Flood and Debris-flow Effects on Virginia Brook Trout Populations

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Abstract: Streams and rivers in the Blue Ridge Mountains of Virginia provide an excellent cold water resource and have historically supported exceptional wild trout populations. In June 1995, a flood of greater than 500-year recurrence interval created a unique opportunity to assess the impact on trout populations within 3 rivers of the Shenandoah National Park (SNP). Debris flows impacted the lower one- to two-thirds of the Rapidan, Staunton, and North Fork Moormans rivers, either extirpating or greatly depressing trout populations. The number of trout collected in debris flow areas were significantly reduced ($P \leq 0.05$) in 1996, 1997, and for the post-flood 3-year mean when compared to pre-flood means. Trout populations in the flooded headwater reaches of all 3 rivers were not reduced. Debris flows, in association with severe flooding, greatly depress and even extirpate native brook trout *(Salvelinus fontinalis)* populations, but flooding alone may have little effect on populations. Trout number and biomass were also greatly influenced post-flood by high numbers of young-of-the-year trout. The rapid recovery, to date, of the trout populations reflects the remarkable resiliency of native brook trout.

Proc. Annu. Conf. Southeast. Assoc. Fish & Wildl. Agencies 53: 91–99

The streams and rivers in the Blue Ridge Mountains provide an excellent cold water resource and historically many have supported excellent trout populations (Mohn and Bugas 1980). The 80,000-ha SNP, established in 1930, lies in the northern Blue Ridge Mountains of Virginia (Fig. 1) and provides many recreational opportunities, especially for residents of the highly urbanized areas of eastern and northern Virginia, Washington, D.C., and Maryland. The principal sport fish in the SNP is the native brook trout, but populations can fluctuate considerably due to environmental factors (Lennon 1961, Sheridan 1961, Larimore et al. 1959). Within the SNP, the Rapidan, Staunton, and North Fork Moormans rivers have maintained large populations of native brook trout, with a small naturalized population of brown trout *(Salmo trutta)* on the North Fork Moormans, that are managed by a catch and release regulation.

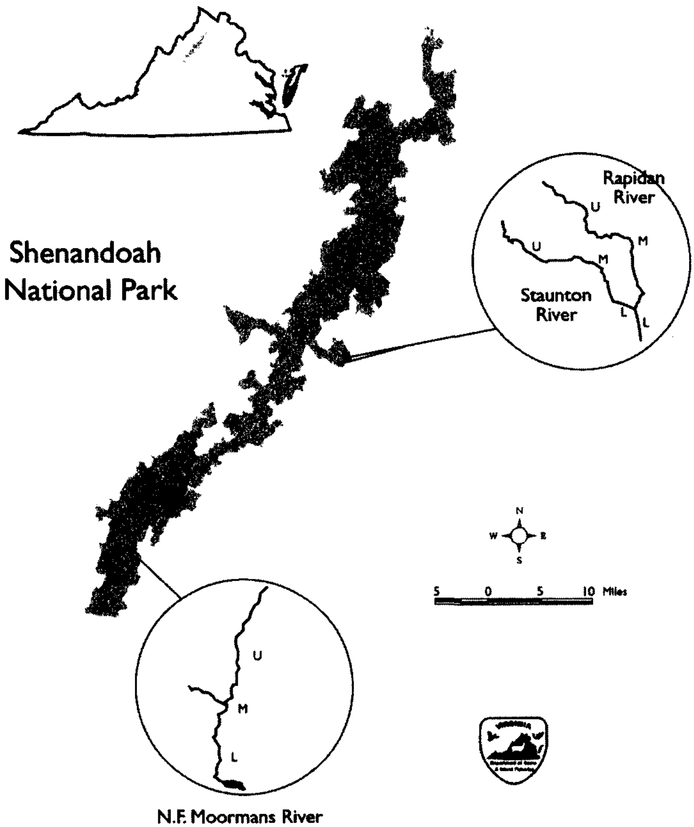

Figure 1. Location of Shenandoah National Park and Rapidan, Staunton, and N. F. Moormans rivers. Sample locations are indicated as U, M, and L, for the upper, middle, and lower sites, respectively.

In June 1995, a prolonged rainfall event occurred in isolated areas of the Blue Ridge Mountains of a magnitude that was considered greater than a 500-year recurrence interval (Karish et al. 1997). Isolated areas received an estimated 10 cm or more of precipitation per hour (Wieczorek et al. 1996). As a result, widespread flooding occurred and rain-soaked mountain soils were dislodged causing mudslides and catastrophic debris flows throughout the SNP. The Rapidan, Staunton, and the North Fork Moormans rivers were heavily impacted by both flooding and debris flows, with debris flows occurring in areas associated with mud slides (Karish et al. 1997). Visual observations made within 1 to 2 weeks after the flood revealed that the lower sections of all 3 rivers and the middle sections of the Staunton and North Fork Moormans rivers were devastated by debris flows. These debris flows resulted in huge log jams and rock and boulder deposits 3 to 6 m in depth, or in newly cut river channels, 3 to 6 m below the old river beds. Most of the lower reaches of the 3 rivers had become boulder and rubble fields, often as wide as 40 to 50 m, in which all forest canopies had been removed. In the most heavily impacted areas, all or most of the fishes appeared either severely reduced in number or extirpated, depending on the magnitude of the destruction in any given area (Karish et al. 1997). However, the headwater areas of each river, as well as the middle section of the Rapidan River, were only impacted by floods. Visual observation revealed only minor habitat damage and the impact on fish populations was less obvious.

Flooding and the wide spread occurrence of debris flows are not unusual in the Appalachian Mountains. Geological evidence has indicated that catastrophic flooding and landslides are the principal erosional processes that have shaped the present-day Appalachian Mountains. (Gori and Burton 1996). Records indicate that 52 similar events have occurred in various areas throughout the Appalachians over the last 150 years and geological evidence suggests that similar events have frequently occurred over the last 34,000 years. McCullough (1997) documented catastrophic degradation of fish habitat and significant adverse impacts on recruitment and population structure of wild trout populations associated with severe flooding during January and May 1996 in rivers within the Monongahela National Forest in eastern West Virginia.

The catastrophic June 1995 flood created a unique opportunity for biologists working for the SNP and the Virginia Department of Game and Inland Fisheries (VDGIF). Historical data existed on fish populations for the Rapidan, Staunton, and Moormans rivers that could be compared to trout population estimates following the 1995 flood. Impacts of severe flooding and debris flows on native trout populations in the 3 rivers as well as the time frame for natural recolonization of these populations could be assessed. We hypothesized that trout populations would not return to historical levels for perhaps 2 or 3 decades. The objective of this study was to quantify the immediate, short-term, impact of the flood on brook trout populations.

The authors gratefully acknowledge Randy Farrar for his statistical analysis and Eva Stanley for her dedication and perseverance in processing this manuscript. This study was partially funded through the Federal Aid in Sport Fish Restoration Program.

Methods

Permanent sample sections and sampling protocols were established by the VDGIF on various rivers throughout the SNP during a statewide Virginia trout stream inventory that began in 1975 (Mohn and Bugas 1980). Sample sites were placed approximately 2 km apart beginning at the lowest elevation of documented native trout water. The VDGIF sampled each site periodically to monitor fish populations (see Tables 1, 2). Sampling consisted of electrofishing with backpack shockers using DC current and utilizing natural barriers and breaks to prevent fish from escaping. Quantitative sampling on the Rapidan and North Fork Moormans rivers consisted of 3-run (pass) depletions on approximately 100-m sections. Qualitative sampling on the Staunton River throughout the 1980s was of a similar protocol except only 1 intensive run, or pass, was made for each 100-m section. After the June 1995 flood, sampling protocol was identical on all 3 rivers.

Table 1. Estimated number and biomass of trout per hectare by sample site (lower, middle, upper) in Rapidan and North Fork Moorman rivers.

	Rapidan River						North Fork Moormans					
	Lower		Middle		Upper		Lower		Middle		Upper	
Year	*N*/ha	Kg/ha	*N*/ha	Kg/ha	*N*/ha	Kg/ha	*N*/ha	Kg/ha	*N*/ha	Kg/ha	*N*/ha	Kg/ha
1975	605	33	1,067	106	2,544	133						
1977			738	90								
1981							59	0.1	3,162	35	1,591	24
1986	538	49	583	69	911	45						
1988							366	30	1,620	52	1,336	9
1991							556	23	1,877	100	2,314	120
1993	2,361	292	3,246	328	2,169	267	704	31	1,292	94	1,388	5
Pre-flood mean	1,168	125	1,409	148	1,875	148	418	21	1,988	70	1,657	40
SE	±597	±84	±620	±60	±494	±64	±139	±7	±409	±16	±226	±27
1996	0[a]	0[a]	924	39[a]	1,917	61	49[a]	7	252[a]	2[a]	2,010	65
1997	0[a]	0[a]	2,083	63	1,489	31	227	2	1,927	18[a]	6,610	67
1998	202	6	1,159	51	2,597	74	62	13	800	34	4,525	109
Post-flood mean	67[a]	2	1,389	51	2,001	55	113[a]	7	993	18[a]	4,382	80
SE	±67	±2	±354	±7	±322	±13	±57	±3	±493	±9	±1330	±14

a. indicates significant decrease from pre-flood mean.

Table 2. Number of trout collected on the Staunton River by sample site. Single pass electrofishing samples were performed and first pass electrofishing counts were used post-flood. Percentage of young-of-the-year in parenthesis.

Year	Lower		Middle		Upper	
1983	72	(15)	100	(9)	114	(6)
1984	66	(47)				
1985	124	(87)	92	(65)	129	(50)
1987	58	(78)	61	(66)	70	(43)
1989	102	(64)	88	(44)	116	(24)
1991	93	(50)	102	(45)	111	(37)
1993	68	(32)	100	(30)	71	(31)
Pre-flood mean	83±9		78±6		87±10	
1996	0[a]		23[a]	(96)	90	(72)
1997	0[a]		57[a]	(63)	165	(58)
1998	27	(100)	137	(57)	82	(53)
Post-flood mean	9[a]±9		72±34		112±26	

a. Indicates significant decrease from pre-flood mean.

The habitat on many historical sample sites was significantly altered after the June 1995 flood. During the winter of 1995–96, at least 3 sample sites were chosen from among the historical sites on each of the 3 rivers (Fig. 1). Sites included highly impacted lower and middle sections as well as lightly impacted headwater (upper) sections. If any of the historical sample locations had been altered so that they were unrecognizable, sample sites were reestablished approximating historical locations. The locations of all 9 sample sites were permanently logged using the Global Positioning System to ensure future location of sample sites.

Fish population sampling during summer 1995 was severely restricted due to flood damage. Only 2 quantitative samples, both on the lower site of the North Fork Moormans River, were conducted by SNP personnel. A 15 June sample, just prior to the flood, was repeated on 10 July, 2 weeks after the flood. From 1996 through 1998, the 9 reestablished sample sites (3 per river) were electrofished annually in July or August by personnel from the SNP and VDGIF as well as volunteers. All fishes collected were separated by species to determine species richness, then counted, measured, and weighed to the nearest tenth of a gram. Trout data were expanded to obtain estimates of fish numbers and biomass for each sample site as well as population estimates per hectare. Data from 1996 through 1998 samples were compared to historical data obtained from Mohn (1994), Karish et al. (1997), and from unpublished VDGIF data.

Population estimates and biomass (number and kilograms of trout per hectare) were determined using methods developed by Carle and Strub (1978). Sampling after the 1995 flood event (1995–1998) followed protocols established in the 1970s by the VDGIF, except Microfish Population Estimator programs were used to expand data. The number of quantitative samples collected by the VDGIF on the Staunton River before the flood was insufficient for accurate comparison with post-flood data.

Therefore, single run electrofishing data, collected by the SNP on the Staunton River before 1995, were compared to the first run of each depletion sample obtained from 1996 – 1998. Natural logarithms were applied to the data to minimize the correlation between the means and variances of the data. All statistical analyses were conducted with nonparametric Wilcoxon Rank Scores (2-sample tests) using statistical significance of $P \leq 0.05$ (SAS Inst. 1989).

Results

Visual observations by the authors of the Rapidan, Staunton, and North Fork Moormans Rivers within 2 weeks of the June flood indicated that many sections of these rivers were either devoid of fish or that the fish populations were greatly depressed. Sampling on the lower site of the North Fork Moormans River on 15 June, 10 days prior to the flood, resulted in the collection of 824 fish (13 species) which included 32 trout. On 10 July, the same site was resampled and only 6 fish representing 4 species were collected (1 of which was a brook trout), confirming the visual assessment of the authors.

Sampling the lower sites on the Rapidan, Staunton, and the North Fork Moormans rivers in July and August 1996, 1 year after the June 1995 flood, indicated that trout numbers were drastically reduced compared to pre-flood conditions (Tables 1, 2). No trout were collected on the Rapidan and Staunton rivers, which was a significant reduction ($P=0.03$ and $P=0.02$ respectively). No trout were collected on the Rapidan and Staunton rivers until 1998 when 6 brook trout were collected on the lower Rapidan and 27 on the Staunton, which were not significant reductions ($P=0.21$ and $P=1.00$, respectively). The 49 trout collected on the lower North Fork Moormans River in 1996 was also a significant reduction ($P=0.02$), but the 227 and 62 trout collected in 1997 and 1998, respectively, were not significant reductions from the pre-flood mean. Comparing means for trout numbers collected pre- and post-flood on the 3 lower sites, the greatest drop in numbers occurred on the Rapidan River (94%) followed by the Staunton River (89%) and the North Fork Moormans River (73%). All of these reductions in the means were also significant ($P=0.02$ for each of the 3 rivers). Historically, brown trout were most prevalent at the lower site of the North Fork Moormans River; however, no brown trout have been collected at any site post-flood on the North Fork Moormans River.

There were significant differences between pre- and post-flood brook trout collections on the middle sample sites of the Staunton and North Fork Moormans rivers. The record low 23 brook trout in 1996 and the 57 in 1997 (Table 2) collected on the Staunton River were significantly lower ($P=0.03$) than the historical mean; however, the number of trout had recovered by 1998 and the post-flood mean of 72 almost equaled the historical mean of 78. The 252/ha brook trout estimate for the middle site of the North Fork Moormans River in 1996 (Table 1) was a significant drop ($P=0.02$), when compared to the pre-flood mean. The number of trout collected on the same site in 1997 and 1998 rose sharply to 1,927 and 800 trout, respectively; and the post-flood mean of 993 trout (Table 1), although low, was not a significant decrease

(P=0.28) compared to the historical (pre-flood) mean. No major changes in the number of trout collected on the middle site of the Rapidan River occurred for post-flood years (1996–1998) when compared to the pre-flood mean.

There were no statistical differences found for the upper sample sites of all 3 of the study rivers. The number of brook trout actually increased at all sites. Comparing means for brook trout numbers collected pre- and post-flood on the 3 upper sample sites, the mean number of brook trout on the North Fork Moormans River increased by 264%, followed by an increase on the Staunton River of 129%, and on the Rapidan River of 6%.

Many of the trout collected on all 3 rivers after the flood were young-of-the-year. The most reliable historical data available for trout-size-classes were for the Staunton River (Table 2) and these were compared to Staunton River post-flood collections. The only trout collected at the lower site after the flood were the 27 young-of-the-year collected in 1998. High numbers (96% and 72%, respectively) of the young-of-the-year trout were collected on the middle and upper sample sites in 1996, and although this unusually high collection rate declined over the next 2 years, young-of-the-year continued to dominate the collection. Dramatic decreases in trout biomass on all but 1 site on the Rapidan and North Fork Moormans rivers were evident after the flood (Table 1) partially due to the large numbers of young-of-the-year in the post-flood trout population. Significant decreases in biomass occurred on the lower site of the Rapidan River in 1996 and 1997 (P=0.02), on the middle sites on the Rapidan River (P=0.04) in 1996, and in 1996 and 1997 on the middle site of the North Fork Moormans River (P=0.001 and P=0.02, respectively). Biomass did increase on the upper site of the North Fork Moormans River where mean biomass doubled from 40 to 80 kg/ha (pre- and post-flood).

Discussion

The June 1995 storm event in the SNP caused widespread flooding and debris flows that had adverse local impacts on trout populations. The effects on trout populations depended on location, with the greatest adverse impacts occurring on the lower sample sites of all 3 rivers and on the middle sites of the Staunton and North Fork Moormans rivers. These 5 locations were all sites that had experienced widespread, devastating debris flows. All 3 upper sites and the middle site on the Rapidan River had only been flooded and the trout populations showed little or no declines. Trout numbers, primarily young-of-the-year fish, showed signs of rapid recovery within the 3-year study.

Migration of trout and other fish species influenced recolonization of disturbed areas (Dolloff, pers. commun.) The lack of competition from a resident population of fishes may play a part in rapid and high immigration rates. Trout recolonization was evident in all impacted sections of the 3 rivers, and reached the lowest, most highly impacted, reaches of the Rapidan and Staunton Rivers by 1998. Similar long-range migrations of fishes were also noted after a severe disturbance in the Roanoke River system (Ensign et al. 1997).

Equally important to migration, recruitment played a major role in reestablishing trout populations. The high number of young-of-the-year trout collected on all 3 rivers reflected a statewide trend. In 1997, young-of-the-year trout numbers were the highest on record throughout Virginia due to favorable weather conditions during winter 1996–97 (Mohn, pers. commun.).

The decrease in mean estimated trout biomass on the Rapidan and North Fork Moormans rivers reflected the reduction or lack of fish in the lower sample sites, the reduction in number of adult trout on the middle sites, and the dominance of young-of-the-year fish in the population at all sites. Increases in the numbers of trout at a particular sample site after the flood did not necessarily equate to a corresponding increase in biomass. Biomass may increase in the future as the trout population structure improves.

Wild brook trout populations in the Shenandoah National Park have been characterized as a fragile but resilient resource (Ney et al. 1998) and subject to wide fluctuations depending on weather conditions (Mohn et al. 1980). Drought and higher than normal temperatures in summer can severely reduce trout populations particularly in those sections of rivers lacking a forest canopy. Trout populations apparently can reestablish quickly after devastating floods and debris flows when weather conditions are favorable. The rapid recovery of trout on all sections of the 3 rivers over the 3 years of the study presents a favorable outlook for trout populations in general. As riparian forests reestablish along the Rapidan, Staunton, and North Fork Moormans rivers, with complementary stable flows and desirable water temperatures, the highly resilient brook trout populations should also stabilize.

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