinschmidt Associates 2008). These operational changes will ensure that adequate water is available to sustain aquatic habitats by maintaining flow needs and reduce the incidence of high flows in LSR. In other tailraces, studies have shown that increasing minimum flows has correspondingly resulted in increased macroinvertebrate abundance and diversity, improved fish condition, and enhanced conditions for trout reproduction (Weisburg and Burton 1993, Bettoli et al. 1999).

This study was designed to inform fishery management decisions by assessing the trout population in the Lower Saluda River after the onset of environmental improvements. The study objectives were to 1) estimate size structure and condition of rainbow trout and brown trout populations, 2) estimate first-year mortality and growth of stocked catchable-sized trout, and 3) estimate angler catch and exploitation rates of stocked-catchable trout.

Study Area

The LSR is a 16-km tailwater of the Saluda River from the Lake Murray Dam downstream to its confluence with the Broad River. The LSR drains approximately 6527 km^2 (South Carolina Water Resources Commission 1984). Mean annual flow (1989–2018) is 60.6 m^3 sec^{-1} (SE = 30.8) with high flows in excess of 509.7 m^3 sec^{-1} (U.S. Geological Survey [USGS] gage #02168504). At that same gage mean annual water temperatures is 13.7° C (SE = 0.16) and mean annual maximum and minimum temperature is 19.9° C (SE = 0.45) and 8.6° C (SE = 0.22), respectively. Maximum water temperature and minimum DO levels in the LSR just below Lake Murray Dam (USGS gage #02168504) are usually observed between August and October. During those months mean daily maximum water temperature was 17.8° C (SE = 0.05) before the new flow program and 15.9° C (SE = 0.05) after the new flow program. During this study mean daily minimum DO during the months of August, September, and October was 6.5 mg L^{-1} (SE = 0.09), and 91% of daily DO observations ($n = 272$) during those months were 4.0 mg L^{-1} or greater. Before modifications were made to the turbines to improve oxygen saturation, mean daily minimum DO was 1.3 mg L^{-1} (SE = 0.04) and 79% of the observations ($n = 892$) were 2.0 mg L^{-1} or lower. Under flow conditions of 17.0 m^3 sec^{-1} the river comprises 8.5% riffle, 20% run, 59% pool, and 12.5% split channel (Isely et al. 1995). The riparian zone for the entire LSR is mostly forested with a small amount of industrial and residential development.

Methods

Approximately 4000 rainbow trout (200 to 250 mm TL) and 13,000 brown trout (130 to 180 mm TL) were stocked in the second or third week of December for three consecutive years starting in 2012. Each of those stockings included approximately 3000 tagged rainbow trout and 2000 tagged brown trout. All rainbow trout stocked during December received an adipose fin clip to distinguish them from 11,000 additional rainbow trout stocked in subsequent months. All fish were stocked by helicopter at multiple locations on a single day. Trout were produced and tagged at the Walhalla State Fish Hatchery in South Carolina.

The tagging process involved 1) anesthetizing the fish with tricaine methanesulfonate (MS-222); 2) inserting a t-bar anchor tag (model FD-68B fine fabric, Floy Tag, Seattle, Washington), color coded for each year, at the posterior base of the dorsal fin; 3) clipping the adipose fin (rainbow trout only); and 4) returning the fish to a raceway 21 days post-MS-222 exposure. One third of the tagged trout were double tagged to estimate tag retention (Pine et al. 2012). Each tag was printed with an identification number and the SCDNR website address.

Anglers were informed of the tagging study by posters on kiosks at the upper (Saluda Shoals Park near dam), middle (Gardendale Landing just above I-26 Bridge), and lower (Columbia Riverwalk just below the Broad River confluence) reaches of the river (Figure 2) and via a website that explained the tagging program with instructions on what to do if a tagged fish was caught. Tag return drop boxes placed at four access locations contained pre-addressed tag return envelopes. Anglers were asked to place the clipped tag in the envelope, complete the information form on the envelope, and return it to SCDNR via the drop box or U.S. Postal Service. An online service containing an interactive data sheet that could be filled out and emailed directly or printed and mailed was also available. Anglers were asked to provide the general location of where the tagged fish was caught. These locations were assigned to four reaches based on proximity to the dam and other major landmarks (Figure 2). We encouraged anglers to record, measure, and photograph fish that were released, leaving the tag(s) attached. The Saluda River Chapter of Trout Unlimited assisted with fish tagging and provided rewards in the form of hats for participating anglers and entry into a lottery for lifetime fishing licenses, one for each year of the study.

Daily catch (C) and exploitation (μ for each cohort of stocked catchable rainbow trout and brown trout was calculated as

$$C(\mu) = \frac{(N_c)(N_h)}{[(N_t)(1-P_{nr})(1-P_t)]}$$

where N_c = number of tagged fish that were reported as caught by anglers, N_h = number of tagged fish that were reported as harvested by anglers, N_t = number of tagged fish at large, P_{nr} = angler nonreporting rate, and P_t = daily tag loss rate. Annual estimates of C and μ were calculated by summing the daily estimates for the first 365 days post stocking for each cohort stocked. Because all fish were stocked alive roughly 21 days post tagging no corrections were made for tagging mortality. Angler nonreporting rate was determined based on the proportion of tagged fish observed in anglers' creels during a concurrent creel survey that were not reported to the tagging program. Tag loss rate was estimated using a logistic model from the number of double-tagged fish that had a single tag when they were recaptured and returned by anglers or observed in field collections:

$$P_t = 1 - \frac{e^{(b_1 * \log_e d + b_0)}}{1 + e^{(b_1 * \log_e d + b_0)}}$$

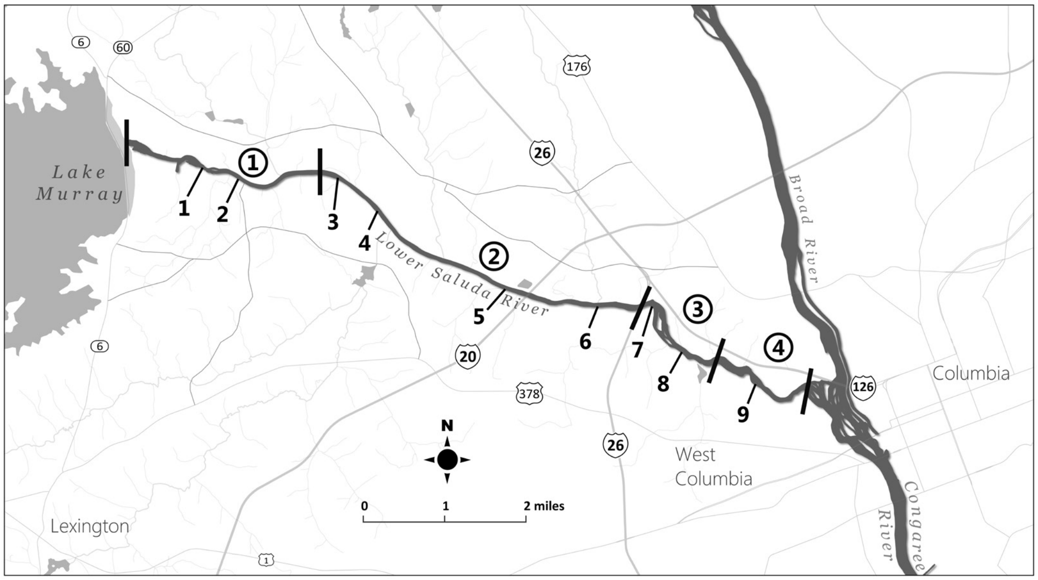

Figure 2. Four sample reaches and nine fixed trout collection sites sampled by boat electrofishing in the Lower Saluda River from December 2012 through October 2015.

where P_t = probability of tag loss, b_1 = parameter estimate, d = days between stocking and recapture, and b_0 = y-intercept estimate (Miranda et al. 2002). Due to the limited number of observations during some years all years were pooled to create two tag loss models, one for each species.

Boat electrofishing was conducted at nine fixed sample locations between river kms 1.5 and 13 (Figure 2). Dissolved oxygen, water temperature, conductivity, and turbidity (YSI 85, Yellow Springs Instruments, Yellow Springs, Ohio, and La Motte 2020e, LaMotte Co., Chestertown, Maryland) were recorded with each sample. Sampling was initiated within one week after stocking and repeated monthly through April and bi-monthly June through October. Trout were sampled during the day when flows were below 85 m^3 sec^{-1}. The electrofishing gear consisted of a 2700-W generator, GPP 2.5 electrofishing unit (Smith-Root, Inc., Vancouver, Washington) and boom-mounted steel cable electrodes on a 4.88-m, tunnel-hull, aluminum boat. Frequency was set at 60 pulses per second with a maximum generator output of 4.5 A. Each sample was conducted for 20 min (electrofishing pedal down time), and captured trout were placed in a circular oxygenated live-well until the sample was completed. Trout were inspected for tags, examined for an adipose fin clip, measured (TL, mm), weighed (g), and released.

Electrofishing CPUE (trout h^{-1}) pooled across sites and sample dates was calculated for stocked cohorts during their first year after release and for all trout captured. Relative weight (*Wr*) was determined for rainbow trout and brown trout using the standard weight (lotic populations) and relative weight equations presented in Neumann et al. (2012). Comparisons of *Wr* among years and proportional size distribution (PSD) size classes pooled across years were made with Kruskal-Wallis tests. We used the Dwass-Steel-Critchlow-Fligner (DSCF) multiple comparison analysis to determine significant differences between years and PSD size classes (SAS Institute 2013).

Survival of each cohort of tagged and/or clipped rainbow trout and brown trout during their first year was estimated by regressing $\log_e$-transformed monthly electrofishing catch versus months post stocking (Miranda and Bettoli 2007). The slope of each linear regression was used as an estimate of instantaneous monthly mortality (Z). Annual survival (S) for each cohort was calculated as the antilog of the product of Z and 12 (i.e., months). Because brown trout and tagged and clipped rainbow trout were stocked on the same day each December, capture numbers from January through October were used to estimate survival. Holdover trout from previous years' stockings were identified based on their longer lengths (≥330 mm TL and ≥390 mm for brown trout and rainbow trout, respectively) and were omitted from the catch curve analysis.

Initial examination of stocked rainbow trout and brown trout growth during their first year post-stocking appeared to be linear, so first year growth of each cohort was estimated with linear regression of total length (TL) against days post-stocking. Analysis of covariance (ANCOVA) was used to determine if the growth of catchable-sized rainbow trout and brown trout stocked during December of each year differed among years (SAS Institute 2013). Only fish collected within 300 days post-stocking were used in the analysis. During 2014 and 2015, rainbow trout well below stock size (200–250 mm TL) were captured by electrofishing; they were considered to be wild (i.e., naturally produced) fish and therefore were not included in our analysis

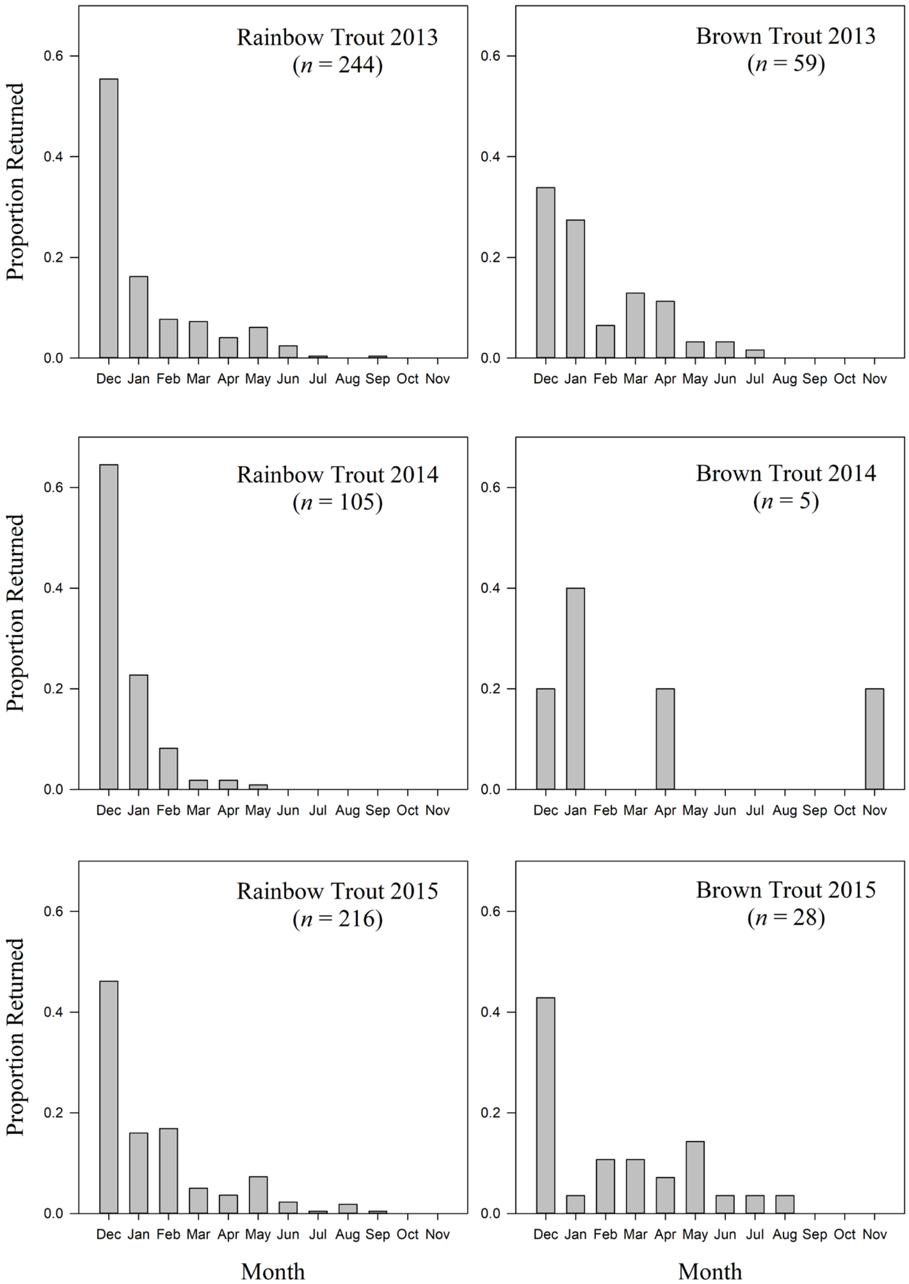

Figure 3. Proportion of rainbow trout and brown trout tags returned by anglers each month for each cohort stocked into the Lower Saluda River, South Carolina, during 2013–2015.

Results

A total of 692 hatchery-tagged fish were reported by anglers, of which 593 (86%) were rainbow trout and 99 (14%) were brown trout; 320 (46%) were from the 2012 stocking, 119 (17%) from the 2013 stocking, and 253 (37%) from the 2014 stocking. Nearly half were reported shortly after stocking with a sharp drop off in the following months (Figure 3). Tag returns declined as distance from Lake Murray Dam increased, with more than half of the tag returns reported from Reach 1 and only 2% from Reach 4 (Table 1). Anglers reported 386 (60%) tagged trout were released and 254 (40%) were harvested; 75% of brown trout and 57% of rainbow trout were released.

The estimated non-reporting rate was 31%, based on 10 of 32 tagged trout in angler creels that were not reported. There was a significant effect of time (days post-stocking) on tag loss for rainbow trout ($X^2 = 13.45$, df = 1, $P < 0.01$) and brown trout ($X^2 = 5.15$, df = 1, $P = 0.02$). The parameter estimates were $b_1 = -0.503$ (SE = 0.137) and $b_0 = 2.62$ (SE = 0.489) for rainbow trout and $b_1 = -0.689$ (SE = 0.303)

Table 1. A comparison of tag return numbers and percent of total for both rainbow (RBT) and brown (BNT) trout by river reach based on capture locations reported by anglers.

	n	Reach 1	Reach 2	Reach 3	Reach 4
All trout	683	64	20	14	2
BNT	76	83	14	3	0
RBT	607	61	21	15	2

Table 2. First year catch (*C*) and exploitation rates (μ) for three cohorts of catchable-size rainbow trout and brown trout stocked into the Lower Saluda River, South Carolina.

	Rainbow trout		Brown trout	
Year	C (%)	μ (%)	C (%)	μ (%)
2013	17.1	8.7	6.9	1.5
2014	6.7	2.5	0.7	0.3
2015	15.9	6.0	3.6	0.9
Mean	13.3	5.8	3.8	0.9

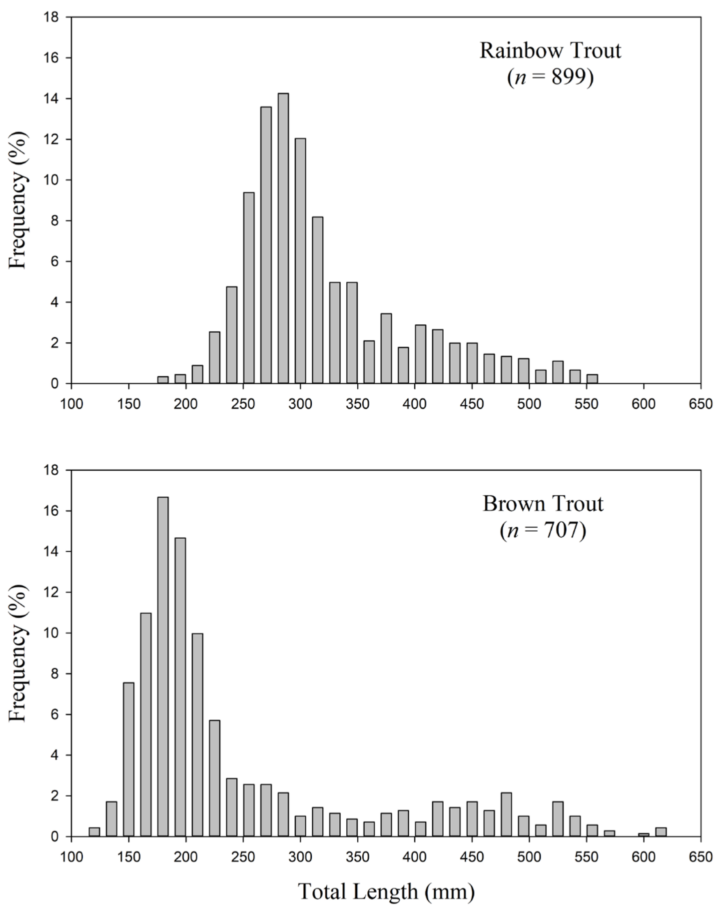

Figure 4. Length frequency of rainbow trout and brown trout captured from the Lower Saluda River, South Carolina, with boat electrofishing between December 2012 and October 2015.

and $b_0 = 3.24$ (SE = 1.281) for brown trout. Thirty days post stocking tag loss was similar with both species losing roughly 30% of their tags; however, over time brown trout tag retention was lower than rainbow trout. After 365 days the models predicted that 59% of rainbow trout and 69% of brown trout lost their tag. Angler catch rates ranged annually from 6.7% to 17.1% (mean = 13.3%) for rainbow trout and from 0.7% to 6.9% (mean = 3.8%) for brown trout (Table 2). Exploitation rates ranged annually from 2.5% to 8.7% (mean = 5.8%) for rainbow trout and from 0.3% to 1.5% (mean = 0.9%) for brown trout (Table 2).

Mean monthly water temperature ranged from 9.4° to 18.0° C and mean monthly turbidity ranged from 0.2 to 6.6 nephelometric turbidity units. Mean DO recorded from December 2012 to October 2015 was 9.4 mg L^{-1}, with the lowest DO recorded (4.7 mg L^{-1}) at the most downstream samples (sites 6, 7, 8, and 9). The highest daily average DO (12.3 mg L^{-1}) occurred on sampling days in December 2012 and January 2013. The lowest daily average DO (5.7 mg L^{-1}) occurred on sampling days in October 2015. The conductivity for all samples averaged 79.3 μmho cm^{-1} (Range, 55.6 to 98.6 μmho cm^{-1}).

A total of 71.3 h of electrofishing resulted in the capture of 1606 trout: 899 (56%) rainbow trout and 707 (44%) brown trout. Brown trout length ranged from 117 to 610 mm TL with a mean length of 241 mm TL. Brown trout weight ranged from 16 to 3065 g with a mean weight of 305 g. Nine percent of the brown trout captured were within the trophy category (≥460 mm; Figure 4). Rainbow trout length ranged from 174 mm to 555 mm TL with a mean length of 312 mm TL. Sixteen percent reached the quality stock category (≥400 mm) or larger with no memorable (≥650 mm) or trophy (≥800 mm) sized fish (Figure 4). Sixteen percent of the captured trout were considered to be holdovers and 12% were tagged prior to stocking. Mean annual CPUE of all trout was 22.5 trout h^{-1} and ranged from 17.9 to 25.8 trout h^{-1} (Table 3). Mean CPUE of stocked catchable trout during the first year after stocking ranged annually from 7.6 to 14.5 trout h^{-1} for rainbow trout and 6.0 to 10.3 trout h^{-1} for brown trout (Table 3). First-year stocked catchable trout composed more than 70% of the total trout caught. The CPUE for rainbow trout and brown trout were highest in the winter and spring months and lowest in the summer and fall (Figure 5). The CPUE was highest near the dam and lowest at the downstream sites where no brown trout and very few rainbow trout were captured (Figure 6). Most trout were captured in shoal areas where numerous pool, riffle, and run microhabitats occurred.

Pooled across years and PSD size classes, mean *Wr* of rainbow trout and brown trout was 104 (SE = 0.4) and 106 (SE = 0.6), respectively. There were significant differences in *Wr* for brown trout and rainbow trout among years (X^2 range = 105 to 110, df = 2, *P*

Table 3. Mean CPUE (trout h^{-1}) and SE of rainbow trout (RBT) and brown trout (BNT) from three years of boat electrofishing in the Lower Saluda River. First-year trout were hatchery-raised trout that had been in the river less than a year.

	All trout			First year RBT			First year BNT		
Year	***n***	**CPUE**	**SE**	***n***	**CPUE**	**SE**	***n***	**CPUE**	**SE**
2012–13	566	23.9	3.9	230	9.7	1.9	244	10.3	2.7
2013–14	421	17.9	4.6	180	7.6	3.2	142	6.0	1.5
2014–15	619	25.8	5.9	347	14.5	4.1	185	7.9	1.6
All years	1606	22.5	4.4	756	10.6	2.6	571	8.0	2.0

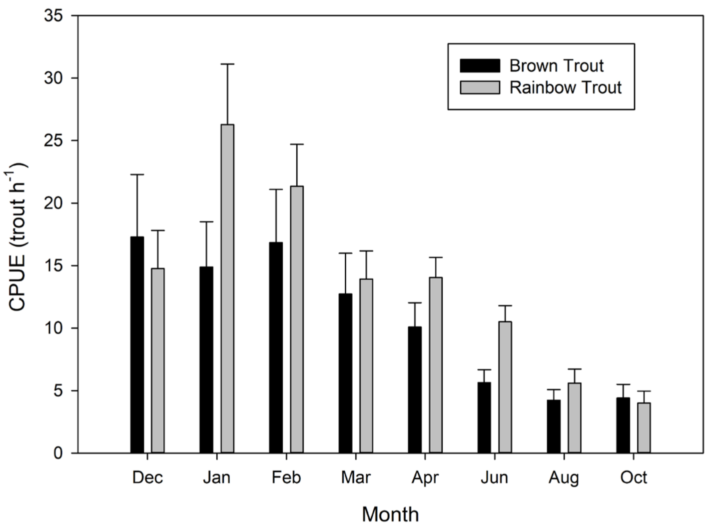

Figure 5. Monthly catch per unit effort (trout h^{-1}) and SEs of rainbow trout and brown trout captured by boat electrofishing between December 2012 and October 2015 from the Lower Saluda River, South Carolina.

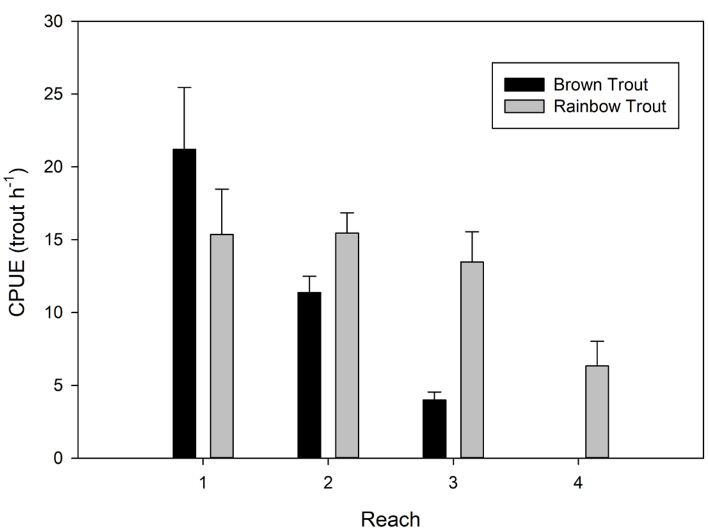

Figure 6. Catch per unit effort (trout h^{-1}) and SEs for rainbow trout and brown trout captured with boat electrofishing from four reaches of the Lower Saluda River between December 2012 and October 2015.

< 0.001). For brown trout, *Wr* during 2013 (mean = 99, SE = 0.8), 2014 (mean = 113, SE = 1.1) and 2015 (mean = 109, SE = 0.9) was significantly different each year (DSCF range = 4.1 to 13.4; $P \leq 0.01$). For rainbow trout, *Wr* during 2013 (mean = 98, SE = 0.7) was significantly lower than during 2014 (mean = 108, SE = 0.9) or 2015 (mean = 106, SE = 0.5) (DSCF range = 12.2 to 12.8; $P \leq 0.01$). Rainbow trout *Wr* appeared to decrease with size but brown trout *Wr* increased with size (Figure 7). When pooled across years, *Wr* differed among PSD size classes for brown trout ($X^2 = 151$, df = 5, $P < 0.001$) and rainbow trout ($X^2 = 9$, df = 3, $P = 0.027$). Brown trout in the "below stock" and "stock" categories were in poorer condition than those in the larger size classes (DSCF range = 5.8 to 11.1; df = 5; $P < 0.001$). There was no difference in the *Wr* of "below stock" and "stock" size classes (DSCF = 2.5; $P = 0.49$) or between the larger PSD size classes (DSCF range = 0.1 to 3.9; $P \geq 0.06$). While the global test for differences in *Wr* among size classes for rainbow trout was significant, there were no pairwise differences detected between size classes (DSCF range = 0.7 to 3.5; $P \geq 0.07$).

The total monthly catch for stocked brown trout ranged from 51 trout captured in March to zero trout captured in October. Catch-curve regressions for the 2013, 2014, and 2015 cohorts resulted in annual survival rates 8% or lower each year (Figure 8) with an average annual survival rate of 4.5% (SE = 2.0%). The total monthly catch for tagged and/or fin clipped rainbow trout ranged from 43 trout in January to zero trout in October. Catch-curve regressions for the 2013, 2014, and 2015 cohorts resulted in annual survival rates 11% or lower each year (Figure 6) with an average annual survival rate of 4.8% (SE = 3.0%).

Growth differed among years for rainbow trout ($F = 6.25$; df = 2, 5; $P = 0.002$) and brown trout ($F = 7.48$; df = 2, 5; $P = 0.001$) (Figure 9). The growth of both trout species was slowest during 2013 with both rainbow trout and brown trout growing approximately 0.52 mm day^{-1}, but during 2014 and 2015 both species grew at least 0.61 mm day^{-1}.

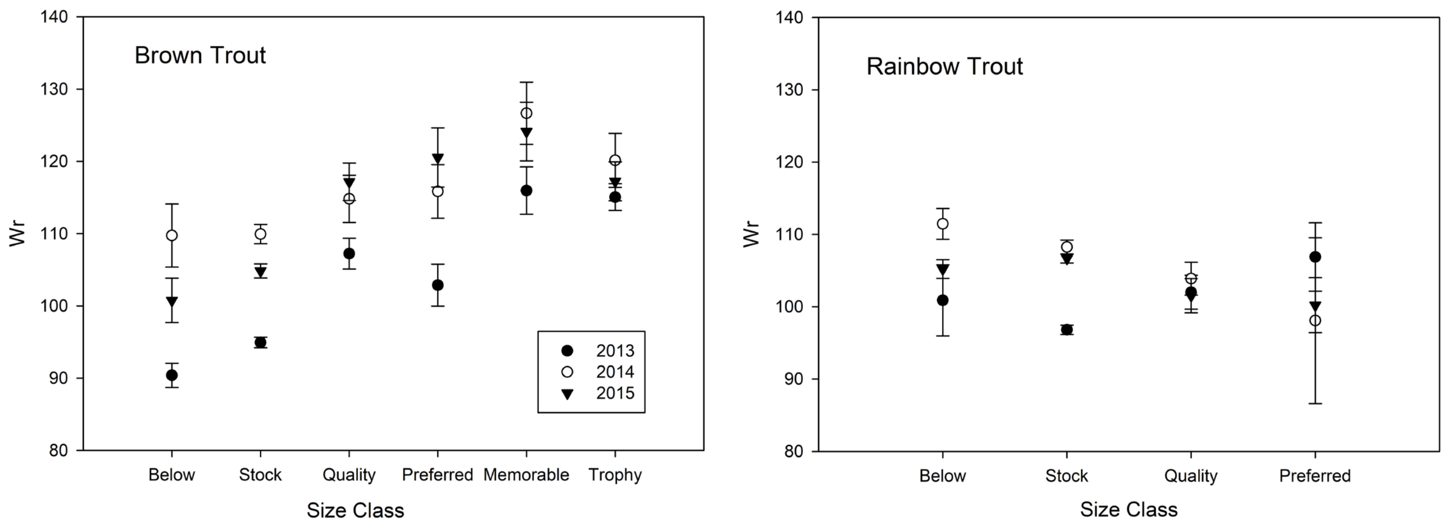

Figure 7. Relative weight (*Wr*) by size class (PSD group) and year for rainbow trout and brown trout caught from the Lower Saluda River from December 2012 through December 2015.

Discussion

The existing LSR trout fishery has been managed by SCDNR since the 1960s using brown trout and rainbow trout. Until recently, little to no holdover of trout occurred due to poor water quality (Bales et al. 2005), but this has improved with the advent of increased minimum flow releases and the installation of turbine vents and hub baffles. For example, water temperatures (8.5° C to 20.1° C) are now well within the suitable range for both rainbow trout and brown trout, and DO has been greatly improved. In addition, an instream flow study conducted during project relicensing indicated the amount of useable habitat for trout would increase with increased minimum flows (Kleinschmidt Associates 2008).

The rate of angler non-reporting in this study was similar to those (24% and 31%) reported in the Chattahoochee River below the Buford Dam (Klein 2003). Anglers returned more than six times more tags from rainbow trout than brown trout, but species distribution in electrofishing samples was similar to the stocking rate of each species stocked. This was consistent with reports that brown trout are less susceptible to angling (Anderson and Nehring 1984, Hudy 1990). As seen in other trout fisheries (Bettoli and Bohm 1997, Klein 2003), catch-and-release fishing was common with 60% of tagged trout caught released. More than half of the tag returns came from Reach 1, the area with the best public access. This finding illustrates the importance of angler access for a put-grow-and-take fishery. Devlin and Bettoli (1999) reached a similar conclusion from a creel study on the Caney Fork River, Tennessee, where trout stocked in areas with limited access were rarely reported.

Many factors may have influenced angler utilization of stocked catchable trout. The mean angler catch and the harvest rates for rainbow trout were 3.5- and 6.4-fold higher, respectively, than those for brown trout. Similar low return rates were reported for brown trout from the Cumberland River below Lake Cumberland Dam, Kentucky (Kosa 1999). In the LSR, the lower return rate for brown trout may be related to the smaller size (130–180 mm TL) of stocked brown trout. Hartwig (1998) found that smaller brown trout were not desired by Smith River, Virginia, anglers even when high numbers of small brown trout were available.

Lower electrofishing CPUE and angler catch rates of tagged trout were found during 2014. A two-and-a-half-day high-flow release (>396 m^3 sec^{-1}) in January may have caused reductions in tag return rates. Bettinger and Bettoli (2002) reported that high-volume hydro releases could result in a large dispersal of hatchery stocked trout that could not cope with high water velocities. Dispersion downstream would likely result in an expenditure of energy leading to higher exposure to predation and increased mortality (Bachman 1984). Investigations of the Elk River and Caney Fork River tailwaters in Tennessee documented poor survival of stocked catchable rainbow trout possibly due to a lack of instream refuge during high flows (Besler 1996, Devlin and Bettoli 1999). High-flow releases in 2013 and 2015 were of short duration (<24 h) and did not appear to cause sudden changes in CPUE or tag return rates. A similar finding was reported by Heggenes (1988), who reported no movement of yearling brown trout nor change in habitat use after a short-term peaking discharge.

The high mortality rates observed in the LSR for stocked catch-

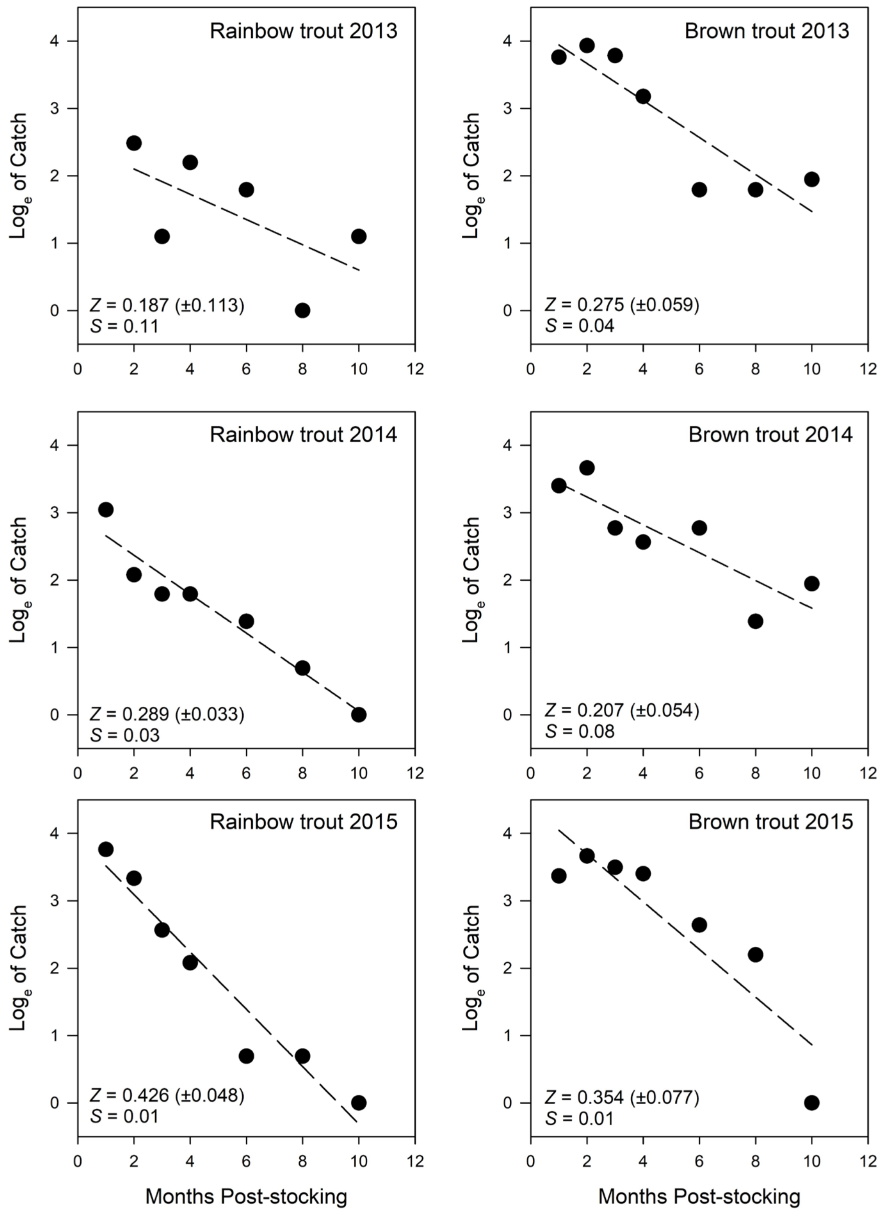

Figure 8. Catch-curve results for three cohorts of rainbow trout and brown trout stocked during December 2012, 2013, and 2014 and sampled at monthly intervals with boat electrofishing gear in the Lower Saluda River, South Carolina. Instantaneous monthly mortality rates (*Z*), SE (in parentheses), and annual survival rates (S) are presented.

able brown and rainbow trout are typical for a put-grow-and-take tailwater fishery. For example, Bettoli and Bohm (1997) found annual mortality rates (94% to 98%) for four cohorts of catchable size rainbow trout and 95% annual mortality rates for brown trout stocked in the Clinch River, Tennessee. In the Chattahoochee River, Georgia, annual mortality for stocked catchable (>228 mm) rainbow trout and brown trout was 69% and 87%, respectively (Klein 2003). In that same fishery, where natural reproduction of brown trout occurs, a five-year cessation of brown trout stocking resulted in no changes in electrofishing CPUE, size distribution, or angler catch rates (O'Rouke and Martin 2011), indicating the poor survival and contribution of stocked brown trout to the fishery. The low exploitation observed in the LSR is also consistent with several other southeastern tailrace fisheries where angler exploitation was ≤17% (Bettoli 2000, Luisi and Bettoli 2001, Klein 2003).

An inability of stocked trout to convert to natural forage may contribute to their poor survival in the LSR. Differences in diet (Teixeira and Cortes 2006, Fischer et al. 2019) and foraging behavior (Bachman 1984) have been observed between wild and stocked trout. The incidence of empty stomachs is higher in recently stocked fish than those that have been in the river for several months (O'Rouke 2013) or that of wild fish (Fisher et al. 2019).

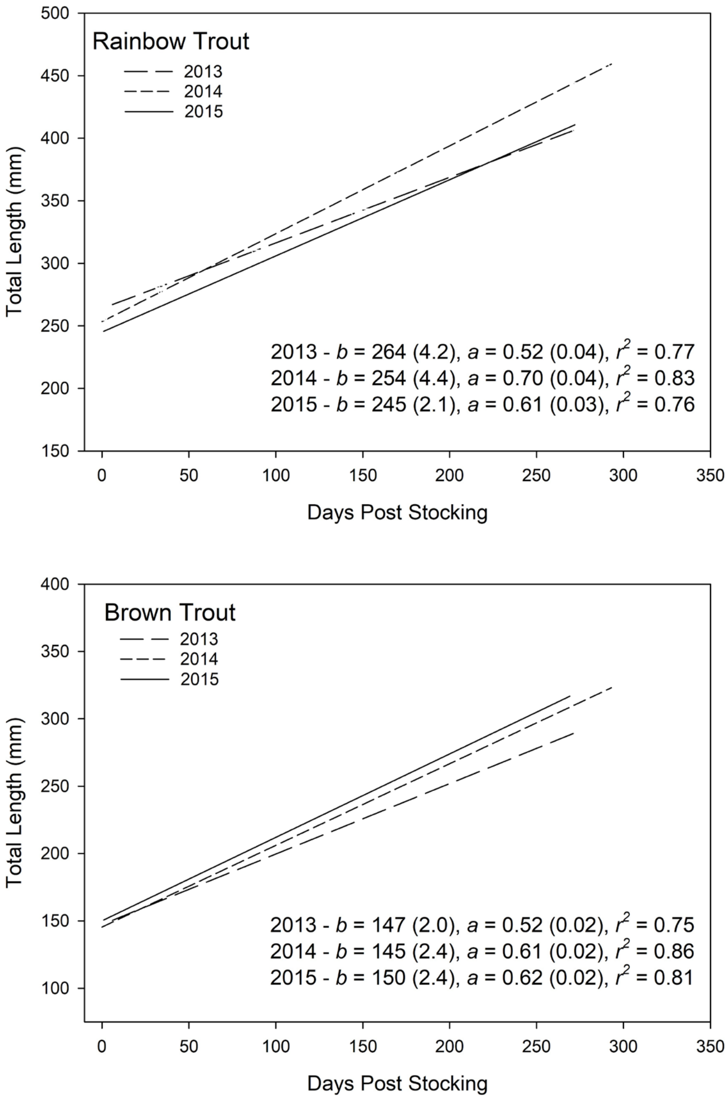

Figure 9. Linear relationship between rainbow trout (top panel) and brown trout (bottom panel) length and days post stocking for the 2013 (long dash), 2014 (medium dash), and 2015 (solid line) cohorts of trout stocked into the Lower Saluda River, South Carolina. Linear regression estimates of the intercept (*b*) and slope (*a*) with associated SE in parentheses are presented.

Even when stocked trout adapt to natural forage after stocking they can become inflexible to seasonal changes in forage (Ersbak and Haase 1983). Forage availability and foraging success of stocked trout in the LSR are currently unknown but are unlikely to differ greatly from these systems studied by other researchers.

Poor survival of recently-stocked trout in the LSR may be influenced by predation. The potential predator list is extensive, including chain pickerel (*Esox nigra*), largemouth bass (*Micropterus salmoides*), striped bass (*Morone saxatilis*), and flathead catfish (*Pylodictis olivaris)*, as well as river otter (*Lontra canadensis*), great blue heron (*Ardea herodias*), osprey (*Pandion haliaetus*), and bald eagle (*Haliaeetus leucocephalus*). Many researchers have implicated striped bass as predators of stocked trout (Deppert and Mense 1979, Walters et al. 1997, Bettoli 2000). Hess and Jennings (2000) found that 7%–28% of the trout stocked annually in the Chattahoochee River, Georgia, were consumed by striped bass. Striped bass are present in the LSR between April and October of each year where a segment of the Santee-Cooper population seeks thermal refuge after spawning (Bettinger 2008). The number of striped bass occupying the LSR is unknown; however, roughly 50% of adult striped bass that spawn in the Congaree River enter the Saluda River during late spring and early summer (Bettinger 2008) where they may be a significant source of predation on stocked trout. High natural mortality rates for rainbow trout and brown trout in the LSR illustrate the continued need for annual stocking to maintain the fishery.

Rainbow trout showed a slight decline in condition with increasing length while brown trout showed a steady increase until trophy size. The condition and abundance of memorable and trophy size brown trout suggested that the LSR is well suited to adult brown trout that have likely transitioned to piscivory, as was reported in the Chattahoochee River, Georgia (O'Rouke 2016). Brown trout are known to be less dependent on riffle habitat and can effectively use pool habitat (Devlin and Bettoli 1999) which is the dominant habitat type in the LSR. The decline in condition for rainbow trout could be related to spawning activities, forage preferences, and/or habitat limitations.

A study initiated by South Carolina Electric and Gas after the onset of turbine venting demonstrated that trout growth in the LSR could, with improved flow rates and aerated discharges, exceed many other southeastern tail waters (Kleinschmidt Associates 2003). Our study exceeded their calculated growth of 0.56 mm day^{-1} in two of three years. During the first year post stocking, average monthly growth rates (TL) for rainbow trout and brown trout were similar, even though the rainbow trout were 11.5 months older at the time of stocking. The growth rate for brown trout found in this study was more than double the rate previously reported for the LSR (Jöbsis 1991), which could be due to improved environmental conditions. For example, water temperatures between 13° and 18° C, considered optimum for brown trout (Spigarelli and Thommes 1979), were present in the LSR from April to December due in part to increased minimum flows. The rainbow trout growth rate was higher than rates (4.9–12.0 mm mo^{-1}) reported in many tailwater trout fisheries in the southeastern United States. (Fry and Hanson 1968, Bettoli and Bohm 1997, Klein 2003). However, rainbow trout growth rates up to 20 mm mo^{-1} have been reported in the South Fork of the Holston, Tennessee, and the White River, Arkansas (Aggus et al. 1977, Bettoli et al. 1999).

The study established the presence of holdover rainbow and brown trout in the LSR. Brown trout were found at larger sizes than rainbow trout and are likely surviving multiple years after stocking. Many researchers have reported that brown trout, being less vulnerable to angling and more capable of naturalizing, reside in tailwater rivers longer than rainbow trout (Hudy 1990, Bettoli and Bohm 1997, Devlin and Bettoli 1999). Wood et al. (2017) reported four age-classes of stocked brown trout occurred in the Bridgewater tailrace in western North Carolina even though, as in the LSR, high mortality occurs in the first year after stocking.

We also collected small rainbow trout that could not be explained by our stocking program and were thought to be natural reproduction. Redds with rainbow trout actively spawning were seen and rainbow trout in post-spawn condition were captured during electrofishing. Holbrook and Bettolli (2006) documented wild rainbow trout in the Clinch River after changes in hydro operations. Prior to adherence to the new flow requirements at the Saluda Hydroelectric Project, peaking flows may have limited rainbow trout reproduction by leveling the pit and tailspin configuration of redds as seen in some Tennessee tailwaters (Banks and Bettoli 2000). These wild fish combined with wild trout captured during contemporaneous sampling (Ahle and Bettinger 2019) exhibited excellent growth at a rate of 29 mm mo^{-1} from May until October. They were found in the largest concentrations in the shoals where spawning redds were observed. No evidence was shown for natural reproduction of brown trout. It is possible that water temperatures in the LSR were too warm (ranging from 10° to 17° C) during the brown trout spawning and egg incubation seasons. Brown trout typically spawn from October to December at water temperatures ranging from 6° to 9° C (Raleigh et al. 1986). The presence of wild rainbow trout in the Saluda raises the question of whether they could sustain the fishery. Electrofishing data suggests that recruitment of wild rainbow trout is low based on relative abundance. Bettoli and Bohm (1997) noted similar rainbow trout reproduction in the Norris Tailwater, Tennessee, where they documented natural reproduction leading to limited recruitment. Predation by resident fish species on eggs, fry, and fingerlings likely limits recruitment of rainbow trout (Keith and Barkley 1970). However, the presence of wild rainbow trout suggests that fingerling stockings may be a viable option to augment the fishery.

Our results show that a change from hydro-peaking power production to reserve capacity operation with improved water quality and quantity improved the trout fishery in the LSR. Trout exhibited better growth and a holdover population developed. In addition, evidence was found that natural reproduction of rainbow trout may be contributing to the overall fishery. Because of our findings, several changes were made to the management of the fishery. A modification to the five-fish creel limit, whereby only one trout over 40.64 cm may be harvested as one of those five, was made to ensure the presence of holdover fish. In addition, a 4-km catch-and-release-only zone was established that will serve as a nursery for young-of-the-year fish and provide additional enhancement to the holdover population.

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Literature Cited

Aggus, L. R., D. I. Morias, and R. F. Baker. 1977. Evaluation of the trout fishery in the tailwater of Bull Shoals Reservoir, Arkansas, 1971–1973. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 31:565–573.

Ahle, R. and J. M. Bettinger. 2019. Completion report for the Lower Saluda River study: December 2012 through December 2015. South Carolina Department of Natural Resources, Division of Wildlife and Freshwater Fisheries, Columbia, South Carolina.

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

Bachman, R. A. 1984. Foraging behavior of free-ranging wild and hatchery brown trout in a stream. Transactions of the American Fisheries Society 113:1–32.

Bales, C. W., D. E. Allen, H. R. Beard, and C. S. Thomason. 2005. Fisheries investigations in lakes and streams-Region 3 Study Completion Report. F-63-10. South Carolina Department of Natural Resources, Columbia, South Carolina.

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

Bear, B. A., T. E. McMahon, and A. V. Zale. 2007. Comparative thermal requirements of westslope cutthroat trout and rainbow trout: implications for species interactions and development of thermal protection standards. Transactions of the American Fisheries Society 136:1113–1121.

Besler, D. A. 1996. Fate of salmonids stocked into the Tims Ford Tailwater, Tennessee. Master's Thesis. Tennessee Technological University, Cookeville.

Bettinger J. M. 2008. Seasonal movements of adult striped bass in the Santee-Cooper drainage. Study Completion Report F-63. South Carolina Department of Natural Resources, Columbia, South Carolina.

_____ and P. W. Bettoli. 2002. Fate, dispersal, and persistence of recently stocked and resident rainbow trout in a Tennessee tailwater. North American Journal of Fisheries Management 22:425–432.

Bettoli, P. W. 2000. Potential impacts of striped bass on the trout fishery in the Norris Dam tailwater. Fisheries Report No 00-31. Tennessee Wildlife Resources Agency, Nashville, Tennessee.

_____ and L. A. Bohm. 1997. Clinch River trout investigations and creel survey. Fisheries Report No. 97–39. Tennessee Wildlife Resources Agency, Nashville, Tennessee.

_____, S. J. Owens, and M. Nemeth. 1999. Trout habitat, reproduction, survival, and growth in the South Fork of the Holston River. Fisheries Report No. 99–3. Tennessee Wildlife Resources Agency, Nashville, Tennessee.

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

Devlin, G. J. and P. W. Bettoli. 1999. Creel survey and population dynamics of salmonids stocked into the Caney Fork River below Center Hill Dam. Final Report No. 99–8. Tennessee Wildlife Resources Agency, Nashville, Tennessee.

Deppert, D. L. and J. B. Mense. 1979. Effect of striped bass predation on an Oklahoma trout fishery. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 33:384–392.

Elliott, J. M. 1981. Some aspects of thermal stress on freshwater teleosts. Pages 209–245 *in* A. D. Pickering, editor. Stress and fish. Academic Press, New York.

Ersbak, K. and B. L. Haase. 1983. Nutritional deprivation after stocking as a possible mechanism leading to mortality in stream-stocked brook trout. North American Journal of Fisheries Management 3:142–151.

Federal Energy Regulatory Commission. 2010. Environmental assessment for hydropower license: Saluda Hydroelectric Project—FERC Project No. 516–459 South Carolina, July 2010. Federal Energy Regulatory Commission, Washington D.C.

Fischer J. R., T. J. Kwak, H. J. Flowers, W. G. Cope, J. M. Rash, and D. A. Besler. 2019. Growth, condition, and trophic relations of stocked trout in Southern Appalachian mountain streams. Transactions of the American Fisheries Society 148:771–784.

Fishery Information Management Systems. 1997. Lower Saluda River recreational angler survey: April 1, 1996 to March 31, 1997. Report to South Carolina Department of Natural Resources, Columbia, South Carolina.

Fry, J. P. and W. D. Hanson. 1968. Lake Taneycomo: a coldwater reservoir in Missouri. Transactions of the American Fisheries Society 97:138–145.

Hartman, K. J. and M. A. Porto. 2014. Thermal performance of three rainbow trout strains at above-optimal temperatures. Transactions of the American Fisheries Society 143:1445–1454.

Hartwig, J. J. 1998. Recreational use, social and economic characteristics of the Smith River and Philpott reservoir fisheries, Virginia. Master's Thesis. Virginia Polytechnic Institute and State University, Blacksburg.

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.

Hess, B. J. and C. A. Jennings. 2000. Striped bass in trout waters of the upper Chattahoochee River, Georgia: can these two fisheries coexist? Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 54:107–117.

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

Holbrook, C. and P. W. Bettoli, 2006. Spawning habitat, length at maturity, and fecundity of brown trout in Tennessee Tailwaters. Fisheries Report No. 06-11. Tennessee Wildlife Resources Agency, Nashville, Tennessee.

Hudy, M. 1990. Brown trout population structures in White River tailwaters currently managed under no special regulations. Trout Committee, Southern Division, American Fisheries Society. Federal Report 37:94–97.

Isely, J. J., G. Jöbsis, and S. Gilbert. 1995. Instream flow requirements for the fishes of the Lower Saluda River. Report to Federal Energy Regulatory Commission, Saluda Project-FERC No. 516, Washington D.C.

Jöbsis, G. J. 1991. Assessment of tailwater fisheries in South Carolina. South Carolina Wildlife and Marine Resources Department-Fisheries Resource Coordination. Study Completion Report F-30. Columbia, South Carolina.

Kaya, C. M. 1978. Thermal resistance of rainbow trout from a permanently heated stream, and of two hatchery strains. Progressive Fish-Culturist 40:37–39.

Keith, W. B. and S. K. Barkley. 1970. Predation of stocked rainbow trout by chain pickerel and largemouth bass in Lake Ouachita, Arkansas. Proceedings of the Annual Conference of Southeastern Association of Game and Fish Commissioners 24:401–407.

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

Kleinschmidt Associates. 2003. Saluda dissolved oxygen standard project: Lower Saluda River dissolved oxygen technical study report. Report to South Carolina Electric and Gas, Columbia, South Carolina.

_____. 2008. Report on instream flow studies for Saluda Hydroelectric Project, FERC No. 516. Report to South Carolina Electric and Gas, Columbia, South Carolina.

Kosa, J. 1999. Evaluation of the rainbow and brown trout stockings in the Lake Cumberland tailwater. Fisheries Bulletin of the Kentucky Department of Fish and Wildlife Resources No. 102. Frankfort, Kentucky.

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

McKellar, H. N., Jr. and M. K. Stecker. 1988. Oxygen dynamics in the Lower Saluda River. Department of Environmental Health Services, University of South Carolina. Report to Trout Unlimited, South Carolina Wildlife and Marine Resources Department, and South Carolina Department of Health and Environmental Services, Columbia, South Carolina.

Miranda, L. E. and P. W. Bettoli. 2007. Mortality. Pages 229–277 *in* C. S. Guy and M. L. Brown, editors. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland.

_____, R. E. Brock, and B. S. Dorr. 2002. Uncertainty of exploitation estimates made from tag returns. North American Journal of Fisheries Management 22:1358–1363.

Neumann, R. M., C. S. Guy, and D. W. Willis. 2012. Length, weight, and associated indices. Pages 637–676 *in* A. V. Zale, D. L. Parrish, and T. M. Sutton, editors. Fisheries Techniques, 3rd edition. American Fisheries Society, Bethesda, Maryland.

O'Rouke, P. M. 2013. Diet composition of wild brown trout and stocked rainbow trout in a coldwater tailwater fishery in north Georgia. Journal of the Southeastern Association of Fish and Wildlife Agencies 1:83–88.

_____. 2016. Movement and growth of wild brown trout in the Chattahoochee River below Lake Lanier, Georgia. Journal of the Southeastern Association of Fish and Wildlife Agencies 4:46–51.

_____ and C. R. Martin. 2011. Fishery viability of a wild brown trout population in the Chattahoochee River near Atlanta, Georgia. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 66:131–135.

Pine, W. E., J. E. Hightower, L. G. Coggins, M. V. Lauretta, and K. H. Pollock. 2012. Design and analysis of tagging studies. Pages 521–572 *in* A. V. Zale, D. L. Parrish, and T. M. Sutton, editors. Fisheries Techniques, 3rd edition. American Fisheries Society, Bethesda, Maryland.

Raleigh, R. F., L. D. Zuckerman, and P. C. Nelson. 1986. Habitat suitability index models and instream flow suitability curves: brown trout. U.S. Department of the Interior, Fish and Wildlife Service Biological Report 82 (10.124), Washington D.C.

SAS Institute. 2012. Base SAS 9.4 Procedures Guide. SAS Institute, Inc. Cary, North Carolina.

South Carolina Electric and Gas 2009. Saluda hydroelectric project (FERC Project No. 516) relicensing comprehensive settlement agreement. Federal Energy Regulatory Commission, Washington D.C.

South Carolina Water Resources Commission. 1984. Lower Saluda River management plan, Report No. 145. South Carolina Water Resources Commission, Columbia, South Carolina.

Spigarelli, S. A. and M. M. Thommes. 1979. Temperature selected and estimated thermal acclimation by rainbow trout (*Salmo gairdneri*) in a thermal plume. Journal of Fisheries Board of Canada 36:366–376.

Teixeira, A. and R. M. V. Cortes. 2006. Diet of stocked and wild trout, *Salmo trutta*: is there competition for resources. Folia Zoologica 55(1):61–73.

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

Weisburg, S. B. and W. H. Burton. 1993. Enhancement of fish feeding and growth after an increase in minimum flow below the Conowingo Dam. North American Journal of Fisheries Management 13:103–109.

Wood, C., D. Goodfred, and J. Rash. 2017. The Bridgewater Tailrace brown trout fishery. North Carolina Wildlife Resources Commission, Raleigh, North Carolina.