Trout Population and Temperature Monitoring within Nantahala River Bypass Reach, North Carolina, in Response to Recreational Flow Releases

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Abstract: Recreational flow releases were established within the Nantahala Bypass Reach through the Federal Energy Regulatory Commission relicensing of Duke Energy's Nantahala Project. In 2012–2013, the North Carolina Wildlife Resources Commission, in conjunction with other resource managers, attempted to monitor the influence of recreational flow events on wild rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*) populations within Nantahala Bypass Reach and Nantahala Tailwater. Monitoring included temperature loggers and fish population sampling. Temperature effects of release events were most pronounced during late summer and fall. Densities and standing crop estimates of wild trout > 100 mm TL did not vary substantially among the sample dates; however, rainbow trout ≤100 mm TL were not present during the last sample date at either site. Although recreational releases have the potential to affect wild trout populations and further wild trout monitoring is warranted, stocking trout in the bypass reach remains a viable management approach.

Key words: survival, density, tailwater, *Oncorhynchus mykiss*, *Salmo trutta*

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Efforts to establish flood control and hydropower generation have led to the creation of numerous reservoirs throughout the United States during the twentieth century (Miranda 1996). Altered temperature regimes in rivers below dams resulting from dam operation have allowed creation of economically important coldwater fisheries (e.g., Long and Martin 2008, Scholten et al. 2008), including multiple river systems in western North Carolina. These fisheries depend on cold-water releases from upstream dams to persist and can be vulnerable to competing demands from other user groups (Goudreau et al. 2008).

In 1942, a dam and hydroelectric powerhouse were constructed on the Nantahala River, North Carolina, forming Nantahala Lake. Unlike many hydropower reservoirs that discharge water immediately below their dam, the majority of water from Nantahala Lake is directed through an approximately 9-km pipeline and tunnel system to the powerhouse, where water is then discharged into the Nantahala Tailwater (hereafter, "Tailwater"). This diversion results in a 15-km reach of river with reduced flows, known as the Nantahala Bypass Reach (hereafter, "Bypass"; Figure 1). Median annual flow within the Bypass is 2.7 m^3 sec^{-1} which represents 23% of the median annual flow of the Nantahala River at the confluence of the Bypass and the Nantahala hydropower discharge canal (Duke Energy Corporation 2004).

Hydropower releases from the Nantahala Powerhouse (hereafter, "Powerhouse") create whitewater features within the Tailwater

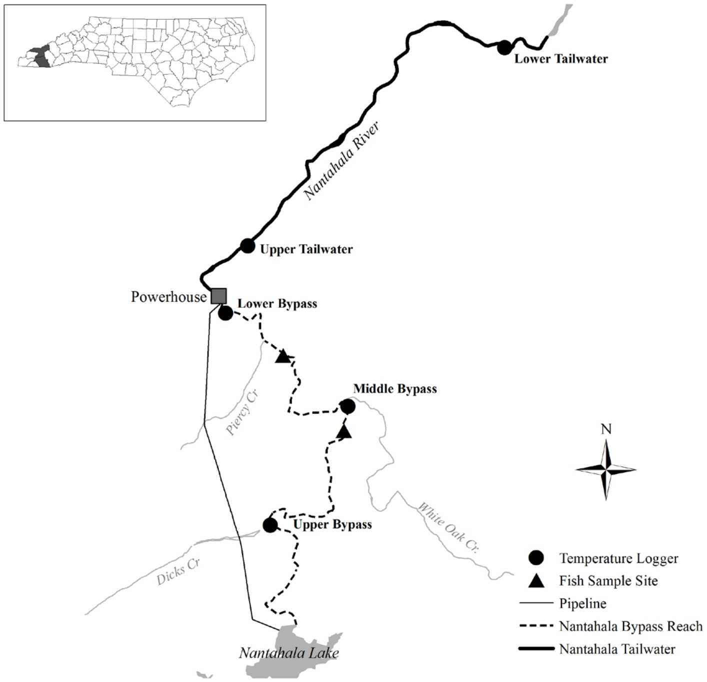

Figure 1. Temperature logger (circle) and electrofishing (triangle) locations within Nantahala Bypass Reach and Nantahala Tailwater, North Carolina, sampling September 2012–July 2014.

making it a popular destination for recreational whitewater paddlers. Paddling enthusiasts also wished to use the Bypass, but flow events suitable for paddling were restricted to spillway releases or natural hydrological events that resulted in spillage over Nantahala Dam. As such, the need for predictable events to accommodate paddling was identified via collaborative stakeholder input within the Federal Energy Regulatory Commission (FERC) relicensing of Duke Energy's Nantahala Project (Smutko and Addor 2004).

Provisions of the new FERC license established the delivery of eight high-flow events per year within the Bypass via scheduled spillway releases from the epilimnion of Nantahala Lake (FERC 2012). These recreational flows began in September 2012 and were designed to provide whitewater paddling opportunities. The North Carolina Wildlife Resources Commission (NCWRC) and other resource managers (North Carolina Division of Water Resources, U. S. Fish and Wildlife Service, and U. S. Forest Service) were charged with monitoring the fish populations in response to the newly established releases, and all monitoring efforts were required to occur within the first two years of recreational flow events (Smutko and Addor 2004). Currently, the NCWRC manages trout fisheries within the Bypass and Tailwater under its Public Mountain Trout Waters program. Two regulatory classifications are present on three contiguous stream segments: Hatchery Supported Trout Waters (Nantahala Dam to Whiteoak Creek); Delayed Harvest Trout Waters (Whiteoak Creek to the Nantahala hydropower discharge canal); and Hatchery Supported Trout Waters (Nantahala hydropower discharge to Fontana Reservoir water level; Figure 1). Together, the Bypass and Tailwater are stocked annually with a total of 25,500 brook trout (*Salvelinus fontinalis*), rainbow trout (*Oncorhynchus mykiss*), and brown trout (*Salmo trutta*). These resources also contain self-reproducing populations of rainbow trout and brown trout, and occasionally brook trout from Nantahala River tributaries.

Public Mountain Trout Waters are popular destinations for anglers (Responsive Management 2007) and contribute substantially to local economies (Responsive Management 2009). Spillway releases from Nantahala Dam introduce surface water into the Bypass that has the potential to alter temperature regimes. Water temperature affects the survival and growth of fishes, especially salmonids, and temperatures consistently below or above a species thermal threshold can result in stress or mortality (Krause et al. 2005). Although limited in temporal scope, this two-year study sought to provide information regarding thermal and biological influences of recreational flow releases into the Bypass and Tailwater below Lake Nantahala.

Table 1. Release events within the Nantahala Bypass Reach, North Carolina, during the 2012 to 2014 study period. The second day of the fall event consists of two flow levels with the higher flow in the morning followed immediately by the lower flow level.

Season	Target release window	Release dates			Target flow ($m^3 sec^{-1}$)	Release duration (h)
		2012	2013	2014		
Spring	15–30 Apr	–	27 Apr	26 Apr	7.1	6
		–	28 Apr	27 Apr	9.9	6
Summer	15 Jun–31 Aug	–	22 Jun	21 Jun	7.1	3
		–	1 Jul	2 Jul	7.1	3
		–	17 Jul	19 Jul	7.1	3
		–	1 Sep[a]	16 Aug	7.1	3
Fall	15–30 Sep	29 Sep	28 Sep	27 Sep	8.5	7
		30 Sep	29 Sep	28 Sep	12.0	5
		30 Sep	29 Sep	28 Sep	7.1	2

a. Date moved outside of time frame with FERC approval

Methods

From 2012–2014, temperature and wild salmonid population monitoring efforts were conducted at 7 sites in the Nantahala River below Nantahala Dam (Figure 1). These survey efforts concentrated on temporal periods associated with scheduled releases of water from Nantahala Lake's epilimnion into the Bypass to create recreational flows (Table 1). Per the relicensing agreement, recreational releases occurred on a total of eight days annually in spring (15–30 April), summer (15 June–31 August), and fall (15–30 September). Releases varied in duration (2–7 h) and flow (7.1–12.0 m^3sec^{-1}) among events (Table 1). Events in the spring and fall occurred on consecutive days. The second day of the fall event consisted of a higher flow in the morning that was reduced to a lower flow in the afternoon. In addition, concurrent releases from the Powerhouse into the Tailwater accompanied all Bypass release events during the study. Discharge from the Powerhouse supplies water from the hypolimnion of Nantahala Lake and thus has the potential to mitigate downstream thermal impacts associated with recreational flow releases.

Temperature Monitoring

From 1 August 2012–15 July 2014, Onset Computer Corporation HOBO Pro v2 temperature data loggers (Bourne, Massachusetts) were deployed at three locations in the Bypass and two in the Tailwater: upstream of Dicks Creek (upper Bypass), upstream of White Oak Creek (middle Bypass), upstream of Nantahala Powerhouse (lower Bypass), and in two areas of the Tailwater (upper and lower Tailwater; Figure 1). Temperature recordings were generally obtained at 5-min intervals during the study; however, several loggers were inadvertently set to record at 1-h intervals for certain periods. Mean and maximum temperatures were calculated for

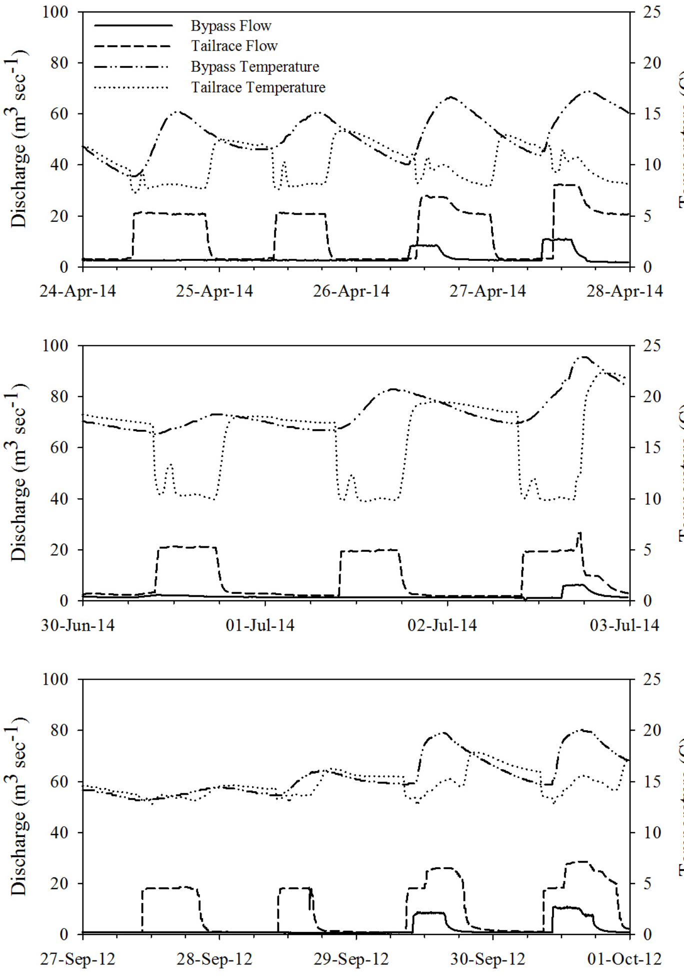

Figure 2. Example of flow and temperature changes two days prior to and during release events on 26–27 April 2014 (top), 2 July 2014 (middle), and 29–30 September 2012 (bottom) within the Nantahala Bypass Reach and the Nantahala Tailwater.

each release event and the two-day period prior to each event. For the spring and fall an event was considered to comprise the two consecutive days of releases. Mean temperatures of each event and prior two-day period were compared using a Student's *t*-test ($P < 0.05$).

Fish Surveys

Depletion population estimates were conducted as described by the Southern Division of the American Fisheries Society Trout Committee (1992) at two 100-m sites within the Bypass: upstream of White Oak Creek and upstream of the Powerhouse (Figure 1). Surveys were conducted on 24 September 2012 (prior to the first release event), 4 October 2012 (after first release event), and 3 October 2013 (after first full year of releases). Block nets were used at each site to ensure that the sample population was closed during sampling, and three upstream electrofishing passes were conducted via one backpack electrofisher and netter per every 3 m of the average wetted stream width. For each pass, all trout were weighed (g) and measured for total length (TL, mm). Non-trout species were identified, enumerated, and the range in total length (mm) and an aggregate weight (g) were recorded. All fish from each pass were placed into live cages outside of the sample site and released throughout the sample site following completion of the final pass. Trout density (number fish ha^{-1}), standing crop (kg ha^{-1}), and associated 95% confidence intervals were generated for trout ≤ 100 mm TL and > 100 mm TL by site according to Burnham's maximum likelihood estimate (Van Deventer and Platts 1989). These size classes typically represent age-0 and adult wild trout in southern Appalachians streams during the time of year sampled (Larson and Moore 1985, Kulp and Moore 2000, Habera et al. 2010).

Results

Temperature Monitoring

Temperatures were recorded from August 2012–July 2014. Release events influenced temperatures within the Bypass and Tailwater by varying amounts depending on year and season (Figure 2). Release events always raised water temperatures in the Bypass, and the most pronounced differences occurred during summer and fall (Table 2). During release events, the highest temperatures were observed at the upper Bypass site and decreased downstream (Table 2). In the Bypass, mean temperatures during the release events were always higher than the mean temperatures of the two-day period prior to events (t range = 6.22 – 27.41; $P < 0.001$; Table 2). Average variations between maximum temperatures of the release events and the two-day periods prior to releases were 0.6 C (SE = 0.6) in spring, 2.4 C (SE = 0.3) in summer, and 3.8 C (SE = 0.3) in fall (Table 2). The highest release temperature was 25.9 C in July 2014 (Table 2) and water temperatures remained at that temperature for 55 min.

Mean temperatures in the Tailwater differed during release events (t range = 2.32 – 21.51; $P < 0.05$) except at the lower Tailwater site in September 2013 ($t = 1.70$; $P = 0.090$; Table 3). However, temperature increases within the Tailwater were not as pronounced as those within the Bypass. Changes in maximum temperatures of the two-day period prior to releases events and release events in the spring, summer, and fall were −0.4 C (SE = 0.4), 0.3 C (SE = 0.4), and 0.9 C (SE = 0.3), respectively (Table 3). Temperatures at the upper Tailwater site reached 22.3 C for 1 h during the July 2014 event, but the average temperature during the event was only 16.7 C (SE = 0.3; Table 3).

Table 2. Maximum (Max), mean, and SE of temperature (C) in the Nantahala Bypass Reach, North Carolina, for high-flow release events and two days prior to the flow event. Temperature data were collected on 5-min intervals ($n = 288$ for 1 day and $n = 576$ for 2 days) except for September 2012, when prior day sample sizes were 202 (Upper), 463 (Middle), and 455 (Lower). All comparisons of mean temperature between events and prior days were significant ($P < 0.001$).

	Upper						Middle						Lower					
	Prior			Event			Prior			Event			Prior			Event		
Season/Date	Max	Mean	SE	Max	Mean	SE	Max	Mean	SE	Max	Mean	SE	Max	Mean	SE	Max	Mean	SE
Spring																		
27–28 Apr 2013	15.6	13.7	0.1	14.9	14.1	0.1	15.5	12.9	0.1	14.5	13.4	0.0	14.5	12.4	0.1	14.0	12.8	0.0
26–27 Apr 2014	15.9	13.4	0.1	17.7	15.0	0.1	15.4	13.0	0.1	17.6	14.5	0.1	15.5	12.9	0.1	17.6	14.3	0.1
Summer																		
22 Jun 2013	19.5	18.1	0.0	23.0	19.5	0.1	18.1	16.6	0.0	22.0	17.9	0.1	18.2	16.6	0.0	20.9	17.5	0.1
1 Jul 2013	20.4	18.8	0.0	24.6	20.3	0.1	19.1	17.3	0.0	22.8	18.6	0.1	19.0	17.5	0.0	21.3	18.1	0.1
17 Jul 2013	22.4	20.2	0.1	22.6	21.7	0.0	21.8	19.1	0.1	22.2	20.8	0.0	22.2	19.1	0.1	22.1	20.6	0.1
1 Sep 2013	21.6	19.8	0.0	24.9	21.2	0.1	20.7	19.0	0.0	23.9	20.0	0.1	20.5	19.3	0.0	22.7	19.9	0.1
21 Jun 2014	22.4	20.2	0.1	24.3	21.3	0.1	21.7	18.9	0.1	23.1	20.0	0.1	20.3	18.0	0.1	22.3	19.3	0.1
2 Jul 2014	23.0	19.9	0.1	25.9	22.4	0.0	21.7	18.6	0.1	24.7	20.2	0.1	20.7	18.3	0.0	23.9	20.2	0.1
Fall																		
29–30 Sep 2012	16.2	15.4	0.1	21.3	19.0	0.1	16.2	14.8	0.0	20.7	17.9	0.1	15.8	14.9	0.0	19.4	17.1	0.1
28–29 Sep 2013	17.9	16.5	0.0	21.3	19.0	0.1	17.4	15.7	0.0	20.4	17.7	0.1	16.6	15.2	0.0	19.8	16.7	0.1

Table 3. Summary statistics of temperature (C) in the Nantahala Tailwater, North Carolina, for high-flow release events and two days preceding the flow event. Mean temperatures were different between events and prior days ($P < 0.05$), except for the lower site during September 2013 ($P = 0.09$).

	Upper								Lower							
	Prior two days				Event				Prior two days				Event			
Season/Date	Max	Mean	(SE)	*n*	Max	Mean	(SE)	*n*	Max	Mean	(SE)	*n*	Max	Mean	(SE)	*n*
Spring																
27–28 Apr 2013	11.1	8.8	(0.2)	48	10.3	9.9	(0.0)	48	12.2	9.6	(0.2)	48	10.9	10.5	(0.0)	48
26–27 Apr 2014	13.3	9.9	(0.1)	576	13.1	10.4	(0.1)	576	12.7	9.3	(0.1)	576	13.4	10.5	(0.1)	576
Summer																
22 Jun 2013	12.8	10.8	(0.0)	576	12.6	11.2	(0.0)	288	13.4	11.5	(0.1)	48	13.7	12.1	(0.2)	24
1 Jul 2013	18.0	14.0	(0.1)	576	16.2	12.9	(0.1)	288	17.9	13.9	(0.2)	48	15.8	12.6	(0.2)	24
17 Jul 2013	14.9	13.3	(0.0)	576	14.5	13.8	(0.0)	288	17.3	14.3	(0.2)	48	16.4	15.0	(0.2)	24
1 Sep 2013	19.1	16.9	(0.1)	576	21.5	17.8	(0.1)	288	18.4	16.1	(0.0)	576	18.5	16.4	(0.0)	288
21 Jun 2014	19.0	13.3	(0.2)	576	20.8	16.1	(0.3)	288	17.0	11.4	(0.1)	576	18.3	13.1	(0.1)	288
2 Jul 2014	19.5	15.2	(0.2)	576	22.3	16.7	(0.3)	288	18.0	13.5	(0.1)	576	18.8	14.0	(0.1)	288
Fall																
29–30 Sep 2012	16.3	14.2	(0.0)	477	17.9	15.3	(0.1)	576	15.5	14.0	(0.0)	466	16.1	14.8	(0.0)	576
28–29 Sep 2013	15.7	15.3	(0.0)	576	16.6	15.5	(0.0)	576	17.1	15.8	(0.0)	576	17.4	15.8	(0.0)	576

Trout Population Characteristics

Brook trout, brown trout, and rainbow trout were captured during fish surveys in the Bypass during the 2012–2013 survey period. Rainbow trout (79.8%) were the most common salmonid captured followed by brown trout (19.8%) and brook trout (0.4%). Only wild brown trout and wild rainbow trout were captured at each site during the three surveys. One brook trout was captured during the study period at the lower site during the October 2013 sample. Given its coloration and eroded pectoral and caudal fins, the fish was most likely of hatchery origin and was therefore excluded from density and standing crop estimates. Eight non-trout fish species were observed at rates consistent with previous collections (Duke Energy Corporation 2004).

Brown trout and rainbow trout captured during the September 2012 sampling varied from 103 to 483 mm TL (mean = 198 mm TL; SD = 108) and 71 to 355 mm TL (mean = 140 mm TL; SD = 54),

Table 4. Trout density (fish ha^{-1}) estimates and associated 95% confidence intervals by species for the Nantahala Bypass Reach, North Carolina, during 2012–2013. Confidence intervals were not calculated for samples of less than two fish.

		Brown trout		Rainbow trout		All trout	
Date	**Site**	**≤100 mm TL**	**>100 mm TL**	**≤100 mm TL**	**>100 mm TL**	**≤100 mm TL**	**>100 mm TL**
24 Sep 2012	Upstream	0	166 (186, 146)	176 (185, 168)	404 (437, 371)	176 (185, 168)	570 (608, 532)
	Downstream	0	30 (56, 4)	109 (122, 96)	208 (235, 182)	109 (122, 96)	238 (274, 202)
4 Oct 2012	Upstream	34 (69, –1)	136 (166, 106)	113 (124, 103)	374 (399, 349)	147 (168, 127)	510 (549, 472)
	Downstream	0	20 (28, 12)	10	150 (175, 125)	10	170 (196, 144)
3 Oct 2013	Upstream	0	101 (122, 80)	0	343 (374, 311)	0	443 (481, 405)
	Downstream	0	40 (59, 20)	0	366 (476, 257)	0	406 (517, 295)

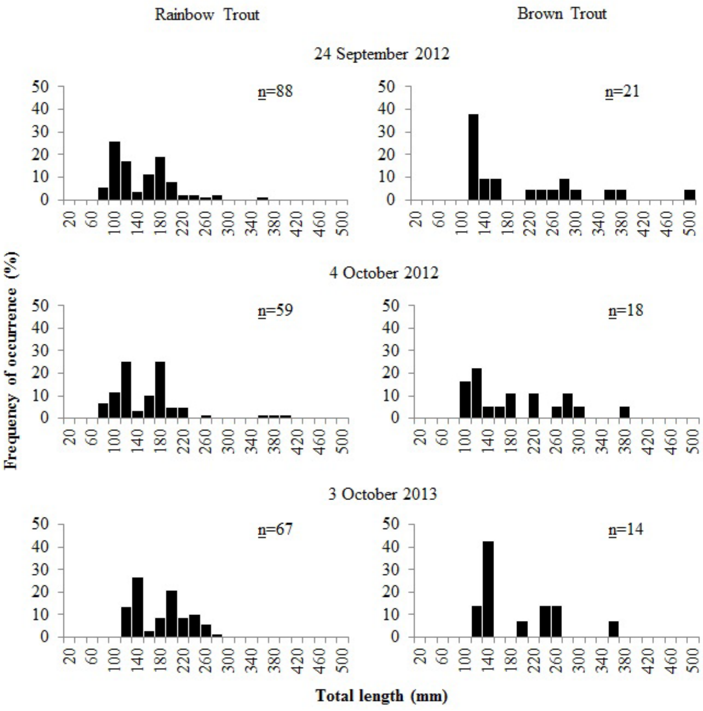

Figure 3. Brown trout and rainbow trout length-frequency histograms (sites pooled) from the Nantahala Bypass Reach, North Carolina, electrofishing samples on 24 September 2012, 4 October 2012, and 3 October 2013.

respectively (Figure 3). During October 2012, size structures for brown trout and rainbow trout varied from 91 to 379 mm TL (mean = 180; SD = 83) and 74 to 383 mm TL (mean = 151; SD = 65), respectively (Figure 3). Brown trout lengths varied from 116 to 349 mm TL (mean = 182; SD = 70) and rainbow trout lengths varied from 101 to 279 mm TL (mean = 171; SD = 46) during the final collection event in October 2013 (Figure 3).

Length-frequency distributions revealed that the overall proportion of rainbow trout ≤100 mm TL declined throughout the survey period: 32% (September 2012), 19% (October 2012), and 0% (October 2013). The proportion of brown trout ≤100 mm was also low during the study period (range = 0 – 17%). Accordingly, density and standing crop estimates of trout ≤ 100 mm TL were variable over all sampling events and sites, but densities declined at both sites during the study period (Table 4). Densities of rainbow trout ≤ 100 mm TL in the upstream and downstream sites declined from 176 fish ha^{-1} and 109 fish ha^{-1}, respectively, to 0 fish ha^{-1} in October 2013. Standing crop estimates followed a similar pattern; except at the upstream site, where rainbow trout standing crop increased from 1.1 kg ha^{-1} to 1.2 kg ha^{-1} before declining to 0 kg ha^{-1} in October 2013 (Table 5). Brown trout ≤ 100 mm TL were rarely captured during the study.

Densities and standing crop estimates of trout > 100 mm TL were less variable than the smaller size class of trout during the study period. Total densities of trout > 100 mm TL varied from 170 fish ha^{-1} to 570 fish ha^{-1} across areas and samples (Table 4), and total standing crop likewise varied from 12.3 kg ha^{-1} to 32.0 kg ha^{-1} (Table 5). Densities of rainbow trout > 100 mm TL steadily decreased at the upstream site during the study period, but standing crop was highest (20.3 kg ha^{-1}) during the last sample in October 2013. Rainbow trout densities and standing crop estimates at the downstream site were highest on the final sample date (Table 4 and Table 5). Densities of brown trout > 100 mm TL followed a spatial and temporal pattern similar to rainbow trout (Table 4).

Discussion

Although temporal constraints due to FERC relicensing requirements restricted our study to a two-year period, we were still able to examine potential influences of these releases in the Bypass. This information provided insight into the unique situation that surrounded these releases: multi-season, epilimnion discharges into a bypassed river channel that contains popular coldwater fish-

Table 5. Trout standing crop (kg ha^{-1}) estimates and associated 95% confidence intervals by species for the Nantahala Bypass Reach, North Carolina, during 2012–2013. Confidence intervals were not calculated for samples of less than two fish.

		Brown trout		Rainbow trout		All trout	
Date	**Site**	**≤100 mm TL**	**>100 mm TL**	**≤100 mm TL**	**>100 mm TL**	**≤100 mm TL**	**>100 mm TL**
24 Sep 2012	Upstream	0.0	15.4 (19.0, 12.0)	1.1 (1.3, 1.0)	16.6 (20.0, 14.0)	1.1 (1.3, 1.0)	32.0 (36.0, 28.0)
	Downstream	0.0	0.8	0.9 (1.1, 0.7)	11.5 (15.0, 8.0)	0.9 (1.1, 0.7)	12.3 (15.0, 8.0)
4 Oct 2012	Upstream	0.4 (0.9, –0.2)	8.2 (13.0, 3.0)	1.2 (2.3, 0.1)	14.4 (17.0, 11.0)	1.6 (2.6, 0.5)	22.6 (28.0, 17.0)
	Downstream	0.0	4.1 (7.0, 1.0)	0.1	19.2 (24.0, 15.0)	0.1	23.3 (28.0, 19.0)
3 Oct 2013	Upstream	0.0	7.3 (8.0, 7.0)	0.0	20.3 (24.0, 17.0)	0.0	27.6 (31.0, 24.0)
	Downstream	0.0	4.8 (9.0, 0.0)	0.0	19.4 (25.0, 14.0)	0.0	24.2 (30.0, 18.0)

eries. Biological data were limited; however, thermal data documented the magnitude and extent of the effects of the introduction of Nantahala Lake's surface water into the Bypass. Temperature changed during all release events but to a greater extent during fall and summer releases. Summer release events produced the highest maximum water temperatures in the Bypass, and summer temperatures there were generally above reported preferred temperatures of brown trout (12.4–17.6 C; MacCrimmon and Marshall 1968, Coutant 1977) and rainbow trout (12–19 C; Raleigh et al. 1984) prior to the releases, and temperatures further increased during release days. Furthermore, maximum temperatures were close to or within the upper incipient lethal temperature range of 24–26 C for brown trout and rainbow trout (Hokanson et al. 1977, Raleigh et al. 1984, Eaton et al. 1995, Weherly et al. 2007) at sites within the Bypass during some mid-summer and fall releases. However, duration of these temperatures was brief, and it has been reported that both species can withstand temperatures in these ranges for up to one day (Raleigh et al. 1984, Weherly et al. 2007). Brown trout and rainbow trout within the Bypass may also have sought out thermal refuge during the short period of elevated temperature (Ebersole et al. 2001 and 2003, Kaya et al. 2007, Petty et al. 2012). In general, the warmest temperatures were found upstream of the confluence of Dicks Creek, while temperatures in downstream portions of the Bypass were below the lethal range and therefore could have provided thermal refuge during summer recreational flows.

Within the Tailwater, temperature effects of the releases were much less pronounced. While the difference between the mean temperatures two days prior to and during release events were almost always statistically significant, the differences were small and the maximum temperatures stayed well below the upper lethal temperature limit for brown trout and rainbow trout. However, maximum temperatures were above the preferred temperature range for brown trout and rainbow trout at the upper site during the final summer release in 2013 and both summer releases in 2014. Temperature effects within the Tailwater were lessened due to concurrent releases from the Powerhouse that discharged cold water from the hypolimnion of Nantahala Lake. Thus, these concurrent releases appear to be very important in maintaining thermal trout habitat in the Tailwater.

Temperature data collected during summer and fall releases in the Bypass and Tailwater showed that maximum water temperature can be near or above the preferred temperature range of trout. However, temperatures recorded during summer and fall 2013 were most likely not representative of typical conditions expected during release events. Water temperatures were likely cooler than normal given uncharacteristically high precipitation and cooler ambient air temperatures for the period. Warmer and dryer conditions were present in 2014, but monitoring only lasted through the first two summer releases. Therefore, further monitoring is needed to assess the thermal impacts of summer and fall spillway releases on the Bypass and Tailwater.

Estimates of trout densities and standing crop were limited due to the short study period and low sample size. We found that all trout densities and standing crop estimates were highly variable over the study period, but this is consistent with other trout populations in western North Carolina and could be attributed to natural environmental variation (Borawa et al. 2001). Based on data observed in this study, sources of this variability were difficult to identify and differentiate from natural processes.

While estimates were variable among all sample dates, rainbow trout ≤100 mm TL were not present during the final sample at either site. Length-frequency distributions revealed that the overall proportion of these rainbow trout declined throughout the survey period from 32% in 2012 to 0% in 2013. There are several factors that could have contributed to the decrease in the capture of rainbow trout in this smaller size class. Western North Carolina experienced elevated rainfall in 2013 resulting in increased discharge in the Bypass especially during summer months. High flows associated with natural and release events during spring and summer had the potential to influence observed rainbow trout values. Rainbow trout spawn during late winter to late spring and usually emerge at the swim up stage 45–75 days later, depending on temperature (Raleigh et al. 1984). During this period of life, young fish have limited swimming capabilities and are susceptible to downstream displacement (Irvine 1986, Heggenes and Traaen 1988, Nuhfer et al. 1994, Jenson and Johnson 1999). Additionally, spring and summer release events may coincide with the swim-up stage of rainbow trout and present the potential of downstream displacement, but due to potential confounding effects associated with naturally occurring high-flow events, determining the influence of scheduled releases on trout recruitment during years is difficult. Furthermore, susceptibility of trout ≤100 mm TL to electrofishing can be variable, so differences in these densities could be a function of capture efficiency (SDAFSTC 1992, Habera et al. 2010).

Although this study focused on wild trout resources, it is important to note that popular stocked-trout fisheries remain in the study area. It does not appear that spillway releases during the study impacted these resources or the NCWRC's ability to manage them. Flows did alter angler use patterns for these fisheries due to unsafe or undesirable angling conditions, but improvements to informational signage along the Bypass during the study increased angler awareness of spillway-release events. It is important that these and other efforts to educate the angling public about release events continue. Additionally, spillway releases should remain in periods outside of NCWRC stocking events to avoid heightened angler usage and minimize the loss of stocked trout via downstream displacement.

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Literature Cited

Borawa, J. C., J. H. Mickey, Jr., C. J. Goudreau, and M. M. Clemmons. 2001. Wild trout population monitoring summary, 1989–1996. North Carolina Wildlife Resources Commission, Federal Aid in Sport Fish Restoration, Raleigh.

Coutant, C. C. 1977. Compilation of temperature preference data. Journal of the Fisheries Research Board of Canada 34:739–745.

Duke Energy Corporation. 2004. Nantahala hydroelectric project, FERC #2692, license application volume I, Charlotte, North Carolina.

Eaton, J. G., J. H. McCormick, B. E. Goodno, D. G. O'Brien, H. G. Stefany, M. Hondzo, and R. M. Scheller. 1995. A field information-based system for estimating fish temperature tolerances. Fisheries 20:10–18.

Ebersole, J. L., W. J. Liss, and C. A. Frissell. 2001. Relationship between stream temperature, thermal refugia and rainbow trout (*Oncorhynchus mykiss)* abundance in arid-land streams in the northwestern United States. Ecology of Freshwater Fish 10:1–10.

———, ———, and ———. 2003. Thermal heterogeneity, stream channel morphology, and salmonid abundance in northeastern Oregon streams. Canadian Journal of Fisheries and Aquatic Sciences 60: 1266–1280.

Federal Energy Regulatory Commission (FERC). 2012. Order issuing new license. 138 FERC 62,093, Washington, D.C.

Goudreau, C. J., R. W. Christie, and D. H. Barwick. 2008. A comprehensive approach to balancing water for fish and people. Pages 49–62 *in* M. S. Allen, S. Sammons, and M. J. Maceina, editors. Balancing fisheries management and water uses for impounded river systems. American Fisheries Society, Symposium 62, Bethesda, Maryland.

Habera, J.W., M.A. Kulp, S.E. Moore, T.B. Henry. 2010. Three-pass depletion sampling accuracy of two electric fields for estimating trout abundance in a low-conductivity stream with limited habitat complexity. North American Journal of Fisheries Management 30:757–766.

Heggens, J. and T. Traaen. 1988. Downstream migration and critical water velocities in stream channels for fry of four salmonid species. 1988. Journal of Fish Biology 32:717–727.

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.

Irvine, J. R. 1986. Effects of varying discharge on the downstream movement of salmon fry, (*Oncorhyncus tshawytscha)* Walbaum. Journal of Fish Biology 28:17–28.

Jenson, A. J. and B. O. Johnson. 1999. The functional relationship between peak spring floods and survival and growth of juvenile Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*). Functional Ecology 13:778–785.

Kaya, C.M., L.R. Kaeding, and D.E. Burkhalter. 1977. Use of a cold-water refuge by rainbow and brown trout in a geothermally heated stream. The Progressive Fish-Culturist 39:37–39.

Krause, C. W., T. J. Newcomb, and D.J. Orth. 2005. Thermal habitat assessment of alternative flow scenarios in a tailwater fishery. River Research and Applications 21:581–593.

Kulp, M.A. and S.E. Moore. 2000. Multiple electrofishing removals for eliminating rainbow trout in a small southern Appalachian stream. North American Journal of Fisheries Management 20:259–266.

Larson, G.L. and S.E. Moore. 1985. Encroachment of exotic rainbow trout into stream populations of native brook trout in the southern Appalachian Mountains. Transactions of American Fisheries Society 114:195–203.

Long, J. M., and C. R. Martin. 2008. Fisheries management in the upper Chattahoochee River Basin in response to water demands. Pages 21–35 *in* M. S. Allen, S. Sammons, and M. J. Maceina, editors. Balancing fisheries management and water uses for impounded river systems. American Fisheries Society, Symposium 62, Bethesda, Maryland.

MacCrimmon, H. R. and T. L. Marshall. 1968. World distribution of brown trout, (*Salmo trutta)*. Journal of the Fisheries Research Board of Canada 25:2527–2548.

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

Petty, J. T., J. L. Hansbarger, and B. M. Huntsman. 2012. Brook trout movement in response to temperature, flow, and thermal refugia within a complex Appalachian riverscape. Transactions of the American Fisheries Society 141:1060–1073.

Nuhfer A. J., R. D. Clark Jr., and G. R. Alexander. 1994. Recruitment of brown trout in the South Branch of Au Sable River, Michigan, in relation to stream flows and winter severity. Michigan Department of Natural Resources Research Report, 2006, Lansing.

Raleigh, R. F., T. Hickman, R. C. Solomon, and P. C. Nelson. 1984. Habitat suitability information: rainbow trout. U.S. Fish and Wildlife Service. FWS/OBS-82/10.60, Washington D.C.

Responsive Management. 2007. North Carolina trout anglers' participation in and satisfaction with trout fishing and their opinions on specific regulations. North Carolina Wildlife Resources Commission, Federal Aid in Sport Fish Restoration, Raleigh.

———. 2009. The economic impact of mountain trout fishing in North Carolina. North Carolina Wildlife Resources Commission, Federal Aid in Sport Fish Restoration, Raleigh.

Scholten, G. D., T. N. Churchill, and W. L. Poppe, 2008. Peace in the Valley: Competing interests on Tennessee Valley Authority reservoirs. Pages 103–116 *in* M. S. Allen, S. Sammons, and M. J. Maceina, editors. Balancing fisheries management and water uses for impounded river systems. American Fisheries Society, Symposium 62, Bethesda, Maryland.

Southern Division of the American Fisheries Society Trout Committee (SDAFSTC). 1992. Standardized sampling guidelines for wadeable trout streams. Southern Division of the American Fisheries Society Trout Committee, Bethesda, Maryland. Available: http://www.sdafs.org/trout/. (October 2011).

Smutko, L. S. and M. L. Addor. 2004. Duke Power – Nantahala Area, Nantahala Cooperative Stakeholder Team, Nantahala River Project (#2692). Natural Resources Leadership Institute, Final Report, Raleigh.

Van Deventer, J. S. and W. S. Platts. 1989. Microcomputer software system for generating population statistics from electrofishing data–user's guide for MicroFish 3.0. General Technical Report INT-254. USDA Forest Service, Intermountain Research Station, Ogden, Utah.

Weherly, K. E., L. Z Wang, and M. Mitro. 2007. Field-based estimates of thermal tolerance limits for trout: incorporating exposure time and temperature fluctuations. Transactions of the American Fisheries Society 136:706–717.