

and

John Windell, Department of Evolutionary, Population and Organismic Biology,  
University of Colorado, Boulder, Colorado 80309

## Age, Growth and Condition of Brook Trout (*Salvelinus fontinalis*) from an Unexploited Alpine Lake

### Abstract

The purpose of this study was to provide baseline data on fish populations in the Green Lakes Valley (Colorado Front Range) as part of the long-term ecological research program of the University of Colorado. While the results were site specific, the fish sampled (brook trout, *Salvelinus fontinalis*) had been unexploited for the past 50 years. Because data from unexploited fish populations are rare, they are presented here for use by fisheries biologists and ecologists who often need to know the potential for fish growth and longevity under unexploited conditions. Fish were sampled with gill nets from Green Lake 3 (GL3) and total length, weight and sex determined. Otoliths were used to estimate age. Females outlived males; the maximum longevity was 13 years. Growth and condition of GL3 brook trout was within the range observed in other studies of the species in western U.S. lakes with one exception. Brook trout from Bunny Lake, California, had a longer life span (24 years), much lower condition and slower growth than GL3 brook trout. These data will be a valuable reference point for those interested in this species in high elevation lakes, especially since the study site will be part of the long-term ecological research network.

### Introduction

Long-term ecological research (LTER) is being pursued in a number of biomes to understand how natural ecosystems function so that environmental decisions may have a firm foundation (Callahan 1984). The research reported here was part of a long-term ecological study of the Green Lakes (GL) Valley (Colorado Front Range), undertaken by the University of Colorado LTER program. One objective of the first phase of the study was an inventory of fish populations in the Green Lakes (Figure 1). In an initial survey in 1981, one of us (Windell) found only brook trout, *Salvelinus fontinalis*, in Lake Albion, GL2 and GL3. All three populations have been unexploited for the past 50 years by prohibiting trespass and angling in the Green Lakes valley (Platt 1987). The City of Boulder owns the watershed and trespass laws are a means of protecting the water supply of the city.

Unexploited fish populations are relatively rare, although the exact meaning of the term is subject to different interpretations. For example, is occasional removal by a poacher considered exploitation? Almost all public waters can be expected to contain exploited fish populations, unless they are very remote or are protected by trespass laws such as are in force in the Green Lakes valley. Remoteness and trespass laws seem to qualify the GL3 population as unexploited.

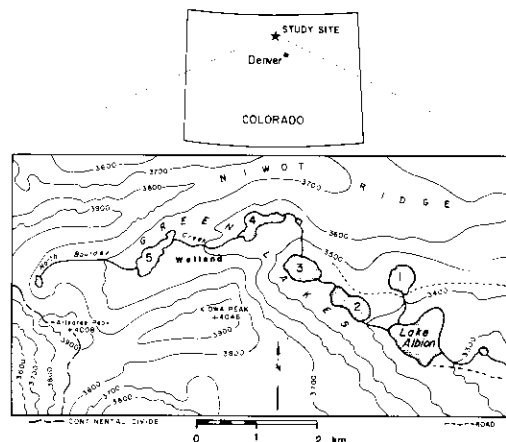


Figure 1. Location map of Green Lake 3.

Unexploited populations are important to ecologists and fisheries biologists because they form a reference point for the study of exploited populations. Angling can be expected to selectively remove larger (older) fish and may alter productivity of different cohorts. In unexploited populations, for example, individuals can be expected to reach maximum longevity.

Brook trout are not native to Colorado and were introduced into the Green Lakes, but no records are available. Brook trout occur in many western North American lakes (MacCrimmon and Cambell 1969) and are often the only fish in alpine

lakes (Donald and Alger 1986) where growth may be stunted (Reimers 1958). In Bunny Lake, California, brook trout live for 24 years, their maximum reported longevity (Carlander 1969, Reimers 1979).

The objectives of this study were to obtain a thorough description of the age, sex ratio, growth and condition of the GL3 population and compare the GL3 population with other higher elevation lake populations of brook trout.

### Study Area

Green Lake 3 is located in the Front Range of the Colorado Rocky Mountains at an elevation of 3,455 m in the Green Lakes valley watershed (Figure 1). North Boulder Creek connects GL3 to two fishless lakes upstream, and several lakes with fish downstream, but steep waterfalls prevent immigration. The lake has surface area of 7.5 ha, a mean depth of 8.7 m, and a maximum depth of 15.8 m (McNeely 1984). It does not stratify and has a surface temperature range of 0-11°C (McNeely 1984). The lake level has been artificially raised (date unknown) and the littoral zone contains remnants of peaty soil and dead willows, *Salix* spp. Substrates range in size from sand to large boulders.

### Methods

Monofilament gill nets (bar mesh ranging from 10-50 mm) were used to collect fish in 1981. Fish were captured in August, 1985, also using monofilament gill nets (bar mesh 25, 51, and 102 mm) set overnight. On the day of capture all fish were measured (total length, TL) to the nearest mm, weighed (weight, W) to the nearest g, and held at 5°C in a refrigerator. Some of the 1985 fish were dissected, sexed, and otoliths removed shortly after capture. The rest of the fish were frozen and dissected later. Fish whose otoliths could not be found were excluded from subsequent analyses.

Otoliths were cleared in glycerol and age determined using the growth rings on both sagittae (Panella 1974). Otoliths from the same specimen were examined several times if a discrepancy was observed between sagittae from the same specimen. Condition factors (K) were calculated using the expression:  $K = W * TL^{-3} * 100$ .

Scales, not otoliths, were used to age brook trout in the studies cited below. Thus, the following comparisons are done with the understanding

that age estimates from otoliths tend to be higher than those from scales in brook trout from high elevation streams (Kozel and Hubert 1987). Further, it is not clear from these literature sources whether the populations were unexploited.

### Results and Discussion

The 1985 length frequency distribution suggests selection for larger fish, whereas the 1981 length frequency distribution included smaller fish (Figure 2). Based on the population structure, there is little reason to believe that age distribution was significantly altered by the removal of 106 trout in 1981.

Although sample size is small, females (n = 3) apparently outlived males. The oldest male was 8

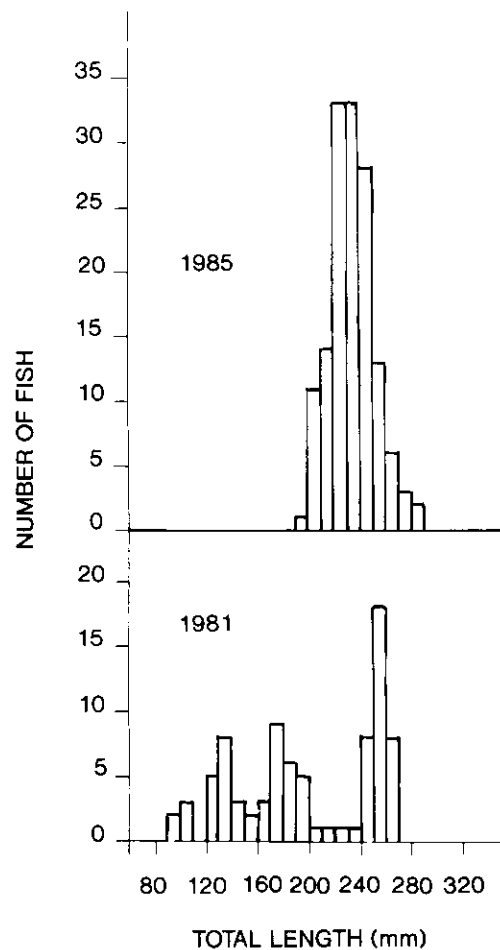


Figure 2. Length frequency histogram of brook trout captured in 1981 and 1985.

years, whereas the oldest female was 13 years (Figure 3). Only four age III trout were captured in the 25-mm mesh, as the gear apparently selected for larger (consequently older) fish. However, the 25-mm mesh was also the only mesh effective for older fish, since the larger mesh sizes captured no fish.

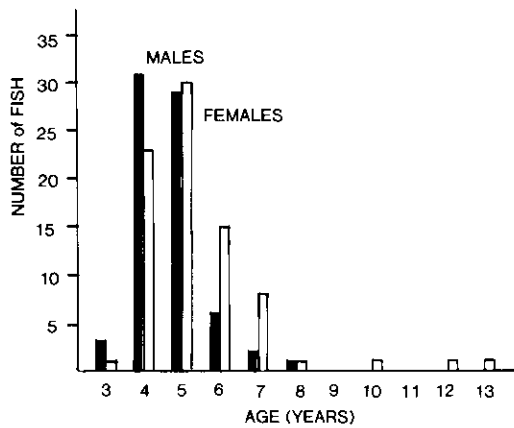


Figure 3. Age frequency histogram of male and female brook trout collected in 1985.

The condition factor of GL3 brook trout was 0.88-1.13 (Table 1) and was not significantly different (paired t-test;  $t = 0.17$ ,  $P = 0.88$ ) between the sexes for fish ages IV-VIII. These values are comparable to those of stunted populations in Colorado beaver ponds (mean 0.99, range 0.63-1.39) (Rabe 1957) and to those in Wyoming lakes (1.03-1.47) (Hepworth 1959) and in alpine Utah lakes (0.80-1.10) (Rabe and Dyer 1964). Maximum longevity is three years in Colorado beaver ponds and five years in Wyoming and Utah lakes.

Where sample size is good there was no significant difference in length between the sexes for fish ages IV-VII (paired t-test;  $t = 2.29$ ,  $P = 0.08$ ).

Comparison of growth of brook trout from four mountain lakes revealed that at ages IV-VI the length of GL3 brook trout is about the same as those from an alpine lake (X-26) in the Uinta mountains of Utah (Rabe and Dyer 1964), and a subalpine lake (Reimers 1958) (Figure 4).

Growth of fish ages IV and V was higher for GL3 fish than for Bunny Lake fish, and the condition factors were also better. For example, at ages IV and V, Bunny Lake brook trout averaged 152 mm and 163 mm TL, respectively (Reimers 1958).

TABLE 1. Total length (mm), weight (g), and condition factor for brook trout from Green Lake 3, Colorado, by age group and sex, 1985.

Age	n	Length		Weight		Condition factor	
		Mean	SD	Mean	SD	Mean	SD
<b>Males</b>							
III	3	216	8.7	113	17.1	1.11	0.04
IV	31	231	13.9	132	20.9	1.06	0.09
V	29	243	16.8	148	26.9	1.02	0.11
VI	6	239	11.1	142	11.7	1.04	0.08
VII	2	276		184		0.88	
VIII	1	281		202		0.91	
<b>Females</b>							
III	1	219		119		1.13	
IV	23	229	12.7	123	12.5	1.01	0.07
V	30	232	15.2	126	17.5	0.99	0.10
VI	14	234	11.6	134	15.2	1.04	0.09
VII	8	234	13.5	129	10.1	1.01	0.12
VIII	1	257		141		0.83	
X	1	258		157		0.91	
XII	1	266		153		0.81	
XIII	1	261		135		0.76	

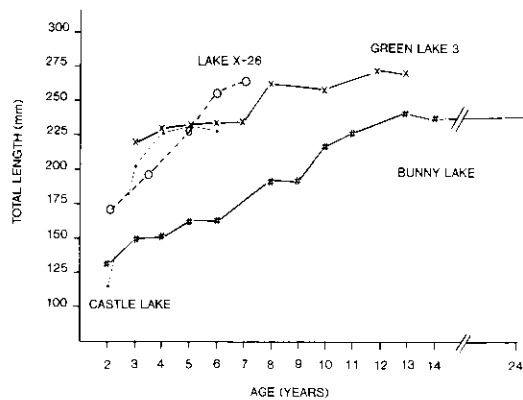


Figure 4. Age and length at capture of brook trout from selected western (US) waters. Bunny Lake, California (Reimers 1958), Lake X-26, Utah (Rabe and Dyer 1964) and Castle Lake, California (Wales and German 1956\*).

\* = References cited by Carlander (1969).

whereas brook trout from GL3 averaged 229 and 232 mm (Figure 4). The condition factor of brook trout in Bunny Lake declined from 1.10 to 0.78 in the first six years after stocking, whereas that of GL3 trout between ages IV and VIII was about 1.0.

Perhaps the difference between Bunny Lake and GL3 brook trout population rests in a

difference in food supply. Bunny Lake lacks an inlet stream, but GL3 receives an exogenous food supply from lakes above. Drift into GL3 from lakes above is mostly Chironomidae (Mihuc 1987). In a study of 23 Canadian mountain lakes, Donald *et al.* (1980) found that amphipod density was the most important factor affecting trout growth. Thus food supply, not elevation per se, may be the most critical factor in explaining brook trout growth in mountain lakes.

In conclusion, brook trout from GL3 had growth rates and condition factors typical of the species in mountain lakes, with the exception of Bunny Lake.

### Literature Cited

- Callahan, J. T. 1984. Long-term ecological research. *Bioscience* 34:363-367.
- Carlander, K. 1969. Handbook of freshwater fishery biology. Vol. 1. Iowa State University Press, Ames, Iowa.
- Donald, D. B., and D. J. Alger. 1986. Dynamics of unexploited and lightly exploited populations of rainbow trout (*Salmo gairdneri*) from coastal, montane, and subalpine lakes in western Canada. *Can. J. Fish. Aquatic Sci.* 43:1733-1741.
- Donald, D. B., Anderson, R. S., and D. W. Mayhood. 1980. Correlations between brook trout growth and environmental variables for mountain lakes in Alberta. *Trans. Amer. Fish. Soc.* 109:603-610.
- Hepworth, W. 1959. A study of the population dynamics of brook trout in two subalpine lakes in southeastern Wyoming. Wyoming Game and Fish Commission Cooperative Research Project No. 2.
- Kozel, S., and W. Hubert. 1987. Age estimates of brook trout from high-elevation Rocky Mountain streams using scales and otoliths. *North. Science* 61:216-219.
- MacCrimmon, H. R., and J. S. Campbell. 1969. World distribution of brook trout, *Salvelinus fontinalis*. *J. Fish Res. Board Can.* 26:1699-1725.
- Mihuc, T. 1987. Personal communication. Oklahoma State University, Stillwater.
- McNeely, R. 1984. Personal communication. Queen's University, Kingston, Ontario.
- Panella, G. 1974. Otolith growth patterns: an aid in age determination in temperate and tropical fishes. In T. B. Bagonal (ed.), *Ageing of Fish*. Unwin Brothers: Old Woking, United Kingdom. Pp. 28-39.
- Platt, T. 1987. Personal Communication. Watershed Manager, City of Boulder, Colorado.
- Rabe, F. W. 1957. Brook trout populations in Colorado beaver ponds. Colorado State University, Fort Collins, M.S. Thesis.
- Rabe, F. W., and V. E. Dyer. 1964. Age and growth study of brook trout from three cirque lakes in the Uinta mountains. *Proc. Utah Acad. Sci. Arts Letters* 41:243-253.
- Reimers, N. 1958. Conditions of existence, growth, and longevity of brook trout in a small, high-altitude lake of the eastern Sierra Nevada. *Calif. Fish Game* 44:319-334.
- \_\_\_\_\_. 1979. A history of a stunted brook trout population in an alpine lake: a lifespan of 24 years. *Calif. Fish Game* 54:196-215.
- Wales, J. H., and E. R. Gorman. 1956. Castle Lake investigation. Second phase: eastern brook trout. *Calif. Fish Game* 42:93-108.

### Acknowledgements

This research was supported by the NSF grant DEB 8012095 and BSR 8514329 to the University of Colorado, by the Mountain Research Station of the University of Colorado, and by the Department of Zoology, Oklahoma State University. It was part of the cooperative program between the City of Boulder, Colorado and the University of Colorado Long-Term Ecological Research Program. Rick Horton assisted in the field. We are indebted to Drs. Shelby Gerking, James Halfpenny, Robert Howells, Wayne Hubert, O. Eugene Maughan, Veronica Pitman and Alexander Zale who reviewed the manuscript at various stages and made helpful comments.

Received 20 December 1989

Accepted for publication 5 September 1990