Suitability of Stocked Brown Trout and Rainbow Trout for Trophy Management in Apalachia Reservoir, North Carolina

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Abstract: Brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*) were stocked at two sizes, small (approximately 254 mm TL) and large (approximately 356 mm TL), in Apalachia Reservoir, North Carolina, to determine the best size and species to create a trophy put-grow-and-take fishery. Trout were tagged and stocked in December 2012–2015 and collected with annual boat electrofishing and gill-net surveys. Small trout of both species grew faster in length than large trout; however, brown trout of both size classes reached larger sizes (≥500 mm TL). Large brown trout were highly piscivorous throughout the study, whereas small trout of both species fed primarily on macroinvertebrates within the first four months in the reservoir and converted to a more piscivorous diet by 16 months when they had reached a mean TL of ≥400 mm. Large rainbow consumed mainly macroinvertebrates until becoming more piscivorous after 16 months in the reservoir. Our results suggested that brown trout were better suited to utilize an abundant alosine forage base in Apalachia Reservoir. While small rainbow trout achieved considerable growth in length, brown trout of both sizes added more weight and reached trophy sizes as they persisted longer in the reservoir and exhibited a more piscivorous diet. With the spread of invasive species such as blueback herring (*Alosa aestivalis*), fisheries managers are tasked with creating new management options that can either mitigate for or take advantage of new reservoir dynamics. Based on the results of this study, brown trout appear to be able to exploit these new forage bases in southeastern U.S. reservoirs, while creating unique fisheries.

Key words: tagging, food habits, growth, survival

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Put-grow-and-take trout fisheries have been popular in reservoirs of the southeastern United States for many decades (Kirkland and Bowling 1966, Baker and Mathis 1967, Axon 1971, Hampton 1993, Barwick et al. 2004). Compared to streams, trout stocked in lakes typically survive better (Swales 2006) and tend to grow very quickly to larger sizes (Wilkins et al. 1967, Wang et al. 1996, Keeley and Grant 2001, Swales 2006), making them very desirable to anglers. Trout require cold, well-oxygenated water, which is often lacking in the hypolimnions of southeastern U.S. reservoirs during late summer and early fall (Kirkland and Bowling 1966, Oliver et al. 1977, Jones 1982, Barwick et al. 2004). When these conditions exist, trout can achieve considerable growth rates in reservoirs that also have an abundant forage base (Kirkland and Bowling 1966, Wilkins et al. 1967, Keeley and Grant 2001, Hyvarinen and Huusko 2005, Hyvarinen and Huusko 2006, Swales 2006). Alosines such as blueback herring (*Alosa aestivalis*) can serve as important forage for a wide variety of salmonids (Jude et al. 1987, Hampton 1993, Bergthold and Bettoli 2009, Savitz 2009) and are ideal prey for put-grow-and-take reservoir trout fisheries because their thermal ecology is similar to trout (Kohler and Ney 1980, Prince and Barwick 1981). In addition to alosines, macroinvertebrates can also serve as important forage for reservoir trout (Kirkland and Bowling 1966, Baker and Mathis 1967, Jude et al. 1987, Hampton 1993).

While sufficient habitat and forage are vital to produce quality put-grow-and-take fisheries, high survival and growth are also necessary, and these can be mediated by the size and species of trout stocked. Optimum size ranges for stocked trout to produce quality fisheries have been suggested to range from 200 to 300 mm total length (TL) because fish in this size range can avoid predation and may convert to a piscivorous diet sooner (Kirkland and Bowling 1966, Baker and Mathis 1967, Wilkins et al. 1967, Jones 1982). However, trout stocked at larger sizes (>300 mm TL) may take advantage of a wider size range of prey available at the time of stocking and convert to piscivory even faster, leading to higher growth rates (Hyvarinen and Vehanen 2003). Brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*) are the predominant salmonid species stocked in put-grow-and-take reservoirs in the southeastern United States (Wilkins et al. 1967). However, little work has been conducted on evaluating the performance of both species stocked at various sizes in a reservoir with an alosine forage base. A recently developed put-grow-and-take reservoir trout fishery in Apalachia Reservoir, North Carolina, afforded us an opportunity to examine this topic for a trophy-trout (≥600 mm TL) fishery. The objectives of this study were to examine growth, condition and diet of two sizes of brown trout and rainbow trout stocked into Apalachia Reservoir, and ultimately determine the optimal size and species of trout to stock to create a trophy trout fishery.

Study Area

Apalachia Reservoir is a relatively small (445 ha), shallow (16 m mean depth), low-elevation (390 m msl) impoundment of the Hiwassee River immediately below Hiwassee Reservoir (Figure 1). Apalachia Reservoir is operated by Tennessee Valley Authority (TVA) for hydroelectric power generation and receives cold, oxygenated, hypolimnetic discharge from Hiwassee Dam (TVA 2009). The reservoir supports a sportfish assemblage of largemouth bass (*Micropterus salmoides*), bluegill (*Lepomis macrochirus*), smallmouth bass (*Micropterus dolomieu*), spotted bass (*Micropterus punctulatus*), and yellow perch (*Perca flavescens*). Wild rainbow trout inhabit the larger tributaries of Apalachia Reservoir and can occasionally be found in the reservoir. Blueback herring are the primary forage fish in Apalachia Reservoir following their introduction into the Hiwassee River watershed in the late 1990s. Gizzard shad (*Dorosoma cededianum*) are the only other clupeid that have been documented in Apalachia Reservoir (Loftis and Willard 2001).

Methods

Tagging and Stocking Brown Trout and Rainbow Trout

Brown trout and rainbow trout were reared to two target sizes (TL): 254 mm (small) and 356 mm (large) in 2012–2015. All trout were triploid, except for large brown trout reared in 2015 which were diploid. In November each year, approximately 1500 small and 1000 large trout of both species were marked with visible implant elastomer (VIE) and coded-wire tags (CWT). Trout were anesthetized prior to marking with 40 mg L^{-1} tricane methanesulfonate (MS-222). Each trout was marked with VIE in the transparent post-ocular eye tissue using a manual injector (a 0.3-cm^3 insulin syringe and 29-gauge needle; Northwest Marine Technology, Inc. [NMT], Shaw Island, Washington). A different color VIE was used each year to distinguish cohorts: red (2012), blue (2013), yellow (2014), and orange (2015). To differentiate between size classes, small trout were marked in the left side, whereas large trout were marked in the right side. Each trout was then injected with a 0.1-×1-mm CWT in the opposite cheek muscle using a NMT Mark IV CWT injector. The CWT injector needle remained in a fixed position and used 89-mm non-beveled needles. All trout were checked for CWTs using a NMT detection wand immediately after marking.

During marking, 100 trout were selected randomly and measured for TL (mm) and weight (g) to estimate mean sizes of each cohort at stocking. Following VIE and CWT marking, all trout were allowed to recover, then held in outdoor raceways for 30 d

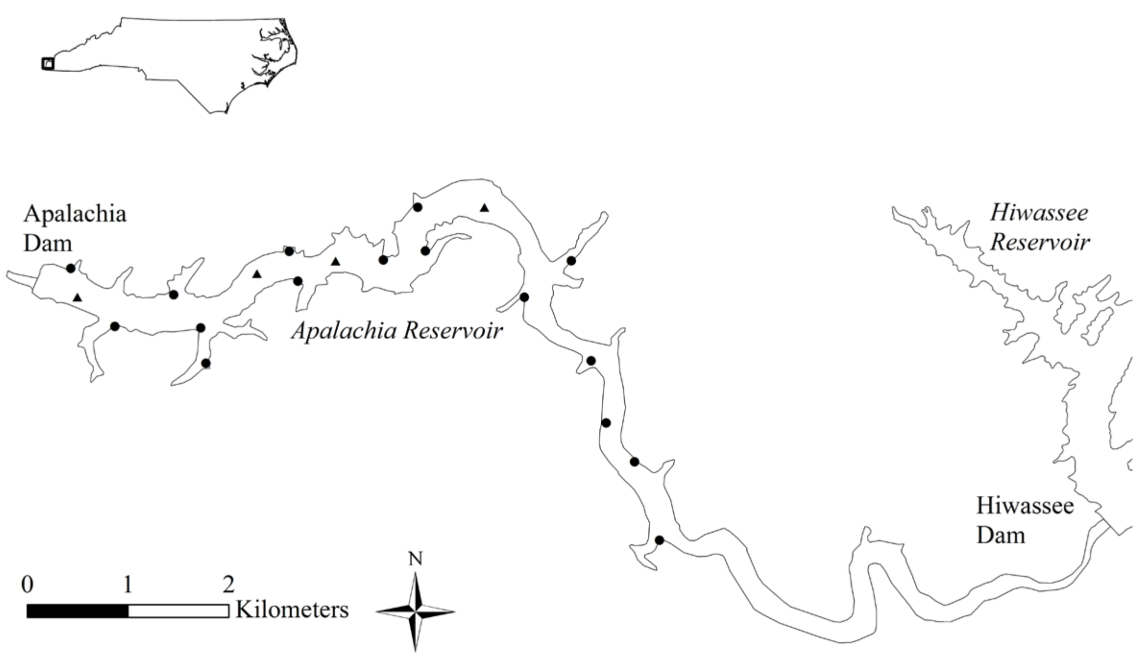

Figure 1. Map of Apalachia Reservoir, North Carolina. Bank-set gill-net sites are represented by dots and triangles represent suspended gill-net sites.

to determine marking-related mortality and to withdraw from the MS-222. At the end of 30 d, 100 individuals from each cohort of trout were examined for a VIE mark using an ultraviolet light (Close 2000, Fitzgerald et al. 2004) under low-light to dark conditions (Josephson et al. 2008), and CWTs were detected with a handheld NMT Blue Wand Detector. The presence or absence of marks were then recorded.

Trout were stocked in December of each year to ensure that surface water temperatures were cold enough to support trout (Baker and Mathis 1967) and to allow adequate time for dispersal and acclimation before thermal stratification begins (Wilkins et al. 1967). In 2012, trout were stocked at a boat ramp located below Hiwassee Dam and were expected to disperse throughout the reservoir quickly (Ivasauskas and Bettoli 2011). However, anecdotal reports from Apalachia Reservoir anglers suggested that these trout did not disperse quickly from the stocking location. The boat ramp used for stocking is located on a narrow channel that experiences high flows from Hiwassee Dam and reports suggested that newly stocked trout schooled in those high flows and were susceptible to angling and high rates of harvest. Therefore, during 2013–2015, trout were stocked from the bank in a more remote area of the reservoir to address angler concerns and reduce harvest immediately after stocking.

Gill-net and Electrofishing Sampling

Gill-net surveys were conducted during September 2013–2015 to assess survival and growth of stocked trout. Experimental gill-net dimensions were 2.4 × 76.3 m and consisted of five 2.4- × 15.3-m panels with 25-, 32-, 38-, 44- and 51-mm bar mesh, which have been shown to catch trout >300 mm TL in other western North Carolina reservoirs (North Carolina Wildlife Resources Commission [NCWRC] unpublished data).

Sixteen sites were sampled each year, all confined to the lower portion of the reservoir to avoid high flows from hydropower generation at Hiwassee Dam (Figure 1). Nets were fished for 24 h. In 2013, gill nets at four of the sites were suspended in open water at depths within the range of trout habitat (<21°C water temperature and ≥5 mg L^{-1} dissolved oxygen concentrations). The remaining 12 sites were bank-set perpendicular to the shore. Due to poor catch rates of suspended nets, all gill nets in 2014 and 2015 were fished perpendicular to the shore. When gill nets were set along the bank, the starting mesh sizes at the near-shore end was randomly selected.

Trout were also collected in April 2014–2016 with boat-mounted electrofishing in a 5.5-m jonboat equipped with a 7500-W generator, and a 7.5-GPP pulsator (Smith Root, Inc., Vancouver, Washington) operated to produce 3 to 5 A of power. Sampling occurred during daylight hours throughout the reservoir but focused primarily in areas where trout were congregated such as directly below Hiwassee Dam and in tributary arms. Total electrofishing effort was 12.2, 18.5 and 12.1 h in 2014, 2015, and 2016, respectively. Surface water temperatures during sampling ranged from 10.5°C –17.8°C.

All trout collected were transported to the lab and measured for TL (mm) and weight (g). All brown trout and rainbow trout were examined for a VIE mark and coded wire tags and presence or absence of marks were recorded. Stomachs of trout collected from electrofishing surveys were removed and frozen.

Diet Analysis

Stomachs of all trout collected during electrofishing surveys were dissected to examine the food habits of trout stocked in Apalachia Reservoir. Stomach contents were identified to the lowest possible taxa, and prey items were grouped into three major categories: macroinvertebrates, fish, and other. Due to varying levels of decomposition fish were further broken down into blueback herring, clupeid spp., and unidentified fish. Miscellaneous items such as vegetation, rocks, and artificial fishing lures were grouped into the "other" category. Insects were wet weighed in aggregate to 0.1 g, and piscine prey were measured when possible to 1 mm and wet weighed to 0.1 g (Hampton 1993). Each category was described by percent by weight and frequency of occurrence in trout containing food items (Bowen 1996).

Growth and Condition of Brown Trout and Rainbow Trout

All brown trout and rainbow trout measured during tagging, spring electrofishing, and fall gillnet samples were assigned an age equivalent to the amount of time spent in the lake. Therefore, length and weight measurements for each cohort taken prior to stocking represented 0 months and time in lake (months) was calculated for each subsequent sample. All trout in each species and size class were pooled according to time in lake. The 2015 cohort of large diploid brown trout were also included in pooled samples as there is limited information describing the growth of diploid versus triploid brown trout (but see Kizak et al. 2013). Changes in total length and weight through time were modeled as a function of species/size class and age and an analysis of covariance (ANCOVA, $\alpha = 0.05$; R Core Team 2018) with an interaction term of species/size class and age was used to determine differences in growth rates and condition through time. Post-hoc multiple comparisons of slopes across groups were made using the compSlopes function in the FSA package (Ogle 2018). The Holm correction was made to *P*-values for post-hoc multiple comparisons (Holm 1979).

Relative weight (W_r) was used to index trout condition during spring electrofishing samples using the standard weight (W_s) equations described by Hyatt and Hubert (2001) for brown trout and Simpkins and Hubert (1996) for rainbow trout. Due to seasonal variation in condition (Blackwell et al. 2000), only W_r values collected during spring electrofishing were pooled for each species/size class and analyzed using a one-way analysis of variance (ANOVA) to compare mean W_r among each species/size class group ($\alpha = 0.05$). Mean differences in W_r among species and size classes were further tested using a Tukey's HSD ($\alpha = 0.05$).

Results

Tagging and Stocking Brown Trout and Rainbow Trout

Target numbers for small and large brown trout and rainbow trout were met each year except in 2012, when 1594 large and 933 small brown trout and 2115 small and 354 large rainbow trout were marked. The discrepancy in 2012 numbers was due to hatchery constraints, which were ameliorated to provide consistent numbers throughout the remainder of the study. Target lengths for small and large size classes were 254 mm and 356 mm TL, respectively, but mean TL of size classes varied among years for each species (Table 1). Mean TLs of small brown trout were variable throughout the study and ranged from 199 (SE = 1.9) to 319 mm (SE = 2.7), while small rainbow trout mean TL ranged from 221 (SE = 2.5) to 282 mm (SE = 2.7). Mean TL of large brown trout ranged from 333 mm (SE = 1.8) to 389 mm TL (SE = 2.2), and large rainbow trout mean TL ranged from 312 (SE = 3.2) to 398 mm TL (SE = 3.1). Thirty-day post-marking mortality was low (0.0%–1.8%), except in 2015 when 11.0% of large brown trout died within 30 d of tagging due to the stress of egg reabsorption (Table 1; Adam Moticak, NCWRC, personal communication). Thirty-day VIE tag retention was >99% every year and the 30-d CWT retention ranged from 99% to 100%.

Gill-net and Electrofishing Sampling

A total of 43 brown trout and two rainbow trout was collected during fall gill-net surveys. Eighty-one percent of brown trout captured were from the large size class, and 100% of rainbow trout collected were from the small size class. More than half of the brown trout collected in 2014 (69%) and 2015 (62%) gill-net samples were from the previous years' stocking and therefore had been in the reservoir for nine months; both of the rainbow trout collected in the 2015 gill-net sample were stocked the previous year in 2014. The remaining brown trout had been in the reservoir for either 21 or 33 months (Table 2).

Spring electrofishing samples yielded 61 brown trout and 166 rainbow trout. Four small (171–199 mm TL) rainbow trout were collected that lacked both VIE and CWT marks; based on size and missing marks, these were considered wild trout that originated from tributaries and omitted from further analyses. More than half (56%) of brown trout were from large size classes, while most rainbow trout were from the small size classes (71%). As with gill-net

Table 1. Summary of two size classes of brown trout (BNT) and rainbow trout (RBT) marked and stocked in Apalachia Reservoir, North Carolina, from 2012–2015. Total length and weight at time of tagging, and 30-d post-tagging mortality are also presented. Standard error values are in parentheses.

Year	Species	Size class	Number tagged	Number measured	Mean total length (mm)	Min length (mm)	Max length (mm)	Mean weight (g)	Mean age at stocking (yr)	30-d mortality (%)	Total number stocked
2012	BNT	Large	1594	101	333 (2)	307	389	469 (10)	2.1	0.1	1592
		Small	933	49	283 (2)	247	306	292 (7)	2.1	0.1	932
	RBT	Large	354	22	325 (3)	308	354	407 (16)	1.2	0.0	354
		Small	2115	128	269 (3)	180	306	235 (6)	1.2	0.1	2113
2013	BNT	Large	1040	100	346 (2)	232	398	571 (12)	2.0	0.4	1036
		Small	1500	100	199 (2)	137	236	107 (3)	1.1	1.7	1475
	RBT	Large	1025	100	312 (3)	228	417	380 (14)	1.7	0.1	1024
		Small	1500	100	237 (3)	118	297	164 (5)	1.2	0.4	1494
2014	BNT	Large	1040	100	352 (3)	270	409	574 (16)	2.0	1.1	1029
		Small	1600	100	206 (2)	134	246	114 (4)	1.0	0.3	1596
	RBT	Large	1000	100	393 (3)	333	494	673 (14)	2.2	0.3	997
		Small	1500	100	282 (3)	202	334	218 (6)	1.3	0.1	1499
2015	BNT	Large	1084	100	389 (2)	330	451	755 (15)	3.0	11.0	965
		Small	1500	99	319 (3)	231	394	352 (9)	2.0	1.8	1473
	RBT	Large	1501	100	398 (3)	317	465	704 (16)	2.8	1.9	1472
		Small	1025	100	222 (3)	115	280	140 (4)	1.1	1.1	1014

Table 2. Catch of each cohort of brown trout (BNT) and rainbow trout (RBT) of two size classes in gill-net (GN) and electrofishing samples (EF) in Apalachia Reservoir, North Carolina. Numbers in parentheses are months post-stocking for each cohort.

Cohort	Species	Size class	GN 2013	EF 2014	GN 2014	EF 2015	GN 2015	EF 2016
2012	BNT	Large	12 (9)	8 (16)	5 (21)	1 (28)	0 (33)	0 (40)
		Small	2 (9)	1 (16)	0 (21)	0 (28)	1 (33)	0 (40)
	RBT	Large	0 (9)	0 (16)	0 (21)	0 (28)	0 (33)	0 (40)
		Small	0 (9)	1 (16)	0 (21)	0 (28)	0 (33)	0 (40)
2013	BNT	Large	–	7 (4)	10 (9)	4 (16)	4 (21)	1 (28)
		Small	–	14 (4)	1 (9)	0 (16)	0 (21)	0 (28)
	RBT	Large	–	13 (4)	0 (9)	1 (16)	0 (21)	0 (28)
		Small	–	36 (4)	0 (9)	2 (16)	0 (21)	0 (28)
2014	BNT	Large	–	–	–	8 (4)	4 (9)	0 (16)
		Small	–	–	–	5 (4)	4 (9)	1 (16)
	RBT	Large	–	–	–	9 (4)	0 (9)	1 (16)
		Small	–	–	–	36 (4)	2 (9)	2 (16)
2015	BNT	Large	–	–	–			5 (4)
		Small	–	–	–			5 (4)
	RBT	Large	–	–	–			24 (4)
		Small	–	–	–			41 (4)

samples, 72% of brown trout and 96% of rainbow trout collected were from the previous year's stocking. We did not collect any trout from the initial, 2012 stocking during the final electrofishing sample (40 months after stocking; Table 2).

Growth and Condition of Brown Trout and Rainbow Trout

Mean TL of large brown trout increased to 596 mm TL (SE = 2) at 28 months, whereas the one small brown trout collected at 33 months had a TL of 560 mm (Table 3). Mean TL of large and small rainbow trout at 16 months increased to 463 (SE = 31) and 444 mm (SE = 27), respectively. Total length was significantly related to species/size class group ($F = 978.6$, df = 3, 1762, $P < 0.001$) and age ($F = 738.9$, df = 1, 1762, $P < 0.001$). The relationship between TL and age varied across species/size class groups ($F = 4.9$, df = 3, 1762, $P < 0.010$); TL increased as age increased for all four groups but at different rates. However, the rate of increase differed significantly between large brown trout and small rainbow trout (Table 4, $P = 0.03$), large rainbow trout and small brown trout ($P = 0.04$), and small rainbow trout and large rainbow trout ($P = 0.004$). No differences were found between small brown trout and large brown trout (Table 4, $P = 0.370$), large rainbow trout and large brown trout ($P = 0.150$) and small rainbow trout and small brown trout ($P = 0.370$). Small rainbow trout grew at the fastest rate followed by small brown trout, large brown trout and large rainbow trout (Table 5, Figure 2).

Mean weight of large brown trout increased to 3299 g (SE = 1271)

Table 3. Mean TL and weight of brown trout (BNT) and rainbow trout (RBT) collected in spring electrofishing at 4, 16 and 28 months and fall gill-net samples at 9, 21, and 33 months in Apalachia Reservoir, North Carolina. One small brown trout was collected that could not be aged due to a missing VIE mark and therefore was labeled unknown (Unk).

Species	Size	Time in lake (month)	*n*	Mean TL (mm)	SE	Mean weight (g)	SE
BNT	Large	4	20	392	6	742	49
		9	26	436	5	873	36
		16	12	483	12	1629	158
		21	9	544	12	1966	161
		28	2	596	2	3299	1271
BNT	Small	4	24	260	8	193	20
		9	7	376	19	553	85
		16	2	419	21	879	304
		33	1	560	–	2128	–
		Unk	1	412	–	1200	–
RBT	Large	4	46	389	7	570	28
		16	2	463	31	1089	254
RBT	Small	4	113	297	2	235	6
		9	2	346	11	355	32
		16	5	444	27	1048	203

Table 4. Results of post-hoc multiple comparisons of slopes across species and size groups for total length and weight of trout collected from Apalachia Reservoir, North Carolina. Difference in slope between groups and 95% lower confidence interval (LCI) and 95% upper confidence interval (UCI) and *P*-value are denoted. The Holm correction was made to all *P*-values. Comparisons that were significantly different are denoted with an asterisk ($P < 0.05$).

Metric	Comparison	Difference	95% LCI	95% UCI	*P*-value
Total length	Small BNT vs Large BNT	1.28	−0.61	3.17	0.368
	Large RBT vs Large BNT	−2.63	−5.25	0.00	0.150
	Small RBT vs Large BNT*	2.57	0.76	4.39	0.027
	Large RBT vs Small BNT*	−3.91	−6.92	−0.90	0.044
	Small RBT vs Small BNT	1.29	−1.04	3.63	0.368
	Small RBT vs Large RBT*	5.20	2.24	8.16	0.003
Weight	Small BNT vs Large BNT*	−20.97	−28.68	−13.26	0.000
	Large RBT vs Large BNT*	−49.80	−60.51	−39.10	0.000
	Small RBT vs Large BNT*	−33.26	−40.65	−25.88	0.000
	Large RBT vs Small BNT*	−28.83	−41.11	−16.56	0.000
	Small RBT vs Small BNT*	−12.29	−21.80	−2.78	0.015
	Small RBT vs Large RBT*	16.54	4.47	28.61	0.015

Table 5. Estimated slope of total length, weight and relative weight for all species and size classes of trout collected from Apalachia Reservoir, North Carolina, through time with 95% lower confidence interval (LCI) and 95% upper confidence interval (UCI).

Metric	Size/Species	Slope	95% LCI	95% UCI
Total length	Large BNT	8.67	7.83	9.51
	Small BNT	9.95	8.26	11.65
	Large RBT	6.04	3.56	8.53
	Small RBT	11.25	9.64	12.85
Weight	Large BNT	63.39	59.96	66.81
	Small BNT	42.42	35.51	49.32
	Large RBT	13.58	3.44	23.73
	Small RBT	30.12	23.58	36.67

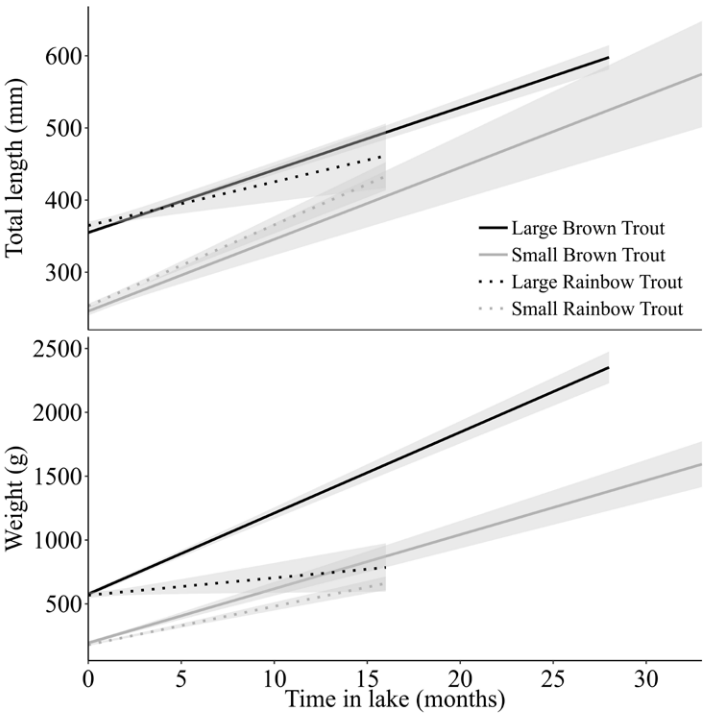

Figure 2. Predicted regression lines for total length (top) and weight (bottom) at time in lake for small and large brown trout and rainbow trout collected from Apalachia Reservoir, North Carolina. Shaded areas are 95% confidence level intervals for the predictions.

at 28 months, while the one small brown trout collected at 33 months weighed 2128 g (Table 3). Mean weights of large and small rainbow trout at 16 months were 1089 (SE = 254) and 1048 g (SE = 203). Total weight was also significantly related to species/size class group ($F = 887.6$, df = 3, 1762, $P < 0.001$) and age ($F = 1402.0$, df = 1, 1762, $P < 0.001$). However, the relationship between total weight and age varied across species/size class groups ($F = 49.2$, df = 3, 1762, $P < 0.001$). Therefore, total weight increased as age increases for all groups, but the rate of increase in total weight differed across groups (Table 4). Large brown trout grew at the fastest rate followed by small brown trout, small rainbow trout and large rainbow trout (Table 5, Figure 2).

Relative weight values during spring electrofishing were significantly different among species/size class groups ($F = 59.1$, df = 3, 223, $P < 0.001$). No difference was found between large and small rainbow trout W_r values ($P = 0.160$), whereas the remaining comparisons were significantly different ($P < 0.010$). Large brown trout were in the best condition during spring electrofishing with a mean W_r of 106 (SE = 4) followed by small brown trout with a mean W_r of 95 (SE = 3). Large and small rainbow trout mean W_r values were 80 (SE = 2) and 75 (SE = 1), respectively.

Diet Analysis

Stomach contents from 61 brown trout (34 large, 27 small) and 166 rainbow trout (48 large, 118 small) were examined from the 2014–2016 electrofishing samples (Table 6). Eight brown trout (6 large; 2 small) and six rainbow trout (3 large; 3 small) had empty stomachs. Fish were found in 71% of all large brown trout and were in ≥50% of large brown trout at 4, 16, and 28 months (Table 6). Blueback herring were identified in 35.7% of large brown trout, whereas clupeid species and unidentified fish were found in 25.0% and 50.0%, respectively. Only 28.6% of large brown trout contained macroinvertebrates and other items. Fish comprised 93.9% of the total weight of large brown trout stomachs, mostly blueback herring and clupeid species (Table 6). Conversely, macroinvertebrates comprised 2.2% of total stomach weight at 4 months and decreased to 0.0% at 28 months.

Fish were found in only 4.5% of small brown trout at 4 months but increased to 50.0% at 16 months (Table 6), when small brown trout had reached a mean TL of 419 mm. Macroinvertebrates were important components of small brown trout diets at 4 and 16 months. By weight, fish comprised 21.2% of small brown trout diets at 4 months and increased to 99% at 16 months (Table 6). In contrast, weight of macroinvertebrates in small brown trout diets decreased from 28.7% at 4 months to 1.0% at 16 months.

Fish were less prevalent in the diets of rainbow trout in both size groups. At 4 months, only 2.3% of large rainbow trout contained fish items and this number represented one trout that contained fish scales with no other evidence of fish consumption (Table 6). By 16 months, 50% of large rainbow trout contained fish, composing 98.2% of their diet by weight. The occurrence of fish in the stomachs of small rainbow trout increased from 14% at 4 months to 60% at 16 months, composing more than 50% of the diet by weight (Table 6). Blueback herring were not identified in the stomachs of large rainbow trout, but clupeids were found in 50.0% collected at 16 months. One blueback herring (155 mm TL) was identified in the stomach of a small rainbow trout that had been in the reservoir for 16 months.

Macroinvertebrates were an important diet item for rainbow trout of both size groups and were found in 82.2% of all large trout collected. By weight, macroinvertebrates comprised 41.8% of large rainbow trout diets at 4 months. Macroinvertebrates were found in 96.4% of small rainbow trout at 4 months and decreased to 60% at 16 months, and total weight also decreased from 61.8% of the diet at 4 months to 4.3% at 16 months. Other items such as vegetation, rocks and lures were found in 72.1% of large rainbow trout at 4 months and decreased to 0.0% at 16 months. Other items in small rainbow trout diets varied less through time and were found

Table 6. Percent of brown trout (BNT) and rainbow trout (RBT) collected from Apalachia Reservoir, North Carolina, containing diet items and stomach contents expressed as percentages of total stomach weight. Diet items are categorized as macroinvertebrates (MI), fish (All fish), and other items (Other). Fish are further broken down into blueback herring (BBH), clupeid spp (CLU), and unidentified fish (UNID fish). Percentages exclude trout with empty stomachs. Trout were collected via boat electrofishing samples 4, 16, and 28 months post stocking in Apalachia Reservoir, North Carolina. One small brown trout was collected that could not be aged due to a missing VIE mark and is therefore not included in age categories but is included in brown trout totals.

					Percent of trout containing diet items						Percent of total stomach contents weight					
Spp.	Size	Time in lake (month)	*n*	Total weight stomach contents (g)	MI (%)	BBH (%)	CLU (%)	UNID fish (%)	Fish total (%)	Other (%)	MI (%)	BBH (%)	CLU (%)	UNID fish (%)	Fish total (%)	Other (%)
BNT	Large	4	17	195.2	41.2	17.6	29.4	47.1	58.8	35.3	2.2	32.8	30.1	12.0	74.9	22.9
		16	9	398.7	11.1	66.7	11.1	55.6	100.0	11.1	0.3	72.4	1.1	26.2	99.7	0.0
		28	2	224.9	0.0	50.0	50.0	50.0	50.0	50.0	0.0	44.6	37.9	17.5	100.0	0.0
		Total	28	818.8	28.6	35.7	25.0	50.0	71.4	28.6	0.7	55.3	18.1	20.4	93.9	5.5
	Small	4	22	18.9	86.4	0.0	0.0	4.5	4.5	40.9	28.7	0.0	0.0	21.2	21.2	50.1
		16	2	20.6	100.0	50.0	0.0	0.0	50.0	0.0	1.0	99.0	0.0	0.0	99.0	0.0
		Total	25	98.1	84.0	8.0	4.0	8.0	12.0	36.0	5.8	55.1	18.5	11.0	84.6	9.7
	BNT total		53	916.9	54.7	22.6	15.1	30.2	43.4	32.1	1.2	55.3	18.2	19.4	92.9	5.9
RBT	Large	4	43	121.9	81.4	0.0	0.0	2.3	2.3	72.1	41.8	0.0	0.0	0.0	0.0	58.2
		16	2	25.8	100.0	0.0	50.0	50.0	50.0	0.0	1.8	0.0	18.4	79.9	98.2	0.0
		Total	45	147.7	82.2	0.0	2.2	4.4	4.4	68.9	34.8	0.0	3.2	14.0	17.2	48.0
	Small	4	110	106.5	96.4	0.0	0.0	13.6	13.6	47.3	61.8	0.0	0.0	1.6	1.6	36.6
		16	5	45.5	60.0	20.0	0.0	40.0	60.0	60.0	4.3	51.3	0.0	5.1	56.5	39.2
		Total	115	151.9	94.8	0.9	0.0	14.8	15.7	47.8	44.6	15.4	0.0	2.6	18.0	37.4
	RBT total		160	299.7	91.3	0.6	0.6	11.9	12.5	55.0	39.8	7.8	1.6	8.2	17.6	42.6

in 47.3% and 60.0% at 4 and 16 months, respectively, and contributed to approximately 40% of the total weight (Table 6).

Discussion

Brown trout stocked into Apalachia Reservoir were able to survive and grow up to 33 months during the study, whereas rainbow trout were only collected in gill-net and electrofishing surveys up to 16 months after stocking. Reduced survival of rainbow trout was also evident in angler harvest during a year-long creel survey in 2015, when 97% of the rainbow trout harvested were from the previous year's stocking and the oldest rainbow trout had been in the reservoir for 15 months (Bushon et al. 2018). In contrast, only 76.1% of brown trout harvested were from the previous year's stocking and the oldest brown trout had been in the reservoir for 32 months. Furthermore, harvest of rainbow trout by anglers was low compared to brown trout; only 24% of all trout harvested were rainbow trout. Therefore, low survival of rainbow trout was unlikely due to angler harvest, nor did size at stocking appear to give any advantage, as both sizes of rainbow trout showed similar survival. Barwick (1985) found similar results in Lake Jocassee, South Carolina, despite stocking approximately four times the number of rainbow trout to brown trout. That study concluded that low catch rates were due to higher mortality rates associated with the strain of rainbow trout stocked. Different strains of rainbow trout have been shown to have varying rates of survival, growth, piscivory, and catchability (Brauhn and Kincaid 1982, Babey and Berry 1989, Hubert et al. 1994). The strain of rainbow trout utilized by NCWRC and stocked in Apalachia Reservoir, Arlee-Erwin, may be ill-suited to reservoir habitat, because these fish have a short life span and may not convert readily to piscivory (Adam Moticak, NCWRC, personal communication).

Diet data confirmed that rainbow trout stocked in Apalachia Reservoir did not switch to piscivory quickly after stocking. Diets of rainbow trout consisted primarily of macroinvertebrates, whereas brown trout were more piscivorous throughout the study. Furthermore, rainbow trout piscivory was not dictated by size at stocking. Fish became a more predominant diet item 16 months after stocking when both size classes of rainbow trout were over 400 mm TL, but even then only 60% of rainbow trout had consumed fish. Weiland and Hayward (1997) found similar results in Lake Taneycomo, Missouri, where they found that rainbow trout across different size groups had very similar diets which contributed to reduced growth after stocking. Large rainbow trout in Lake Taneycomo consumed few fish, whereas brown trout stocked at catchable sizes first fed primarily on benthic macroinvertebrates but gradually included piscine prey as they grew to reach larger sizes (Weiland and Hayward 1997). Numerous other researchers have found that rainbow trout do not convert to piscivory as readily as brown trout, and even once piscivory begins, macroinvertebrates and zooplankton remain large components of their diet (Bivens and Strange 1987, Hubert et al. 1994, Wang et al. 1996, Haddix and Budy 2005, Bergthold and Bettoli 2009, Winters and Budy 2015).

Small brown trout also rarely consumed fish within four months after stocking but fish became a larger portion of their diet at 16 months when they had reached a mean TL of 419 mm. Small brown trout were most likely too small too small at 4 months (mean TL = 260 mm) to exploit the blueback herring available in Apalachia Reservoir at the time. The prey-predator size ratio most often cited for trout is on average 20%–30% of TL, with an upper limit around 50% (Jensen et al. 2008, Winters and Budy 2015). Blueback herring collected from Apalachia Reservoir during 2017 spring electrofishing samples averaged 140 mm TL (NCWRC unpublished data), closely matching the size of blueback herring found in the stomachs of large brown trout (137 mm TL). However, those in the stomachs of small brown trout were considerably smaller (108 mm TL). Mean lengths of blueback herring consumed by small and large brown trout were 26% and 30% of trout length, respectively. Conversely, the average length of blueback herring available during the same time of year were 53% and 47% of the mean lengths of small brown trout and rainbow trout, respectively, likely too large for easy consumption.

Small trout of both species appeared to convert to a piscivorous diet by 16 months when they had reached a mean TL of ≥ 400 mm. However, it is difficult to pinpoint when small trout became piscivorous because diet data was only collected during spring electrofishing samples. Smaller juvenile blueback herring may become abundant in late spring and early summer, and the small trout may have been able to take advantage of the smaller forage base between samples at 4 and 9 months in the reservoir. Furthermore, Taylor and Bulak (2011) found that forage abundance was at an annual low in spring (mid-March to mid-May), corresponding to the timing of our spring electrofishing samples, but recovered following reproduction and recruitment in early summer. A better understanding of the life history of blueback herring in Apalachia Reservoir could improve growth of small brown trout by timing the stocking to coincide with higher densities of juvenile blueback herring. Additionally, increased understanding of long-term variability of the blueback herring population may assist future evaluations of stocked trout performance.

Although the smaller size group of both species did not convert to piscivory quickly after stocking, they grew faster in length compared to the larger size classes. These results are not unexpected since smaller fish have greater growth potential because growth slows at older ages (von Bertalanffy 1957). Small rainbow trout grew in length at the fastest rate, but due to high mortality, they were not able to reach larger sizes. In contrast, brown trout of both size classes were able to reach larger sizes given their higher survival and greater piscivorous diet.

When considering weight gains, large brown trout, followed by small brown trout, grew significantly faster than both sizes of rainbow trout. These weight gains can most likely be attributed to the piscivorous diet of brown trout. Therefore, although brown trout were not growing fastest in terms of changes in length, they were adding weight faster than rainbow trout. Piscivory and associated weight gains by brown trout were also reflected in brown trout condition values. Due to hatchery conditions, all trout were in very good condition and averaged ≥ 95 W_r values when stocked. However, brown trout were in better condition with higher W_r values than rainbow trout during spring electrofishing surveys. In some instances, brown trout were quite robust, for example, we collected a large brown trout after 28 months in the reservoir that contained 36 blueback herring in its stomach and had a W_r of 167.

Stocked trout were difficult to recapture in Apalachia Reservoir and individuals with longer residency times were particularly challenging to collect. Thus, sample sizes of older trout were low and our observations on growth and survival should be viewed with caution. However, we created a popular brown trout fishery and our study demonstrated that brown trout were able to survive and grow to trophy sizes while rainbow trout did not reach larger sizes due to short residence times. As such, our management recommendations are: (1) discontinue rainbow trout stockings, (2) continue to stock 1000 large brown trout, and (3) increase the number of small brown trout to 3000 to mitigate for the loss of rainbow trout to the angler creel. While large brown trout performed the best in Apalachia Reservoir, they are more difficult and expensive to produce in our hatchery system; therefore, increasing the number of small brown trout is a more feasible solution. Fisheries managers are increasingly tasked with creating new management options that can mitigate for or take advantage of new reservoir dynamics created by introduced species. Our data indicated that reservoir brown trout stockings are one such option that can create a popular fishery while exploiting a new invasive alosine forage base.

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