Age and Growth of Brook Trout in Southern Appalachian Streams

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Abstract: Samples of brook trout (*Salvelinus fontinalis*) were collected by electrofishing in 28 streams in 5 southeastern states between June 1977 and March 1978. Whole and sectioned otoliths were used to estimate age and the annual growth increments of 998 fish. General compliance with 4 criteria suggested validity of the otolith ageing method. Although 1 fish was age X, 98% were age III or younger. Brook trout from all streams grew the most in length during their first year. Second-year growth represented 28% (median) of median first-year growth. Growth of males and females did not differ significantly. Growth rates were generally slower than those reported for brook trout from other regions. Age and growth patterns of individual populations were not consistent within a given drainage basin. In several streams, no fish obtained a length of 152 mm (6 inches) or the minimum legal limit, by age III.

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Little age and growth information exists for brook trout from southern Appalachian streams. Mountain streams in Georgia, North and South Carolina, Tennessee, Virginia, and West Virginia constitute the southernmost extension of the native range of brook trout (MacCrimmon and Campbell 1969). Brook trout are the only native salmonid in the southeastern United States.

Some fishery managers have expressed particular concern about brook trout in the southern extension of its range. In Great Smoky Mountains National Park (GSMNP), Kelley et al. (1980) reported a 70% decline in the range of brook trout between 1900 and the mid-1970s. Competition with introduced rainbow trout (*Salmo qairdneri*) and brown trout (*S. trutta*) (Kelley et al. 1980, Larson and Moore

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1985), in conjunction with habitat degradation (King 1937), apparently caused this decline. Population levels of brook trout in most states have declined to a point where special regulations became necessary to protect the fish (Seehorn 1978). The objectives of our study were to (1) assess the age and growth characteristics of brook trout in 28 streams from a 5-state region in the southern Appalachian Mountains, (2) determine whether population age and growth parameters exhibited similar trends within major drainage basins in the study area, and (3) to compare the usefulness of scales and otoliths in ageing brook trout. Funding for this study was provided by the National Park Service and Forest Service. We thank several anonymous reviewers and P. Bettoli for their critical comments on earlier drafts of this manuscript and extend our appreciation to the personnel who graciously assisted us in securing samples.

Methods

Study Area

We selected 28 study streams that were known to contain native brook trout populations in Tennessee (9), North Carolina (9), Virginia (4), West Virginia (3) and Georgia (3) (Table 1). Stream elevations ranged from 700 to 1,200 m above mean sea level. Ten streams were in the GSMNP along the North Carolina-Tennessee state border. Park statutes had prohibited angling for brook trout since 1975 although poaching was known to occur. All other streams were open to angling for brook trout. Regulations on open streams were usually a daily creel limit of 6 to 10 fish and a minimum length of 152 mm (6 inches).

Fish Collection

Various state and federal agency personnel assisted us in collecting fish or provided fish for us to examine. Fish were collected from all 28 streams between mid-June and late August 1977. Fish were again collected from 2 Tennessee streams (Rocky Fork and Rough Ridge) in March 1978 for use in verification of our otolith ageing technique. All collections were made with electrofishing apparati of various designs. Although a random sample from each population was desired, size selectivity occurred in some samples.

Ageing Techniques

Both otoliths from each fish were removed and stored dry in coin envelopes prior to examination. We determined ages by immersing an non-anomalous otolith in water on a depression slide, viewing it at 40×, and counting annuli. We considered the interface between an inner hyaline and an outer opaque zone of deposition an annulus. Growth increments were determined by using an ocular micrometer to measure the distance from the nucleus to the observed annulus. Before ageing and measuring some of the thicker otoliths, a thin-sectioning machine was used to cut portions off the distal side of the otolith to better expose the nucleus. Otoliths were independently aged twice and, when discrepancies occurred, read a third time. High

Table 1. Weighted mean total lengths at each annulus for 28 brook trout populations in the southern Appalachians. An asterisk denotes streams in the Great Smoky Mountains National Park.

	Back-calculated total lengths (mm) at annulus						
State, drainage, and stream (ID)	I	II	III	IV	V	VI ···	X
Georgia							
Chatahoochee River							
Dover Creek (DC)	125						
N	11						
Popcorn Creek (PC)	122						
N	13						
Tennessee River							
Board Camp Creek (BC)	110	145					
N	32	6					
North Carolina							
Tennessee River							
*Bunches Creek (BU)	102	128	156	175	192		
N	20	13	5	2	2		
*Lower Dude Creek (LD)	92	131	163				
N	23	4	1				
*Upper Dude Creek (UD)	97	128	168	182			
N	22	11	1	1			
*Enloe Creek (EC)	115	145	175				
N	10	9	4				
*Flat Creek (FC)	87	120	137	161	178	186	201
N	20	7	3	2	2	2	1
*Forney Creek (FO)	104	136	166				
N	16	10	1				
Long Laurel Creek (LL)	102	133	166				
N	50	35	1				
Ogles & Mitchells Creek (OM)	110	143	164	178			
N	36	34	9	9			
Rough Butt Creek (RB)	102	137	143	151	163		
N	46	16	1	1	1		
Tennessee							
Tennessee River							
Birch Branch (BB)	92	132					
N	22	1					
Chestnut Branch (CB)	105						
N	9						
*Dunn Creek (DU)	97	118	150	165			
N	23	17	4	2			
*Eagles Rock Prong (ER)	125	165	186	193			
N	21	19	3	2			
Fagall Branch (FB)	110	138	168				
N	13	2	1				
*Goshen Creek (GC)	104	140	169	189	210		
N	30	23	9	3	1		
*Indian Camp Creek (IC)	95	125	145	163			
N	20	11	6	1			

Table 1, *continued*

State, drainage, and stream (ID)	Back-calculated total lengths (mm) at annulus I	II	III	IV	V	VI ··· X
Tennessee						
Tennessee River						
Rocky Fork Creek[a] (RF)	96	128	160	197		
N	61	25	7	1		
Rough Ridge Creek[a] (RR)	105	146	180			
N	60	19	4			
Virginia						
New River						
Chestnut Creek (CC)	110	157	191			
N	51	9	3			
Helton Creek (HC)	92	122	160			
N	77	33	5			
Stewarts Creek (ST)	127	164	198	232		
N	48	18	9	4		
Potomac River						
Low Place Run (LP)	95	138	163	178		
N	31	16	10	4		
West Virginia						
Potomac River						
Horse Camp Creek (HO)	108	163				
N	34	1				
Senaca Creek (SE)	129	192				
N	18	6				
Whites Run Creek (WR)	115	168				
N	30	5				

[a]July 1977 and March 1978 samples combined.

correlation between fish length and otolith radius implied an isometric relationship permitting the use of otoliths to back-calculate lengths of fish at earlier ages.

Four criteria were used to verify the otolith ageing method: (1) observance of seasonal changes as indicated by hyaline to opaque deposition at the otolith margin (2) superimposition of the distribution of otolith-assigned ages on length-frequency polygons for samples of more than 50 fish; (3) progression of age-class modes within length-frequency polygons of samples collected 7 months apart from the same stream; and (4) comparison of ages derived from otoliths with ages derived from scales taken from the same fish. Scales from 140 fish (15 populations) were taken from the smallest and largest specimens and were read and verified by a second reader using standard techniques. Although a linear relationship existed between fish total length and otolith radius, a direct proportion (Dahl-Lea) back-calculation program was used to estimate total lengths at previous annuli since many samples lacked age 0 and age I fish. Length at annulus and growth increment estimates are presented as weighted means.

Results

Brook trout otoliths displayed a transition from an opaque to a hyaline outer edge in the months samples during this study. All otoliths had a wide opaque band (with transmitted light) on the outer edge during June, July, and August of 1977. In early March 1978, one-half of 45 fish (from RF2 and RR2) contained otoliths with a hyaline outer margin: the others had a very thin opaque zone on the outer margin, but only in rostrum and postrostrum areas. Annuli apparently formed during February, March, and possibly April, depending upon the population, but not as late as June. Length-frequency polygons constructed from the otolith data yielded approximately normal distributions for most age classes of the larger samples (Fig. 1), with well-defined modes for the more abundant smaller fish (ages 0–II).

The fish in 2 dual samples (RF–RF2, RR–RR2) exhibited modal or age-group progression in the form of mean total length (TL) increases during the 7 months between sampling (Fig. 2). Increases in total length during the interim period corresponded to a like portion of the annual increment of growth estimated by the back-calculation process for all three age-groups in each pair of samples.

Although percent-agreement between assigned ages using scales and otoliths appeared high (89%), a paired *t*-test yielded a significant difference between the 2

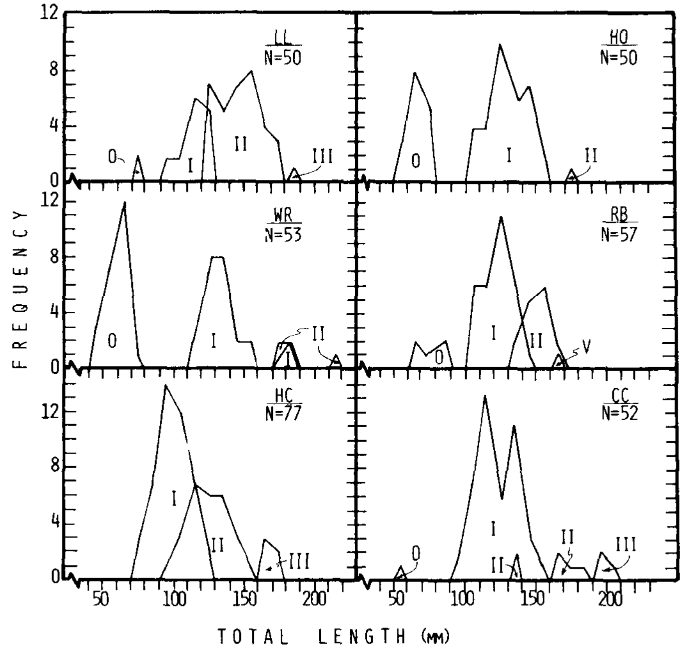

Figure 1. Age class distribution by length for brook trout in samples where $N = 50$. Stream codes are listed in Table 1.

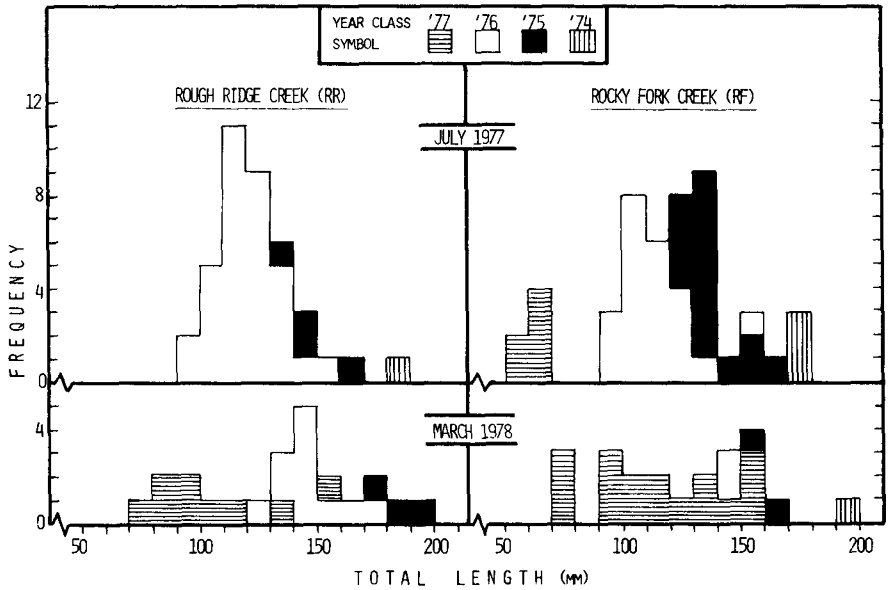

Figure 2. Distribution of total lengths by year class of brook trout collected in Rough Ridge Creek and Rocky Fork Creek, Tennessee, in July 1977 and March 1978.

ageing techniques (mean difference between assigned ages differed from zero, $P \leq 0.05$). Differences usually resulted from assigning 1 to 3 fewer annuli on scales than on otoliths. Frequency-of-agreement between the 2 scale readings was 92% for all fish. Frequency-of-agreement between the first 2 otolith readings averaged 99% for ages 0 through II, and declined to 0 for age X (1 fish). Overall, percent agreement for otoliths varied inversely with the age of the fish ($r = -0.94$) and did not differ appreciable with sex of fish or stream location. On the basis of all the criteria listed above, we concluded that observed rings on the otoliths were true annuli.

Fish of age III or younger comprised 98% of the fish in all samples, with ages ranging from 0 to 10 years. Of the 28 samples collected, 19 contained age 0 fish. Two of the 3 samples that contained no fish older than age II came from Georgia streams. Both of the oldest fish (ages VI and X) were females from Flat Creek in the GSMNP. Most samples contained relatively balanced numbers of fish of each sex in all age groups present. No sample contained more than 2 consecutive age groups in which 1 sex had higher numbers.

Growth data for each sex were combined due to insignificant differences in growth rates between sexes in all samples during the first 2 years of growth (analysis-of-variance, $P > 0.05$). In all cases, fish in each stream grew the most during their first year of life (Table 1). Second-year growth represented 28% (median) of the median increment attained at age I. Complete tables listing annual growth increments and standard errors are given in Konopacky (1978).

The range of fish lengths (maximum TL − minimum TL) among samples at each age increased from 45 mm at age I to 74 mm at age II, but then decreased to 61 mm at age III. Some populations with faster growing age I fish and others with relatively slow growth during the first year continued these trends during the second year and resulted in an increase in range of lengths observed at age II. Lack of age III fish in faster growing populations, and better growth by some younger fish in slower growing populations, caused the reduction in range of lengths observed at age III.

Populations with the oldest fish generally grew at the slowest mean annual rate. A significant negative correlation existed between first year growth and number of age classes in each population ($r = 0.46$; $P < 0.05$). Correlation between second year growth increments and number of age classes was also negative, but not sig-

Table 2. Bonferroni analysis of mean annual growth increments of brook trout at age I and II (if present). River drainage codes are: CH = Chatahoochee; NW = New; PO = Potomac; TN = Tennessee. An asterisk denotes streams in the Great Smoky Mountains National Park. Means with same letter were not significantly different ($P > 0.05$).

Age I					Age II				
ID	*N*	Drainage	Mean increment (mm)	Bonferroni analysis	ID	*N*	Drainage	Mean increment (mm)	Bonferroni analysis
FC	20	TN*	90	a	IC	11	TN	23	a
BB	22	TN	92	ab	BU	13	TN*	23	a
HC	77	NW	92	ab	DU	17	TN*	23	a
LD	23	TN*	93	ab	HC	33	NW	25	ab
IC	20	TN*	95	abc	BC	6	TN	26	abc
LP	31	PO	95	abc	LD	4	TN*	26	abc
RF	61	TN	96	abcd	FO	10	TN*	26	abc
UD	22	TN*	98	abcd	RB	16	TN	26	abc
DU	23	TN*	98	abcde	FC	7	TN*	26	abc
BU	20	TN*	102	abcdef	LL	35	TN	27	abc
GC	30	TN*	102	abcdef	EC	9	TN*	27	abc
LL	50	TN	103	abcdef	FB	2	TN	28	abcd
RB	46	TN	103	abcdef	RF	25	TN	29	abcde
FO	16	TN*	104	bcdef	UD	11	TN*	29	abcde
RR	60	TN	105	bcdef	ST	18	NW	30	abcde
CB	9	TN	105	bcdef	RR	19	TN	32	abcde
HO	34	PO	108	cdef	GC	23	TN*	33	abcde
FB	13	TN	110	defg	OM	34	TN	33	abcdef
OC	51	NW	110	defg	LP	16	PO	35	bcdef
BC	32	TN	110	defg	CC	9	NW	35	cdef
OM	36	TN	110	efg	ER	19	TN*	38	def
EC	10	TN*	115	efgh	WR	5	PO	39	ef
WR	30	PO	115	efgh	SE	6	PO	44	f
PC	13	CH	122	ghi					
DC	11	CH	125	hi					
ER	21	TN*	126	hi					
ST	48	NW	127	hi					
SE	18	PO	129	i					

nificant. The oldest fish (age X) only grew an estimated 15 mm in the 4 years prior to capture.

A Bonferonni analysis (SAS 1982) placed samples containing age I fish into 9 significantly different subsets of growth similarity based on annual mean growth increments (Table 2). Samples containing at least 2 age II fish were divided into 6 significantly different subsets based upon annual growth increments for the second year of life. Analyses placed samples from the same drainage or in the GSMNP into different subsets of growth.

Discussion

Beamish and McFarlane (1983) stressed the need to validate ageing techniques or, at the very least, to consider the possibility of errors in age estimates. Strict validation, in terms of using known-age fish or conducting a mark-recapture study, could not be conducted in our study. However, the results generated by following the 4 criteria for verifying annular marks on otoliths supported the contention that otoliths produced accurate age determinations for brook trout in southern Appalachian streams. Otoliths have also been validated as reliable ageing structures for brook trout in other regions in North America (Donald et al. 1980, Reimers 1979). Our results showed the use of scales frequently underestimated ages when compared to using otoliths, which has been observed in other studies of brook trout (Dutil and Power 1977, Magnam and Fitzgerald 1983) and other freshwater fish (Erickson 1983, Sikstrom 1983).

Our analysis of brook trout ages supported McAfee's (1966) conclusion that the life-span of brook trout is short, particularly in southern Appalachian streams (Whitworth and Strange 1983). We did, however, find 1 10-year-old fish which exceeds the age of other reported stream-dwelling brook trout. Brook trout from alpine lakes have been aged, using otoliths, at 18 to 24 years, (Donald et al. 1980, Reimers 1979). Size selective collection methods probably caused the lack of age 0 fish in many of our samples (Moore et al. 1983). The absence of fish older than age I in some samples suggested the removal of older age groups by other means, e.g. heavy winter mortality (Whitworth and Strange 1983). Brook trout older than age I in this study were generally shorter at successive ages than most fish in other age and growth studies (Carlander 1969).

Results of our analyses did not allow prediction of growth potential of a population based on the parent drainage of the population. Local habitat conditions appeared important in influencing growth rates since the populations of brook trout in the 10 streams in the GSMNP were separated into different subsets of growth but existed under identical fishing regulations (no harvest). Low fertility of the pre-Cambrian shield (Lennon 1967) and low temperatures at higher elevations (King 1937) in the study area may have restricted growth of fish in some streams. Poorly buffered headwater streams in the southern Appalachians are generally associated with low growth and production rates of brook trout (Whitworth and Strange 1983). Of the samples with fast growth, some were from streams (BU,EC,ER) at higher elevations which contradicted an earlier study by Purkett (1960), which found growth decreased as elevation increased. More intensive sampling would be needed to determine what factors regulated growth in the 2 Georgia populations sampled where fish grew well but were apparently short-lived. Since growth rates differed significantly within natural and political boundaries encompassed by this study and unique regulations for an individual stream are usually not feasible, fishery managers must continue to realize that populations in close proximity to one another will possibly have different potentials for a sport fishery. We did not consider the much used 152-mm (6-inch) size regulation to be an effective method of managing many populations because few, if any, fish greater than that length were found. Whitworth and Strange (1983) also observed that few brook trout reached a harvestable size of 152 mm in their southern Appalachian study stream (RF). In addition, anglers may reduce population sizes by hooking and releasing many illegal size fish and increasing mortality rates. Since most fish we examined were mature at lengths <152 mm, managers might allow anglers to harvest a portion of total annual production through use of an "any-size, must-take" regulation. This approach might be very appropriate for populations that never produce legal size fish due to slow growth rates and high natural mortality.

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