Technical Papers

OF THE BUREAU OF SPORT FISHERIES AND WILDLIFE

15. Brook Trout of Great Smoky Mountains National Park

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
BUREAU OF SPORT FISHERIES AND WILDLIFE

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By Robert E. Lennon

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CONTENTS

Page

Abstract 3

Methods 5
Fish collecting 5
Creel census 5
Relative size of body parts 6

Results 6
The Trout 6
Distribution of brook trout 6
Abundance 8
Size 8
Age 8
Sex ratio 9
Fecundity 10
Reproduction 10
Color 10
Size of body parts 11
Resistance to disease 11
Survival of stocked fish 12

The Streams 12
Gradient 13
Water flows 13
Temperatures in winter 13
Water hardness 14
pH 15

Discussion 15

Conclusions 15

Literature cited 16

BROOK TROUT OF GREAT SMOKY MOUNTAINS NATIONAL PARK

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ABSTRACT.--The brook trout (Salvelinus fontinalis) of Great Smoky Mountains National Park are relatively scarce and are found only in remote, headwater streams. They are also small and short-lived. Males outnumber females, especially among sexually mature fish. The fecundity is lower than in fish of comparable size in Wisconsin and Canadian waters. Red spots on the sides of the trout are smaller but more numerous than on northern fish. Selected body parts appear to be larger than on Canadian fish.

The southern trout are more susceptible to furunculosis and ulcer disease than northern fish. They survived and reproduced when stocked in Park waters where northern brook trout had failed, but failed when planted in streams of Shenandoah National Park in Virginia. On the basis of findings, it appears legitimate to consider the southern Appalachian brook trout a distinct strain.

The brook trout in the Park have not extended their range downstream within the past 30 years. The soft, acid headwaters in which they live are relatively infertile. Water temperatures in winter are limiting because the streams freeze severely and extensively. Water temperatures may remain at 32° F. for several days, anchor ice forms in the streams, and flows are reduced. At such times, the redds of brook trout may become dewatered and frozen.

Under present conditions, any increase in exploitation of the brook trout in the Park or damaging alteration of the habitat might have serious consequences for the remnant populations.

The brook trout (Salvelinus fontinalis) is the only salmonid fish native to the southern Appalachian Mountains. Once abundant in the streams of Great Smoky Mountains National Park, wild populations of brook trout are found now only in remote headwaters. They are prized by fishermen but are relatively insignificant in the sport fishery because of small numbers, generally small size, and the difficulty of getting to the streams. There are also small populations in the headwaters of mountain streams outside the Park in North Carolina and eastern Tennessee (Cornell, 1966; and Peterson, 1966) and northern Georgia.

Upon working in the vicinity of the Great Smokies, one often hears fishermen and biologists refer to the native brook trout as the southern Appalachian strain of the species. No evidence has been published, however, in support of a distinct strain. On the other hand, the southern Appalachian Mountains are the extreme limit of the species' range to the south, and the populations have been isolated in various respects for a long time. Much of the brook trout's former territory in this region and within the Park is now inhabited by exotic salmonids, the rainbow trout from western United States and the brown trout from Europe.

Within the decade following establishment of the Great Smoky Mountains National Park in 1926, biologists and Park personnel surveyed the streams, determined the status of game-fish populations, constructed and operated trout rearing pools at various locations in the Park, stocked rainbow trout and brook trout on a large scale, and put new fishing regulations into effect. King's (1937) observations on the distribution of native brook trout and the rainbow trout in Park waters constituted an excellent background for later studies.

The original range of brook trout in the streams extended from about 2,000 feet elevation, upstream to the headwaters. Following the turn of the century, the situation changed and the brook trout became limited to headwaters in most streams and completely exterminated in others. Among the causes, King (1937) listed the widespread logging with its attendant clearing, railroad building, and frequent fires; harmful fishing practices, including nets and dynamite; and the introduction of rainbow trout. Although the National Park Service endeavored to bring abuses of the streams to an end, the longstanding habits of the exceedingly independent, mountain folk were not to be changed quickly. It is significant that the first sentence of the Park's fishing regulations for 1934 says, "Fishing with nets, seines, traps or by the use of drugs or explosives, or in any other way than with rod, artificial fly without bait, and line held in hand, or for merchandise and profit, is prohibited".

Stocking of rainbow trout began soon after 1900 and became frequent and heavy after 1910 in every major stream in the Great Smoky Mountains. Much of this stocking was done by logging companies. The species has thrived and moved upstream and into tributary waters. In some virgin wilderness areas of the Park, the rainbow invaded brook trout habitat and the native species became reduced in numbers and range (King, 1937).

Since inception of the Park, the National Park Service has attempted to preserve and even restore populations of the native trout. It was hoped that the complete protection afforded to the remnant populations in the virgin Wilderness Areas, maintenance stocking, and restorative stocking would enable the brook trout to recover some of its former numbers and range. In 1939, King reported that about 200,000 brook trout, 4 to 6 inches long, were being propagated annually in the Park and stocked in selected waters. In addition, the stocking of rainbow trout in waters more suited to brook trout was discontinued. At this time, he stated that floods are one of the more important natural forces affecting trout populations in the Great Smokies. After continuing investigations, King noted in 1942 that brook trout were not important in terms of total catch by anglers, but that preservation of the species where possible was of more importance than management on a yield basis. Whereas conditions for brook trout were improving, he made mention of an extraordinary situation; in prolonged zero weather the streams may become largely frozen and the flows reduced.

Holloway[1/] pointed out in 1945 that the brook trout stocked abundantly in the Smokies for many years were of the New England strain which, according to tests in the very soft waters, were less hardy than the native, southern Appalachian strain. He maintained that the strains are discernibly different, but both are incapable of competing with large populations of rainbow trout in Park streams. He advocated restoring the native strain in selected streams by stocking it to the exclusion of the New England strain or of rainbow trout. At the time, an effort was being made in some southeastern hatcheries to acquire brood stock of the native strain.

1/ Holloway, Ancil D. Report on the fisheries of the Great Smoky Mountains National Park. U. S. Fish and Wildlife Service, 1945. Typewritten: 21 p.

Smith 2/ made a brief survey two years later and found that the native trout were moving slowly downstream from headwaters into sections formerly occupied exclusively by rainbow trout. In 1948, however, fishing regulations were changed. Size limits on brook trout and rainbow trout were removed, restrictions against natural baits were abolished, a trout hatchery within the Park was abandoned, and brook trout and rainbow trout stocking was sharply curtailed.

Liberal fishing regulations coupled with rising fishing pressure contributed to a decline in the quality of sport fishing. The widespread use of tiny hooks baited with bread or cheese was extremely effective in taking trout, and the swallowed hooks usually caused death to all sizes of fish. Park rangers told me that by 1951 and 1952 it was common to check limit catches of 10 trout with no fish over 4 inches long. As a result, the National Park Service asked the Fish and Wildlife Service for a long-term investigation of the fishery, and it was started in 1953. During a creel census on one watershed that year, 447 fishermen were asked for their preferences in fishing regulations. Seventy-four percent were in favor of permitting artificial lures only in the Park, and 26 percent were opposed (Lennon, 1954). In 1954, bait fishing was again prohibited, a 7-inch size limit was restored, and the creel limit was reduced.

By 1956, many of the brook trout streams had been under Park jurisdiction for 30 years. Many watersheds had recovered from logging damages, but camping, picnicking and fishing were increasing steadily as the Smokies became the most heavily visited National Park in the nation. It was at this time that the National Park Service began Mission 66, with plans for many physical projects in the Park between 1956 and 1966.

2/ Smith, Lloyd L., Jr. Recommendations for management of Great Smoky Mountains National Park fishery. Biology Division, National Park Service, June 27, 1947. Mimeo: 32 p.

METHODS

There are 333 streams in Great Smoky Mountains National Park which have a total of 734 fishable miles 3/. One-hundred-sixteen streams were studied during the period 1952-1959. In the years 1956 through 1959, observations were made on selected streams in all seasons of the year.

Fish collecting

Electrofishing was the means most used to collect fish in Park streams. Alternate-polarity, 230-volt systems were especially effective when used in conjunction with blocks of cattle salt which increased the conductivity of the water (Lennon and Parker, 1957 and 1958). In remote headwaters, a fly-rod electrode system with back-pack unit was very handy for use by a two-man crew (Lennon, 1961).

Cresol was used extensively for collecting fish before the alternate-polarity, electrofishing apparatus was developed. The formulation of cresol and the method described by Wilkins (1955) were used.

Creel census

Roving and fixed-station creel censuses on several watersheds provided considerable information on the distribution and harvest of native brook trout. During the period of study, the fishing seasons each year extended from May 16 through August 31, with the exception of certain Fishing-for-Fun streams which were open to fishing all year (Lennon and Parker, 1960). In the roving census, fishermen were contacted and interviewed on certain streams on certain days. The fixed, creel census stations were operated daily, for the most part, and were

3/ Lennon, Robert E., Phillip S. Parker, and the Staff, Great Smoky Mountains National Park. A check list of fishable streams in Great Smoky Mountains National Park, including the species of game fish present and the number of fishable miles. National Park Service, 1960. Mimeo: 30 p.

located at sites on watersheds where the large majority of anglers had to pass them.

Relative size of body parts

A strain is defined in Webster's Third International Dictionary as "a selected group of organisms sharing or presumed to share a common ancestry and usually lacking clear cut morphological distinctions from related forms but having distinguishing physiological qualities" or "a specified infraspecific group as a stock, line, or ecotype". In connection with the possibility that the brook trout of the southern Appalachians is a distinct strain, we measured selected body parts of specimens according to the method of Wilder (1952) and compared them with data which he obtained on brook trout from Nova Scotia and New Brunswick, Canada.

The measurements of individual fish studied by Wilder (1952) were not given, but the means of groups of 5 to 10 individuals were. We therefore grouped the data on Park fish in units of 3 to 10 fish, and determined the mean of each unit. The group means of the Canadian fish and the Park fish were then analyzed as if they were measurements of individual fish. In comparing the Park fish with Canadian fish, we had to combine data from 6 Park streams and from 5 Canadian streams in order to have a sufficient number of observations for statistical treatment. The assumption in combining the data was that variations in body parts of fish between streams in the same areas would probably be insufficient to mask differences between the areas.

Analyses of covariance were made on data from male and female fish in the manner of Wilder (1952). Tests of significance of differences in body parts were made between adjusted means for each part on a fish 100 mm. in standard length.

RESULTS

The Trout

Distribution of brook trout

The surveys on 116 streams included all streams with 10 miles or more of fishable water, 15 of the 20 streams with 5 to 9.9 miles of fishable water, 44 of the 77 streams with 2 to 4.9 miles of water, but only 47 of the 226 streams with less than 2 miles of fishable water (table 1). Thus, most of the principal streams in the Park were included.

Brook trout occur in 68 of the 116 streams surveyed, rainbow trout in 104 streams, and brown trout in 7 streams. We hoped to find that the brook trout dominate in headwater streams, but this is not the case. In 47 of the small streams with less than 2 fishable miles, brook trout were found alone in only 10 streams whereas rainbow trout occur alone in 21 streams. Mixed populations of brook trout and rainbow trout inhabit 16 of the small streams. Estimates based on simple proportions indicate that brook trout may exist alone in 48 of the 226 headwater streams, rainbow trout alone in 101 streams, and mixed populations of the two species in 77 streams. These estimates have considerable validity because park rangers reported the presence of brook trout in many of the small streams which we did not survey.

Brook trout are found in most of the larger streams (5 to 23 miles long), but in such small numbers that they must be considered as strays from headwaters and tributaries (table 2). A very few specimens are taken consistently during electrofishing or creel census. King (1937), upon making the same finding, suggested the limited occurrence of brook trout at low elevations might be due to freshets or floods.

It appears, in general, that brook trout have not changed in distribution within the 20 years which intervened between King's (1937) observations and ours. He listed the average

Table 1:--A resume of the 116 streams surveyed and the species of trout present from among the 333 streams in Great Smoky Mountains National Park

Fishable miles	Number of streams	Number surveyed	Number not surveyed	Number of streams containing		
				Brook t.	Rainbow t.	Mixed trout
0- 1.9	226	47	179	10	21	16
2- 4.9	77	44	33	2	24	18
5- 9.9	20	15	5	0	3	12
10-23.0	10	10	0	0	0	10
	333	116	217	12	48	56

Table 2:--Streams in which brook trout occurred in 1953-1959. Minimum elevations for collections of brook trout are listed along with maximum elevations for rainbow trout

Watershed stream	Elevation (feet)		Sampling method
	Brook t.	Rainbow t.	
ABRAMS CR.	strays	present	creels
Anthony Cr.	--	present	creels
Forge Cr.	--	present	creels
Panther Cr.	--	present	creels
Tiptons Sugar Cove	--	present	creels
BIG CR.	3,440	4,000	survey
Deer Cr.	4,200	none	creels
Gunter Cr.	3,250	present	survey
McGinty Cr.	3,400	present	survey
Swallow Fk.	3,280	3,880	survey
BRADLEY CR.	2,950	3,200	survey
Chasm Cr.	4,000	present	creels
Chasteen Cr.	3,100	present	survey
Frowning Rock Pr.	4,250	present	creels
Taywa Cr.	3,650	3,700	survey
CATALOOCHEE CR.	strays	present	creels
Beech Cr.	--	present	creels
Pretty Hollow Cr.	--	present	creels
COSBY CR.	2,000	present	survey
DEEP CR.	--	present	creels
Georges Br.	--	none	stocked
Indian Cr.	--	present	stocked
DUNN CR.	2,900	none	survey
EAGLE CR.	--	present	creels
HAZEL CR.	3,060	present	survey
Proctor Cr.	3,000	present	creels
INDIAN CAMP CR.	2,000	none	survey
LITTLE PIGEON R.	--	present	survey
Boulevard Cr.	2,900	present	survey
Buck Fk.	2,950	4,900	survey
Chapman Cr.	3,500	present	survey
Eagle Rocks Br	3,500	present	survey
Injun Cr.	--	present	creels
LITTLE PIGEON R.--continued			
Lost Pr.	4,200	present	survey
Middle Pr.	2,800	present	survey
Porters Cr.	2,800	2,700	survey
Ramsay Cr.	3,000	3,800	stocked
LITTLE R.	4,100	present	survey
Grouse Cr.	4,100	none	survey
Huskey Cr.	2,620	none	survey
Kuwahi Cr.	4,100	none	survey
Meigs Cr.	2,180	none	survey
Meigs Post Cr.	2,800	present	survey
Rattler Br.	4,500	none	survey
Spud Town Cr.	4,100	present	survey
Sweet Cr.	4,100	none	survey
MIDDLE PR., LITTLE R.	strays	present	survey
Lynn Camp Cr.	2,900	present	survey
do.....	3,000	none	survey
Sams Cr.	--	--	creels
Thunderhead Cr.	--	--	creels
NOLAND CR.	2,900	present	survey
OCONALUFTEE R.	3,750	none	survey
Aden Br.	3,750	none	survey
Huskey Cr.	4,000	none	survey
Jack Bradley Br.	3,750	none	survey
Kanati Cr.	2,850	none	survey
Kephart Pr.	3,100	present	survey
Minnie Ball Br.	3,800	none	survey
Sweat Heifer Br.	--	--	creels
RAVEN CR.	4,200	present	survey
ROARING FK.	--	--	creels
STRAIGHT FK.	3,100	present	survey
Ledge Cr.	3,500	present	creels
WEST PR.,L. PIGEON R.	3,450	4,550	survey
Alum Cave Cr.	3,900	4,000	survey
Big Br.	--	--	creels
Road Pr.	3,500	4,300	survey
Trout Br.	--	--	creels
WEST PR., LITTLE R.	strays	present	creels

lower elevation for brook trout in 16 streams as 3,412 feet above sea level, and we found it to be 3,379 feet for 48 streams. There was some extension of range, however, in two streams in the Greenbrier Wilderness Area where no fishing is permitted. King listed the lowest elevations for brook trout in Buck Fork and Eagle Rocks Branch as 4,500 feet and 3,750 in 1936, and we found them to be 2,950 and 3,500 feet respectively. On the other hand, the distribution was practically unchanged in Bradley Creek, one of the better trout streams in the Park in which fishing is permitted. King listed 3,000 feet as the lowest elevation and we list 2,950 feet. We found a few brook trout as low as 3,440 feet in Big Creek whereas King listed 3,900 feet. It therefore appears unlikely that the brook trout populations in the Park will extend their range downstream in the face of competition with the abundant rainbow trout.

Abundance

The populations of brook trout are generally small, and they are even smaller if the immediate habitat is shared with rainbow trout. In 12 small streams where brook trout exist alone, the pounds of trout per acre of water ranged from 2.7 to 36.9 and averaged 18.8 pounds. Seven of the 12 streams had less than 20 pounds per acre. In contrast, in 5 small streams where rainbow trout also occurred, the pounds of brook trout per acre ranged from 4.3 to 18.8 and averaged 9.9 pounds.

The headwaters of Big Creek, a noted trout stream in the Park, provided a fine example of the relative abundance of brook trout and rainbow trout. During extensive surveys of populations in 1956, we found 3.3 pounds of brook trout and 61.9 pounds of rainbow trout per acre in the headwaters; in 1957, there were 5.7 pounds of brook trout and 40.7 pounds of rainbow trout. The decrease of rainbow trout in the latter year was attributed to a poor year class.

The results of creel censuses at fixed stations on Big Creek also demonstrate the scarcity of brook trout of legal size, 7 inches or more in length. In this watershed, access to brook trout waters is not difficult. The census in 1955, estimated to be 91 percent complete, showed that 922 fishermen creeled 19 brook trout and 3,043 rainbow trout. In the census of 1956, 62 percent complete, 888 fishermen caught 31 brook trout and 2,914 rainbow trout. On Bradley Creek, less than 1 percent of the trout caught by fishermen in 1956 were brook trout, and no brook trout were taken in 1957.

Size

King (1937) noted that the brook trout in the Park tend to run small, and we confirmed the observation. In the course of numerous collections, we never took a wild specimen of 10 inches or more in length (table 3). An idea of the size range is afforded by the results of a 5-percent survey made on the fishable waters of upper Little River and tributaries above Elkmont in the fall of 1959. It was estimated that there were 2,321 brook trout present, but only 77 were 7 inches or more in length. In contrast, the estimates included 24,478 rainbow trout of which 4,223 were 7 inches or over.

There are several reasons for the small size of the brook trout in the headwater streams. The streams are small and steep, and gradients range from 400 to 900 feet per mile (Lennon and Parker, 1960). Although pools are generally good, steep cascades replace the riffles. The headwaters are also soft and infertile. Food organisms, mostly tiny insect forms, are much less numerous than in the lower reaches of the streams. Moreover, rainbow trout compete with the brook trout for food and cover in most of the small streams.

Age

Among the 217 brook trout which were aged, 107 were in age group I, 88 in II, 20 in III, and only 2 in IV (table 3). A short life span is typical of the species, and the fish in the southern Appalachian Mountains are no exception. Lennon (1961), for example, found no 5-year old brook trout in Shenandoah National Park in Virginia.

Table 3.--Age, size distribution, and sex ratios of brook trout sampled in selected streams. Some samples were not aged, and some were not sexed

Stream	Age	Number of Fish	Males	Females	Size groups (inches) 3-3.9	4-4.9	5-5.9	6-6.9	7-7.9	8-8.9	9-9.9
Bradley Cr.	--	30	--	--	1	3	12	11	3	--	--
Buck Fk.	--	60	53	7	2	4	14	20	15	5	--
	I	6	--	--	--	--	--	3	3	--	--
	II	3	--	--	--	--	--	--	2	1	--
Chasteen Cr.	II	5	--	--	--	--	1	1	2	1	--
	III	1	--	--	--	--	--	--	1	--	--
Dunn Cr.	I	10	6	4	--	4	6	--	--	--	--
	II	6	3	3	--	--	4	1	1	--	--
Eagle Rocks Br.	--	47	--	--	1	--	10	20	10	3	3
	--	101	64	37	--	--	9	39	37	16	--
	I	26	--	--	--	--	--	15	10	1	--
	II	32	--	--	--	--	--	9	11	12	--
	III	14	--	--	--	--	1	--	9	4	--
	IV	2	--	--	--	--	--	--	--	2	--
Indian Camp Cr.	--	22	14	8	--	7	12	3	--	--	--
Little R.	I	36	21	15	--	10	22	3	1	--	--
	II	20	13	7	--	--	13	6	1	--	--
	III	2	1	1	--	--	--	2	--	--	--
Lost Pr.	--	16	14	2	--	--	2	6	8	--	--
Swallow Fk.	I	29	16	13	--	8	17	4	--	--	--
	II	22	15	7	--	--	4	14	2	1	1
	III	3	3	0	--	--	--	--	3	--	--

We had heard biologists say that the scales of brook trout from Great Smoky Mountains National Park are exceptionally difficult to read, and this indeed is the case. Concurrent with our attempt to age specimens, we were mounting and reading scales of brook trout of similar sizes from New Hampshire and Shenandoah National Park. Thus, there was an opportunity for comparing the scales, and the differences are noteworthy.

In sharp contrast with the scales from New Hampshire and Shenandoah fish, the scales of brook trout from the Great Smokies are extremely thin and fragile and have relatively indistinct circuli and annuli. They are surprisingly lacking in the characters typical of brook trout scales, and upon casual examination, one would tend to discard them as new, incomplete, regenerated scales. They tear easily and often during cleaning and mounting, and they are readable only by use of a high quality microprojector.

Sex ratio

There was a strikingly lopsided sex ratio in favor of male brook trout. Of the 311 brook trout which were sexed during population surveys on several streams, 209 (68 percent) were males and 102 (32 percent) were females (table 3). In contrast, McFadden (1961) noted in his thorough study of brook trout in Lawrence Creek, Wisconsin that the sexes are about equally represented in yearling fish but the proportion of females becomes greater in older age groups.

The ratios were most lopsided in such Wilderness Area streams as Buck Fork, Eagle Rocks Branch, and Lost Fork where no fishing has been permitted for decades. Sexually mature females were very scarce in these streams, and a strange condition was evident in some of the small number of mature specimens collected in summer and early fall. The ovaries were diseased Ova were sparse in a comparatively dense ovarian tissue in some fish. A given ovary might contain some eggs which were white and small, and some yellow, orange, and red-orange eggs of various sizes, including many with black spots.

This disease of the ovaries was not restricted to brook trout. Many of the mature female, rainbow trout collected in the same waters at the same time as the brook trout possessed the same condition. In addition, the body cavities of some fish were jammed with unspawned eggs of the previous spawning season. These eggs in 7- to 9-inch rainbow trout taken in September showed various degrees of resorption, but most were dark colored and relatively intact. Interestingly, these sections of streams yielded very few young-of-the-year rainbows during collections with cresol or electrofishing gear.

Some diseased ovaries of rainbow trout were preserved in formalin and examined later by personnel of the Eastern and Western Fish Disease Laboratories, but the unusual disease remains undiagnosed.

It is possible that the ovarian disease is lethal. Most of the female brook trout taken were juveniles, and adults were scarce. For example, samples of 58 brook trout from upper Little River and 54 trout from Swallow Fork were both sexed and aged. The sex ratio among age I fish distinctly favored the males, but it was much more lopsided among age II fish (table 3).

Fecundity

We limited observations on fecundity because of the scarcity of adult, female brook trout (table 4). Ripe females, however, which ranged from 5 to 7.9 inches long had fewer eggs than ripe trout of the same size in Laurentides Park, Canada (Vladykov and Legendre, 1940) and less than one-half as many eggs as ripe trout in Lawrence Creek, Wisconsin (McFadden, 1961). Our ripe females of 6 to 6.9 inches long, for example, had an average of 107 eggs per fish whereas Canadian fish had 177 eggs and 6.5-inch Wisconsin fish had more than 300 eggs.

McFadden (1961) stated that the markedly lower fecundity of Quebec trout from lakes of low fertility and short growing seasons is significant. Thus, the still lower fecundity of Park trout is even more significant. McFadden added that the possibility of genetic differences among brook trout populations has not been ruled out. Rounsefell (1957) noted that egg numbers in brook trout between different localities vary greatly and that there may be an annual variation in fecundity. Vladykov (1956) also considered the abundance and availability of food as important to fecundity.

Reproduction

In general, there was no evidence in Park streams of the abundant reproduction which is common among brook trout in headwater streams. It was difficult to locate redds in streams to which we had winter access. We attempted to keep selected redds containing viable eggs in the West Prong, Little Pigeon River under observation through the winter of 1956, but they froze completely during the first near-zero weather.

Young-of-the-year brook trout, advanced fry and larger, were considered scarce in the several years we endeavored to find and collect them. Yet, we had no difficulty taking young-of-the-year rainbow trout in the same streams at lower elevations. Also in the same years, we observed and collected many fry and fingerling brook trout in headwater streams of Shenandoah National Park (Lennon, 1961).

Table 4.--Average numbers of eggs in unripe and ripe brook trout collected in July and late October respectively in Great Smoky Mountains National Park as compared with average counts in ripe females from Laurentides Park, Canada1/

Length group (inches)	Great Smoky Mts. Nat'l Park				Laurentides Park	
	Unripe females		Ripe females		Ripe females	
	Numbers of		Numbers of		Numbers of	
	Fish	Eggs	Fish	Eggs	Fish	Eggs
4.0-4.9	10	115	1	79	--	--
5.0-5.9	33	139	11	85	4	131
6.0-6.9	13	214	11	107	14	177
7.0-7.9	5	213	5	161	10	206
	61		28		28	

1/ Vladykov and Legendre (1940).

Some of the factors which limit the reproduction of brook trout in Great Smoky Mountains National Park are discussed in a later section.

Color

The fish in the Park have the bright coloring typical of wild brook trout. It is the size and number of red spots, however, that southern fish differ from northern fish. Holloway4/ noted that the southern brook trout have five to seven rows of red spots instead of the two or three found on New England trout. Bridges (1958) stated that the spots on brook trout in general are large and rather few. Wilder (1952) listed counts of red spots on freshwater and sea-run brook trout from Nova Scotia which, with but one exception, were considerably smaller than counts we made on Park trout (table 5).

The numbers of spots on Park fish vary widely from fish to fish, whereas the variation among Canadian fish is not great. Also, the spots tend to increase in number as the fish grow larger. The fish from Swallow Fork, for example, showed twice as many spots on the average as size was doubled from 4 to 8 inches. Moreover, the spots on the Park fish are much smaller, but no less distinct than those on norther fish.

4/ see footnote on page 2.

Table 5.--Numbers of red spots on the left sides of brook trout from streams in Great Smoky Mountains National Park and Nova Scotia. The data on Canadian fish are from Wilder (1952)

Stream	Length (inches)	Number of trout			Average number of red spots 1/			
		Male	Female	Total	Male	Female	Total	and S.E.
GREAT SMOKY MOUNTAINS NATIONAL PARK								
Eagle Rocks Branch	5.0-5.9	1	4	5	27.0	22.3	23.2	±2.1
	6.0-6.9	14	16	30	30.6	33.7	32.5	±2.4
	7.0-7.9	22	9	31	33.7	42.4	36.3	±2.3
	8.0-8.9	16	0	16	39.8	--	39.8	±1.2
Little River	4.0-4.9	7	4	11	20.4	20.0	20.3	±0.9
	5.0-5.9	21	15	36	24.7	23.8	24.1	±1.3
	6.0-6.9	6	5	11	31.5	26.6	29.3	±1.5
	7.0-7.9	1	0	1	31.0	--	31.0	--
Swallow Fork	4.0-4.9	1	7	8	19.0	15.7	16.1	±1.3
	5.0-5.9	11	10	21	20.8	22.7	21.7	±1.4
	6.0-6.9	15	3	18	22.3	22.0	22.3	±0.3
	7.0-7.9	5	1	6	26.3	31.0	27.0	±1.2
	8.0-8.9	1	0	1	34.0	--	34.0	--
NOVA SCOTIA								
First Fork Brook	4.4- 7.9	--	--	41	--	--	18.7	±0.9
Moser River, freshwater	4.7-13.6	--	--	181	--	--	9.8	±0.4
smolts	5.9- 7.0	--	--	7	--	--	8.2	±2.3
In from sea	7.4-17.3	--	--	156	--	--	9.0	±0.4

1/ Standard error

The taxonomic importance of the numbers and sizes of red spots has not been demonstrated, but Rounsefell (1962) remarked that color should be given equal respect to many anatomical characters in the classification of fish.

Size of body parts

The adjusted means of ten body parts of brook trout from three streams in the Park are given in table 6. For the sake of comparison, they are based on fish of 100 mm. in standard length. Analyses of covariance suggest that significant differences may exist between dorsal to caudal length, head length, eye diameter and pectoral fin length, but not in the remaining six parts.

Wilder (1952) showed that brook trout from rather similar habitats in Nova Scotia and New Brunswick may vary in the relative size of body parts, but he cautioned against reaching any conclusions on heredity based on study of naturally reared populations.

Among the trout from Park waters, the males consistently have larger body parts than females. Wilder found the same to be true with head parts and pectoral fins in Canadian trout.

Comparisons of body parts of trout from 6 Park streams and 5 Canadian streams indicate that there may be significant differences between them (table 7). Of the seven parts listed, there is a possibility of differences in all except the snout length and body width of females and the eye diameter of males.

No attempt was made to substantiate any differences because of the fact that we had to pool the already variable data on trout from Park streams to obtain adequate sample numbers. Moreover, Wilder (1952) advised that comparing samples of trout reared under different conditions is questionable if used, for example, to designate sub-species.

Resistance to disease

Some of the Federal and State fish hatcheries in the Southeast began to rear Appalachian trout in the late-1940's. Holloway 5/ stimulated the effort and observed that the native trout seemed to be hardier than New England brook trout in the local soft waters. In connection with some of our investigations on the native trout, we supplied a lot of fingerlings to the Bureau's Eastern Fish Disease Laboratory at Leetown, West Virginia. Snieszko (1957) exposed them along with fingerlings from the Berlin, New Hampshire, National Fish Hatchery and the Bellefonte, Pennsylvania, State Fish Hatchery to furunculosis (Aeromonas salmonicida) and ulcer disease (Hemophilus piscium). In the first set of tests, the mean mortalities at 6 weeks were 87.7 percent for Appalachian trout, 85 percent for Berlin trout, and 12.6 percent for Bellefonte trout. In a later trial, the mean mortalities were 97.5 percent for Appalachian fish, 87.5 for Berlin fish, and 12.5 percent for Bellefonte fish.

Snieszko concluded that the Appalachian brook trout are highly susceptible to furunculosis and ulcer disease. He also pointed out

5/ see footnote on page 2.

Table 6.--Adjusted mean sizes of body parts of 100-mm. (standard length) brook trout from three streams in Great Smoky Mountains National Park

Body part	Stream	Adjusted mean (mm.) Male	Female
Snout length	Eagle Rocks Branch	10.50	8.06
do.....	Little River	10.77	8.35
do.....	Swallow Fork	10.51	9.15
Eye diameter	Eagle Rocks Branch	8.74	8.25
do.....	Little River	8.35	8.09
do.....	Swallow Fork	9.11	9.19
Post-orbital length of head	Eagle Rocks Branch	20.67	18.46
	Little River	19.62	16.50
do.....	Swallow Fork	19.62	17.38
Upper jaw length	Eagle Rocks Branch	26.62	20.99
do.....	Little River	25.36	19.92
do.....	Swallow Fork	25.33	21.11
Body depth	Eagle Rocks Branch	35.55	30.96
do.....	Little River	34.22	29.39
do.....	Swallow Fork	35.77	30.52
Body width	Eagle Rocks Branch	19.34	19.13
do.....	Little River	20.89	18.23
do.....	Swallow Fork	19.38	17.53
Head length	Eagle Rocks Branch	39.58	34.10
do.....	Little River	38.59	31.81
do.....	Swallow Fork	38.23	33.56
Dorsal to caudal length	Eagle Rocks Branch	56.66	52.63
	Little River	56.27	51.85
do.....	Swallow Fork	54.28	49.77
Snout to dorsal length	Eagle Rocks Branch	66.85	60.16
	Little River	68.43	61.10
do.....	Swallow Fork	68.15	61.40
Pectoral fin length	Eagle Rocks Branch	29.04	25.32
	Little River	25.96	22.89
do.....	Swallow Fork	27.09	24.68

disease resistance is a function of heredity and that there is therefore justification in classifying as populations or sub-populations those strains of brook trout which differ from one another in susceptibility to an infectious disease.

Survival of stocked fish

Before 1954 there were sections of streams in the Park which were devoid of fish because of floods. For the most part, they were at high elevations where barrier falls and cascades are common. Repeated attempts were made by the National Park Service to restore brook trout in these streams by stocking progeny of New England trout, but the attempts failed completely.

Beginning in 1954, we marked and stocked 3-inch Appalachian brook trout from the Erwin, Tennessee National Fish Hatchery in selected streams. Their growth and survival in the West Prong of Little Pigeon River was described by Lennon and Parker (1960). They

Table 7.--Adjusted mean sizes of body parts of 100-mm. (SL) brook trout from Great Smoky Mountains National Park and Nova Scotia. The Canadian data are from Wilder (1952)

Body part	Adjusted mean (mm.) National Park Male	Female	Nova Scotia Male	Female
Snout length	9.48	7.85	8.85	7.56
Eye diameter	8.20	7.89	7.90	7.13
Post-orbital l.	18.15	16.04	17.09	15.14
Upper jaw length	23.26	19.00	19.55	16.67
Body depth	31.87	29.31	27.90	25.90
Body width	18.15	16.43	17.10	15.85
Pectoral length	25.27	22.58	26.41	19.58

reproduced in the fall of the following year, and specimens taken by anglers reached 10 inches in length within 24 months. Thus, the Appalachian trout demonstrated that they are unable to survive outside their normal range. We attempted to restore brook trout in 13 streams which had been drought ravaged in Shenandoah National Park in Virginia (Lennon, 1961). Appalachian trout which averaged 2.7 inches long were stocked in June 1955. Fish from the same lot were stocked also in Great Smoky Mountains National Park in the same month. The survival in Shenandoah through the first summer was very poor, and the stocking was considered a failure. In contrast, the fish stocked in the Smokies did well.

The Streams

King (1937), Stupka (1962), and Cornell (1966) pointed out that man's activities have caused the removal of the Appalachian brook trout from much of its former range and restricted remnant populations to remote headwaters. Although the species persists in the high-altitude headwaters, it would be a mistake to consider these streams, in general, as favorable habitat. Many of the headwater streams are very lovely and relatively undisturbed, especially in the Wilderness Areas of the Park. Both the scarcity and small size of the fish, however, convinced us that there were inimical factors present. We expanded our program to include year-around observations in an attempt to detect them. Some factors which alone or in combination might

influence trout populations adversely are discussed below.

Gradient

As mentioned earlier, the gradients of brook trout waters in the Park are very steep. Barrier falls and cascades are common, and they undoubtedly inhibit the movement of fish seeking cover, food or spawning situations. We often found excellent pools in the vicinity of barriers which seemed devoid of trout.

Water flows

The flows in the headwater streams are generally torrential in character. In addition, there is abundant precipitation at the higher elevations in the Smokies. Shanks (1954) listed a 5-year mean rainfall of 89 inches at 5,000 feet in 1946-1950, with a range of 80 to nearly 100 inches. In the spruce-fir zone above 5,000 feet, the 5-year average rainfall exceeds 90 inches per year. Thus, many of the brook trout waters lie in what Shanks calls super-humid, rain forest, and it is a situation which differs greatly from the remainder of the Appalachian Mountains northward to Maine.

Freshets occur commonly in the Park because of the great amount of precipitation, and the resultant scouring has been known to damage fish populations (King, 1939; and Lennon and Parker, 1960). Much of the rainfall takes place in summer and usually in the form of brief, very heavy showers in late afternoon. For example, we recorded showers on 49 consecutive days in early summer of 1954 at a creel census station on the Little Pigeon River at Greenbrier. The streams often stay bank full in summer, and smaller flows typically occur in fall, winter, and spring.

Temperatures in winter

Water temperatures are favorable to fish in the headwaters in summer, but it is in the winter that they cause striking problems. King (1939 and 1942) noted that in zero weather the streams become largely frozen, including the stream beds, and flows are reduced. Stupka 6/ recalled that January 1940 was the coldest month on record at Park Headquarters. Air temperatures were below freezing on 29 of the 31 days and about zero on 12 days. At the time he observed that Ramsey Cascades on Ramsey Fork had frozen solid from top to bottom.

The most impressive characteristic of water temperatures in Park streams is the rapid reflection of air temperatures, especially in winter. A sudden cold snap quickly drops stream temperatures to freezing, a situation which contrasts sharply with northern trout streams. A thermograph in Little River in 1957 and 1958, indicated that stream temperatures could drop from 48 to 32° F. within 48 hours. Thermograph records for downstream sections of Abrams Creek and Little River in December 1958, the coldest month of that year, are given in table 8. They demonstrate that the water can remain at freezing temperatures or below for days at a time. During such periods, striking formations of anchor ice occur.

Benson (1955) made some observations on anchor ice in a Michigan trout stream which contrast with ours in the Park. He reported that anchor ice in the Pigeon River does not occur often; it forms only in portions of the stream; it has a mean thickness of 2 inches and a maximum thickness of 7 inches; and it is usually released from the bottom and floats away by mid-morning after persisting for not more than 12 hours.

Anchor ice occurs frequently in the Park, and the formations are extensive throughout a stream rather than limited to portions. We measured thicknesses up to 1.5 feet. And, the formations last for days during sub-freezing weather. During one such period on the West Prong, Little Pigeon River, the water temperature was 32° F. at 1,460 feet elevation near

6/ Stupka, A. Nature Note in Park and Views, February 6, 1958.

Table 8.--Water temperatures in °F. recorded by thermograph in Abrams Creek at 1,100 feet elevation and Little River at 1,500 feet elevation during August and December 1958, the warmest and coldest months of the year

Date	Abrams Creek (°F.)				Little River (°F.)			
	August		December		August		December	
	Low	High	Low	High	Low	High	Low	High
1	67	70	36	39	68	72	36	37
2	68	70	40	41	69	72	40	42
3	66	68	42	43	68	70	42	43
4	65	70	43	45	65	72	43	45
5	66	71	44	48	66	75	45	47
6	66	70	39	46	69	77	33	42
7	66	71	45	48	69	77	32	33
8	68	73	34	35	68	76	32	34
9	69	71	34	35	69	74	32	33
10	68	72	34	35	68	76	32	34
11	68	72	34	35	71	76	32	34
12	68	71	33	34	71	75	32	32
13	67	68	33	34	68	78	32	32
14	67	69	33	34	68	77	32	34
15	67	71	32	32	67	74	32	34
16	69	71	32	32	71	75	33	34
17	67	68	32	32	65	82	33	33
18	64	67	32	32	65	82	33	34
19	64	69	32	32	65	82	33	34
20	65	69	32	32	69	78	34	36
21	65	71	32	32	70	76	34	36
22	67	72	32	32	69	77	35	35
23	68	69	32	34	69	74	35	37
24	67	68	32	36	69	73	37	40
25	66	67	35	36	68	71	36	38
26	64	67	32	34	65	71	34	36
27	64	66	32	34	64	71	35	35
28	61	67	35	38	61	70	36	42
29	61	68	39	40	64	75	42	44
30	65	71	41	41	65	77	44	47
31	65	71	40	40	69	78	44	46

Park Headquarters, and there was abundant anchor ice. The same temperature and ice condition prevailed for miles upstream. In the headwaters at 3,800 to 4,700 feet elevation, the water temperature was 31.8° on a laboratory-grade thermometer, and the stream was very heavily burdened with anchor ice. The proof of super-cooling was even more dramatic when we attempted on this and other occasions to collect water in 8-ounce bottles and small vials for chemical analyses. The water froze solidly and instantly as the containers were lifted above the surface of the stream.

King (1942) observed no effects of anchor ice on trout, but Hart (1959) reported that when frazil ice conditions in certain Canadian streams were severe in winter, the stocks of underyearling brook trout were low in the following summer. We saw no direct effects of the anchor ice in Park streams on trout because the thick and extensive formations made observations impossible. This situation was unique because in the same winters we had no difficulty electrofishing during zero weather in streams of Shenandoah National Park about 200 miles north.

We had a number of brook trout redds containing viable eggs under observation in 1956 on headwaters of the West Prong, Little Pigeon River. The stream froze badly during the first severe weather in late fall, the volume of flow was greatly reduced, and the redds were soon left high, dry, and frozen. Not one escaped.

The brook trout in headwater streams often build redds at the side or tail of pools because riffle areas are largely supplanted by cascades. They therefore appear to be more vulnerable to damage when freezing and anchor ice cause reduced flows. This could be a major cause of low recruitment of brook trout in the Park. The rainbow trout, on the other hand, spawn in March or April, and their redds are not exposed to freezing conditions.

Benson (1953) reported that ground water, because of its relative warmth, controls the location of brook trout redds in a stream. He found that redds were present only in those sections of the Pigeon River, Michigan, where there was much seepage of ground water. These sections rarely drop to 32° F. and typically remain free of ice. He concluded that ground water is basic to trout production in the Pigeon River. There is, therefore, a great difference in the temperature quality of Park headwater streams in winter as compared with trout waters elsewhere. We assume that the ground water sources at high altitudes in the Park are very shallow and lack the relatively homothermous advantage of typical springs or the relative warmth of typical ground water.

Water hardness

The Great Smoky Mountains are one of the oldest upland areas in the world and the principal formations are pre-Cambrian sandstone,

quartzites, conglomerates, shale, and slate. The waters draining them are extremely soft, deficient in carbonates, with total alkalinities of 10 ppm or less, and total dissolved solids under 20 ppm (Billingsley and Joyner, 1953). Lennon (1959) demonstrated that the Park streams in general had smaller concentrations of total dissolved solids than trout streams in Shenandoah National Park, Virginia, and in White Mountains National Forest, New Hampshire.

Such soft and infertile waters are considered to be less than optimum for brook trout. McFadden and Cooper (1964) and McFadden et al. (1965) studied infertile streams in Pennsylvania and concluded that brown trout in them had smaller average size, lower fecundity, and lower reproductive rate than brown trout in fertile streams. Thus, the small average size of brook trout in the Park and their low fecundity may be attributable to the infertility of the streams.

pH

King (1943) listed a pH range of 4.7 to 6.9 for brook trout waters in the Park. We measured a range of 5.2 to 6.0 in the headwater streams, and 6.8 to neutrality in the main streams. The low pH's in the headwaters are typical of soft, infertile streams.

DISCUSSION

Stupka (1962) mentioned that the brook trout in the Park are highly prized by anglers and added that the National Park Service was attempting to reestablish the native strain in some of its former haunts. The restoration can be done with hatchery-reared fish of the Appalachian strain, but only in waters where it is free from the overwhelming competition from rainbow trout and other species. The experimental reclamation of Indian and Abrams Creeks in the Park by Lennon and Parker (1959) demonstrated the feasibility of using a toxicant to improve conditions for trout.

Peterson, in a 1966 paper in which he alleges the Appalachian strain is on the brink of inclusion among endangered species, opposes the construction of a new road across the wild and remote, western section of the Park because of possible physical damages to one or more important trout streams.

Our studies in the Park demonstrate some of the natural and serious limitations of headwaters as habitat for the native brook trout. There is little doubt that man's activities and the subsequent introduction of the rainbow trout relegated the brook trout to the upper and less favorable portion of its former range. It has persisted there in something less than a satisfactory state of well-being only because the headwaters are, in general, very remote and very rough. Very few fishermen care to put forth the effort to hike in and fish them.

There is good justification for concern over the fate of the native brook trout if any of man's activities increase in the headwater areas. The remaining habitat of the species is unique in many respects, and all considerations for change must be based on the unique features.

CONCLUSIONS

1. The brook trout in Great Smoky Mountains National Park are limited principally to headwater streams above 3,000 feet elevation. There has been no significant extension of range down stream since the Park was established.

2. Estimates indicate that brook trout may exist alone in only 48 of the 226 headwater streams. They are not abundant when found alone, and their numbers are smaller when the habitat is shared with rainbow trout.

3. Small size and short life are typical of the species in the Park. We took no wild brook trout over 10 inches long in our many collections, and few fish of age IV.

4. The sex ratio was highly atypical at the time of the surveys. In general, male brook

trout outnumbered females two to one. The scarcity of mature females in some streams may have been due to an unidentified disease of the ovaries.

5. The fecundity of female brook trout in the Park is lower than that of Canadian and Wisconsin fish. There was also less evidence of reproduction, i.e. numbers of redds or young-of-the-year fish than in typical headwater streams.

6. Red spots on the sides of brook trout in the Park were smaller and significantly more numerous than on northern fish.

7. A comparison of relative sizes of certain body parts of brook trout from the Park and Canadian streams indicates that there may be some significant differences between them. No conclusions regarding heredity are made, however, based on this investigation of naturally reared fish from different areas and conditions. Moreover, there appeared to be significant differences in body parts among trout collected in three streams of the Park.

8. The southern brook trout are highly susceptible to furunculosis and ulcer disease in contrast to a Pennsylvania strain of brook trout. Since resistance to disease is considered to be a function of heredity, the two strains of fish may be distinctly different.

9. Hatchery-reared, native brook trout were able to survive and reproduce in Park streams whereas New England brook trout repeatedly failed. Conversely, the native fish were unable to survive when stocked in streams of Shenandoah National Park under favorable conditions.

10. On the basis of the above conclusions, it is obvious that the native brook trout in the Park differ from northern fish in some interesting and significant respects. It seems valid, therefore, to designate the Park fish as a southern Appalachian strain of brook trout.

11. The steep, very soft, and acid waters in headwater streams are relatively infertile. Stream flows are heavy because of the 80 inches or more of rain per year at high elevations in the Park. The not-infrequent freshets are at times damaging to fish, their redds and young.

12. Water temperature in winter is a limiting factor for brook trout in the headwaters. Water temperatures quickly reflect air temperatures and drop to freezing and even supercooled conditions. The streams remain badly frozen for days at a time, and water flows are greatly reduced. The de-watering and freezing of brook trout redds occurs at such times. Furthermore, the amounts, depths, extensiveness, and persistence of anchor ice in the streams during cold weather are phenomenal.

13. The remnant populations of Appalachian brook trout in the Park are therefore restricted to less than favorable habitat. They must be given protection from substantial increases in fishing pressure or damaging alterations of the streams if they are to survive.

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