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STOCK ASSESSMENT AND BIOLOGICAL CHARACTERISTICS OF LAKE TROUT POPULATIONS IN INTERIOR ALASKA, 1988[1]

By

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ABSTRACT

During 1988, lake trout *Salvelinus namaycush* were sampled from Paxson Lake of the Copper River system, from Butte Lake of the Susitna River system and from Fielding, Twobit, Sevenmile, and Upper Tangle Lakes of the Tanana River system. Size composition of lake trout estimated as Relative Stock Density varied widely between lakes. Most large lake trout (greater than 780 millimeters fork length) were found in Paxson Lake. A few fish in this size category were captured from Upper Tangle and Fielding Lakes. Most other lake trout sampled from the Tanana River system and from Butte Lake were smaller, with most less than 500 millimeters. Ages of lake trout determined with otoliths (sagitta) ranged from 0 to 36 years, with most between 4 and 20 years. No fish greater than age 15 were found in Butte, Fielding or Sevenmile Lakes. Age at which 50 percent of all lake trout were mature ranged from 4.8 years for males in Paxson Lake to 11.0 years for females in Twobit Lake. Males typically matured at younger ages than females. Length at which 50 percent of lake trout were mature ranged from 335 millimeters for males in Twobit Lake to 426 millimeters for females in Paxson Lake.

Population abundance of lake trout was estimated with mark-recapture experiments in three lakes located in the Tanana River drainage. The estimated abundance of lake trout greater than 250 millimeters was 647 (19.6 fish per hectare) in Sevenmile Lake and 211 (1.4 fish per hectare) in Upper Tangle Lake. The estimated abundance of lake trout greater than 240 millimeters in Twobit Lake was 1,621 (14.9 fish per hectare). The estimated density of lake trout of mature size was 13.9 fish per hectare in Sevenmile Lake, 10.9 fish per hectare in Twobit Lake, and 0.6 fish per hectare in Upper Tangle Lake.

KEY WORDS: Lake trout, *Salvelinus namaycush*, population abundance, age, growth, maturity, yield, Sevenmile Lake, Twobit Lake, Upper Tangle Lake, Paxson Lake, Butte Lake, Fielding Lake.

INTRODUCTION

Lake trout *Salvelinus namaycush* support important recreational fisheries in both roadside and remote waters. Most fishing for lake trout occurs on easily accessible waters. However, since lake trout are often considered a trophy species, anglers seek guided and other fly-in fishing opportunities in remote areas of the state. Since 1977, the statewide harvest of lake trout has averaged about 18,000 fish annually with this level of harvest remaining essentially constant (Mills 1988). Over one half of the total harvest comes from lakes located in the Tanana River drainage and the Glennallen area. In the Glennallen area, harvest has remained at a level of 7,000 to 8,000 lake trout annually since 1977. In the Tanana River drainage and the Arctic-Yukon-Kuskokwim region (AYK), lake trout harvests increased five percent annually up through 1985 but have since declined by an average of 40% annually.

Due to a number of biological attributes, lake trout populations may be easily overharvested. This species is long lived and slow growing. Records of fish older than 25 years are not unusual, and lake trout older than 50 have been captured in Alaska. A trophy size lake trout weighing 8.7 kg (20 lbs) in Alaska would typically be 20 or more years old. In interior Alaska, lake trout spawn for the first time at age 5 to 10 at fork lengths (FL) of 350 mm to 500 mm (14 to 20 in). Mature lake trout do not spawn every year. Healey (1978) suggests that average maximum sustainable yield of lake trout populations is less than 0.5 kg of fish per surface hectare of lake per year.

Burr (1987a) found that the present knowledge of population abundance, size structure, population dynamic rates, and harvest levels for Alaska lake trout populations is limited. Based on harvest estimates (Mills 1986) and the average size of lake trout obtained from creel sampling and test netting, he found that the maximum sustainable harvest rate was being exceeded for all populations in the Tanana River drainage and Glennallen area for which harvest estimates were available. Harvest in these waters was as much as seven times the recommended maximum sustainable yield (Healey 1978). Based on this information, the Alaska Board of Fisheries reduced bag limits from 12 to 2 fish per day in all waters in the Tanana River drainage and Glennallen area. In addition, a minimum length limit of 450 mm total length (TL) (18 in) was included for several high use roadside lakes. For the Tangle Lakes system, which has sustained the highest harvest rates of any lake trout fishery in Alaska in recent years, a one fish daily bag limit and a 450 mm minimum length limit was instituted.

This research project began in 1986 and this report represents the third in a series of annual data reports. The long-term goal of the project is to quantify dynamic rates of lake trout populations in Alaska to accurately estimate sustainable yield for lake trout fisheries. However, the experience of management of lake trout fisheries in North America is that estimates of sustainable yield are decades in the making. Therefore, the short term goal of this program is to refine our ability to promulgate effective regulations for fisheries in interior Alaska which will keep harvests at or below levels shown to be sustainable for other lake trout populations (see Healey 1978). In pursuit of this goal, populations were sampled, fisheries were monitored, and angler attitudes were surveyed regarding various management options.

The specific project objectives during the 1988 field season were to:

1. estimate population abundance of lake trout larger than 250 mm (FL) in Twobit, Upper Tangle, and Butte Lakes;

2. estimate the Relative Stock Density (Gabelhouse 1984) of the lake trout populations in Upper Tangle, Twobit, Butte, and Fielding Lakes;

3. estimate age at maturity (AM_{50}) and length of maturity (LM_{50}) of both sexes of lake trout in Upper Tangle, Twobit, Butte, and Fielding Lakes; and,

4. estimate the mean length at age for populations of lake trout in Upper Tangle, Twobit, Butte, and Fielding Lakes.

METHODS

Data were collected from populations of lake trout from six lakes in central Alaska: Paxson Lake of the Copper River drainage, Fielding, Twobit, Sevenmile, and Upper Tangle Lakes in the Tanana River drainage (Figure 1) and Butte Lake of the Susitna River drainage (Figure 2). The lakes range widely in size from Sevenmile Lake (surface area 32 ha) to Paxson Lake (surface area 1,575 ha; Figure 1). All lakes are located in the Alaska Mountain Range at elevations from 778 to 1,006 m, and with the exception of Paxson Lake, within alpine tundra/scrub birch habitat. Paxson Lake is in a mixed spruce forest.

Information on the location, size, and elevation for the lakes which were sampled but where mark-recapture experiments were not conducted is given in Figure 1.

Sevenmile Lake is located at an elevation of 975 m and is adjacent to the Denali Highway (Figure 1). The estimated surface area of the lake is 32 ha and the maximum recorded depth is 12.5 m. There are no active inlet or outlet streams, so it is closed to immigration and emigration.

The estimated surface area of Twobit Lake is 81 ha, and the maximum depth is 23 m. The lake is located at an elevation of 1,006 m (Figure 1). There are numerous small inlets which drain the hillsides around the lake. A single outlet flows from the north end of the lake to Fielding Lake approximately 2.5 km downstream. The steep gradient of this stream provides a barrier to fish passage upstream into Twobit Lake.

Upper Tangle Lake is located at an elevation of 868 meters within the Tangle Lake system (Figure 1). The estimated surface area is 142 ha, and the maximum recorded depth is 28 m. There are two small inlet streams; one from a large shallow (2 m or less) lake located approximately 1.5 km to the south and the other, Rock Creek, which flows from Glacier Lake located approximately 5 km to the northwest. A single shallow outlet stream connects Upper Tangle Lake with the remainder of the Tangle Lakes system.

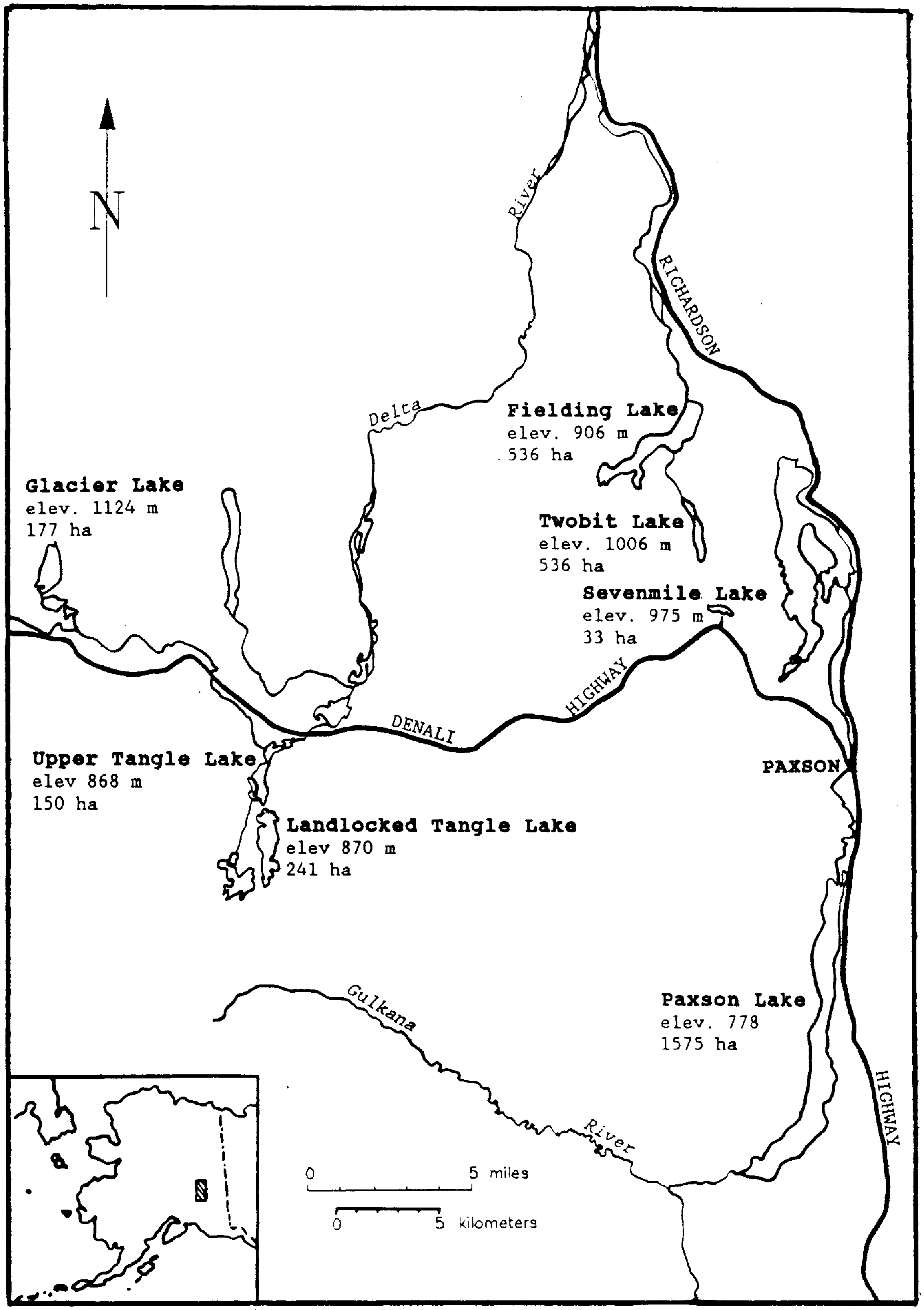

Figure 1. Study area near Paxson Alaska. Elevations of lakes are given in meters and approximate surface areas are in hectares.

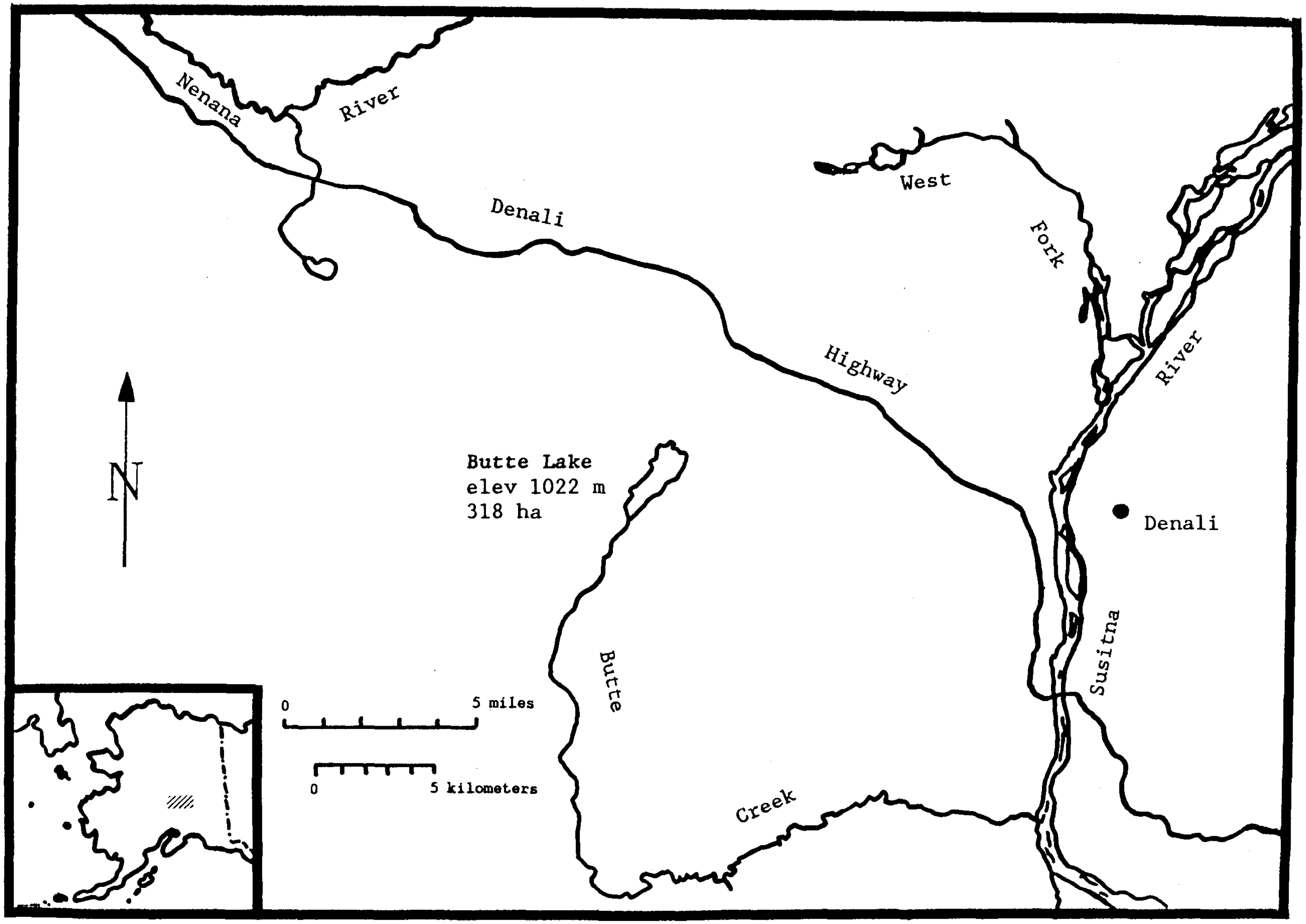

Figure 2. Map of Butte Lake, Alaska. Elevation of the lake is in meters and approximate surface area is in hectares.

Abundance Estimators

Mark-recapture experiments were conducted to estimate the population abundance of lake trout larger than 250 mm FL in Upper Tangle Lake, Twobit Lake, Sevenmile Lake, and Butte Lake during 1988. For Upper Tangle Lake, a modified Petersen mark-recapture estimator was selected (Chapman 1951) with both sampling events conducted during 1988. Abundance of lake trout in Twobit and Sevenmile Lakes was estimated with marking events and recapture events performed in separate years (Seber 1982). The marking events were conducted in 1987 and the recapture events were performed in 1988. Lake trout were marked in Butte Lake in 1988 and abundance will be estimated from recapture efforts in 1989. The estimated abundance in each lake is germane to the time of marking. Population abundance and the approximate variance of this estimate were calculated with the following formulas (Seber 1982):

(1) $$\hat{N} = \frac{(C+1)(M+1)}{(R+1)} - 1; \text{ and,}$$

(2) $$V[\hat{N}] = \frac{(M+1)(C+1)(M-R)(C-R)}{(R+1)^2(R+2)};$$

where:

M = the number marked during the marking sample period;

C = the number captured during the recapture sample period; and,

R = the number captured during the recapture period with marks from the marking period.

Conditions for the accurate use of the Petersen mark-recapture estimator include (Seber 1982):

1. a closed population (no change in the number of fish in the population during the experiment);

2. all lake trout have the same probability of capture in the marking sample or in the recapture sample, or marked and unmarked lake trout mix completely between marking and recapture events;

3. marking of lake trout does not affect their probability of capture in the recapture sample;

4. lake trout do not lose their mark between the marking and recapture events; and,

5. all marked lake trout are reported when recovered in the recapture sample.

In all sampled lakes, efforts were made to meet these requirements. To promote mixing of marked fish with the unmarked population, marked fish were released throughout the lake. The length of time between the capture events (one month minimum) should have been sufficient to permit mixing of marked and unmarked fish. As a test of mixing, each lake was divided in half and numbers of fish recaptured and not recaptured in each half was tested with chi-square analysis. To measure tag loss, all fish were given an adipose fin clip as well as a numbered tag. To minimize differential mortality between marked and unmarked fish, only fish which appeared to be in good condition were released. Handling induced "net shyness" should have been minimized by the period of time between the marking and recapture events.

Growth recruitment in these lake trout populations was assumed to be minimal when marking and recapture events were preformed within a season but not so when the experiment was conducted over more than one year. The Petersen estimator is valid for multiyear experiments if either mortality or recruitment (but not both) occurs between sampling events (Seber 1982). To evaluate recruitment through growth between the marking period and the subsequent recapture period, a nonparametric method of testing for recruitment was used (Robson and Flick 1965). When growth recruitment was found, the length beyond which no significant growth recruitment is detectable (L_r) was determined and separate estimates of abundance for each portion of the population were made. The abundance of fish larger than L_r is calculated with the Petersen estimator. The abundance of fish below L_r was calculated with the model from Robson and Flick (1965):

(3) $\hat{N} = (m + 1)(\bar{u}_r) - 1$ and,

(4) $V[\hat{N}] = (m + 1)^2\ V[\bar{u}_r]$;

where:

$\hat{N}$ = estimated abundance of fish smaller than the upper extent of growth recruitment (L_r);

m = number of marked fish from the marking period that are smaller than the upper extent of growth recruitment (L_r); and,

$\bar{u}_r$ = frequency of unmarked fish averaged over the cells formed by the fish recaptured in the recapture period beyond the upper extent of growth recruitment (L_r).

The variance of $\bar{u}_r$ was calculated using standard normal procedures to find the variance of a mean over the u_i where i is from r to M.

The hypothesis of equal probability of capture during each sampling event for fish of different sizes was tested with the Kolmogorov-Smirnov two-sample test (Conover 1980) and contingency table analysis. The data were grouped by length classes for the contingency table analysis. The first test involved the frequencies of tagged fish recaptured versus those not recaptured by size group. Frequencies of fish captured during the marking event were compared with fish captured during the recapture event for the second test (Seber 1982).

Sevenmile Lake:

In 1987, a mark-recapture experiment was conducted to estimate abundance of lake trout larger than 250 mm FL in Sevenmile Lake (Burr 1988). Between 22 and 25 July 1988, lake trout were captured with 25 mm (square measure) x 3 m x 46 m sinking gill nets, baited hoop nets, and fyke nets. Gill nets were checked at one half hour intervals. The hoopnets were baited with cut herring *Clupea harengus* which was placed in perforated bait containers. These nets were set in all parts of the lake in various depths from 1 to more than 12 meters. Fyke nets were set near shore in approximately 1.2 m with center lead nets attached to shore.

Twobit Lake:

In 1987, lake trout were captured during two sampling events with variable mesh sinking gill nets, baited hoopnets, and by angling. From these data an estimate of abundance for lake trout 350 mm FL and larger was generated (Burr 1988). Additional sampling was conducted from 12 July to 17 July 1988 to obtain an estimate for lake trout 250 mm and larger. The same gear types used in 1987 were used in 1988. To minimize mortality of lake trout, gill nets were checked every half hour. Nets were set in all parts of the lake in various depths from 0.5 to more than 20 meters.

Upper Tangle Lake:

Between 3 June and 11 July 1988, lake trout were captured in Upper Tangle Lake with 25 mm mesh sinking gill nets, baited hoopnets, and a purse seine which was also used as a beach seine. In addition, trot lines with hookless bait were fished to capture lake trout. Initially, gill nets were checked at one half hour intervals, but because of very low catch rates toward the end of the marking sampling period the intervals increased up to three hours. Nets were set in all parts of the lake in various depths from 0.5 to more than 25 meters. During the recapture sampling period (5 to 30 August), lake trout were captured with 25 mm mesh sinking gill nets. Baited hoop nets, were also fished. The hookless trot lines were not fished during the recapture sampling period due to problems with vandalism and very low catch rates. All portions of the lake were netted as were various depths.

The magnitude of lake trout movement through the streams connecting Upper Tangle Lake with the rest of the Tangles system is unknown but was assumed to be minimal. Sampling, which was directed at capturing Arctic grayling *Thymallus arcticus*, was conducted in these streams through the open water season. This sampling would help determine if movement of lake trout occurred.

Population Structure

Age, weight, length, sex, and maturity data were obtained from the lake trout populations in all six study lakes. When a lake trout was captured in good condition, it was measured to the nearest mm FL, the adipose fin was removed, and the fish was tagged with an individually numbered Floy anchor tag. When killed, lake trout were weighed and dissected to obtain otoliths for age determination and to obtain information on sex and maturity. These data were obtained from sampling for the abundance estimates at Sevenmile, Twobit, Upper Tangle, and Butte Lakes and from test netting at Fielding and Paxson Lakes. In Paxson Lake, lake trout were captured during September at spawning sites with beach seines for an egg take.

Age Determination:

All age and growth data presented in this report are based on ages obtained from otoliths. Sharp and Bernard (1988) found that scales provided lower estimates of age than did otoliths, particularly for lake trout older than age 5. The estimates of age obtained from the scale samples are not presented in this report. They will be used for validation of age determination with tagged lake trout recaptured in future years. Otoliths (sagitta) were collected from all lake trout dissected during the various field activities. Whole otoliths were prepared by hand grinding surfaces on a carborundum honing stone and were viewed with a compound microscope under reflected light. Sets of opaque and hyaline bands were counted as years of growth with the hyaline bands used as "annuli". A scale sample was taken from all lake trout handled during various project activities. Scales were cleaned and placed between glass slides and were archived for future analysis.

Sex Composition and Relative Stock Density:

The proportions of the populations corresponding to each sex and size category were estimated with formula (5) and the variance of the proportions with formula (6) (Cochran 1977):

(5) $$\hat{p}_j = \frac{n_j}{n}; \text{ and,}$$

(6) $$V[\hat{p}_j] = \frac{\hat{p}_j(1-\hat{p}_j)}{n - 1};$$

where:

n_j = the number in the sample from group j;

n = the sample size; and,

p_j = the estimated fraction of the population that is made up of group j.

The proportions of males, females, and immature lake trout were estimated from dissected samples collected during test netting in all six study lakes and from all samples from Paxson Lake. Relative Stock Density (RSD) was estimated for lake trout from the samples from each lake. The categories of "stock", "quality", "preferred", "memorable", and "trophy" were determined as outlined by Gabelhouse (1984).

Length at Maturity and Age of Maturity:

The length and maturity of the sampled lake trout were recorded as percent mature in length categories. Since more than one length category generally had mature and immature fish, probit analysis was used to estimate the LM_{50} (the length at which 50% of the fish are mature; Finney 1971). The procedure PROBIT from SAS Institute Inc., Cary, NC 27511 was used for this analysis.

The age of maturity, AM_{50}, was estimated using the same procedures as described in the previous paragraph, except that ages rather than lengths were used as variables. The same samples were used for both analyses.

To compare densities of mature lake trout from lakes for which estimates have been made, the abundance estimates were reduced by the proportion of the fish sampled which were less than the LM_{50} for the population from each lake. The proportion of mature fish in each sample was estimated with formula (5) and the variance of the proportion with formula (6). The estimated abundance of mature fish was calculated with formula (7) and the variance of the estimate (equation 8) is the variance of a product (Goodman 1960):

(7) $\hat{N}_m = \hat{p}\,\hat{N}$; and,

(8) $V[\hat{N}_m] = \hat{p}^2\, V[\hat{N}] + V[\hat{p}]\, \hat{N}^2 - V[\hat{p}]\, V[\hat{N}]$;

where:

$\hat{N}$ = estimate of abundance of lake trout in each lake;

$\hat{N}_m$ = estimate of abundance of lake trout of mature size in each lake; and,

$\hat{p}$ = estimate of the proportion of mature fish in $\hat{N}$.

Size at Age:

Estimates of mean length at age were generated with standard normal procedures. Simple averages and squared deviations from the mean were used to calculate means and variances of the means.

RESULTS

Abundance Estimates

Estimates of population abundance were completed for Sevenmile Lake, Twobit Lake, and Upper Tangle Lake.

Sevenmile Lake:

The abundance of lake trout larger than 250 mm FL in Sevenmile Lake at the end of 1987, estimated from data collected in 1987 and 1988, was 871 fish (SE = 123; Table 1). The estimated density was 26.4 lake trout per hectare (10.8 LT/acre). The estimate of the abundance of lake trout of mature size (LM_{50} and larger) in Sevenmile Lake in 1987 is 459 (SE = 85) giving a density of 13.9 mature lake trout per hectare (5.7 LT/acre; Table 2).

During sampling in 1987, 166 lake trout 250 mm (FL) or larger were marked in Sevenmile Lake. Of these 166 lake trout, 128 were caught in gill nets, two in hoopnets, 10 in fyke nets, and 26 in the seine (Table 1). During the recapture event in 1988, 166 lake trout 250 mm (FL) or larger were captured; 162 in gill nets, 3 in hoop nets, and 1 in fyke nets. Thirty-one of the 166 lake trout had been marked in 1987. One hundred fifty-one were captured alive, tagged, and released, and 15 died in the sampling gear. Six of the 31 lake trout recaptured had lost the Floy tags inserted in 1987, but since all tagged fish were also marked with an adipose clip, the fish were recognized as recaptures.

Inspection of plots of length frequencies of lake trout recaptured during 1988 and unmarked fish captured in 1988 indicate that no growth recruitment occurred between 1987 and 1988 (Figure 3). In addition, growth recruitment was not detected with the nonparametric test of Robson and Flick (1965). However, it is unlikely that no recruitment through growth occurred between 1987 and 1988.

Comparison of lengths of marked and recaptured fish (test 1) and lengths of all fish captured during the marking event in 1987 and during the recapture event in 1988 (test 2) failed to detect significant difference between capture rates among length categories (test 1: $D = 0.2375$, $P = 0.32$; test 2: $D = 0.1099$, $P = 0.19$; Appendix Tables 1 - 4). Therefore, a single nonstratified abundance estimate was calculated for Sevenmile Lake.

The Petersen estimator is valid if either mortality or recruitment (but not both) occurs. Since sampling was conducted in different years, mortality undoubtedly occurred between sampling events and recruitment through growth is likely. The use of the Petersen estimator over more than one year is predicated on our ability to detect growth recruitment and to cull those recruits from the estimate. Since we are unable to detect this recruitment and adjust for it, these factors (recruitment and mortality) would tend to inflate the estimate of abundance resulting in a biased estimate. In fact, this appears to be what has occurred. The estimates of abundance for Sevenmile Lake from sampling conducted only in 1987 (N = 647, SE = 118) is

Table 1. Abundance estimates for lake trout larger than 250 mm FL in Sevenmile Lake in 1987 using data collected in 1987 only and data collected in 1987 and 1988.

Data Source	Gear	Number of Lake Trout: Marked	Recaptured	Examined	Abundance Estimate	SE	Lake Trout per Hectare
	Gill Net	128	29	162			
1987	Fyke Net	10	0	1			
and	Hoop Net	2	2	3			
1988	Purse Seine	26	---	---			
	Total	166	31	166	871	123	26.4
	Gill Net	24	18	144			
1987	Fyke Net	24	0	12			
only[1]	Hoop Net	2	0	3			
	Purse Seine	26	0	0			
	Total	76	18	159	647	118	19.6

[1] Data are from Burr 1988.

Table 2. Estimated abundance and density of mature lake trout in Landlocked Tangle, Upper Tangle, Glacier, Twobit, and Sevenmile Lakes.

Lake (surface area)	Abundance	SE	Density (fish/ha)	LM_{50}
Upper Tangle (150 ha)	96	17	0.6	402 mm
Twobit (109 ha)	1,112	171	10.2	343 mm
Sevenmile (33 ha)	459	85	13.9	367 mm

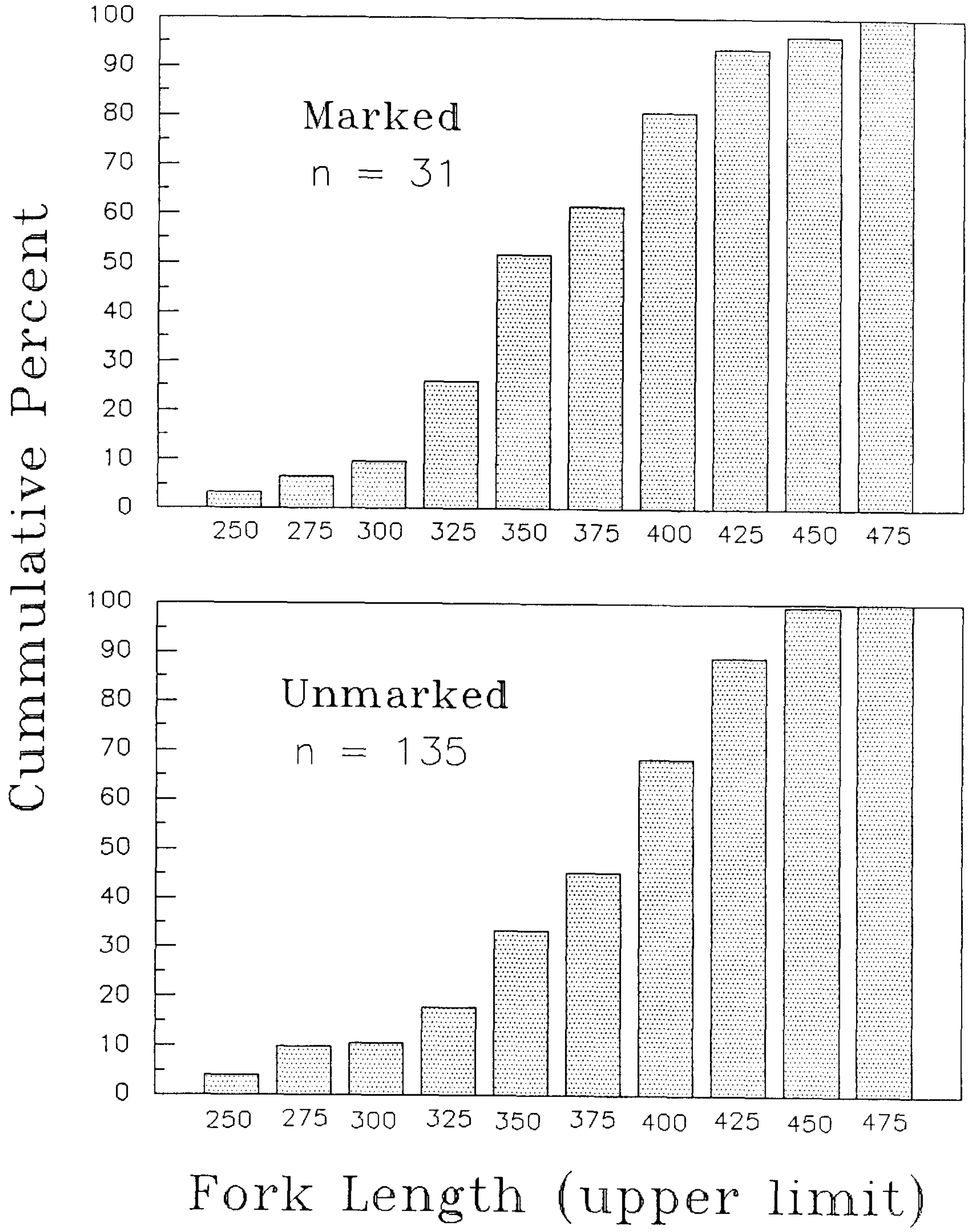

Figure 3. Cumulative distribution of lengths of marked and unmarked lake trout captured during 1988 in Sevenmile Lake.

substantially lower than the estimate obtained from sampling performed in both 1987 and 1988 (N = 871, SE = 123; Table 1). Therefore, the first estimate (1987 data only) is preferred since it is statistically unbiased and more precise. Hence, the first estimate of abundance (1987 data only) was used to estimate the abundance and density of lake trout of mature size.

Twobit Lake:

The estimated abundance of lake trout larger than 240 mm FL in Twobit Lake at the end of the 1987 season was 1,621 (SE = 226; Table 3). The surface area of Twobit Lake is 109 ha (268 acres) hence the estimated density of lake trout 240 and larger in the lake was 14.9 lake trout per hectare (6.1 LT/acre). The estimated abundance of lake trout of mature size (LM_{50} and larger) in Twobit Lake in 1987 was 1,112 (SE = 171) for a density of 10.2 mature lake trout per hectare (4.2 LT/acre; Table 2).

During 1987, 382 lake trout 240 mm or larger were marked in Twobit Lake; 171 in gill nets, 204 in hoopnets, and seven with rod and reel (Table 3, Appendix Table 5). In 1988, 163 lake trout 240 mm or larger were captured; 99 in gill nets, 54 in hoopnets, and 10 by rod and reel (Table 3, Appendix Table 8). One hundred forty-three were captured in good condition, tagged and released. The remaining 20 fish were killed by the sampling gear.

Twenty-three of the 163 lake trout caught in 1988 were recaptured from 1987. Five of the lake trout captured during 1988 lost the floy tags from 1987, but since all tagged fish were also marked with a clipped adipose fin, the fish were recognized as recaptures.

Comparisons of lengths of marked and recaptured fish (test 1) and lengths of all fish captured during the marking event in 1987 and during the recapture event in 1988 (test 2) failed to detect significant difference between capture rates among length categories (test 1: D = 0.1729, P = 0.65; test 2: D = 0.0764, P = 0.43; Appendix Tables 5 - 8). However, plots of the lengths of fish recaptured in 1988 versus unmarked fish captured in 1988 indicate that recruitment through growth between the two sampling periods occurred (Figure 4). Growth recruitment of fish less than 357 mm FL was confirmed by the Robson and Flick (1965) test. Hence, fish were grouped by length class and a separate population estimate was calculated for each group. The estimated abundance of lake trout 357 mm FL and larger was made using the Petersen estimator. The estimated abundance of this strata using only data collected in 1987 was more precise than the estimate using data obtained in both 1987 and 1988 (Table 4). One hundred forty-nine lake trout 357 mm FL and larger were marked during the first event in 1987; 116 lake trout were examined in event two of 1987, of which 19 were recaptures (Table 3).

The abundance of fish 240-356 mm was estimated with the formula of Robson and Flick. Within the 240-356 mm size group, 141 lake trout were marked in 1987; 75 lake trout were examined in 1988, of which 5 were recaptured from the marked population (Table 3).

Table 3. Estimated abundance of lake trout larger than 240 mm FL in Twobit Lake in 1987.

Strata	Gear	Number of Lake Trout			Abundance Estimate	SE	Lake Trout per Hectare
		Marked	Recaptured	Examined			
240 - 356 mm[1]	Gill Net	59	2	35			
	Hoop Net	80	3	34			
	Rod & Reel	2	0	6			
	Total	141	5	75	745	157	6.8
> 356 mm[2]	Gill Net	52	14	78			
	Hoop Net	94	5	37			
	Rod & Reel	3	0	1			
	Total	149	19	116	877	162	8.1
Total					1,621	226	14.9

[1] Data are from fish marked in 1987 and recaptured in 1988.
[2] Data are from fish marked in 1987 and recaptured in 1987, see text.

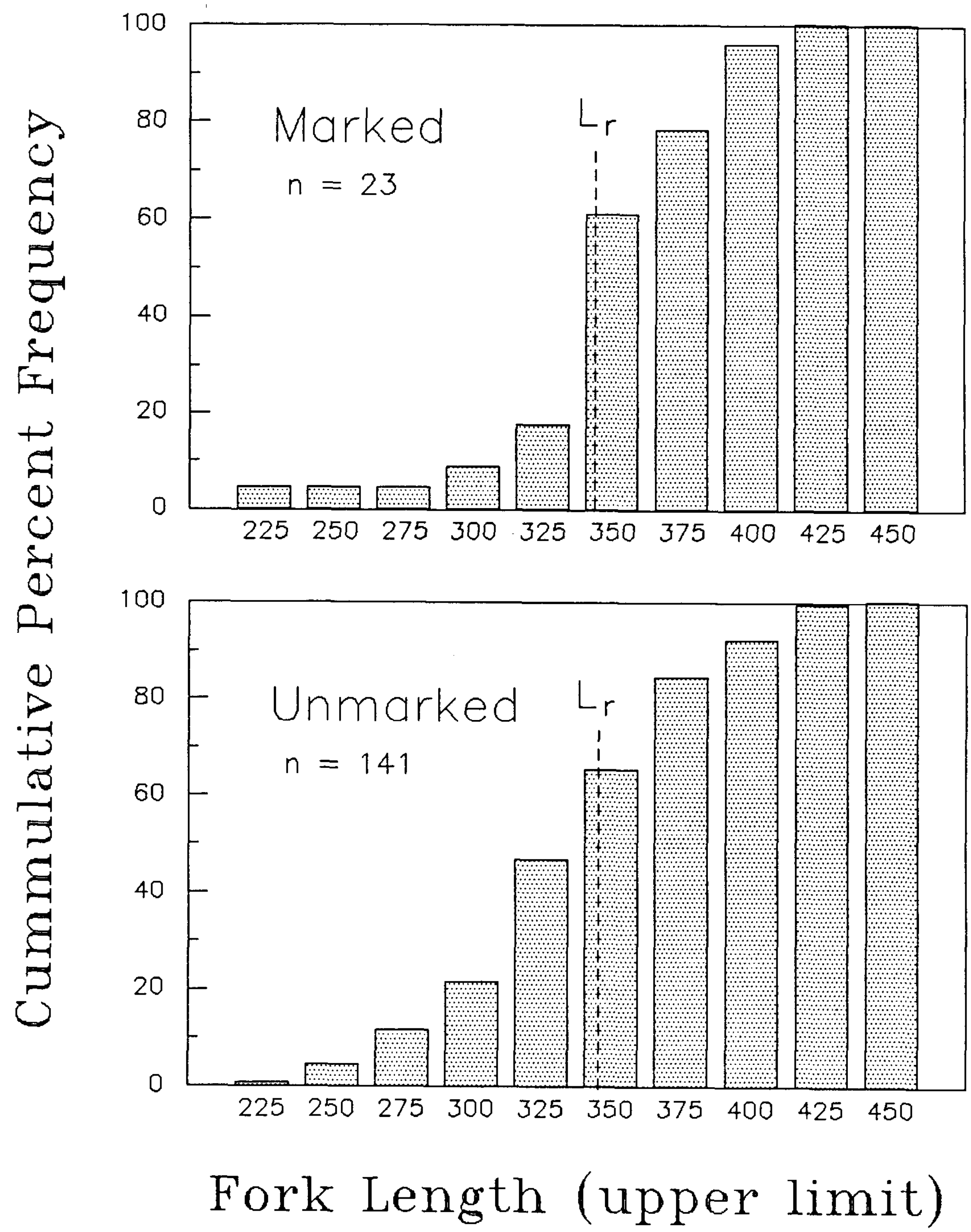

Figure 4. Cumulative distribution of lengths of marked and unmarked lake trout captured during 1988 in Twobit Lake. L_r indicates the length of recruitment.

Table 4. Abundance estimates for lake trout larger than 356 mm in Twobit Lake, using data collected in 1987 only and data collected in 1987 and 1988.

Data Source	Number of Lake Trout: Marked	Recaptured	Examined	Abundance Estimate	SE
1987 only[1]	149	19	116	877	162
marked 1987 recap 1988	241	18	88	1,133	216

[1] Data are from Burr 1988.

Upper Tangle Lake:

There were an estimated 211 lake trout larger than 250 mm FL in Upper Tangle Lake in 1988 (SE = 33; Table 5). With an estimated surface area of 150 ha (372 acres), the estimated density of lake trout in the lake was 1.4 lake trout per hectare (0.6 LT/acre). The estimate of the abundance of lake trout of mature size (LM_{50} and larger) in Upper Tangle Lake in 1988 is 96 (SE = 17) giving a density of 0.6 lake trout per hectare (0.3 LT/acre; Table 2).

During the marking sampling period in June and July 1988, 109 lake trout 250 mm or larger were caught: 101 in gill nets, 4 in hoop nets, 3 with the seine and 1 on the trot lines. Ninety were captured in good condition, tagged, and released (Table 5). The rest (19) were killed in the sampling gear. During the recapture sampling period in August, 40 lake trout 250 mm or larger were captured in gill nets, and 1 was caught with the seine. No lake trout were caught with other gear types. Of the 41 lake trout examined during the recapture sampling period, 17 had Floy tags from the first sampling period, 25 were captured alive and released, and 16 were killed in the sampling gear. During the recapture period, two lake trout were recaptured from the marking period that had lost Floy tags. But, since the adipose fin was missing from these fish, they were recognized as recaptures.

The contingency test to determine if fish mixed between sampling events was not possible due to the low capture rate in the northern half of the lake during the recapture sampling event. However it does appear that significant mixing did occur. The only lake trout captured in the northern half of the lake during the second sampling period was originally marked in the southern half (Tables 6 and 7). Additionally, of the 35 fish marked in the northern part of the lake, five were recaptured in the south.

No lake trout were caught in the streams which flow into or out of Upper Tangle Lake. Additionally, no marked lake trout from Upper Tangle Lake were caught in the other lakes in the Tangle system by anglers or by other research crews. While this does not rule out the possibility of lake trout leaving or entering the lake during the experiment, the probability of this movement is low and is assumed to be negligible.

A comparison of plots of length frequencies of lake trout recaptured and unmarked lake trout captured in August 1988 indicated no recruitment through growth between the two sampling periods for fish larger than 250 mm FL (Figure 5). In addition, growth recruitment was not detected with the nonparametric test of Robson and Flick (1965).

Comparison of lengths of marked and recaptured fish (test 1) and lengths of all fish captured during the marking event and during the recapture event (test 2) failed to detect significant differences between capture rates among length categories (test 1: $D = 0.09$, $P = 0.99$; test 2: $D = 0.19$, $P = 0.18$; Appendix Tables 9-12). Therefore, a single abundance estimate for lake trout $\geq$ 250 mm FL was calculated for Upper Tangle lake.

Table 5. Estimated abundance of lake trout larger than 250 mm FL in Upper Tangle Lake in 1988.

Gear	Number of Lake Trout			Abundance Estimate	SE	Lake Trout per Hectare
	Marked	Recaptured	Examined			
Gill Net	84	16	40			
Hoop Net	4	0	0			
Seine	2	1	1			
Trot Line	0	---	---			
Total	90	17	41	211	33	1.4

Table 6. Number of lake trout marked and recaptured by area in Upper Tangle Lake, 1988.

Area Marked	Area Recaptured		Not Recaptured	Total Marked
	North	South		
North	0	5	30	35[1]
South	1	9	66	76[1]
Total	1	16[1]	96	113

[1] Area of marking is unknown for two fish due to tag loss.

Table 7. Area of capture of marked and unmarked lake trout during the recapture sampling event in Upper Tangle Lake, 1988.

Lake Trout	Area of Capture		Total
	North	South	
Marked	1	16	17
Unmarked	0	28	28
Total	1	44	45

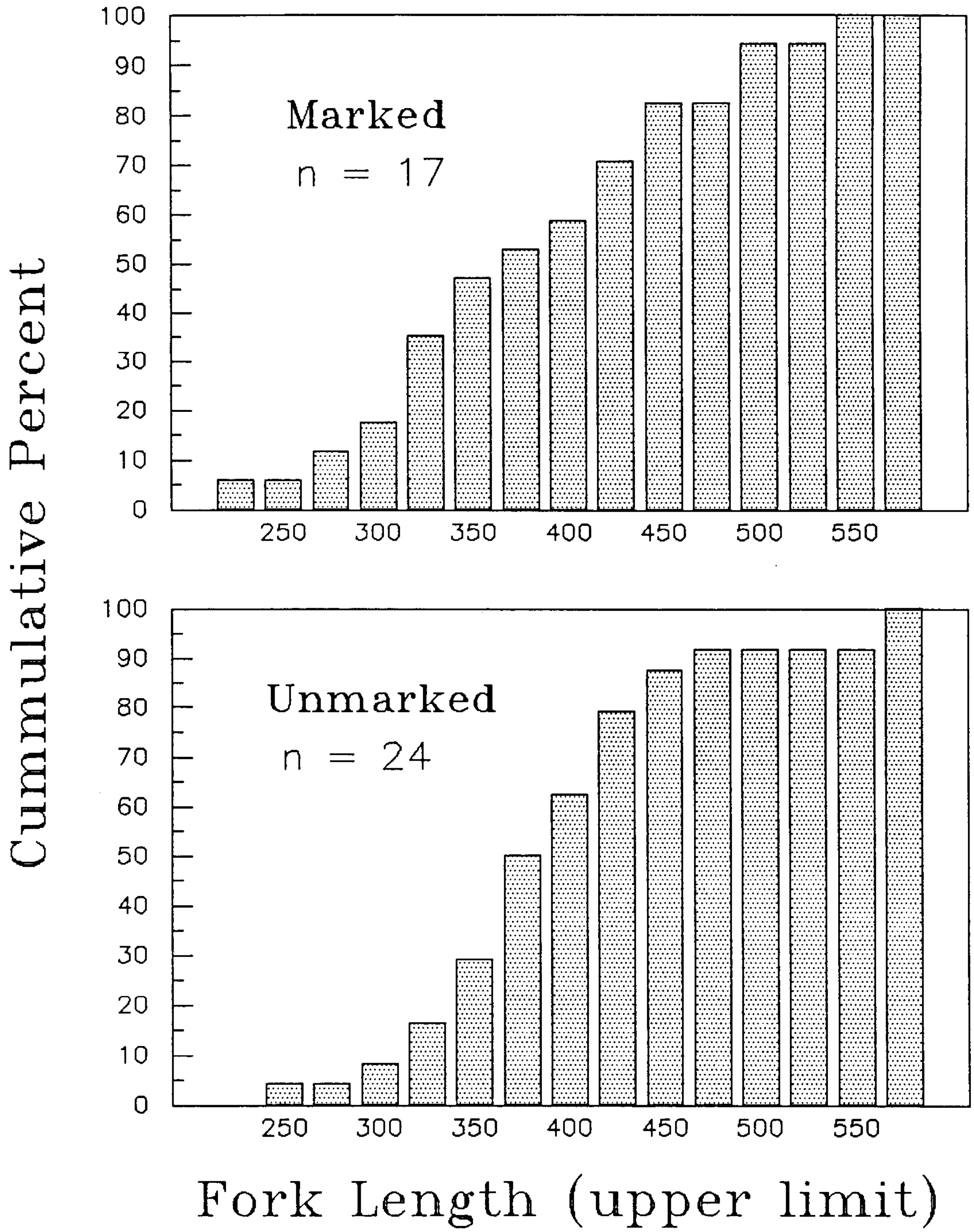

Figure 5. Cumulative distribution of lengths of marked and unmarked lake trout captured during the recapture sampling event in Upper Tangle Lake.

Population Structure

Although data on sex composition and RSD were obtained from the six lake trout populations sampled in 1988, unbiased estimates of sex composition and relative stock density are available only for lake trout populations for which abundance estimates were conducted. We were unable to determine if the gear used to capture lake trout in Fielding and in Paxson Lakes was size and/or sex selective without the mark-recapture experiments, so the data collected from these populations could be biased. Since the length biases, if any, in the samples from Paxson and Fielding Lakes are unknown the RSD from these samples are not included here in the results but are given in Appendix Table 13.

Sex Composition:

Proportions of males, females, and immature lake trout were estimated using all of the lake trout that were killed during the mark recapture experiments in 1987-88 (Table 8). Females were more common than males in the samples from each of the lakes; Butte Lake 0.5:1, Twobit Lake 0.6:1, Sevenmile Lake 0.6:1, and Upper Tangle Lake 0.75:1.

Relative Stock Density:

No lake trout captured from the six lakes sampled in 1988 were of trophy size (> 974 mm FL; Table 9, Figure 6). A small portion of the lake trout sampled from Upper Tangle Lake (2%) were memorable (779-974 mm FL). Preferred (595-778 mm FL) lake trout composed 3% of the lake trout sampled from this lake while only one fish of preferred size was caught in Butte Lake. The highest proportion of lake trout of quality size (495-594 mm FL) was from Upper Tangle Lake (11%); lake trout of quality size composed one percent or less of the lake trout from Butte, Sevenmile, and Twobit Lakes. Most of the lake trout sampled from these three lakes (99%) were of stock size (260-494 mm FL) or smaller.

Maturity:

Estimates of length at maturity and age of maturity were calculated for six lakes in the study area.

Length at Maturity. Estimates of the length at which 50% of the lake trout mature (LM_{50}) ranged from 343 mm FL for lake trout from Twobit Lake to 444 mm FL for fish from Fielding Lake (Table 10; Figure 7). Lake trout mature at similar size in Butte Lake (LM_{50} = 361 mm), Sevenmile Lake (LM_{50} = 367 mm), and Paxson Lake (LM_{50} = 362 mm). In Upper Tangle Lake, the LM_{50} for lake trout was 402 mm. In all lakes, males matured at somewhat smaller size than did females.

Age of Maturity. The age at which 50% of the lake trout were mature (AM_{50}) in the sample from Paxson Lake is 5.4 years (males = 4.9, females = 5.7; Table 11, Figure 7). In Fielding Lake, the AM_{50} was 7.6 years and in Upper Tangle Lake the AM_{50} was 8.1 years (males = 7.7, females = 7 - 8). For Twobit Lake the AM_{50} was 10.5 years (males = 9.7, females = 11.0). The AM_{50} for lake trout in Butte Lake was 8.5 years (males = 8.6, females = 7 - 9). Because

Table 8. Sex composition of lake trout killed during sampling at Paxson, Butte, Fielding, Twobit, Sevenmile, and Upper Tangle Lakes.

Lake		Males	Females	Immature
Paxson[2]	n[1]	1,201	333	0
	%	78	22	0
	SE (%)	1	1	
Butte	n	50	105	0
	%	32	68	0
	SE (%)	4	4	
Fielding	n	22	24	0
	%	48	52	0
	SE (%)	7	7	
Twobit	n	65	102	0
	%	39	61	0
	SE (%)	4	4	
Sevenmile	n	25	39	9
	%	34	53	12
	SE (%)	6	6	4
Upper Tangle	n	16	21	0
	%	43	57	0
	SE (%)	8	8	

1 Sample size.
2 All samples were from spawning lake trout.

Table 9. Relative Stock Density of the lake trout populations in Upper Tangle, Sevenmile, Butte, and Twobit Lakes, (after Gabelhouse 1984).

Lake		Length Group[1]				
		Stock (260 mm)	Quality (495 mm)	Preferred (595 mm)	Memorable (779 mm)	Trophy (975 mm)
Upper Tangle	n	140	19	5	3	0
	%	84	11	3	2	0
	SE(%)	3	2	1	1	---
Sevenmile	n	411	3	0	0	0
	%	99	1	0	0	0
	SE(%)	0.4	0.4	---	---	---
Butte	n	495	4	1	0	0
	%	99	1	0	0	0
	SE(%)	0.4	0.4	0	---	---
Twobit	n	696	1	0	0	0
	%	100	0	0	0	0
	SE(%)	0.1	0.1	---	---	---

[1] Lower limit of length category in parenthesis.

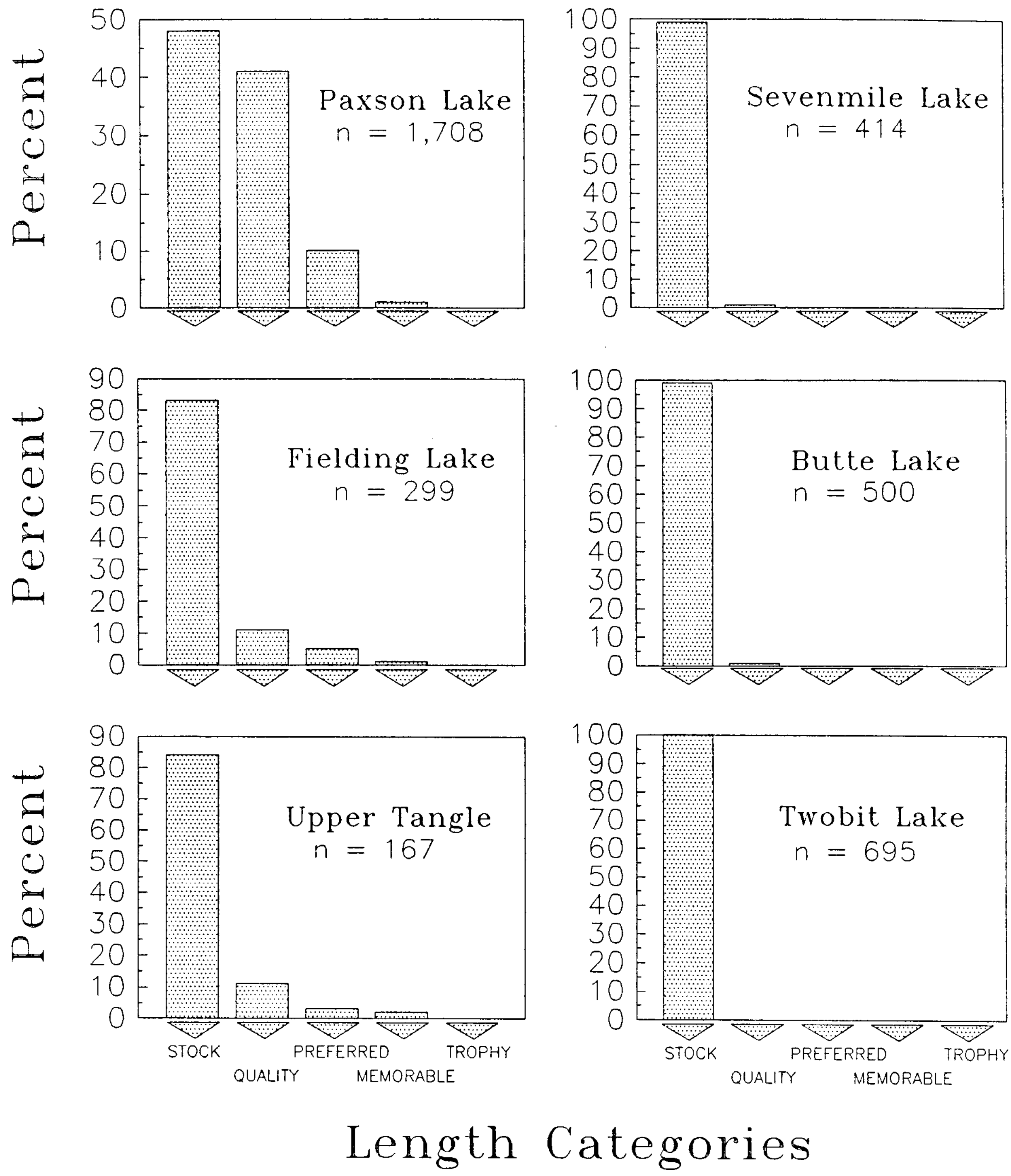

Figure 6. Relative Stock Density of the lake trout populations in Upper Tangle, Sevenmile, Butte, and Twobit Lakes and Relative Stock Density of lake trout sampled from Paxson and Fielding Lakes.

Table 10. The LM_{50}, LM_1, and LM_{99} and their fiducial limits for lake trout sampled from Paxson, Butte, Fielding, Twobit, Sevenmile, and Upper Tangle Lakes.

Lake	Sample Size	LM_{50}	95% Fiducial Limits Lower	95% Fiducial Limits Upper	LM_1	95% Fiducial Limits Lower	95% Fiducial Limits Upper	LM_{99}	95% Fiducial Limits Lower	95% Fiducial Limits Upper
PAXSON										
Both	1620	362	341	376	289	250	314	454	443	471
Females	382	426	410	436	373	336	393	486	471	516
Males	1234	351	310	370	286	218	320	429	418	451
BUTTE										
Both	101	361	349	382	314	283	328	415	389	490
Females	52	365	347	409	312	241	331	427	391	644
Males	47	354	337	401	316	250	333	395	368	597
FIELDING										
Both	38	444	420	469	374	282	403	527	490	700
Females	18	450 - 525								
Males	20	426	306	461	344	?	392	526	477	?
TWOBIT										
Both	174	343	314	363	240	164	276	490	439	654
Females	97	352	328	371	229	158	266	543	479	739
Males	63	335	308	351	255	190	286	439	406	530
SEVENMILE										
Both	102	367	352	382	311	264	331	433	406	512
Females	35	373	352	401	320	249	343	436	404	577
Males	21	367	331	394	324	173	347	417	390	724
UPPER TANGLE										
Both	34	402	380	438	342	226	368	473	436	764
Females	19	375 - 425								
Males	13	375 - 450								

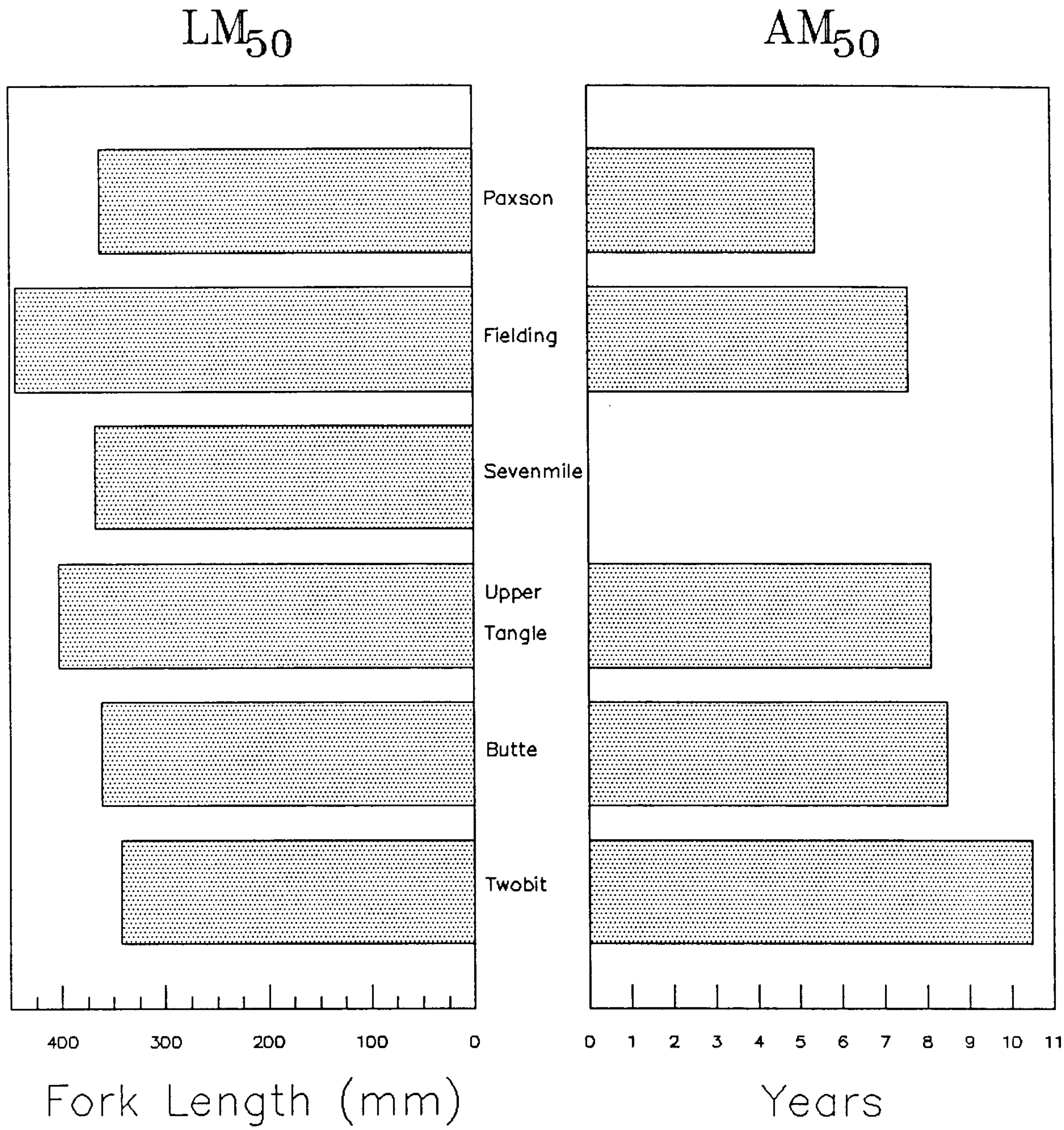

Figure 7. Estimated length at maturity (LM_{50}) and age of maturity (AM_{50}) of lake trout from Paxson, Fielding, Sevenmile, Upper Tangle, Butte, and Twobit Lakes.

Table 11. The AM_{50}, AM_{1}, and AM_{99} and their fiducial limits for lake trout sampled from Paxson, Butte, Fielding, Twobit, Sevenmile, and Upper Tangle Lakes.

Lake	Sample Size	AM_{50}	95% Fiducial Limits		AM_{1}	95% Fiducial Limits		AM_{99}	95% Fiducial Limits	
			Lower	Upper		Lower	Upper		Lower	Upper
PAXSON										
Both	223	5.4	4.9	5.7	3.5	2.6	4.0	8.3	7.5	10.2
Females	114	6.2	5.6	6.6	4.4	3.0	5.0	8.7	7.7	11.9
Males	102	4.8	3.9	5.3	3.1	1.3	3.9	7.5	6.5	12.6
BUTTE										
Both	104	8.5	7.9	9.6	6.3	5.4	6.8	11.5	10.1	15.5
Females	55	7 - 9								
Males	47	8.6	7.8	10.5	6.2	4.7	6.9	11.8	9.9	20.7
FIELDING										
Both	22	7.6	?	?	3.7	?	5.8	15.0	8.6	?
Females	13	?								
Males	9	?								
TWOBIT										
Both	172	10.5	9.3	10.8	5.7	4.3	6.6	18.0	15.7	22.7
Females	96	11.0	9.3	11.7	5.2	3.1	6.6	21.1	17.2	33.0
Males	62	9.7	7.4	10.1	5.9	2.8	7.3	13.8	11.9	22.5
SEVENMILE										
Both	69	5 - 6	(NO AM_{50}'s are possible, all Age 4 and younger were immature;							
Females	34		all Age 6 and older were mature; partial maturity at Age 5)							
Males	20									
UPPER TANGLE										
Both	33	8.1	7.2	11.5	5.7	1.2	6.6	11.5	9.4	?
Females	19	7 - 8								
Males	12	7.7			4.2	?	6.3	14.3	9.3	?

probit analysis requires two or more data pairs with percentages other than 0 or 100, it was not possible to estimate the AM_{50} for lake trout from Sevenmile Lake. However, all fish age 4 and younger were immature, and all fish age 6 and older were mature. Approximately 70% of the age 5 fish were mature.

Size at Age:

Estimates of the mean length at age were calculated for lake trout sampled from Paxson, Butte, Fielding, Twobit, Sevenmile, and Upper Tangle Lakes and are given in Tables 12-17. Lake trout in the samples from Paxson Lake grew fastest and attained the largest size of any of the lakes sampled. Growth of lake trout from Fielding Lake was similar to the growth seen in the younger age classes of fish from Paxson Lake, but no fish older than age 13 were present in our sample. Lengths at age for lake trout from Sevenmile Lake indicate growth rates similar to the rates of lake trout from Fielding Lake up to age 6, but slower for older fish. Estimates of length at age for fish from Upper Tangle and Butte Lakes are very similar showing slower growth than fish from Paxson, Fielding, or Sevenmile Lake. Lake trout were the smallest at age in the samples from Twobit Lakes.

DISCUSSION

Abundance Estimates

Abundance of mature lake trout in lakes for which estimates were performed in 1988 ranged from 0.6 fish per hectare in Upper Tangle Lake to 13.9 fish per hectare in Sevenmile Lake. Burr (1988) estimated abundance of mature lake trout (> 373 mm FL) in Glacier Lake (177 ha) to be 1,724 fish (SE = 403) or 9.7 fish per hectare; and estimated abundance of mature lake trout (> 357 mm FL) in Landlocked Tangle Lake (241 ha) was 1,645 lake trout (SE = 359) or 6.8 fish per hectare (Table 2). Comparable estimates of lake trout density from other areas of Alaska are not available. The few estimates available from outside Alaska indicate that most lake trout stock densities are between one and 14 fish per hectare (Martin and Olver 1980). The estimated stock of mature lake trout (age 6 and older) in Swan Lake, Alberta, calculated from mark-recapture experiments, was 226 fish or 1.13 fish per hectare for this 200 ha lake (Patterson 1968). In the much larger Thompson Lake, Maine (1,791 ha), the estimated abundance of lake trout larger than 356 mm was 19,252, or 10.7 fish per hectare (De Roche unpublished, from Martin and Olver 1980). The estimates of lake trout densities from four of the five lakes in Alaska lie in the middle to upper range of reported densities.

The estimated density of lake trout in Upper Tangle Lake is an order of magnitude lower than any of the other estimates from Alaska. This estimate indicates an alarmingly small population size which is of particular concern since Upper Tangle Lake is located within one of interior Alaska's most popular recreational areas. Concern over the rate of harvest of lake trout from the Tangle Lakes system resulted in a complete closure to the harvest of lake trout in 1987. The lakes were reopened in 1988 with a more restrictive size and bag limit (Burr 1988).

Table 12. Estimated mean length (mm FL) at age (from otoliths) of lake trout from Paxson Lake, 1987-1988.

AGE	ALL LAKE TROUT			FEMALE LAKE TROUT			MALE LAKE TROUT		
	mean length	sample size	SE	mean length	sample size	SE	mean length	sample size	SE
0		0			0			0	
1		0			0			0	
2		0			0			0	
3		0			0			0	
4	377	4	9	390	1		364	2	14
5	410	32	5	397	8	9	420	19	6
6	444	39	6	444	18	11	436	14	6
7	463	33	7	483	9	14	453	23	8
8	499	33	8	526	17	11	469	13	9
9	498	13	8	508	5	11	485	7	11
10	508	7	26	568	3	32	464	4	18
11	556	11	11	568	6	20	543	4	7
12	528	5	28	570	3	13	465	2	25
13	604	10	37	541	4	8	646	6	57
14	605	6	32	614	5	38	558	1	
15	567	19	5	567	12	7	563	6	4
16	601	7	15	606	6	16	572	1	
17	572	10	6	565	4	11	577	6	8
18	585	3	8	577	2	3	601	1	
19	614	9	31	645	4	69	582	3	20
20	618	2	9	618	2	9		0	
21	568	7	11	583	1		569	5	15
22	577	4	8	579	3	12	572	1	
23	638	6	51	655	5	59	553	1	
24	673	7	50	681	6	58	625	1	
25		0			0			0	
26	638	2	28	610	1			0	
27		0			0			0	
28	649	2	4	652	1		645	1	
29	582	3	7	575	2	5		0	
30		0			0			0	
31		0			0			0	
32		0			0			0	
33	610	1		610	1			0	
34		0			0			0	
ALL	513	275	5	541	129	8	488	121	7

Table 13. Estimated mean length (mm FL) at age (from otoliths) of lake trout from Butte Lake, 1988.

AGE	ALL LAKE TROUT			FEMALE LAKE TROUT			MALE LAKE TROUT		
	mean length	sample size	SE	mean length	sample size	SE	mean length	sample size	SE
0		0			0			0	
1		0			0			0	
2		0			0			0	
3		0			0			0	
4	274	1			0		274	1	
5	285	7	5	285	6	5		0	
6	299	45	2	298	24	3	301	21	3
7	320	34	3	324	15	5	316	18	3
8	396	1			0		396	1	
9	385	2	13	397	1		372	1	
10	393	7	14	374	4	10	419	3	26
11	400	1			0		400	1	
12	438	1			0		438	1	
13	426	1		426	1			0	
14		0			0			0	
15	466	1		466	1			0	
ALL	319	101	4	318	52	6	322	47	6

Table 14. Estimated mean length (mm FL) at age (from otoliths) of lake trout from Fielding Lake, 1987-1988.

AGE	ALL LAKE TROUT			FEMALE LAKE TROUT			MALE LAKE TROUT		
	mean length	sample size	SE	mean length	sample size	SE	mean length	sample size	SE
0		0			0			0	
1		0			0			0	
2		0			0			0	
3		0			0			0	
4	327	4	20	332	2	48		0	
5	372	9	17	378	2	23	437	2	34
6	399	17	9	392	4	20	416	4	21
7	436	14	9	456	3	15	410	1	
8	502	11	37	492	3	55	471	2	42
9	537	3	28	547	1			0	
10	482	1			0		482	1	
11		0			0			0	
12		0			0			0	
13	700	2	6	705	1			0	
14		0			0			0	
15		0			0			0	
ALL	435	61	12	443	16	26	437	10	14

Table 15. Estimated mean length (mm FL) at age (from otoliths) of lake trout from Twobit Lake, 1987-1988.

AGE	ALL LAKE TROUT			FEMALE LAKE TROUT			MALE LAKE TROUT		
	mean length	sample size	SE	mean length	sample size	SE	mean length	sample size	SE
0		0			0			0	
1		0			0			0	
2		0			0			0	
3		0			0			0	
4		0			0			0	
5	244	3	22	252	1		278	1	
6	262	5	9		0		283	1	
7	282	15	7	298	8	9	262	4	9
8	301	17	10	304	10	16	321	4	12
9	319	18	10	323	11	13	335	5	11
10	347	13	7	354	6	7	344	6	15
11	379	7	15	379	7	15		0	
12	378	20	7	374	9	10	382	11	9
13	375	13	7	377	7	11	373	6	9
14	401	12	7	401	7	10	402	5	13
15	379	6	9	391	4	5	354	2	4
16	385	7	9	373	4	5	402	3	16
17	416	10	14	421	5	24	410	5	16
18	411	6	10	415	4	15	403	2	10
19	416	7	5	414	4	7	419	3	10
20	418	2	37	455	1		381	1	
21	407	5	11	404	2	27	410	3	12
22	414	2	9	422	1		405	1	
23	437	3	4	437	3	4		0	
24	390	1		390	1			0	
25	377	2	2	377	2	2		0	
26	416	2	3	416	2	3		0	
27		0			0			0	
28	485	1		485	1			0	
29		0			0			0	
30	422	1			0		422	1	
ALL	359	178	4	367	100	5	368	64	6

Table 16. Estimated mean length (mm FL) at age (from otoliths) of lake trout from Sevenmile Lake, 1987-1988.

AGE	ALL LAKE TROUT			FEMALE LAKE TROUT			MALE LAKE TROUT		
	mean length	sample size	SE	mean length	sample size	SE	mean length	sample size	SE
0		0			0			0	
1	93	12	4		0			0	
2	188	8	10	173	2	3	218	2	37
3	309	4	20	320	3	24	277	1	
4	334	20	7	328	13	10	344	7	10
5	377	9	11	371	6	15	390	3	18
6	403	3	4	403	3	4		0	
7	417	5	8	426	2	0	411	3	13
8	409	3	7	420	1		404	2	7
9	426	3	31	458	2	1	364	1	
10	422	3	5	425	2	8	418	1	
11	422	1			0		422	1	
12	412	1			0		412	1	
13	429	1		429	1			0	
14	456	3	8	462	2	10	445	1	
15	430	1		430	1			0	
ALL	312	77	14	364	38	12	365	23	13

Table 17. Estimated mean length (mm FL) at age (from otoliths) of lake trout from Upper Tangle Lake, 1988.

AGE	ALL LAKE TROUT			FEMALE LAKE TROUT			MALE LAKE TROUT		
	mean length	sample size	SE	mean length	sample size	SE	mean length	sample size	SE
0		0			0			0	
1		0			0			0	
2		0			0			0	
3	220	1			0		220	1	
4		0			0			0	
5	338	4	22	353	3	23	292	1	
6	268	2	14	282	1			0	
7	359	15	13	354	8	12	351	6	24
8	391	9	12	373	4	12	405	5	18
9	373	3	36	445	1		338	2	7
10	588	1		588	1			0	
11		0			0			0	
12		0			0			0	
13		0			0			0	
14	650	1		650	1			0	
15		0			0			0	
16		0			0			0	
17	566	1		566	1			0	
18		0			0			0	
19		0			0			0	
20		0			0			0	
ALL	377	37	14	396	20	22	355	15	17

However, there are indications that overharvest of the lake trout stock in Upper Tangle Lake does not completely explain the estimated low population size. For example, a relatively high proportion of the lake trout encountered during sampling were large (Table 9, Figure 5). Also, this stock showed a relatively slow growth rate (Table 17) and a late age of maturity (Figure 7). Exploitation of the degree suggested by the estimate of density is not consistent with these population characteristics.

Since Upper Tangle Lake is not physically closed to emmigration and immigration, the argument could be made that the estimated abundance is not representative of the true abundance. However, the high recapture rate of marked fish (41%) argues against immigration. No lake trout were caught in the streams and since the loss of fish during the experiment would have the effect of inflating the estimate, emmigration or higher mortality of marked fish seems unlikely.

If the estimate of abundance is assumed to be realistic, and the other characteristics of the population are accurately estimated, another explanation for the small population abundance is required. An alternative cause for the low density of lake trout is that our estimate of suitable habitat is too large. Lake trout typically inhabit oligotrophic lakes where the species obtains its greatest abundance. Lake trout are generally found in deeper lakes, typically in lakes with depths exceeding 15-20 meters. In the Arctic and in alpine conditions lake trout may live in quite shallow waters where temperatures remain well below 10° C through out the year (Martin and Olver 1980). By 6 August, water temperatures were in excess of 10° C (50° F) at all depths in the northern part of Upper Tangle Lake. The only location where colder water was found was in a deep basin in the southern most bay (Appendix Table 14). This was also the only part of the lake in which we were able to capture lake trout consistently during the recapture sampling period. Although a bathymetric map of the lake is not available, we estimate that the deep water (14 m or more) in this bay represents 22% or less of the total surface area of the lake. A much greater proportion of deep water is found in the other four lakes for which we have estimated lake trout abundance. Lake trout appear to be restricted to this deeper cooler portion of Upper Tangle Lake in mid to late summer and hence the amount of suitable habitat for lake trout may be much less than that estimated from total surface area. If 22% of the surface area or 32 hectares is used to calculate the density of lake trout in the lake, the estimated density of lake trout of mature size becomes 3.1 fish per hectare. This estimate is still less than half that estimated for the other four lakes (Table 2). It appears therefore, that the very low lake trout density in Upper Tangle Lake is due a high exploitation rate on a stock that occupies less than optimal habitat for the species.

Densities of lake trout in the four other lakes from Alaska show an inverse relationship with lake surface area (Table 2). An inverse relationship with density and/or yield, and lake area, is consistent with reports by Carlander (1977), Goddard et al. (1987) and others. This implies that smaller lakes produce more fish than larger lakes on a per unit area basis. Such a trend is intuitively reasonable since larger oligothrophic lakes in which lake trout are typically found, generally have a greater proportion of deep, relatively less productive habitat than do smaller lakes.

However, abundance in numbers does not necessarily correlate well with the biomass of a population. For example, planktivorous and piscivorous populations of lake trout of equivalent biomass may differ widely in abundance because of the typically small average size of the planktivorous fish. Martin and Olver (1980) report that the densest stocks of lake trout generally occur in those lakes where fish mature at a small size, are planktivorous, and where the average size of fish is between 300-400 mm. Hence the relatively high densities of lake trout found in the four lakes in Alaska is likely related to the small surface area of the lakes studied, the small average size of fish, and the small size at maturity of lake trout in these populations.

Population Structure

Data collected in 1988 have provided estimates of the sex and size composition from four populations of lake trout in the study area, and estimates of maturity for all six lake trout populations. However, in many cases the sample sizes were too small to provide conclusive comparisons, particularly for estimates of age composition and size at age. Alaska Department of Fish and Game will continue to collect data from the populations in each of these lakes from creel census contacts and from test netting. These data will be accumulated across years and added to the existing data base to improve the accuracy and precision of the estimates of population structure.

Lake trout stocks usually exhibit balanced sex ratios (Martin and Olver 1980). A nearly balanced sex ratio is seen in the samples from Upper Tangle, and Fielding Lakes. The dominance of males in the sample collected from the spawning grounds from Paxson Lake is typical of spawning congregations (Martin and Olver 1980). That females should dominate our samples from the other four lakes is unexpected and the source of this skewed sex ratio is unclear. A number of factors have been suggested which would result in such a bias (eg. different catch rates or mortality rates for males and females). However, since sex is determined only from dead fish (except when sampled during spawning) we are unable to detect, and therefore correct, any bias in our samples for estimating the sex composition of lake trout populations. Hence, we recommend that estimates of sex composition for lake trout populations be included in future study objectives only when the sex of each fish that is captured can be determined.

The size composition of lake trout populations estimated as Relative Stock Density (RSD) is similar for the populations of lake trout from Butte, Sevenmile, and Twobit Lakes. In each of these lakes, very few fish of large size were found and nearly all of the lake trout sampled were less than 495 mm FL (stock). The size composition of lake trout from Upper Tangle Lake is somewhat larger although most (84%) of these lake trout were of stock size and less. A much higher proportion of large lake trout (52% $\geq$ 495 m FL) occurred in our large sample from Paxson Lake. However this difference in the size composition of lake trout from Paxson Lake is undoubtedly due in part to the fact that all of these fish were captured from spawning concentrations.

The estimates of length at which lake trout of both sexes mature are very similar for the four lakes for which we have sufficient sample sizes; LM_{50}'s ranged from 343 to 367 mm (Table 10). The estimates from Upper Tangle (402 mm) and Fielding (444 mm) were much higher but our samples were too few for complete analysis. Burr (1988) suggested that the size of maturity was larger for faster growing Alaska populations. Female lake trout from fast growing populations (eg. Paxson Lake) are mature at relatively larger size. Although lake trout of both sexes from the slow growing population in Twobit Lake are mature at a somewhat smaller size, the similarity of the estimates of LM_{50} for both sexes for the other lakes would seem to indicate that size of maturity, particularly for males, may not be highly dependent on growth rate. When comparing these data with size of maturity data from other geographical areas, recall that the populations with which we are working are living in relatively small lakes.

Though data are too few to estimate age composition of the populations that were sampled, the limited age data together with size composition of our samples do provide information on the age structure of these lake trout populations. No fish older than age 15 have been sampled from Sevenmile and Fielding Lakes. In addition, estimates of mean length at age have been calculated for the entire range of lengths encountered indicating that there are very few, if any, old age fish in these populations. In Upper Tangle and Butte Lakes, no fish older than age 15 and 17, respectively, were killed. However, in these two lakes lake trout were captured that were larger than those for which we have estimates of age. This documents that at least a few older fish are present in these populations. In contrast, relatively old lake trout (age > 25) were well represented in the samples from the populations of Paxson and Twobit Lakes. All lakes sampled, with the exception of Twobit Lake, show a dominance of younger age (age 4-8) fish. Except for Twobit Lake, all sampled lakes also have good road or trail access. The absence of significant proportions of older fish in most of these populations appears to be a result of fishing having cropped off the older age classes. The presence of numerous old, albeit small, fish in Twobit Lake is probably attributable to its relatively remote location.

Lake trout from Paxson Lake (Copper River system) are larger, grow faster, and mature at a younger age than do lake trout from the other lakes sampled in 1988. The faster growth of lake trout in Paxson Lake is probably a result of the availability of large numbers of sockeye salmon *Oncorhynchus nerka* fry and smolt and, to a lesser degree, round whitefish *Prosopium cylindraceum* and humpback whitefish *Coregonus pidschian* and Arctic grayling which provide an excellent forage base. The forage base in Butte Lake and in the Tanana drainage lakes is lower. Whitefish and other fish species are present in most of the other lakes sampled, but sockeye salmon are absent. Lake trout are essentially the only fish species in Twobit Lake where their diet is composed primarily of snails and aquatic invertebrates. Lake trout from Upper Tangle, Butte, and Twobit Lakes are mostly small, grow slowly and mature at relatively old age. Lake trout in Sevenmile lake are small, although growth is good and fish mature at young age. The good growth, the absence of older age classes, and young age of maturity suggests a response by the lake trout population in Sevenmile Lake to fishing pressure in this small lake which has excellent road access.

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APPENDIX

Appendix Table 1. Length frequencies (listed by gear type) of all lake trout marked during June and July 1987 in Sevenmile Lake.

FORK LENGTH[1]	GEAR TYPE									
	Gill Nets		Seine		Fyke Nets		Hoop Nets		All	
	n[2]	%	n	%	n	%	n	%	n	%
200	0	0	0	0	2	5	0	0	2	15
225	3	2	0	0	9	24	0	0	12	7
250	2	2	0	0	16	43	0	0	18	5
275	9	7	0	0	6	16	0	0	15	7
300	6	5	0	0	1	3	0	0	7	8
325	2	2	3	12	0	0	0	0	5	28
350	4	3	1	4	1	3	1	50	7	43
375	6	5	1	4	1	3	0	0	8	39
400	22	17	5	19	0	0	1	50	28	10
425	33	25	10	38	0	0	0	0	43	3
450	34	26	5	19	0	0	0	0	39	1
475	8	6	1	4	1	3	0	0	10	0
500	3	2	0	0	0	0	0	0	3	0
525	1	1	0	0	0	0	0	0	1	0
550	0	0	0	0	0	0	0	0	0	0
Total	133		26		37		2		198	

[1] Upper limit of length category.
[2] Sample size.

Appendix Table 2. Length frequencies (listed by gear type) of all lake trout captured during 1987 in Sevenmile Lake.

FORK LENGTH[1]	GEAR TYPE									
	Gill Nets		Seine		Fyke Nets		Hoop Nets		All	
	n[2]	%	n	%	n	%	n	%	n	%
200	0	0	0	0	2	5	0	0	2	1
225	3	2	0	0	9	24	0	0	12	5
250	2	1	0	0	16	43	0	0	18	8
275	10	6	0	0	6	16	0	0	16	7
300	13	8	0	0	1	3	0	0	14	6
325	2	1	3	12	0	0	0	0	5	2
350	5	3	1	4	1	3	1	50	8	3
375	8	5	1	4	1	3	0	0	10	4
400	26	16	5	19	0	0	1	50	32	14
425	40	24	10	38	0	0	0	0	50	22
450	40	24	5	19	0	0	0	0	45	20
475	12	7	1	4	1	3	0	0	14	6
500	3	2	0	0	0	0	0	0	3	1
525	1	1	0	0	0	0	0	0	1	0
550	0	0	0	0	0	0	0	0	0	0
Total	165		26		37		2		230	

[1] Upper limit of length category.
[2] Sample size.

Appendix Table 3. Length frequencies (listed by gear type) of lake trout marked in 1987 and recaptured in 1988 in Sevenmile Lake.

FORK LENGTH[1]	GEAR TYPE									
	Gill Nets		Seine		Fyke Nets		Hoop Nets		All	
	n[2]	%	n	%	n	%	n	%	n	%
200	0	0			0	0	0	0	0	0
225	0	0			0	0	0	0	0	0
250	0	0			0	0	0	0	0	0
275	1	3			0	0	0	0	1	3
300	1	3			0	0	0	0	1	3
325	1	3			0	0	0	0	1	3
350	5	17			0	0	0	0	5	16
375	8	28			0	0	0	0	8	26
400	3	10			0	0	0	0	3	10
425	4	14			0	0	2	100	6	19
450	4	14			0	0	0	0	4	13
475	1	3			0	0	0	0	1	3
500	1	3			0	0	0	0	1	3
525	0	0			0	0	0	0	0	0
550	0	0			0	0	0	0	0	0
Total	29				0		2		31	

[1] Upper limit of length category.
[2] Sample size.

Appendix Table 4. Length frequencies (listed by gear type) of all lake trout captured in 1988 in Sevenmile Lake.

FORK LENGTH[1]	GEAR TYPE									
	Gill Nets		Seine		Fyke Nets		Hoop Nets		All	
	n[2]	%	n	%	n	%	n	%	n	%
200	0	0			0	0	0	0	0	0
225	0	0			4	67	0	0	4	2
250	2	1			1	17	0	0	3	2
275	6	4			0	0	0	0	6	3
300	9	5			0	0	0	0	9	5
325	2	1			0	0	0	0	2	1
350	15	9			0	0	0	0	15	9
375	29	18			0	0	0	0	29	17
400	19	12			0	0	0	0	19	11
425	35	21			0	0	2	67	37	21
450	31	19			1	17	0	0	32	18
475	15	9			0	0	0	0	15	9
500	1	1			0	0	1	33	2	1
525	0	0			0	0	0	0	0	0
550	0	0			0	0	0	0	0	0
Total	164				6		3		173	

[1] Upper limit of length category.
[2] Sample size.

Appendix Table 5. Length frequencies (listed by gear type) of all lake trout marked during 1987 in Twobit Lake.

FORK LENGTH[1]	Gill Nets		Hoop Nets		Rod & Reel		All	
	n[2]	%	n	%	n	%	n	%
200	0	0	1	0	0	0	1	0
225	1	1	8	4	0	0	9	2
250	8	5	13	6	0	0	21	5
275	7	4	12	5	0	0	19	5
300	5	3	7	3	0	0	12	3
325	13	7	13	6	1	14	27	7
350	22	13	29	13	1	14	52	13
375	39	22	53	24	1	14	93	23
400	38	22	51	23	2	29	91	23
425	32	18	23	11	2	29	57	14
450	9	5	8	4	0	0	17	4
475	1	1	1	0	0	0	2	0
500	1	1	0	0	0	0	1	0
525	0	0	0	0	0	0	0	0
550	0	0	0	0	0	0	0	0
total	176		219		7		402	

[1] Upper limit of length category.
[2] Sample size.

Appendix Table 6. Length frequencies (listed by gear type) of all lake trout captured during 1987 in Twobit Lake.

FORK LENGTH[1]	Gill Nets		Hoop Nets		Rod & Reel		All	
	n[2]	%	n	%	n	%	n	%
200	2	1	1	0	0	0	3	1
225	3	1	12	5	0	0	15	3
250	12	5	13	6	0	0	25	5
275	13	5	12	5	0	0	25	5
300	14	5	7	3	0	0	21	4
325	20	8	13	6	1	14	34	7
350	36	14	29	13	1	14	66	13
375	51	20	53	24	1	14	105	21
400	47	18	51	23	2	29	100	20
425	43	17	23	10	2	29	68	14
450	15	6	8	4	0	0	23	5
475	1	0	1	0	0	0	2	0
500	2	1	0	0	0	0	2	0
525	1	0	0	0	0	0	1	0
550	0	0	0	0	0	0	0	0
total	260		223		7		490	

[1] Upper limit of length category.
[2] Sample size.

Appendix Table 7. Length frequencies (listed by gear type) of lake trout marked in 1987 and recaptured in 1988 in Twobit Lake.

FORK LENGTH[1]	Gill Nets		Hoop Nets		Rod & Reel		All	
	n[2]	%	n	%	n	%	n	%
200	0	0	0	0	0	0	0	0
225	0	0	0	0	0	0	0	0
250	1	6	0	0	0	0	1	4
275	0	0	0	0	0	0	0	0
300	0	0	0	0	0	0	0	0
325	0	0	1	17	0	0	1	4
350	1	6	1	17	0	0	2	9
375	7	44	2	33	1	100	10	43
400	4	25	0	0	0	0	4	17
425	2	13	2	33	0	0	4	17
450	1	6	0	0	0	0	1	4
475	0	0	0	0	0	0	0	0
500	0	0	0	0	0	0	0	0
525	0	0	0	0	0	0	0	0
550	0	0	0	0	0	0	0	0
total	16		6		1		23	

[1] Upper limit of length category.
[2] Sample size.

Appendix Table 8. Length frequencies (listed by gear type) of all lake trout captured during 1988 in Twobit Lake.

FORK LENGTH[1]	Gill Nets		Hoop Nets		Rod & Reel		All	
	n[2]	%	n	%	n	%	n	%
200	0	0	1	2	3	21	4	2
225	0	0	3	5	1	7	4	2
250	2	2	0	0	0	0	2	1
275	2	2	3	5	0	0	5	3
300	5	5	3	5	2	14	10	6
325	7	7	6	10	2	14	15	9
350	15	15	20	34	2	14	37	22
375	21	21	13	22	3	21	37	22
400	25	25	5	9	1	7	31	18
425	12	12	3	5	0	0	15	9
450	10	10	1	2	0	0	11	6
475	1	1	0	0	0	0	1	1
500	0	0	0	0	0	0	0	0
525	0	0	0	0	0	0	0	0
550	0	0	0	0	0	0	0	0
total	100		58		14		172	

[1] Upper limit of length category.
[2] Sample size.

Appendix Table 9. Length frequencies (listed by gear type) of lake trout marked during the marking sample period (3 June - 11 July 1988) in Upper Tangle Lake 1988.

FORK LENGTH[1]	GEAR TYPE									
	Gill Nets		Seine		Hoop Nets		Trot Lines		All	
	n[2]	%	n	%	n	%	n	%	n	%
200	0	0	0	0	0	0	0	0	0	0
225	4	4	0	0	0	0	0	0	4	4
250	5	6	0	0	0	0	0	0	5	5
275	5	6	0	0	0	0	0	0	5	5
300	7	8	0	0	0	0	0	0	7	7
325	13	14	0	0	0	0	0	0	13	14
350	11	12	0	0	0	0	0	0	11	11
375	6	7	0	0	0	0	0	0	6	6
400	5	6	0	0	0	0	0	0	5	5
425	5	6	0	0	1	25	0	0	6	6
450	5	6	0	0	0	0	0	0	5	5
475	7	8	1	50	2	50	0	0	10	10
500	4	4	0	0	0	0	0	0	4	4
525	5	6	0	0	0	0	0	0	5	5
550	1	1	0	0	1	25	0	0	2	2
575	1	1	0	0	0	0	0	0	1	1
600	0	0	1	50	0	0	0	0	1	1
625	0	0	0	0	0	0	0	0	0	0
650	0	0	0	0	0	0	0	0	0	0
675	0	0	0	0	0	0	0	0	0	0
700	0	0	0	0	0	0	0	0	0	0
725	1	1	0	0	0	0	0	0	1	1
750	1	1	0	0	0	0	0	0	1	1
775	1	1	0	0	0	0	0	0	1	1
800	1	1	0	0	0	0	0	0	1	1
825	1	1	0	0	0	0	0	0	1	1
850	1	1	0	0	0	0	0	0	1	1
875	0	0	0	0	0	0	0	0	0	0
900	0	0	0	0	0	0	0	0	0	0
Total	90		2		4		0		96	

[1] Upper limit of length category.
[2] Sample size.

Appendix Table 10. Length frequencies (listed by gear type) of lake trout captured during the marking sample period (3 June - 11 July 1988) in Upper Tangle Lake, 1988.

FORK LENGTH[1]	GEAR TYPE									
	Gill Nets		Seine		Hoop Nets		Trot Lines		All	
	n[2]	%	n	%	n	%	n	%	n	%
200	0	0	0	0	0	0	0	0	0	0
225	4	4	0	0	0	0	0	0	4	4
250	5	5	0	0	0	0	0	0	5	5
275	6	6	0	0	0	0	0	0	6	6
300	11	10	0	0	0	0	0	0	11	11
325	15	14	0	0	0	0	0	0	15	15
350	14	13	0	0	0	0	0	0	14	14
375	8	7	0	0	0	0	0	0	8	8
400	6	6	0	0	0	0	0	0	6	6
425	7	6	0	0	1	25	0	0	8	8
450	5	5	0	0	0	0	0	0	5	5
475	9	8	1	33	2	50	0	0	12	12
500	4	4	1	33	0	0	0	0	5	5
525	5	5	0	0	0	0	0	0	5	5
550	1	1	0	0	1	25	0	0	2	2
575	2	2	0	0	0	0	0	0	2	2
600	0	0	1	33	0	0	0	0	1	1
625	0	0	0	0	0	0	0	0	0	0
650	0	0	0	0	0	0	1	100	1	1
675	0	0	0	0	0	0	0	0	0	0
700	0	0	0	0	0	0	0	0	0	0
725	1	1	0	0	0	0	0	0	1	1
750	1	1	0	0	0	0	0	0	1	1
775	1	1	0	0	0	0	0	0	1	1
800	1	1	0	0	0	0	0	0	1	1
825	1	1	0	0	0	0	0	0	1	1
850	1	1	0	0	0	0	0	0	1	1
875	0	0	0	0	0	0	0	0	0	0
900	0	0	0	0	0	0	0	0	0	0
Total	108		3		4		1		116	

[1] Upper limit of length category.
[2] Sample size.

Appendix Table 11. Length frequencies (listed by gear type) of lake trout recaptured during the recapture sample period (5 - 30 August 1988) in Upper Tangle Lake, 1988.

FORK LENGTH[1]	GEAR TYPE									
	Gill Nets		Seine		Hoop Nets		Trot Lines		All	
	n[2]	%	n	%	n	%	n	%	n	%
200	0	0	0	0	0	0	0	0	0	0
225	0	0	0	0	0	0	0	0	0	0
250	1	6	0	0	0	0	0	0	1	6
275	0	0	0	0	0	0	0	0	0	0
300	1	6	0	0	0	0	0	0	1	6
325	1	6	0	0	0	0	0	0	1	6
350	3	19	0	0	0	0	0	0	3	18
375	2	13	0	0	0	0	0	0	2	12
400	0	0	1	100	0	0	0	0	1	6
425	1	6	0	0	0	0	0	0	1	6
450	2	13	0	0	0	0	0	0	2	12
475	2	13	0	0	0	0	0	0	2	12
500	0	0	0	0	0	0	0	0	0	0
525	2	13	0	0	0	0	0	0	2	12
550	0	0	0	0	0	0	0	0	0	0
575	1	6	0	0	0	0	0	0	1	6
600	0	0	0	0	0	0	0	0	0	0
625	0	0	0	0	0	0	0	0	0	0
650	0	0	0	0	0	0	0	0	0	0
675	0	0	0	0	0	0	0	0	0	0
700	0	0	0	0	0	0	0	0	0	0
725	0	0	0	0	0	0	0	0	0	0
750	0	0	0	0	0	0	0	0	0	0
775	0	0	0	0	0	0	0	0	0	0
800	0	0	0	0	0	0	0	0	0	0
825	0	0	0	0	0	0	0	0	0	0
850	0	0	0	0	0	0	0	0	0	0
875	0	0	0	0	0	0	0	0	0	0
900	0	0	0	0	0	0	0	0	0	0
Total	16		1		0		0		17	

[1] Upper limit of length category.
[2] Sample size.

Appendix Table 12. Length frequencies (listed by gear type) of lake trout captured during the recapture sample period (5 - 30 August 1988) in Upper Tangle Lake, 1988.

FORK LENGTH[1]	GEAR TYPE									
	Gill Nets		Seine		Hoop Nets		Trot Lines		All	
	n[2]	%	n	%	n	%	n	%	n	%
200	0	0	0	0	0	0	0	0	0	0
225	4	9	0	0	0	0	0	0	4	9
250	1	2	0	0	0	0	0	0	1	2
275	1	2	0	0	0	0	0	0	1	2
300	1	2	0	0	0	0	0	0	1	2
325	2	4	0	0	0	0	0	0	2	4
350	5	11	0	0	0	0	0	0	5	11
375	5	11	0	0	0	0	0	0	5	11
400	5	11	1	100	0	0	0	0	6	13
425	4	9	0	0	0	0	0	0	4	9
450	7	16	0	0	0	0	0	0	7	13
475	4	9	0	0	0	0	0	0	4	9
500	1	2	0	0	0	0	0	0	1	2
525	2	4	0	0	0	0	0	0	2	4
550	0	0	0	0	0	0	0	0	0	0
575	1	2	0	0	0	0	0	0	1	2
600	2	4	0	0	0	0	0	0	2	4
625	0	0	0	0	0	0	0	0	0	0
650	0	0	0	0	0	0	0	0	0	0
675	0	0	0	0	0	0	0	0	0	0
700	0	0	0	0	0	0	0	0	0	0
725	0	0	0	0	0	0	0	0	0	0
750	0	0	0	0	0	0	0	0	0	0
775	0	0	0	0	0	0	0	0	0	0
800	0	0	0	0	0	0	0	0	0	0
825	0	0	0	0	0	0	0	0	0	0
850	0	0	0	0	0	0	0	0	0	0
875	0	0	0	0	0	0	0	0	0	0
900	0	0	0	0	0	0	0	0	0	0
Total	45		1		0		0		46	

[1] Upper limit of length category.
[2] Sample size.

Appendix Table 13. Relative Stock Density of lake trout sampled from Fielding and Paxson Lakes (after Gabelhouse 1984).

Lake		Length Group[1]				
		Stock (260 mm)	Quality (495 mm)	Preferred (595 mm)	Memorable (779 mm)	Trophy (975 mm)
Fielding	n	249	34	14	2	0
	%	83	11	5	1	0
	SE(%)	2	2	1	--	--
Paxson	n	813	708	174	13	0
	%	48	41	10	1	0
	SE(%)	1	1	1	0.2	--

[1] Lower limit of length category in parenthesis.

Appendix Table 14. Water temperatures recorded at depths from three sites in Upper Tangle Lake on 6 August 1988.

DEPTH	Water Temperature[1]		
m (ft)	Site A[2]	Site B[3]	Site C[4]
0.0 (0)	12.8	13.9	12.2
1.5 (5)	12.8	11.7	12.2
3.0 (10)	12.8	11.1	12.2
4.6 (15)	11.7	11.1	12.2
6.1 (20)	10.6	11.1	12.2
7.6 (25)	8.9	10.6	12.2
9.1 (30)	5.6	10.6	12.2
10.7 (35)	4.4	10.6	12.2
12.2 (40)	3.9	10.0	12.2
13.7 (45)	3.6	10.0	12.2
15.2 (50)	3.3		12.2
16.8 (55)	3.3		
18.3 (60)	3.3		

1 Degrees Centigrade.
2 Southern bay over 30 meters of water.
3 Northern part of lake near mouth of Rock Creek.
4 Northern most bay near outlet.