A REVISED OUTLOOK FOR TENNESSEE'S BROOK TROUT

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ABSTRACT—A 1974–1984 survey of Tennessee's brook trout *Salvelinus fontinalis* populations indicated that distribution of the State's only native salmonid had substantially declined and additional losses were anticipated. Because of concerns about the future of this resource, another survey was conducted during 1991–1999. Existing brook trout populations outside Great Smoky Mountains National Park (GSMNP) were identified, distribution changes were documented, and their genetic heritage was determined. Abundance also was estimated for many populations. Brook trout currently inhabit about 237 km in 106 streams in nine counties. Seventy-one of 73 populations (97%) identified outside GSMNP in the previous survey still exist. Additionally, brook trout populations have been restored in 17 streams since 1985, and 18 previously undocumented populations were located. Most brook trout populations (65) had portions that were sympatric with other salmonids. However, the downstream limit of brook trout distribution advanced (elevation decreased) or did not change in 16 (64%) of 25 previously surveyed streams. These streams had encroaching rainbow trout *Oncorhynchus mykiss* populations and were not managed to control or remove the non-native species. Overall, Tennessee's known brook trout resource has increased by about 85 km (56%) since 1985. Genetic analyses classified 56 brook trout populations as native, southern Appalachian (53%), 15 as descendants of northern (hatchery) stocks (14%), and 31 as hybrids (29%). The success of restoration efforts, identification of new populations, and lack of evidence that unmanaged populations are being systematically replaced by other salmonids suggest that Tennessee's brook trout currently constitute a viable fishery resource.

As Tennessee's only native salmonid, brook trout *Salvelinus fontinalis* are a valuable natural resource from both ecological and recreational perspectives. The most recent brook trout inventories (1974–1984; Bivens et al., 1985) revealed a 56% reduction in the number of brook trout streams relative to Tennessee Wildlife Resources Agency (TWRA) surveys in the late 1960s. It was estimated that brook trout had lost 68% of the stream length they formerly occupied north of Great Smoky Mountains National Park (GSMNP) and 70–80% of their entire historic distribution in Tennessee (Bivens et al., 1985). Habitat degradation prior to the 1930s, particularly at lower elevations (610–915 m), initially caused much of this loss (King, 1937). Subsequent declines were largely attributed to establishment and expansion of non-native rainbow trout *Oncorhynchus mykiss* populations (King, 1937; Kelly et al., 1980; Bivens et al., 1985; Larson and Moore, 1985).

Lennon (1967) regarded brook trout native to the southern Appalachian Mountains as a distinct strain because of phenotypic differences from fish native to the northeastern United States and Canada. However, brook trout from northern populations were the source of hatchery stocks used throughout the southern Appalachians in many attempts to supplement or restore native populations. Hatchery (northern) brook trout were stocked in Tennessee streams until about 1990, but documentation was inconsistent.

Subsequent genetic comparisons using protein electrophoresis showed that northern and southern brook trout, as well as their hybrids, could be accurately differentiated (Stoneking et al., 1981; McCracken et al., 1993). Although southern Appalachian brook trout have not received taxonomic recognition, they do represent a unique and identifiable native fish stock (a distinct evolutionary unit) that fishery managers are interested in preserving.

Because of past distribution losses, potential hybridization caused by extensive stocking of hatchery fish and stock transfers among watersheds, and concerns raised by previous authors (Kelly et al., 1980; Bivens et al., 1985; Larson and Moore, 1985) the future of Tennessee's native (southern Appalachian) brook trout was uncertain. Consequently, we began a survey of all known brook trout streams outside GSMNP in 1991. The primary objectives were to identify each extant population and determine its genetic heritage. The number and location of remaining southern Appalachian populations were of particular interest. Other objectives were to document the current downstream limit of each brook trout population, to assess changes since 1985, and to measure abundances.

METHODS

Potential survey streams were obtained from the list published by Bivens et al. (1985) and were located in nine counties along Tennessee's eastern border. Because the National Park Service was conducting its own distribution surveys, only streams outside GSMNP were included. Several streams in which TWRA and the United States Forest Service (USFS) cooperatively attempted to re-established brook trout populations also were surveyed. Additionally, local residents and anglers provided information that led to the identification of several previously undocumented brook trout populations.

Sampling was conducted from 1991–1999. Backpack AC electrofishing gear was used in all streams except two in Monroe

TABLE 1. Current distribution and status of Tennessee brook trout streams outside Great Smoky Mountains National Park.

County	Number of streams			Stream length (km)			Net increase[3] (km)	Restorations[4]	Previously undocumented streams[5]
	CNF[1]	Private[2]	Total	CNF	Private	Total			
Monroe	11		11	31.3		31.3	14.4	3	2
Sevier		1	1			2.1	2.1		1
Cocke	2	2	4	2.6	5.2	7.8	3.5	2	
Unicoi	3	3	6	6.0	5.5	11.5	3.0		1
Greene	7	3	10	18.1	4.9	23.0	18.1	7	
Washington	2		2	7.6		7.6	7.6	1	1
Carter	26	16	43[6]	48.5	39.0	89.5[6]	23.3	2	9
Sullivan	1		1	2.3	2.3	2.3			
Johnson	21	7	28	48.8	13.2	62.0	12.8	2	4
Totals	73	32	106	165.2	69.9	237.1	84.8	17	18

[1] Streams primarily located on the Cherokee National Forest.
[2] Streams primarily located on privately-owned lands.
[3] Includes changes in brook trout distribution since 1985 as well as restored and previously undocumented streams.
[4] Streams not included in Bivens et al. (1985) in which brook trout populations have been successfully restored by the USFS and TWRA.
[5] Previously undocumented brook trout streams identified during this survey and not included in Bivens et al. (1985).
[6] Total includes Left Prong Hampton Creek. This stream has 2 km of brook trout water and is located on the Hampton Cove State Natural Area (state-owned).

County and one in Greene County. These streams were sampled by angling (no abundance estimates) because they were located in designated wilderness areas where internal combustion engines could not be used. Sampling began in each stream at the lowest elevation where brook trout were reported by Bivens et al. (1985) or at an access point near where brook trout were believed to occur. Elevations were obtained with an electronic altimeter (3 m resolution) and checked against 7.5′ topographic maps (1: 24,000 scale). If brook trout were collected at the first sampling point, the stream was sampled at intervals of about 100–300 m downstream until they were no longer present. If brook trout were not collected at the first sampling point, the stream was checked at similar intervals upstream until they were located. Elevation at the endpoint, in either case, was considered to be the lower limit of distribution. In a few streams, an isolated young-of-the-year (age-0) or adult brook trout was found several hundred meters below the primary brook trout population (where both age-0 and adult fish were present). These outliers were ignored when determining distribution. Changes in stream length occupied by brook trout populations were considered to be the map distances (corrected for gradient) between current and previous (if available) lower limits of distribution.

Upper limits of brook trout distribution were not re-checked for streams listed by Bivens et al. (1985). The upper distribution of brook trout in other streams was obtained from USFS records or in some cases was assumed to coincide with the estimated upper extent of trout habitat. This information was used to determine stream lengths occupied by brook trout. The presence of rainbow and brown trout *Salmo trutta* was noted, but attempts to identify the extent of sympatry with brook trout were typically not made.

Tissue samples (eye, liver, and skeletal muscle) from 1,444 brook trout (~14/population; 102 populations) were collected and frozen in liquid nitrogen for genetic analyses. No tissue samples were obtained from four populations in Carter and Johnson counties. Starch gel electrophoresis of 17 presumptive loci was used to analyze each set of samples (Kriegler, 1993; Saidak, 1995; S. Guffey, Univ. Tennessee Dept. Ecol. Evolut. Biol.). Populations were then classified as southern Appalachian (native), northern (hatchery-derived) or hybrid (southern Appalachian x northern) following the rationale of McCracken et al. (1993). Details regarding tissue preparation, electrophoretic techniques, enzymes surveyed, locus designations, etc., are provided and referenced in McCracken et al. (1993), Kriegler et al. (1995), and Saidak (1995).

A total of 84 three-pass depletion samples (Carle and Strub, 1978; Raleigh and Short, 1981; Van Deventer and Platts, 1983) were completed in 55 streams during June through October of 1991–1999 to estimate brook trout biomasses. Additionally, alkalinity (mg/l as $CaCO_3$) and pH (colorimetric test with a 0.1 unit resolution) were measured in the field for all streams surveyed.

RESULTS

Brook trout currently inhabit about 237 km in 106 streams in east Tennessee (Table 1), including 71 of the 73 streams (97%) known to contain populations in 1985 (Bivens et al., 1985). Carter County, with 43 streams (41%) totaling nearly 90 km (38%), contains the largest portion of Tennessee's brook trout resource outside GSMNP (Table 1). Carter and Johnson counties together contain about two-thirds of all brook trout streams and stream length (Table 1). The Cherokee National Forest (CNF) contains about 70% of the entire Tennessee brook trout resource outside GSMNP (Table 1).

Thirty-five brook trout populations (streams) not listed by Biv-

TABLE 2. Genetic heritage of Tennessee brook trout populations and presence of non-native salmonids in streams outside Great Smoky Mountains National Park.

County	Genetic heritage[1]			Allopatric populations[2]	Populations sympatric with		
	Southern	Hybrid	Northern		Rainbows	Browns	Both
Monroe	2	3	6	6	4		1
Sevier			1	1			
Cocke	4			1	3		
Unicoi		1	5	2	4		
Greene	2	7	1	2	7	1	
Washington	2				2		
Carter	23	16	2	12	17	11	3
Sullivan	1			1			
Johnson	22	4		16	9		3
Totals	56	31	15	41	46	12	7

[1] Southern = native southern Appalachian origin; northern = descended from hatchery stocks from the northeastern United States; hybrid = populations containing both southern and northern alleles. Two populations in Carter County and two in Johnson County were not analyzed.

[2] Number of brook trout populations not in contact with non-native salmonids (rainbow and brown trout).

ens et al. (1985) were identified. Seventeen of these represent successful restoration efforts by the USFS and TWRA (Table 1). Ten restoration projects were underway in the early 1980s, but Bivens et al. (1985) did not include those populations because the efforts were incomplete at that time. The presence of brook trout in the other 18 streams (Table 1) was apparently never documented. Overall, the known brook trout resource has increased by 33 populations (45%) since 1985.

Our survey had 25 streams in common with Bivens et al. (1985) in which encroaching rainbow trout had not been controlled and barriers did not limit their movement. The elevation where brook trout began increased in 9 (36%), decreased in 8 (32%), and did not change in 8 (32%) of these streams; distribution (stream length occupied by brook trout) increased by 109 $\pm$ 82 m. Considering all distribution changes and the 35 "new" and restored populations, there has been a net increase of 85 km (56%) in total stream length occupied by brook trout since 1985 (Table 1).

Fifty-six brook trout populations (53%) were classified as southern Appalachian, 15 as northern, and 31 as hybrid (Table 2). Carter and Johnson counties contained 80% of Tennessee's southern Appalachian brook trout, but at least one southern Appalachian population occurred in each county except Sevier and Unicoi (Table 2). Southern Appalachian brook trout also were present in all major watersheds in east Tennessee that contain brook trout (South Fork Holston, Watauga, Nolichucky, French Broad, and Tellico/Little Tennessee). Approximately two-thirds (67%) of all southern Appalachian brook trout populations are located in CNF streams.

Sixty-five brook trout populations (61%) were sympatric to some extent with other salmonids (Table 2). Brook trout were sympatric with rainbow trout in 46 streams, with brown trout in 12 streams, and with both species in seven streams.

Overall, brook trout biomass averaged 21.44 kg/ha (95% confidence interval, 17.42–25.46 kg/ha; median, 15.69 kg/ha). Biomass estimates for 49 allopatric samples (>90% of total trout biomass was brook trout) from 40 streams averaged 24.20 kg/ha (95% confidence interval, 18.29–30.10 kg/ha; median, 21.21 kg/ha). Most biomass estimates ranged from 10–30 kg/ha, although some allopatric populations exceeded 50 kg/ha (Fig. 1).

The size distribution of 3,823 brook trout from our quantitative samples (Fig. 2) indicated that 94% were <178 mm (7 inches). The 51–76 mm (2 inch) size class was proportionally largest overall (37%) and age-0 fish (<102 mm) comprised the most abundant age group (Fig. 2). Approximately 14% of the brook trout collected were 152 mm (6 inches), making them harvestable under current angling regulations. Less than 1% of all brook trout were >229 mm and no specimens >305 mm were collected.

Brook trout streams typically had soft, slightly acidic water. Median alkalinity was 10 mg/l as $CaCO_3$ (range, 5–40 mg/l) and median pH was 6.6 (range, 6.0–7.5).

DISCUSSION

Our survey revealed that Tennessee's brook trout resource was in much better condition than anticipated. We located 97% of the populations recognized in 1985 (Bivens et al.). Where encroaching rainbow trout were present, brook trout sustained no net loss in the amount of stream length occupied (Strange and Habera, 1998). The two streams in which brook trout were not found, but had previously occurred (Johnson County), were small tributaries of larger brook trout streams. Each had only a few brook trout (possibly transients) near its mouth when surveyed by Bivens (1984).

Additionally, 17 brook trout populations have been re-established since 1985, and 18 other previously undocumented populations were identified during our survey. Rainbow trout removal efforts have been made in two of these previously undocumented streams, and brook trout distribution was extended in one (Sevier County) by transplanting progeny of wild brook trout produced at TWRA's Tellico facility. Two Carter County streams in this group had been surveyed during 1978–1979, but were reported to have poor habitat and no trout at that time (Bivens,

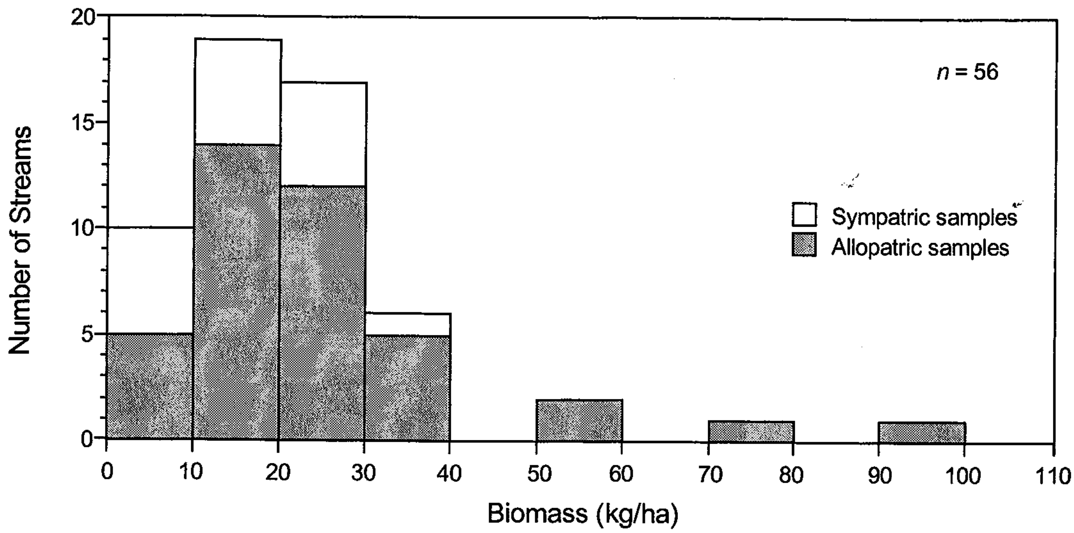

FIG. 1. Distribution of brook trout biomass estimates for 56 streams sampled quantitatively during 1991–1999. Means were used for streams sampled more than once.

1984; Whitworth and Strange, 1979). The manner in which brook trout re-occupied these streams is unknown.

Brook trout restoration projects are currently underway on two streams not accounted for in Table 1. Long Branch in Unicoi County was stocked with native southern Appalachian brook trout from Carter County in 1996. The status of this population is still being evaluated. The only brook trout present in the Hiwassee/Ocoee river system, which includes Polk and part of Monroe County in Tennessee, were located in headwater tributaries in North Carolina and Georgia (Williams, 1996). Brook trout from some of the Georgia streams were transplanted to Short Creek (Ocoee River tributary) by the USFS and TWRA in 1998, and their establishment will require additional evaluation.

Bivens et al. (1985) projected that if the distribution trend perceived at that time continued, Tennessee's brook trout might be entirely lost within a few decades. Similarly, Larson and Moore (1985) expressed concern that without management, rainbow trout encroachment could lead to extermination of brook trout or their reduction to small, isolated populations in many southern Appalachian streams. Brook trout populations that have been managed by removing and excluding other salmonids represent approximately one-third of Tennessee's current resource. It now seems unlikely all of these populations would have failed to survive in the absence of such protection, but contemporary management strategy tended to err on the side of caution. Regardless of the potential impacts of non-native salmonid encroachment, we consider the return of a portion of Tennessee's coldwater streams to their natural condition (allopatric brook trout) a valid management goal.

Many Tennessee brook trout populations exist on privately-owned lands where habitat is much less secure than on publicly-owned lands. Habitat degradation and the presence of an introduced competitor (rainbow trout) have been considered primarily responsible for previous brook trout losses in Tennessee (Bivens

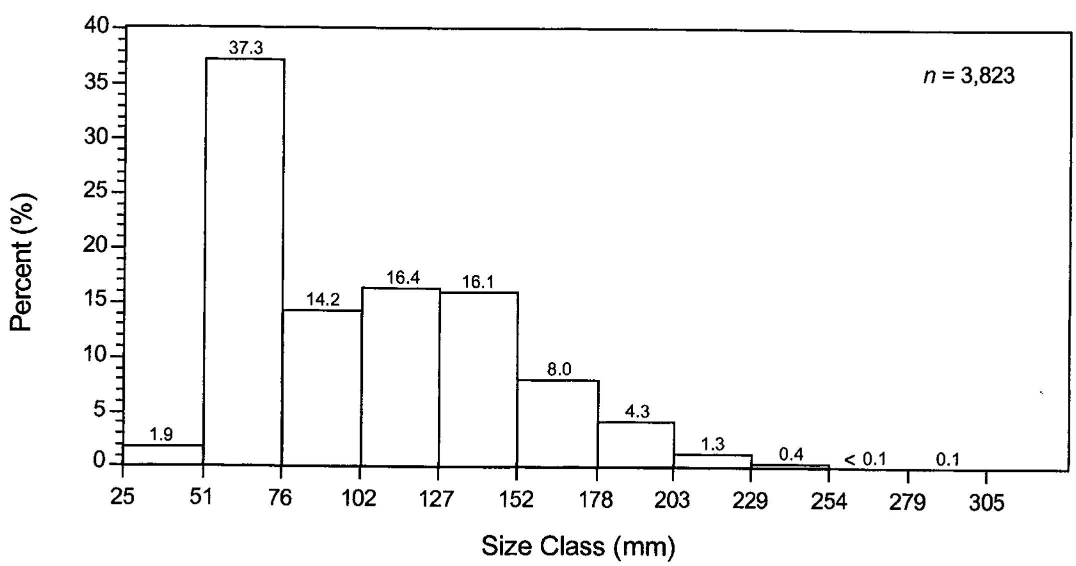

FIG. 2. Length frequency distribution of brook trout from 84 quantitative samples representing 56 Tennessee streams sampled during 1991–1999.

et al., 1985). However, habitat degradation currently does not appear to be impacting brook trout populations to the extent it once did. There is evidence that rainbow trout have replaced brook trout in portions of some streams since 1985, yet this has not happened in most instances (Strange and Habera, 1998). Given that competitive exclusion of brook trout by rainbows was generally believed to be occurring on a much wider scale, it remains to be determined if there has been a change, and if so, what factors are responsible.

Perhaps rainbow trout simply do not hold the competitive advantage for which they have previously been credited. Clark and Rose (1997) recognized that replacement of brook trout by rainbow trout has not been explained by the conventional theory involving a niche shift induced by the presence of a superior competitor. Nagel (1991) successfully established brook trout in a stream occupied by rainbow trout and suggested that brook trout might not be susceptible to replacement by rainbows unless reduced or eliminated by a flood or other natural catastrophe. Results of sympatric population modeling by Clark and Rose (1997) substantiated the importance of brook trout year-class failures (those caused by floods) to rainbow trout dominance. Documentation of actual brook trout extirpation from areas of sympatry with rainbow trout over time, however, is limited. Temporal ebbs and flows, such as those reported for rainbow trout by Larson et al. (1995), may explain many of the differences in distribution observed between various surveys.

Southern Appalachian brook trout were well represented in our survey, and overall, did not appear to be sustaining distribution losses. Therefore, we believe they currently require no special management attention in the form of angling restrictions (stream closures, reduced creel limits, etc.). Future brook trout management involving manipulations such as wild brook trout transplantation should follow the recommendations of Kriegler et al. (1995). This will ensure that the genetic integrity of Tennessee's southern Appalachian populations is not compromised.

Brook trout in our survey were small and occurred at relatively low abundances. However, these characteristics are comparable to populations in GSMNP (S. Moore, GSMNP, personal communication) that have been protected from angling for 25 years. Meager food supplies related to the soft, infertile waters typical of the southern Appalachians tend to limit trout productivity. Food limitation is particularly severe during summer, when trout metabolic rates are highest and food resources are least abundant (Cada et al., 1987). Consequently, summer energy intake may fall short of maintenance metabolism needs (Ensign et al., 1990), making larger, older (beyond age 3) brook trout uncommon.

Most restoration or enhancement of brook trout populations in small streams (first and second order) is probably now complete. Future efforts primarily will focus on a few larger (third order) streams that historically supported brook trout (King, 1937), but typically do not contain them now. Future management also should include another survey of Tennessee's brook trout resource in 10–15 years. It will be important to determine if the relative stability of brook trout distributions observed since the mid-1980s continues, particularly in unmanaged streams.

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