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ABSTRACT

Mark-recapture and catch sampling experiments were conducted to estimate the abundance, survival rates and recruitment to lake trout *Salvelinus namaycush* populations in Paxson Lake in the Copper River drainage, and Lake Louise and Susitna Lake in the Susitna River drainage. Maximum sustainable yields and carrying capacities of populations in Paxson Lake, Lake Louise and Susitna Lake were estimated with thermal habitat volume (THV) measurements: the average volume of water between 8° and 12°C. The mark-recapture experiment conducted at Paxson Lake in 1993 generated an estimate of abundance for 1992 of 2,190 (SE = 164) mature male lake trout on the sampled spawning beds, a decrease from 1991 levels. An estimated 1,392 (SE = 97) mature males were present on the sampled spawning beds of Lake Louise in 1992. The estimate of mature lake trout in Paxson Lake for 1992 was 19,388 (SE = 8,175), an increase over 1991 levels. During spring sampling, lake trout which spawned in Susitna Lake were found to mix completely with fish which spawned in Lake Louise. Therefore, a combined estimate of the abundance of mature lake trout in both lakes was 15,804 (SE = 6,140), an increase from 1991. Strong year classes are present in harvest samples from Paxson Lake from spawning which occurred in 1981 and 1986. Lake trout in harvest samples from Lake Louise and Susitna Lake were older and larger than lake trout harvested from Paxson Lake. The maximum sustainable yield of lake trout from Paxson Lake was 0.91 kg $ha^{-1}$ $y^{-1}$, 0.86 kg $ha^{-1}$ $y^{-1}$ from Lake Louise and 0.73 kg $ha^{-1}$ $y^{-1}$ for Susitna Lake. Current harvests from Paxson Lake continue to exceed sustainable levels while harvests from Lake Louise and Susitna Lake are below sustainable yields.

KEY WORDS: Lake trout, *Salvelinus namaycush*, population abundance, age, thermal habitat volume, yield, harvest, homing behavior.

## INTRODUCTION

Lake trout *Salvelinus namaycush* are a popular target of sport anglers in Alaska. Sought in many lakes and some streams, the number of lake trout harvested annually from Alaska has averaged about 17,000 fish since 1977 (Mills 1991) (Figure 1a). Over 40% of the annual harvest has been taken from the lakes and streams which drain into the upper Copper and upper Susitna rivers, which includes 17% from the Gulkana drainage and 16% from the Tyone drainage (Mills 1979-1992) (Figure 1b). Since 1984, harvest statistics have been available for the state's two largest lake trout sport fisheries: Paxson Lake, through which the Gulkana River flows on its way to the upper Copper River, and Lake Louise, a major source of the Tyone River, a tributary to the Susitna River (Figure 2). Together, these two lakes have produced an average of 20% of the annual statewide harvest. The annual harvest from both lakes has been relatively stable since 1984. The average annual harvest from Paxson Lake is estimated at 1,374 fish. The average harvest estimate from Lake Louise since 1984 is 1,711 lake trout. Other major sport fisheries for lake trout in the area occur at Summit Lake (near Paxson Lake), Crosswind Lake (also in the Gulkana drainage) and Susitna Lake (downstream of Lake Louise) (Figure 2). These lakes contribute between 2% and 4% of the statewide harvest of lake trout.

Lake trout are a slow growing, long-lived species. Lake trout as old as 25 years are common and fish older than 50 years have been recorded in Alaska (Burr 1987). Age at complete maturity ranges from 7 to 20 years in Alaska; maturity is later in more northerly latitudes (Burr 1987). Generally, female lake trout do not spawn every year (Healy 1978). Sustainable yields are suggested to be less than 0.5 kg per surface hectare per year (Healy 1978). As a result of their life history characteristics and their allure to anglers, the species is vulnerable to overharvest.

A study by the Alaska Department of Fish and Game (ADF&G) of the structure, abundance and sustainable yield of the lake trout populations in 11 interior lakes commenced in 1986. In 1987, bag limits for lake trout were reduced in the Tanana River drainage, upper Copper and upper Susitna river drainages upon determination that the harvest exceeded the maximum sustained yield by as much as seven times in some of the study lakes. A minimum harvestable size of lake trout was also established in 1987 to allow female lake trout to spawn once, on average, before they were subject to harvest. During 1994, the Board of Fisheries voted to increase the minimum size limit to 24 inches in the Tyone River drainage and in Paxson, Summit and Crosswind lakes because harvests exceeded sustainable levels in Paxson and Summit lakes and minimum size limits were not protecting spawners. The daily bag and possession limit was reduced from two to one lake trout in the Tyone River drainage.

The goals of our study of lake trout in Paxson Lake and Lake Louise, along with its neighbor Susitna Lake, are to: (1) verify that yields from these stocks conform to historical relationships developed for populations elsewhere and (2) monitor stocks as part of regulating fisheries to sustain these yields. The specific objectives in 1993 were to:

1. estimate the abundance of mature lake trout in Paxson Lake, Lake Louise and Susitna Lake;

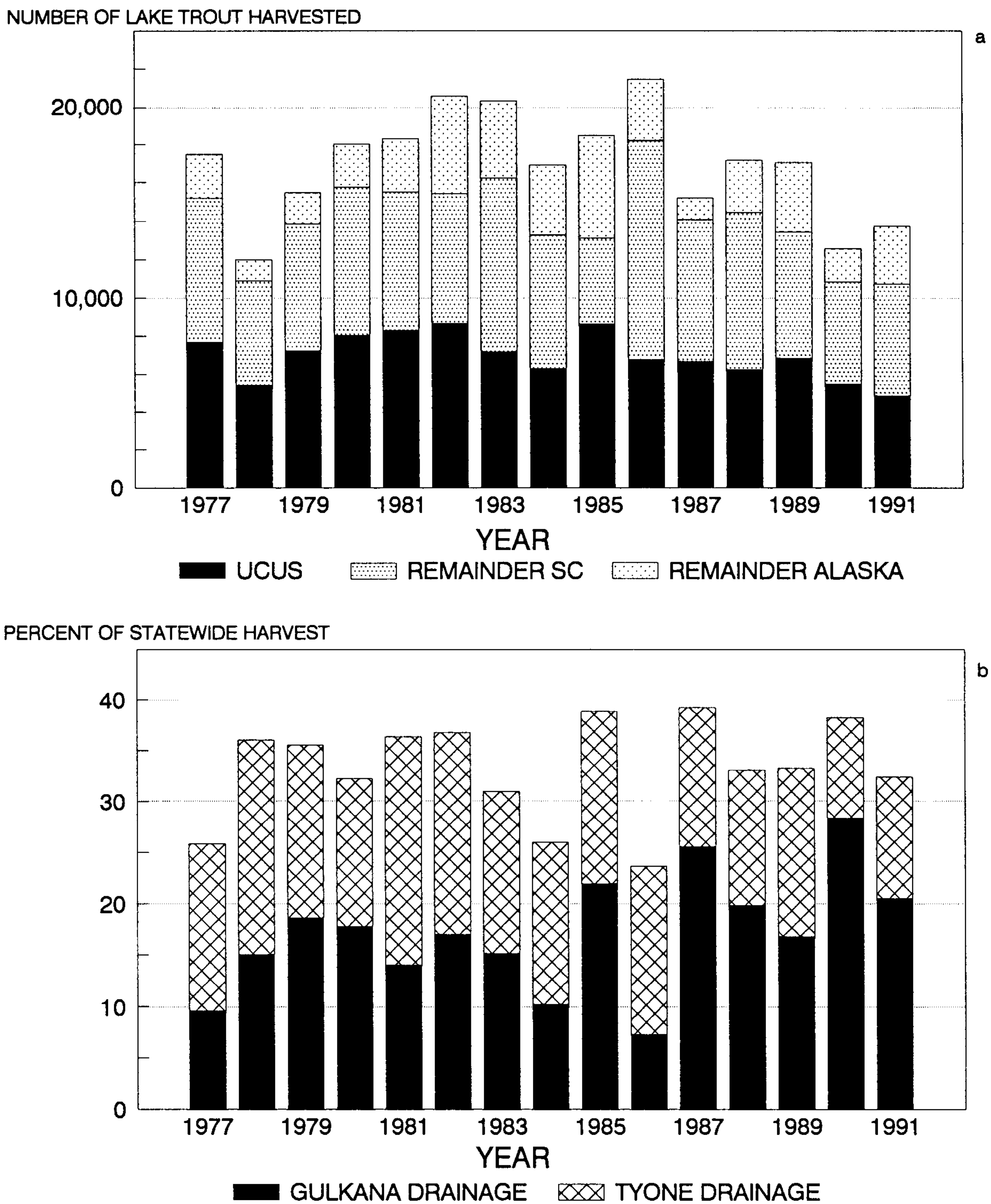


Figure 1. Estimated lake trout harvests in Alaska 1977-1991 with (a) contribution upper Copper and upper Susitna river drainages (UCUS) and Southcentral (SC) harvests, and (b) contribution of Gulkana and Tyone harvests to the statewide harvest (Mills 1979-1992).

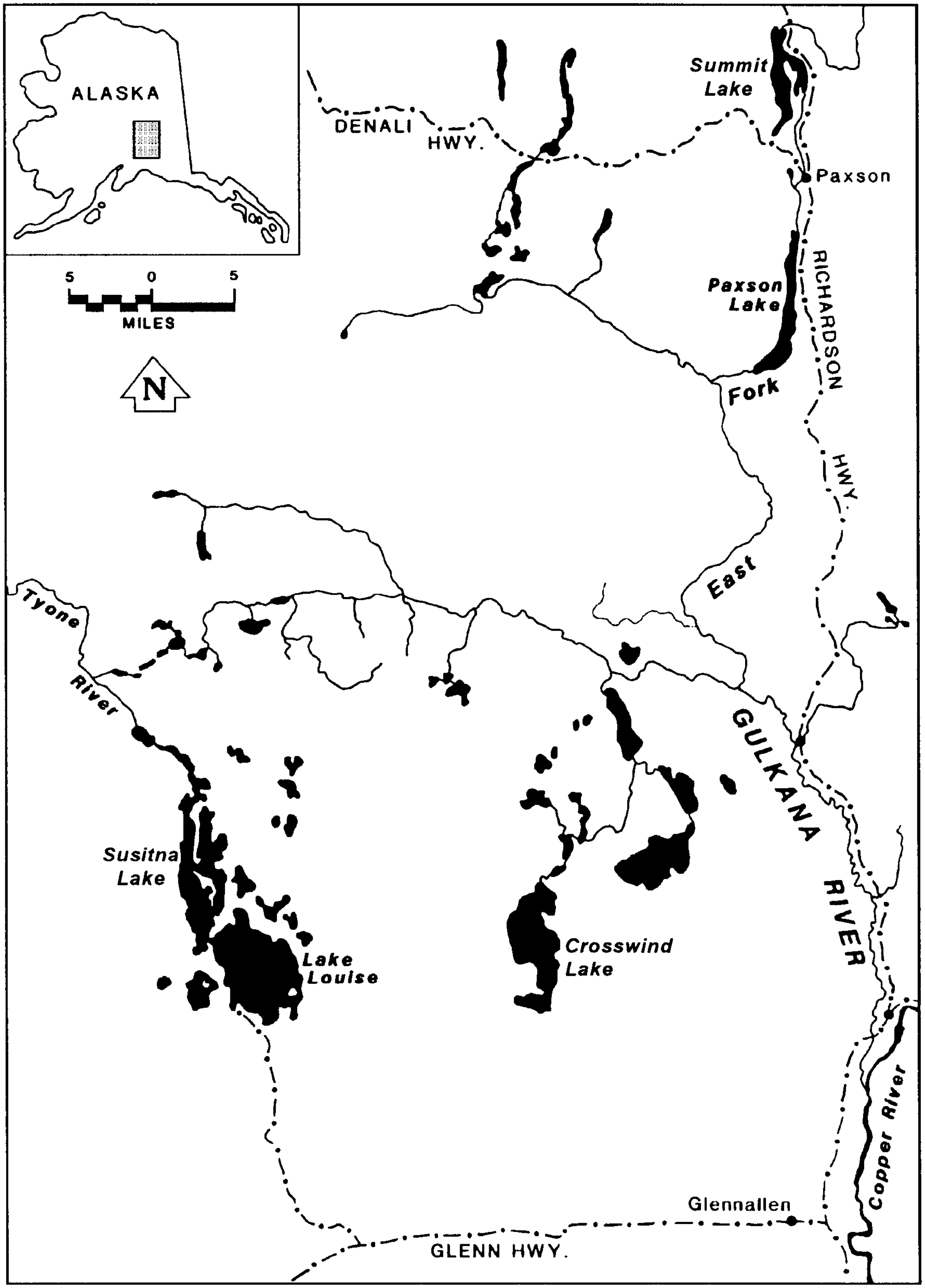


Figure 2. Major sport fisheries for lake trout in the upper Copper and upper Susitna river drainages.

2. estimate the abundance of mature male lake trout in Paxson Lake, Lake Louise and Susitna Lake;

3. estimate the sex composition of lake trout in the populations at Paxson Lake, Lake Louise and Susitna Lake;

4. estimate the length composition of the lake trout populations spawning in Paxson Lake, Lake Louise and Susitna Lake;

5. estimate the mean lengths and mean weights of lake trout from the sport harvests at Paxson Lake, Lake Louise and Susitna Lake;

6. estimate the thermal habitat volume of Paxson Lake, Lake Louise and Susitna Lake; and

7. estimate age at maturity ($AM_{50}$) and length at maturity ($LM_{50}$) for lake trout of both sexes harvested from Lake Louise and Susitna Lake.

## METHODS

### Site Descriptions

Characteristics of Paxson Lake, Lake Louise and Susitna Lake (Figure 2) are:

**Lake Louise** (61°53' N, 145°40' W) and **Susitna Lake** (62°25' N, 146°38' W) are part of a complex of lakes in the Tyone River drainage which ultimately flow into the upper Susitna River. Lake Louise is 6,519 ha with a maximum depth of 51 m and an elevation of 720 m. It is accessible from the Glenn Highway via a 32 km gravel road. A state maintained campground with a boat launch, four lodges and numerous cabins are located along the lake shore. Susitna Lake is 3,816 ha with a maximum depth of 37 m and an elevation of 720 m; a narrow channel connects Lake Louise and Susitna Lake.

**Paxson Lake** (62°50' N, 145°35' W) is located along the Gulkana River, and is part of the Copper River watershed. It lies beside the Richardson Highway, 8 km south of the community of Paxson. Paxson Lake is 1,575 ha with a maximum depth of 29 m and an elevation of 625 m. Numerous cabins are located along its shore. A campground and two boat launches are located on the lake.

### Abundance Estimates

Abundance of mature lake trout in Paxson Lake and Lake Louise was estimated with a combination of two mark-recapture experiments and a catch sampling program on each fishery. Spawning male lake trout were captured with beach seines in the fall and were marked with individually identifiable tags. Only males were included in this experiment because males generally spawn every year; females do not (Burr 1991). Numbers of male lake trout marked and recaptured each year on each lake were used to estimate abundance, survival rates, surviving recruitment and number of tagged male lake trout in the spawning population with the program RECAP by Buckland (1980, 1982). RECAP is based on the Jolly-Seber model (Seber 1982). Four hundred bootstrapped samples were drawn from the original capture histories to produce variances for the estimates according to the procedures described in Efron (1982) and in Buckland and Garthwaite (1991).

The second mark-recapture experiment was used to expand the estimated number of males from the spawning population that was sampled to the number of mature males in the entire lake. Lake trout are faithful to their spawning beds, returning each year to the same area to spawn (Szarzi 1992, 1993, this report). However, not all spawning beds can be sampled with benign sampling gear such as beach seines. Those fish sampled in the first experiment represent male lake trout that spawn in accessible locations and are, therefore, only a subset of all male lake trout. The abundance of all spawning males in the lake in year i ($N_{mi}$) was estimated as:

$$\hat{N}_{mi} = \frac{\hat{M}_i + t_i}{\hat{q}_{(i+1)}}, \qquad (1)$$

where:

$M_i$ = number of marked, male lake trout just prior to sampling during the fall in year i,

$t_i$ = number of newly marked, male lake trout added to the population during the fall sampling in year i, and

$q_{(i+1)}$ = fraction of 7-year old and older male lake trout with marks in the population during the spring of year i+1.

By spring, all marked male lake trout should have mixed completely with unmarked males and be subject to sampling through inspection of creels. Because males in Paxson Lake are fully mature at age 6 years in the fall (Burr 1993), the estimate of the marked fraction of males (q) in the catch sampling program in the spring was restricted to age 7 and older fish to remove bias in the estimate of abundance from growth recruitment. An estimate of the age at maturity could not be determined for Lake Louise so age-at-maturity of males was assumed to be 6 also. The variance of the estimate of abundance of males in year i was approximated according to the delta method:

$$\hat{V}[N_{mi}] \approx \left[\frac{\hat{M}_i}{q_{(i+1)}}\right]^2 \left[\frac{\hat{V}[M_i]}{\hat{M}_i^2} + \frac{\hat{V}[q_{(i+1)}]}{\hat{q}_{(i+1)}^2}\right]. \qquad (2)$$

$\hat{V}[M_i]$ came from the first mark-recapture experiment while

$\hat{V}[q_{(i+1)}]$ was estimated from the catch sampling program as follows:

$$\hat{q} = \frac{n_{mx}}{n_x} \quad ; \quad \hat{V}[q] = \frac{\hat{q}\,(1 - \hat{q})}{n_x - 1}, \qquad (3)$$

where:

$n_x$ = the number of male lake trout sampled from the creel in the spring that are mature (age 7+), and

$n_{mx}$ = the number in that sample with marks.

The catch sampling program occurred each spring and was used to expand estimates of abundance of males (as described above) to estimates of abundance of lake trout of both sexes. The abundance of all spawning lake trout in year i ($N_i$) was estimated as:

$$\hat{N}_i = \frac{\hat{N}_{mi}}{\hat{P}(i+1)}, \quad (4)$$

where:

$P(i+1)$ = fraction of the population of mature lake trout comprised of males in the spring of year i+1.

The variance of the estimate of abundance in year i of both sexes was approximated according to the delta method:

$$\hat{V}[N_i] \approx \left[\frac{\hat{N}_{mi}}{P(i+1)}\right]^2 \left[\frac{\hat{V}[N_{mi}]}{\hat{N}_{mi}^2} + \frac{\hat{V}[P(i+1)]}{\hat{P}(i+1)^2}\right]. \quad (5)$$

$\hat{V}[p_{(i+1)}]$ was estimated from the catch sampling program as follows:

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

where:

n = the number of mature lake trout in the catch sample.

Sampling events in the first experiment have been conducted each fall in Paxson Lake from 1987 through 1993. Sampling in Lake Louise began in fall 1991 and in Susitna Lake in fall 1992. Abundance estimates for Susitna Lake will be generated following sampling in the fall of 1994.

Sampling during the fall occurred at previously identified spawning beds in Lake Louise and Paxson Lake (Szarzi 1992, 1993). Spawning beds were numbered consecutively and sampled throughout each night between sundown and 0600 hours, when weather permitted (Table 1). A beach seine, 60 m X 3 m X 38 mm (200 ft X 10 ft X 1 in), was used to capture lake trout in Lake Louise.

Table 1. Sampling dates at Paxson Lake, Lake Louise, and Susitna Lake, 1993.

| | Paxson Lake | Lake Louise | Susitna Lake |
|---|---|---|---|
| Mark-recapture Experiment | 7-10 Sep | 2-3 Sep | 2-3 Sep |
| | 13-17 Sep | 7-10 Sep | 7-10 Sep |
| | 21-22 Sep | 13-17 Sep | 13-14 Sep |
| | | 20-22 Sep | 16-17 Sep |
| Catch Sampling | 5-7 Jun | 29-31 May | 7 Jun |
| | 9-15 Jun | 2 Jun | 11-13 Jun |
| | 17-21 Jun | 5-6 Jun | 20 Jun |
| | 24 Jun | 10-14 Jun | 26 Jun |
| | 26-27 Jun | 17-18 Jun | 1 Jul |
| | 30 Jun | 20-21 Jun | 4-5 Jul |
| | 2-5 Jul | 24 Jun | |
| | 7 Jul | 26-28 Jun | |
| | 13 Jul | 1-5 Jul | |
| | | 10 Jul | |
| | | 12 Jul | |
| | | 15 Jul | |
| | | 20-21 Jul | |
| | | 31 Jul | |
| Thermal Sampling | 11 Jun | 10 Jun | 26 Jun |
| | 29 Jun | 26 Jun | 8 Jul |
| | 13 Jul | 8 Jul | 15 Jul |
| | 23 Jul | 15 Jul | 27 Jul |
| | 30 Jul | 27 Jul | 10 Aug |
| | 6 Aug | 10 Aug | 17 Aug |
| | 20 Aug | 17 Aug | 27 Aug |
| | 25 Aug | 27 Aug | |

Fish were captured from Susitna Lake and Paxson Lake with a seine 46 m X 3 m X 9.5 mm (150 ft X 10 ft X 3/8 in). Sampling began at the bed identified by a random number and proceeded in a systematic fashion around the lake. If fish were not found at the chosen spawning location, the next spawning bed was sampled. The fish captured at each bed were sexed, measured for length from snout to the fork of the tail and marked with individually numbered Floy tags. Tags were inserted in the left side of the fish at the base of the dorsal fin. To estimate tag loss, the adipose fin was removed. The spawning bed where each fish was captured was recorded to allow the movement of fish to be traced between spawning locations inseason and between seasons. Recaptured fish were noted, sexed and measured.

During the spring fishery in 1993, harvested lake trout were sampled from Paxson Lake, Lake Louise and Susitna Lake (Table 1). Successful anglers were contacted during two randomly selected 3.5-hour periods, 5 to 7 days per week. Collection boxes were placed at access points to each lake to obtain lake trout heads, lengths and sex information. Collection boxes were equipped with tape measures and report forms. All whole fish were weighed to the nearest 50 grams with a hand-held scale, all gutted and whole fish were measured to the nearest millimeter fork length and sagittal otoliths were collected from all fish. Ages of fish were estimated later as counts of concentric opaque zones (annuli) on whole otoliths under magnification as described in Sharp and Bernard (1988).

### Length at Maturity and Age of Maturity

Gonads were collected from lake trout caught in the spring fishery at Lake Louise and Susitna Lake, examined and compared to the criteria in Burr (1993) and Martin and Olver (1980) to determine maturity. Sample sizes are as yet too small to estimate the parameters for either lake with acceptable precision.

### Yield Estimates

Maximum sustainable yields (MSY) in kg/ha/yr of lake trout were estimated for each population in our study from an empirical relationship between estimated harvests and thermal habitat volume (THV) from lakes in Ontario, Canada (Payne et al. 1990):

$$\log_{10}MSY = 2.15 + 0.714 \log_{10}THV \quad (7)$$

$$THV = \frac{(D_2 - D_1)(A_1 + A_2 + [A_1 \cdot A_2]^{1/2})}{300} \quad (8)$$

where:

$D_1$ = the average depth at which water temperature in a lake is 12°C during the summer,

$D_2$ = the average depth at which water temperature is 8°C,

$A_1$ = the cross-sectional area of the lake at depth $D_1$, and

$A_2$ = the cross-sectional area of the lake at $D_2$.

Water temperatures should be measured after each lake has reached stable thermal stratification in the summer. To determine when this occurred, water temperatures were measured at 2.5 m depth intervals to the bottom of Paxson Lake, Lake Louise, and Susitna Lake during June, July and August 1993 (Table 1). A monthly temperature profile was estimated for each lake by averaging the readings at each depth interval during the month. The cross-sectional area of each lake at the depth where 12°C and 8°C temperatures were encountered was measured on a bathymetric map using a planimeter. The THV of each lake was estimated using Equation 8.

Estimates of MSY were transformed into estimates of carrying capacity (K) for Lake Louise, Susitna and Paxson lakes according to the concept of logistic surplus production and the empirical relationship between instantaneous rates of natural mortality (M) and the intrinsic rate of increase (r) (Gulland 1983):

$$K = \frac{(4)MSY}{r} \quad ; \quad r = 2.0\ M. \tag{9}$$

From Healy (1978), the instantaneous rate of natural mortality averaged over 14 populations is 0.30. Considering estimates of the instantaneous rate of total mortality (Z) estimated in our mark-recapture experiment at Paxson Lake (0.39, 0.16, 0.29, 0.11, 0.27), the estimate of M = 0.30 is too high. The annual instantaneous natural mortality rate for lake trout captured in sport fisheries in Great Slave and Great Bear Lakes was estimated at 0.09 (Yaremchuk 1986). Using the method of Pauly (1980) produced an estimate of 0.10 for lake trout in Paxson Lake. Pauly's method uses coefficients from the von Bertalanffy (LVB) growth model at temperature. Natural mortality was estimated using the method of Pauly (1980) with coefficients from the von Bertalanffy growth model at water temperature; the temperature coefficient came from Payne et al. (1990). The estimate of M (0.26) from the mark-recapture experiment at Lake Louise was comparable to the values reported by Healy (1978), therefore this estimate was used to calculate (K) for Lake Louise and Susitna Lake.

The actual yield (Y) in kg/ha/yr from populations in Paxson Lake, Lake Louise, and Susitna Lake in their sport fisheries was estimated from data collected during catch sampling programs in the spring and estimates of annual harvest (H) from the Statewide Harvest Survey:

$$Y = H\bar{w} \tag{10}$$

where:

$w$ = mean weight of lake trout sampled in each catch sampling program.

Since most harvest occurs when the catch sampling occurs, growth of lake trout after completion of sampling should not significantly bias estimates of mean weights. Since statistics from the Statewide Harvest Survey are not available until more than a year after the catch sampling programs, estimated yields for 1992 are presented in this report; estimated yields for 1993 will be presented in next year's report.

# RESULTS

## Abundance Estimates

Estimated abundance of mature male lake trout spawning on the sampled grounds in Paxson Lake during the fall, 1992, is 2,190 (SE = 164); estimated abundance of all mature males spawning during the fall throughout Paxson Lake in 1992 is 9,694 (SE = 4,087); and estimated abundance of all mature lake trout in the fall, 1992, is 19,388 (SE = 8,175) (Table 2). Seven hundred thirty-three male lake trout were captured during fall sampling in 1993 of which 47% (348) had been marked in previous years (Table 3). An estimated 901 (SE = 76) male lake trout were extant with marks just prior to sampling during the fall, 1992 and 1,310 (SE = 75) just after (Table 2) (409 newly marked males were released during sampling in 1992). During catch sampling in the spring, 1993, 102 lake trout were sampled of which 86 were $\geq$ 7 years. Of these 86 fish, 37 were males of which five were marked, making q = 0.14 and SE[q] = 0.06. Since the proportion of male lake trout $\geq$ 7 years in the catch sample (0.45) is not significantly different than 0.50 ($\chi^2$ = 3.44, $\alpha$ = 0.05, df = 1), estimated abundance of all lake trout 7 years of age or older is double that estimated for males alone (p was set to 0.5 and V[p] was set to 0).

Recovery of tagged fish harvested from Lake Louise in 1993 was consistent with fish released into Susitna Lake in 1992 having dispersed uniformly across both lakes during the intervening winter. Of the 17 lake trout recovered in samples of the harvest from Lake Louise, five were tagged on the spawning beds in Susitna Lake and three of these had been tagged in the fall of 1992. The estimated probability of recovering a male released in Lake Louise (0.01 = 5/589) from the fishery at that lake, and that of recovering a male released in Susitna Lake in the fishery at Lake Louise (0.01 = 4/337) were similar ($\chi^2$ = 0.25, df = 1, 0.75 > P > 0.05). Although this is not a rigorous test to detect the complete mixing of the populations required to produce unbiased estimates of abundance, the estimated probabilities of recovery are consistent with the mixing necessary to treat lake trout in both lakes as a single population. Therefore, the number of mature lake trout estimated with Equations 1, 3 and 4 was a combined estimate for the two lakes.

An estimated 1,392 (SE = 97) male lake trout spawned on the sampled spawning beds of Lake Louise during fall, 1992 (Table 4). The estimate of mature male lake trout in Lake Louise and Susitna Lake combined was 7,902 males (SE = 3,070) with 15,804 (SE = 6,140) mature lake trout of both sexes present in the two lakes just prior to sampling in 1992. Of 838 lake trout captured from Lake Louise during fall sampling in 1993, 335 had been marked previously (Table 5). An estimated 451 (SE = 29) male lake trout were extant with marks just prior to sampling during the fall, 1992 and 878 (SE = 29) just after (427 newly marked males were released during sampling in 1992). During catch sampling in the spring, 1993, all 116 lake trout that could be aged were $\geq$ 7 years. Of these 54 were males; six bore tags from Lake Louise making q = 0.11 and SE[q] = 0.04. Since the proportion of male lake trout $\geq$ 7 years in the catch sample (0.49) is not significantly different than 0.50 ($\chi^2$ = 0.07, $\alpha$ = 0.05, df = 1), estimated abundance of all lake trout 7 years of age or older was set at twice that estimated for males (p was set to 0.05 and V[p] to 0).

Table 2. Statistics used to estimate abundance of mature lake trout in Paxson Lake, 1987-1993.[a]

| Year | Sampled Population | Number w/ Marks (M) | Fraction Marked (q) | Abundance Males ($N_m$) | Fraction Males (p) | Abundance (N) |
|---|---|---|---|---|---|---|
| 1987 | ----- | 142 | ----- | ----- | ----- | ----- |
| 1988 | 2,947<br>(429)<br>(2,106;3,787) | 781<br>(28) | ----- | 4,595 | 0.5[b] | 9,191 |
| 1989 | 2,594<br>(148)<br>(2,303;2,885) | 1,005<br>(34) | ----- | 4,045 | 0.5[b] | 8,091 |
| 1990 | 2,001<br>(96)<br>(1,812;2,190) | 1,348<br>(9) | 0.40<br>(0.07) | 3,341<br>(543) | 0.5[b] | 6,682<br>(1,086) |
| 1991 | 2,694<br>(160)<br>(2,382;3,007) | 1,174<br>(46) | 0.30<br>(0.08) | 3,941<br>(892) | 0.5 | 7,883<br>(1,784) |
| 1992 | 2,190<br>(164)<br>(1,869;2,510) | 1,310<br>(75) | 0.14<br>(0.06) | 9,694<br>(4,087) | 0.5 | 19,388<br>(8,175) |
| 1993 | ----- | >739 | ----- | ----- | ----- | ----- |

[a] Standard errors and 95% confidence intervals are provided (in parentheses) where appropriate. Abundance is germane to just after spawning in the fall of the listed year. Fractions were estimated in the spring of the year following 1990, 1991, and 1992; fractions prior to 1990 are assumptions based on later sampling.

[b] Assumed value based on 1:1 sex ratio.

Table 3. Numbers of mature male lake trout captured, marked and recaptured in Paxson Lake at sampled spawning grounds, 1987-1993.

| | Year of Recapture | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 |
| Year of release: | | | | | | | |
| 1987 | 0 | 40 | 38 | 8 | 8 | 3 | 2 |
| 1988 | | 0 | 217 | 122 | 83 | 26 | 22 |
| 1989 | | | 0 | 215 | 123 | 55 | 35 |
| 1990 | | | | 0 | 203 | 93 | 54 |
| 1991 | | | | | 0 | 108 | 51 |
| 1992 | | | | | | 0 | 184 |
| 1993 | | | | | | | 0 |
| Captured with tags | 0 | 40 | 255 | 345 | 417 | 285 | 348 |
| Captured without tags | 248 | 807 | 594 | 343 | 541 | 409 | 385 |
| Total captured | 248 | 847 | 849 | 688 | 958 | 694 | 733 |
| Released with tags | 211 | 817 | 823 | 648 | 417 | 694 | 733 |
| Released without tags | 0 | 0 | 0 | 0 | 541 | 0 | 0 |
| Total released | 211 | 817 | 823 | 648 | 958 | 694 | 733 |

Table 4. Statistics used to estimate abundance of mature lake trout in Lake Louise and Susitna Lake, 1991 and 1992.[a]

| Year | Sampled Population | Number w/ Marks (M) | Fraction Marked (q) | Abundance Males ($N_m$) | Fraction Males (p) | Abundance (N) |
|---|---|---|---|---|---|---|
| 1991 | ----- | 668 | 0.14<br>(0.04) | 4,797<br>(1,351) | 0.5 | 9,595<br>(2,701) |
| 1992 | 1,392<br>(97)<br>(1,208;1,607) | 878<br>(29) | 0.11<br>(0.04) | 7,902<br>(3,070) | 0.5 | 15,804<br>(6,140) |

[a] Standard errors and 95% confidence intervals are provided (in parentheses) where appropriate. Abundance is germane to just after spawning in the fall of the listed year. The fraction of marked fish was estimated in the spring of the year following 1991 and 1992.

Table 5. Numbers of mature male lake trout captured, marked and recaptured in Lake Louise at sampled spawning grounds, 1991-1993.

| | | Year of Recapture | | |
|---|---|---|---|---|
| | | 1991 | 1992 | 1993 |
| Year of release: | | | | |
| | 1991 | 0 | 205 | 94 |
| | 1992 | | 0 | 241 |
| | 1993 | | | 0 |
| Captured with tags | | 0 | 205 | 335 |
| Captured without tags | | 698 | 427 | 503 |
| Total captured | | 698 | 632 | 838 |
| Released with tags | | 698 | 632 | 838 |
| Released without tags | | 0 | 0 | 0 |
| Total released | | 698 | 632 | 838 |

In Susitna Lake in 1993, 79 lake trout that had been tagged in 1992 were captured, and 292 lake trout were released with tags (Table 6). Locations of lake trout recaptured over spawning beds in Susitna Lake indicate that lake trout home to the same spawning beds to reproduce. Capture histories of lake trout from Susitna Lake were segregated according to two clusters of smaller spawning grounds (Figure 3). Eighty-nine of 91 males (97.8%) and five of five females (100%) were recaptured in the same cluster in 1993 as captured in 1992 (Table 7). The proportions of lake trout recaptured in 1993 were different across both clusters of spawning grounds for males ($\chi^2$ = 10.61, df = 1, $P < 0.005$) but were the same for females ($\chi^2$ = 0.66, df = 1, $0.25 < P < 0.5$) (Table 8). The difference in male proportions between the northern and southern clusters may result from the discovery of a spawning bed after spawning was nearly completed in 1992 that was sampled throughout the spawning season in 1993. Lake trout were found to home to spawning beds in Lake Louise and Paxson Lake from sampling conducted during 1990 and 1991, and 1991 and 1992, respectively (Szarzi 1992 and 1993). The analysis was not repeated for the 1992 and 1993 capture histories.

Survival and Recruitment

Estimates of annual survival rates of lake trout in Paxson Lake range from 0.68 to 0.90 while estimates of surviving recruitment indicate two weak and two strong year classes entering the population (Table 9). Estimates of the annual instantaneous natural mortality rate between 1988 and 1992 were biased low. Instantaneous rates were calculated with estimates of harvest from the Statewide Harvest Survey (Mills 1989-1993) (Table 9), estimates of abundance of all mature males in Paxson Lake (Table 2) and the Baranov catch equation. Since abundance estimates are germane to just prior to sampling (September) and most of the harvest occurs in the spring, harvest estimates from Mills (1988-1992) were lagged one year. Almost all fishing for lake trout at Paxson Lake occurs between March and September, therefore much of the harvest would be composed of male lake trout newly recruited to the fishery, but not yet recruited to our mark-recapture experiments. Under these conditions, instantaneous rates estimated from harvests would be biased to overly large instantaneous rates of fishing mortality. Estimates from the Statewide Harvest Survey, which are based on a calendar year, were used directly to estimate instantaneous rates once they had been halved to estimate the harvest of males.

The estimated survival rate of lake trout in Lake Louise and Susitna Lake between 1991 and 1992 was 0.65 (Table 10). The instantaneous rate of mortality was estimated at 0.44 during the same period. Fishing and natural mortality rates were estimated with the Baranov catch equation with estimates of harvest from the Statewide Harvest Survey (Mills 1992, 1993) (Table 10) and estimates of abundance of all mature males in Lake Louise (Table 4) as described above for fish in Paxson Lake.

Length and Weight Information

The fork lengths of 98 lake trout were measured from the harvest from Paxson Lake, 5 June to 13 July (Table 11 and Appendix A1). The lengths of 154 and 17 lake trout, respectively, were measured from the harvests from Lake Louise and Susitna Lake, 29 May to 31 July (Table 11 and Appendices A2 and A3). The largest fish were taken from Susitna Lake, followed by Lake Louise. Sizes

Table 6. Numbers of mature male lake trout captured, marked and recaptured in Susitna Lake at sampled spawning grounds, 1992 and 1993.

| | | Year of Recapture | |
|---|---|---|---|
| | | 1992 | 1993 |
| Year of release: | | | |
| | 1992 | 0 | 79 |
| | 1993 | | 0 |
| Captured with tags | | 0 | 79 |
| Captured without tags | | 345 | 213 |
| Total captured | | 345 | 292 |
| Released with tags | | 345 | 292 |
| Released without tags | | 0 | 0 |
| Total released | | 345 | 292 |

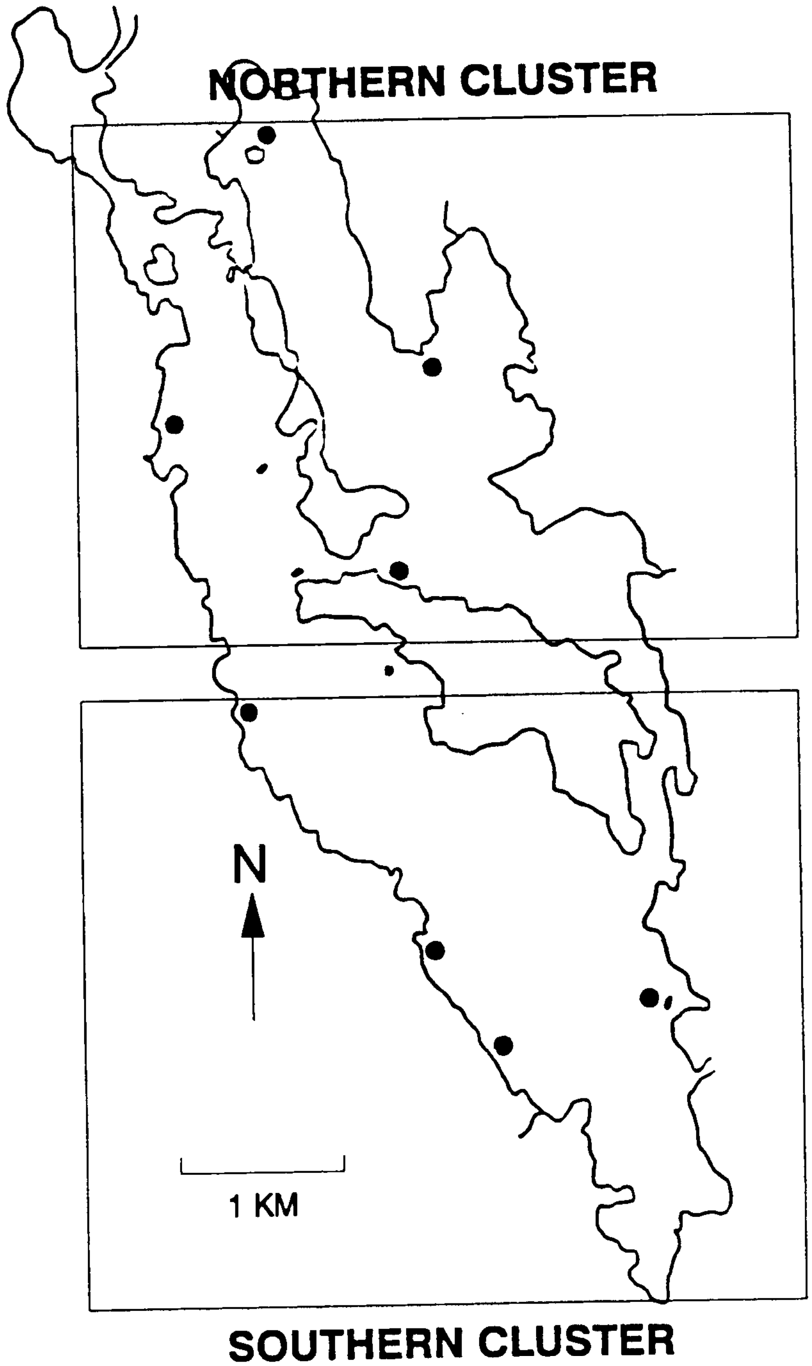


Figure 3. Location of sampled spawning areas (dots) of lake trout in Susitna Lake.

Table 7. Numbers of marked lake trout released in 1992 and recaptured in 1993 by clustered spawning grounds in Susitna Lake.[a]

| MALES: | RECAPTURED IN 1993: | |
|---|---|---|
| RELEASED 1992: | SOUTHERN CLUSTER | NORTHERN CLUSTER |
| SOUTHERN CLUSTER | 53 | 1 |
| NORTHERN CLUSTER | 1 | 36 |

| FEMALES: | RECAPTURED IN 1993: | |
|---|---|---|
| RELEASED 1992: | SOUTHERN CLUSTER | NORTHERN CLUSTER |
| SOUTHERN CLUSTER | 3 | 0 |
| NORTHERN CLUSTER | 0 | 2 |

[a] See Figure 3 for locations of clusters.

Table 8. Numbers of lake trout captured over eight spawning grounds[a] in Susitna Lake in 1993 with marked fish being those that had been released with tags in 1992 and recaptured in 1993.

| CLUSTER | MALE | | FEMALE | | MALE | FEMALE |
|---|---|---|---|---|---|---|
| | Marked | Captured | Marked | Captured | Marked/Cap. | Marked/Cap. |
| NORTHERN | 55 | 218 | 5 | 27 | 0.25 | 0.19 |
| SOUTHERN | 37 | 83 | 2 | 20 | 0.45 | 0.10 |

[a] See Figure 3 for locations of clusters.

Table 9. Estimates of annual harvest, survival rates, instantaneous rates and surviving recruitment for males in Paxson Lake, 1987-1993.[a]

| Period: Fall-Fall | Harvest | Survival Rate | Instantaneous Rates: Total | Fishing | Natural | Surviving Recruitment |
|---|---|---|---|---|---|---|
| 1987-1988 | 655 (249) | 0.68 (0.05) | 0.39 | ---- | ---- | ---- |
| 1988-1989 | 779 (221) | 0.85 (0.03) | 0.16 | 0.18 | -0.02 | 116 (481) |
| 1989-1990 | 1,070 (370) | 0.74 (0.03) | 0.29 | 0.31 | -0.01 | 89 (109) |
| 1990-1991 | 624 (106) | 0.90 (0.05) | 0.11 | 0.20 | -0.09 | 935 (109) |
| 1991-1992 | 559 (112) | 0.77 (0.06) | 0.27 | 0.16 | 0.11 | 542 (110) |
| 1992-1993 | ---- | ---- | ---- | ---- | ---- | ---- |

[a] Harvests are half those reported in the Statewide Harvest Survey for years 1988 through 1992 (Mills 1989-1993). Survival rates, surviving recruitment and total instantaneous mortality rates were estimated for males on sampled spawning grounds only in the mark-recapture experiment based on the Jolly-Seber model (Seber 1982). Other instantaneous rates were estimated with the Baranov catch equation with the presumption that estimated survival rates were indicative of survival rates for all mature male lake trout in Paxson Lake.

Table 10. Estimates of annual harvest, survival rates, instantaneous rates and surviving recruitment for males in Lake Louise and Susitna Lake, 1991-1993.[a]

| Period: Fall-Fall | Harvest | Survival Rate | Instantaneous Rates: Total | Fishing | Natural | Surviving Recruitment |
|---|---|---|---|---|---|---|
| 1991-1992 | 679 (124) | 0.65 (0.04) | 0.44 | 0.17 | 0.26 | ---- |
| 1992-1993 | ---- | ---- | ---- | ---- | ---- | ---- |

[a] Harvests are half those reported in the Statewide Harvest Survey for years 1991 through 1992 for Lake Louise and Susitna Lake combined (Mills 1992, 1993). Survival rates, surviving recruitment and total instantaneous mortality rates were estimated for males on sampled spawning grounds only in the mark-recapture experiment based on the Jolly-Seber model (Seber 1982). Instantaneous rates were estimated with the Baranov catch equation with the presumption that estimated survival rates were indicative of survival rates for all mature male lake trout in Lake Louise and Susitna Lake.

Table 11. Length, weight and age statistics of lake trout from harvest samples from Paxson Lake, Lake Louise and Susitna Lake, 1993.

| | Paxson Lake | | | Lake Louise | | | Susitna Lake | | |
|---|---|---|---|---|---|---|---|---|---|
| | Female | Male | All[a] | Female | Male | All[a] | Female | Male | All[a] |
| LENGTH (mm) | | | | | | | | | |
| mean | 551 | 519 | 533 | 596 | 573 | 587 | 711 | 657 | 679 |
| mode | 485 | 485,550 | 485 | 560 | 560 | 560 | 610 | 840 | ---- |
| sample size | 37 | 55 | 98 | 66 | 62 | 154 | 7 | 10 | 17 |
| standard deviation | 72 | 86 | 80 | 96 | 89 | 99 | 121 | 141 | 132 |
| 95% upper confidence interval | 568 | 538 | 550 | 615 | 592 | 606 | 733 | 681 | 702 |
| 95% lower confidence interval | 535 | 501 | 515 | 577 | 555 | 567 | 690 | 634 | 657 |
| maximum | 787 | 952 | 952 | 914 | 851 | 914 | 851 | 838 | 851 |
| minimum | 415 | 419 | 415 | 457 | 456 | 450 | 482 | 426 | 426 |
| WEIGHT (kg) | | | | | | | | | |
| mean | 1.66 | 1.66 | 1.68 | 1.55 | 2.03 | 2.92 | 5.00 | 4.01 | 4.21 |
| sample size | 9 | 12 | 22 | 11 | 5 | 23 | 1 | 4 | 5 |
| standard deviation | 0.53 | 0.42 | 0.46 | 0.46 | 1.28 | 2.78 | ---- | 2.13 | 1.89 |
| 95% upper confidence interval | 1.70 | 1.70 | 1.72 | 1.60 | 2.10 | 3.02 | ---- | 4.10 | 4.29 |
| 95% lower confidence interval | 1.61 | 1.62 | 1.64 | 1.51 | 1.96 | 2.82 | ---- | 3.92 | 4.12 |
| maximum | 2.30 | 2.60 | 2.60 | 2.70 | 4.20 | 11.20 | ---- | 6.20 | 6.20 |
| minimum | 0.80 | 1.20 | 0.80 | 1.00 | 0.95 | 0.95 | ---- | 1.13 | 1.13 |
| AGE (yr) | | | | | | | | | |
| mean | 11 | 9 | 10 | 12 | 11 | 11 | 12 | 13 | 13 |
| sample size | 32 | 47 | 98 | 52 | 50 | 127 | 4 | 8 | 12 |
| standard deviation | 3.9 | 4.3 | 4.1 | 4.8 | 3.0 | 3.9 | 2.4 | 3.8 | 3.3 |
| 95% upper confidence interval | 15 | 13 | 14 | 16 | 15 | 15 | 15 | 17 | 16 |
| 95% lower confidence interval | 7 | 5 | 6 | 8 | 8 | 8 | 9 | 9 | 9 |
| maximum | 21 | 25 | 25 | 30 | 19 | 30 | 14 | 18 | 18 |
| minimum | 6 | 6 | 6 | 7 | 7 | 7 | 9 | 7 | 9 |

[a] Sex was not determined for all samples. Therefore, the total sample size may be greater than that for each sex.

were generally larger than in 1992 but similar to 1991. Harvested females were larger than males in all three lakes.

The fork lengths of 918 lake trout were measured from the spawning population in Paxson Lake (Table 12 and Appendix A4). Lengths were collected from 1,115 spawning lake trout captured in Lake Louise (Table 12 and Appendix A5) and 350 spawners from Susitna Lake (Table 12 and Appendix A6). Spawning females were larger than male spawners in all three lakes. The largest spawners were sampled from Susitna Lake.

Age and Size Composition

Harvest of lake trout in 1993 was taken from a few strong year classes at Paxson Lake (Figure 4) and more uniformly from many year classes in Lake Louise (Figure 5). Estimated age composition of the harvest from Paxson Lake indicates the entry of two strong year classes into the population following a series of weaker ones. This pattern in the harvest reflects the pattern of surviving recruitment estimated with the mark-recapture experiment on the spawning grounds in that lake (Table 9). The 1981 year class (12 year olds in 1993) still contributed relatively large numbers to the harvest from Paxson Lake. On average, lake trout harvested from Lake Louise were older and larger than those harvested from Paxson Lake (Table 11).

Yield Estimates

In 1992, harvests from Lake Louise and Susitna Lake remained below the threshold of MSY as established through measurement of the THV; harvests from Paxson Lake in 1992 remained above MSY (Figure 6). Average estimates of MSY and carrying capacity are 846 and 16,867 lake trout in Paxson Lake; 2,099 and 16,146 for lake trout in Lake Louise; and 970 and 7,464 for Susitna Lake (Table 13).

The harvest from Paxson Lake in 1992 was 1,118 lake trout or 1.1 kg $ha^{-1}$ based on the average weight of 1.6 kg estimated from harvest samples from 1992 (Szarzi 1993). The 1992 harvest of lake trout from Lake Louise was 1,033 fish or 0.4 kg $ha^{-1}$, based on the average weight of 2.5 kg estimated from the 1992 harvest (Szarzi 1993). An estimated 324 lake trout were taken from Susitna Lake in 1992, a yield of approximately 0.24 kg $ha^{-1}$ using the average weight of lake trout estimated from Lake Louise (2.87 kg).

## DISCUSSION

Although the estimated abundance of mature lake trout in Paxson Lake increased in 1992, the precision of the estimate is poor due to the small number (37) of lake trout sampled for marks during the spring. The abundance of male lake trout on sampled spawning beds in Paxson Lake decreased. The variability in the estimate of mature lake trout and the conflicting trends of spawners versus mature lake trout makes assessment of population trends difficult. The population may be nearing the level where the maximum yield can be achieved. The harvest continues to exceed sustainable levels determined from Healy (1978) and from temperature data (Figure 6), however.

Table 12. Length statistics of spawning lake trout in Paxson Lake, Lake Louise and Susitna Lake, 1993.

| | Paxson Lake | | | Lake Louise | | | Susitna Lake | | |
|---|---|---|---|---|---|---|---|---|---|
| | Female | Male | All[a] | Female | Male | All[a] | Female | Male | All[a] |
| LENGTH (mm) | | | | | | | | | |
| mean | 544 | 513 | 519 | 525 | 509 | 513 | 614 | 524 | 536 |
| mode | ---- | 505 | 505 | 500 | 500 | 500 | 480 | 450 | 480 |
| sample size | 189 | 726 | 918 | 277 | 836 | 1115 | 47 | 299 | 350 |
| standard deviation | 62 | 55 | 58 | 63 | 52 | 55 | 140 | 116 | 123 |
| 95% upper confidence interval | 560 | 527 | 534 | 541 | 522 | 527 | 637 | 545 | 557 |
| 95% lower confidence interval | 529 | 498 | 504 | 510 | 495 | 498 | 590 | 503 | 514 |
| maximum | 927 | 869 | 927 | 942 | 868 | 942 | 895 | 860 | 895 |
| minimum | 447 | 396 | 396 | 432 | 404 | 404 | 435 | 380 | 380 |

[a] Sex was not determined for all samples. Therefore, the total sample size may be greater than that for each sex.

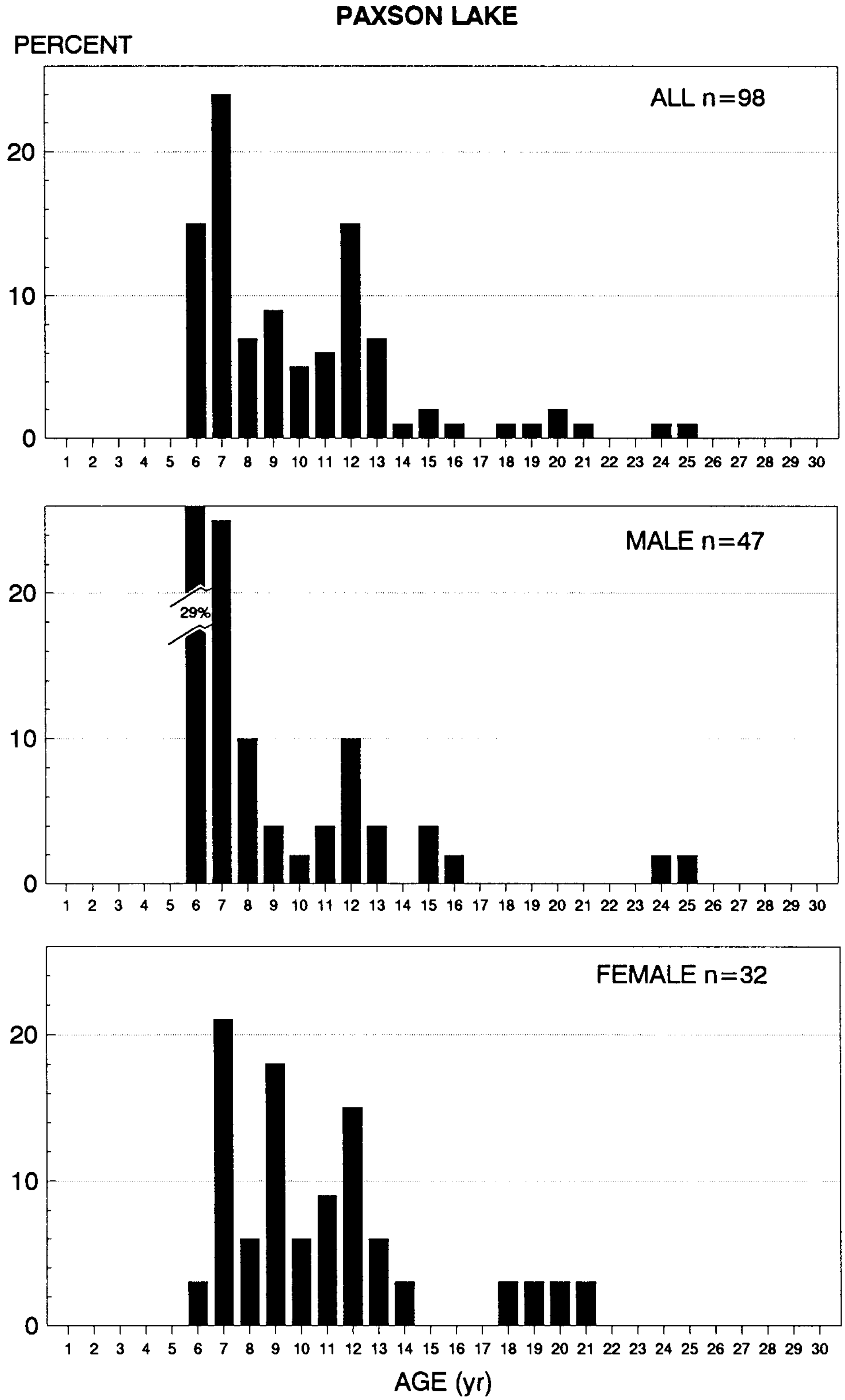


Figure 4. The proportion of the harvest sampled from Paxson Lake in age categories, 1993.

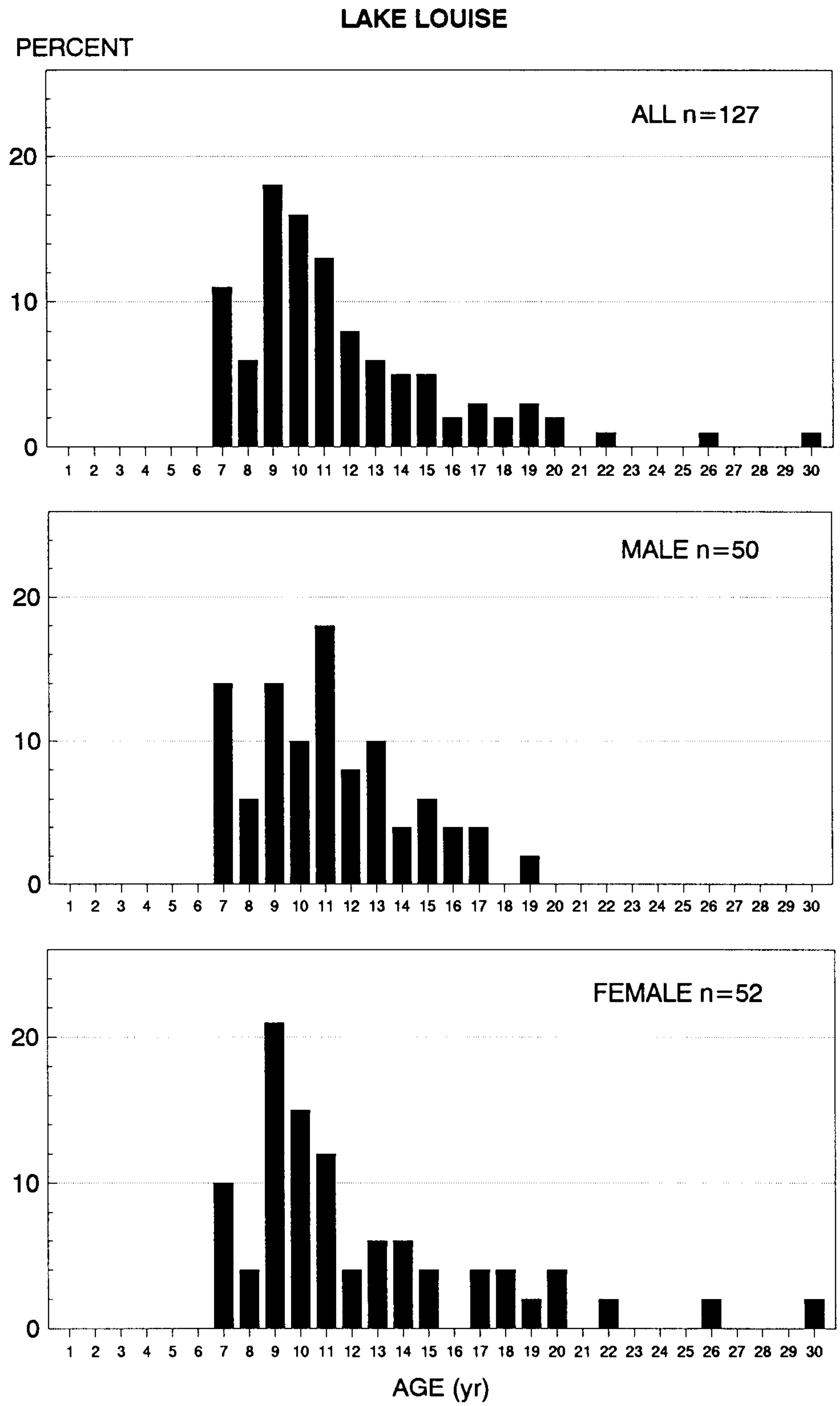


Figure 5. The proportion of the harvest sampled from Lake Louise in age categories, 1993.

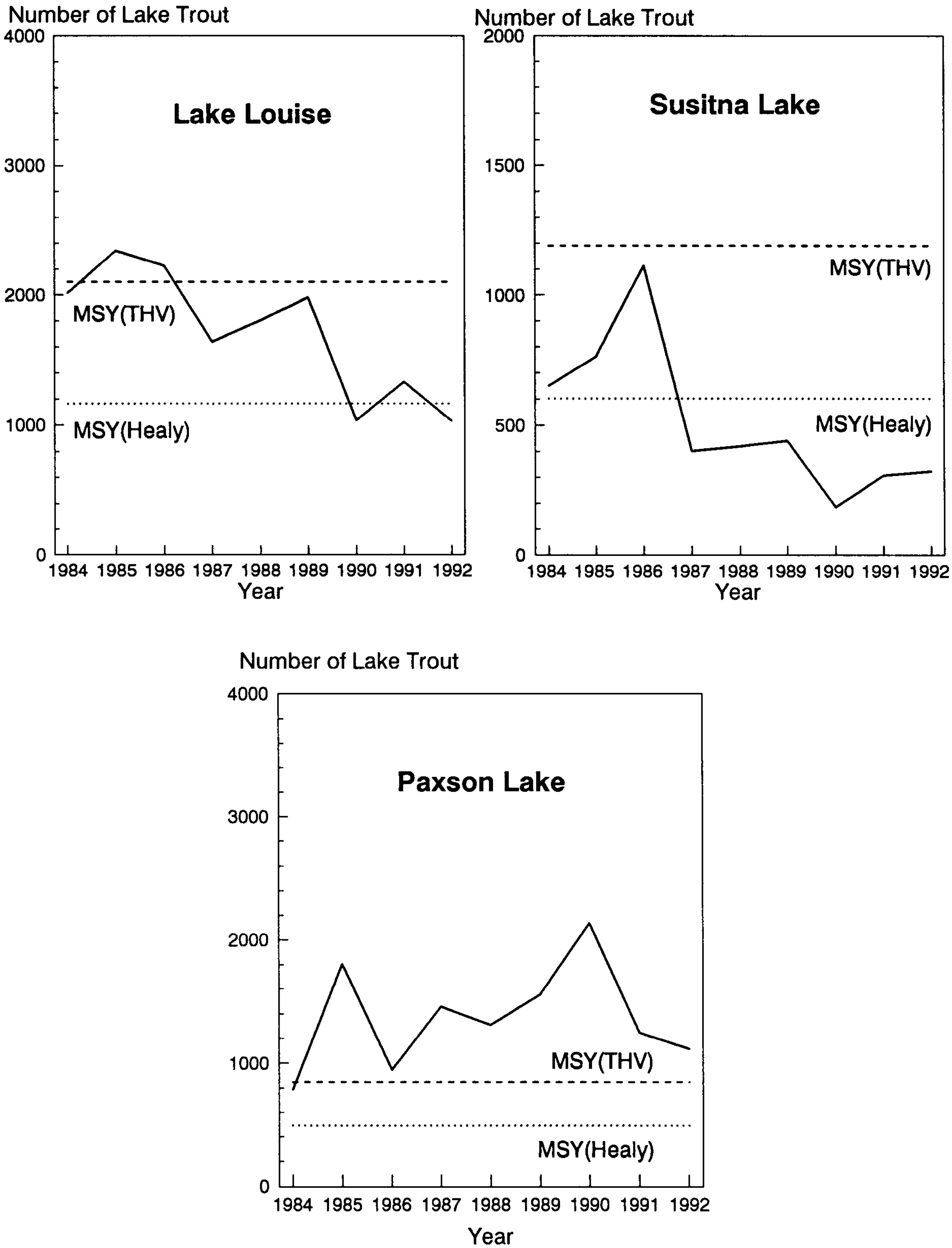


Figure 6. Lake trout harvests compared to estimates of maximum sustainable yield (MSY) as developed through measurements of thermal habitat volume (THV from Payne et al. 1990) and as reported in Healy (1978).

Table 13. Estimates of maximum sustained yield for mature lake trout and the carrying capacity for these fish in Paxson and Louise lakes, 1991-1993, and Susitna Lake, 1992 and 1993.

| | Area (ha) | Year | THV ($hm^3$) | Mean Weight (kg) | Yield | | Carrying Capacity | |
|---|---|---|---|---|---|---|---|---|
| | | | | | kg/ha/yr | Number | kg | Number |
| Paxson | 1,575 | 1991 | 28.9 | 1.80 | 0.99 | 866 | 31,185 | 17,325 |
| | | 1992 | 30.7 | 1.61 | 1.03 | 1,014 | 32,445 | 20,152 |
| | | 1993 | 17.9 | 1.68 | 0.70 | 658 | 22,050 | 13,125 |
| | | Average | | 1.70 | 0.91 | 846 | 28,560 | 16,867 |
| Louise | 6,519 | 1991 | 52.6 | 3.19 | 0.37 | 754 | 18,502 | 5,800 |
| | | 1992 | 291.3 | 2.50 | 1.21 | 3,287 | 63,213 | 25,285 |
| | | 1993 | 217.5 | 2.92 | 1.01 | 2,257 | 50,697 | 17,362 |
| | | Average | | 2.87 | 0.86 | 2,099 | 46,339 | 16,146 |
| Susitna | 3,816 | 1992 | 40.8 | 2.87 | 0.52 | 691 | 15,241 | 5,310 |
| | | 1993 | 92.6 | 2.87 | 0.94 | 1,249 | 27,604 | 9,618 |
| | | Average | | 2.87 | 0.73 | 970 | 21,436 | 7,464 |

The number of lake trout reported tagged and released in 1991 is considerably reduced over the number reported previously. In 1993, 417 were released with tags (Table 3) compared to 558 reported in Szarzi (1992) and 569 in Szarzi (1993). The recapture rates in 1992 and 1993 of fish tagged for the first time in 1991 (0.29 = 153/536) was significantly lower ($\chi^2$ = 29.65, df = 1, P < 0.0001) than the rate for fish recaptured with tags in 1991 and released (0.45 = 198/436). The lower recapture rate for fish in the former group is consistent with either tagging-induced mortality in 1991 or with a high rate of undiscovered tag loss. A punched hole in the left ventral fin was used in 1991 as a secondary mark. The number of lake trout captured in 1991 with tags and recaptured in 1992 and 1993 with no recognizable hole punch in the left ventral fin (0.34 = 58/171) was significant ($\chi^2$ = 19.67, df = 1, P < 0.001). Therefore many tags lost from lake trout tagged in 1991 could go unnoticed in subsequent handlings. Parameter estimates reported for Paxson Lake (Tables 1 and 2) have been adjusted to account for the disparity between recapture rates of fish newly tagged in 1991 and previously marked fish recaptured in 1991.

The presence of strong year classes in Paxson Lake compared to the more uniform age distribution of lake trout harvested from Lake Louise may be the result of exploitation. Year class strengths of long-lived species have been found to be less variable and stable age distributions are reported for unexploited lake trout populations (Martin and Olver 1980).

Regulations will go into effect in the spring of 1994, restricting the minimum total length of harvestable lake trout to 24 inches in Paxson, Summit and Crosswind lakes and the Tyone drainage, which include Lake Louise and Susitna Lake. These restrictions will undoubtedly reduce harvest to below sustainable levels and protect female lake trout through at least one spawning season (Szarzi 1992). The daily bag and possession limits will be reduced from two lake trout to one in the Tyone drainage and Crosswind Lake. Together these measures will protect populations from overharvest should angler effort increase in the future. Additionally, they should allow the abundance of lake trout to increase so regulations can be implemented that meet the full range of angler preferences for small lake trout to eat and trophies to admire, while maintaining harvests at sustainable levels.

## ACKNOWLEDGEMENTS

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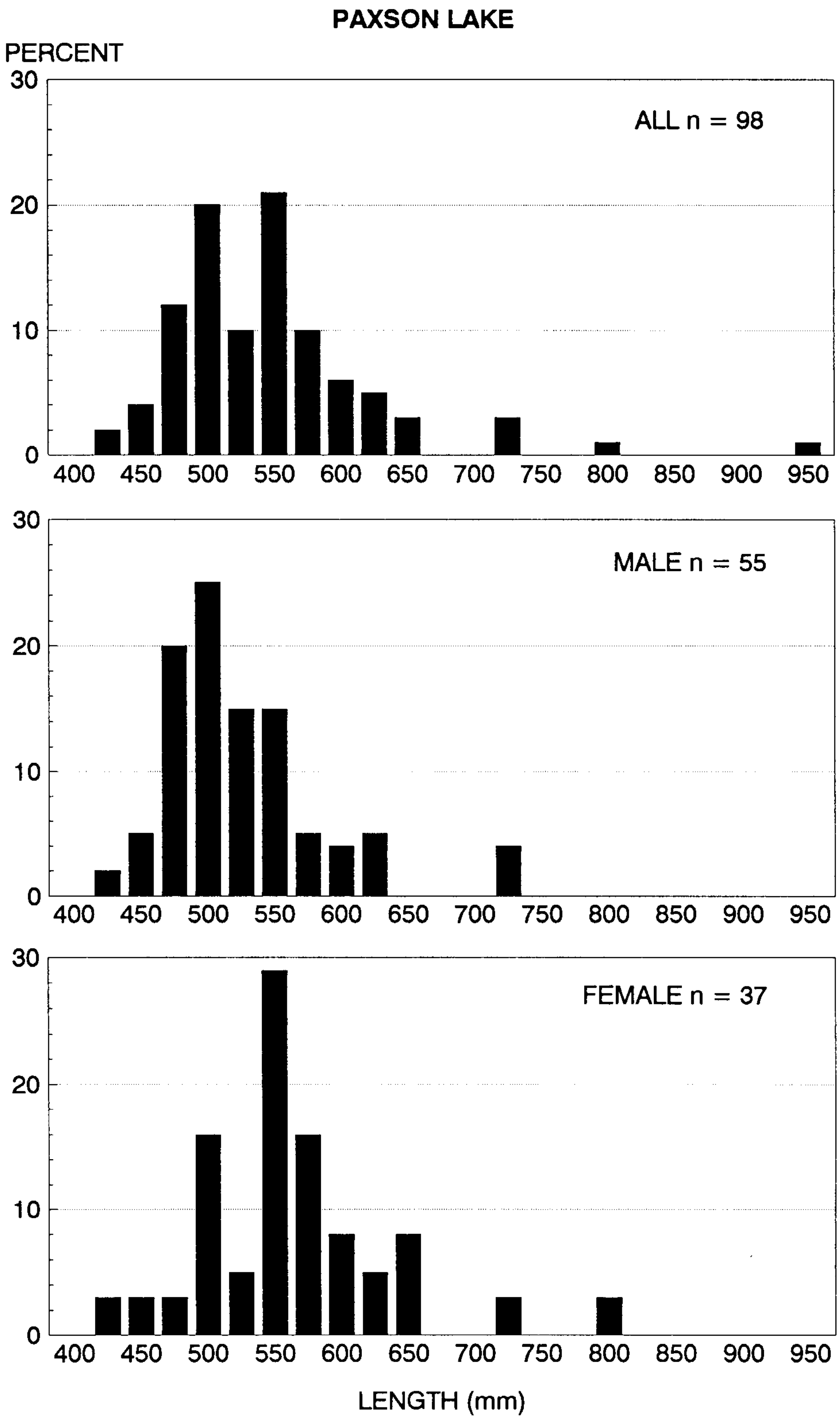
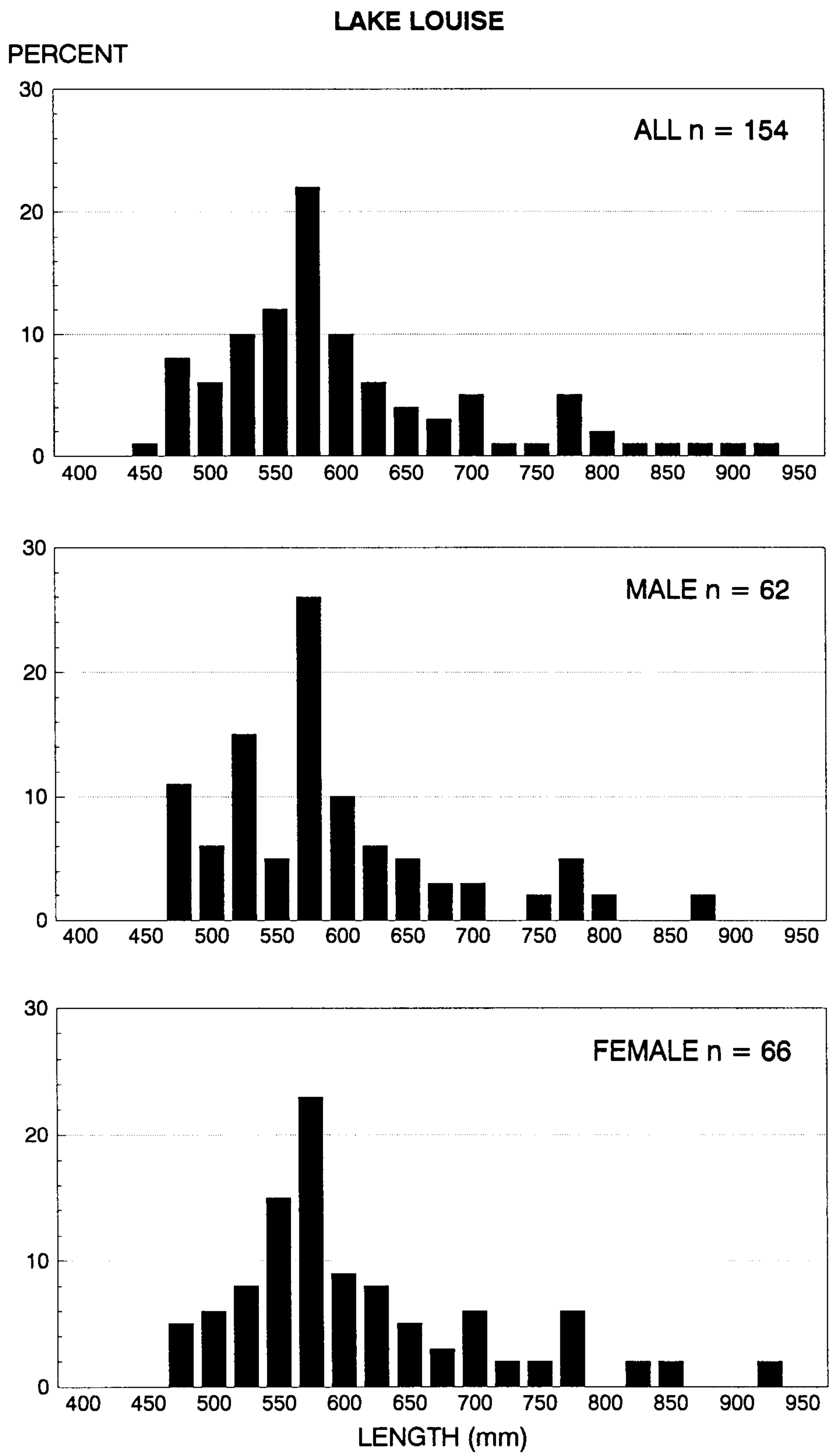
## APPENDIX A

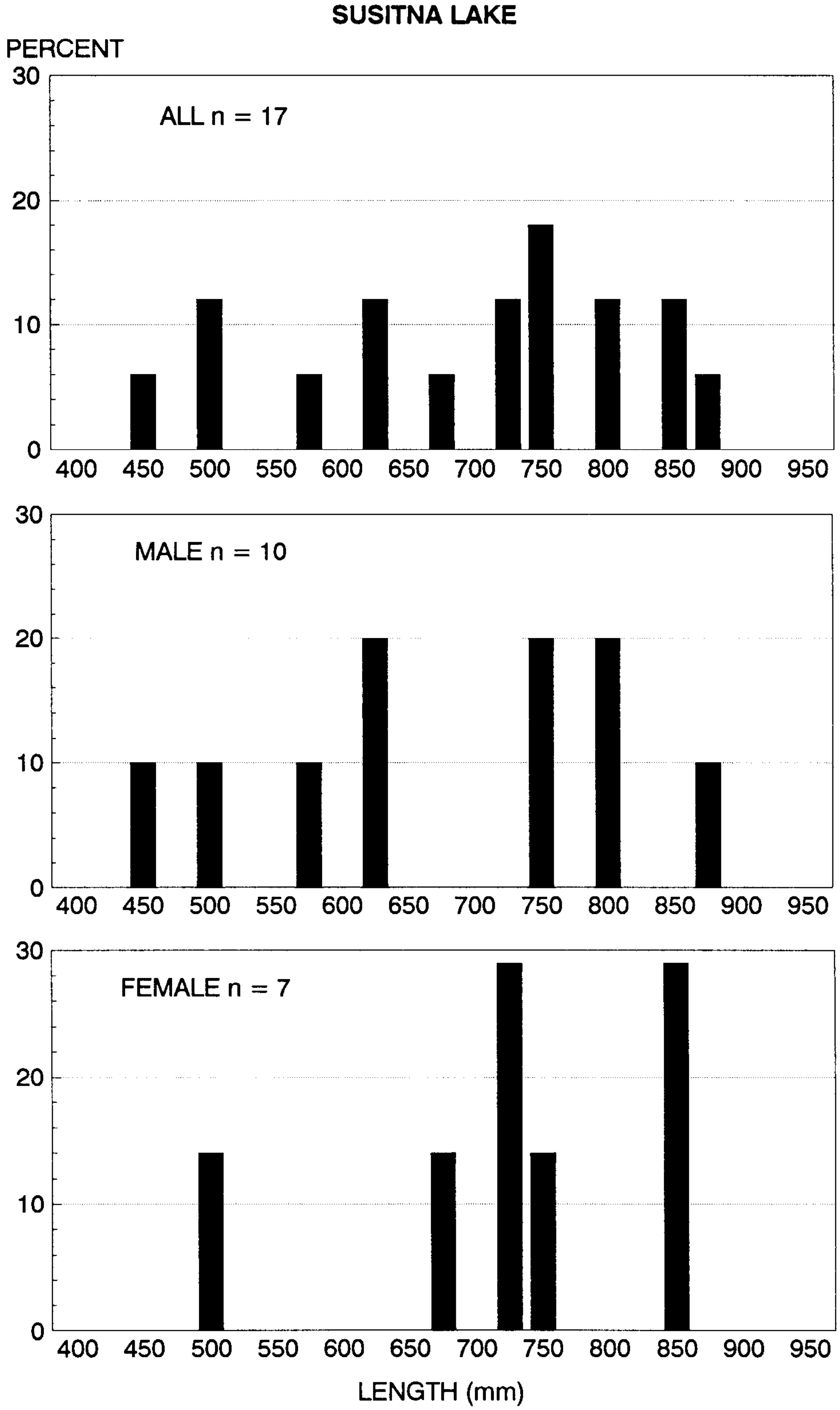
Length and age frequencies of harvested lake trout and length frequencies of spawning lake trout.



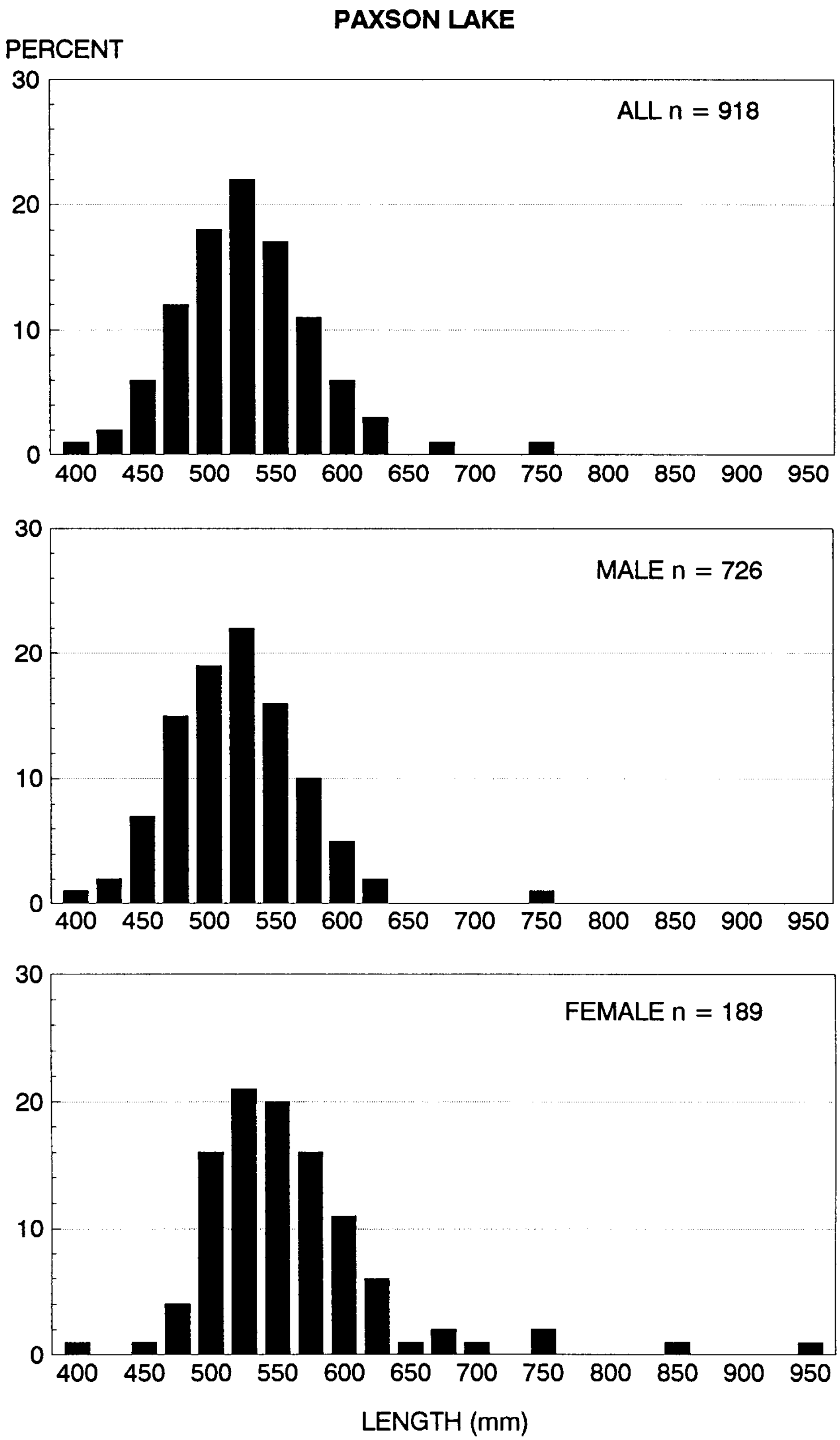

Appendix A1. Fork lengths of lake trout harvested from Paxson Lake, 1993.



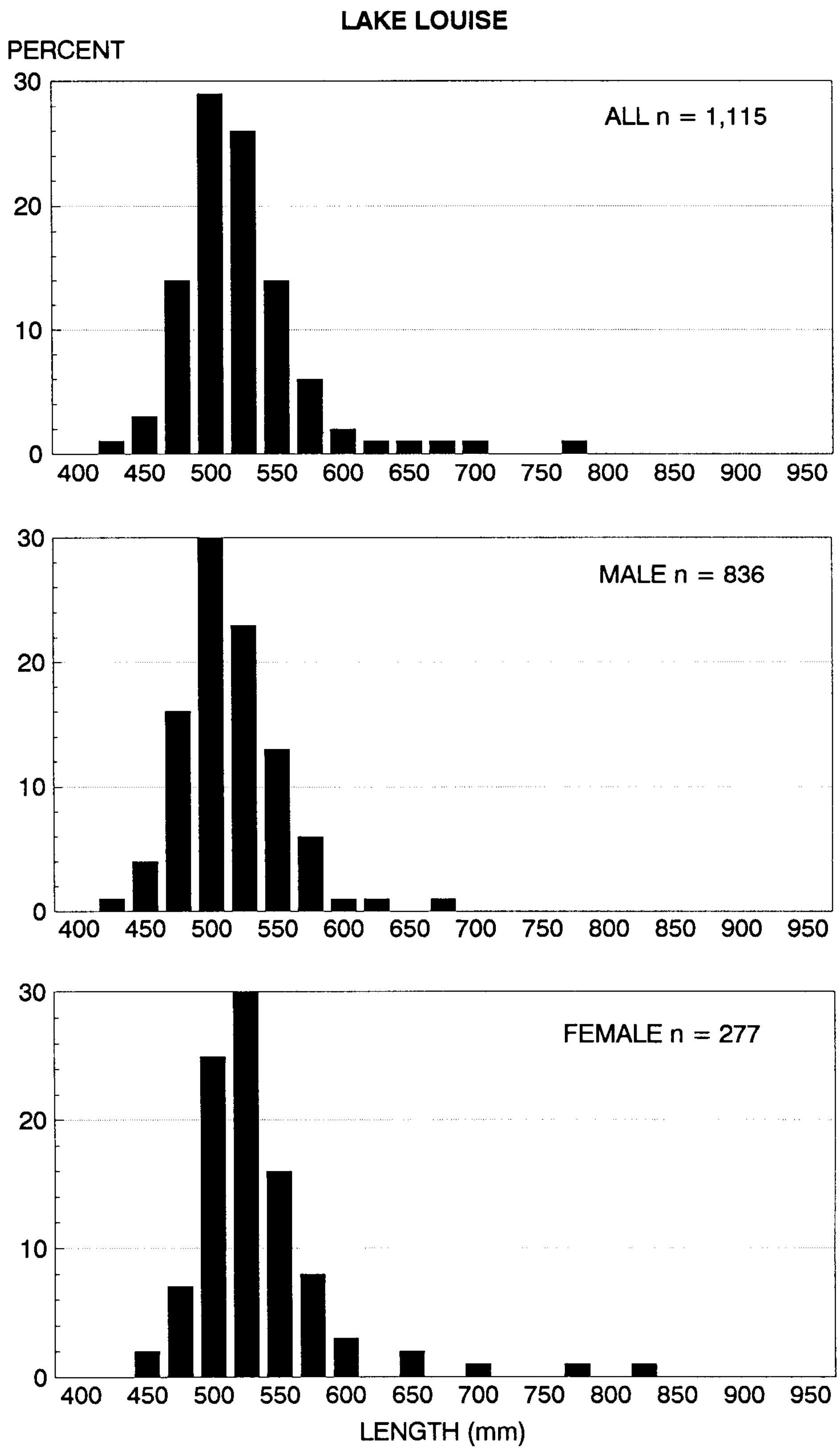

Appendix A2. Fork lengths of lake trout harvested from Lake Louise, 1993.



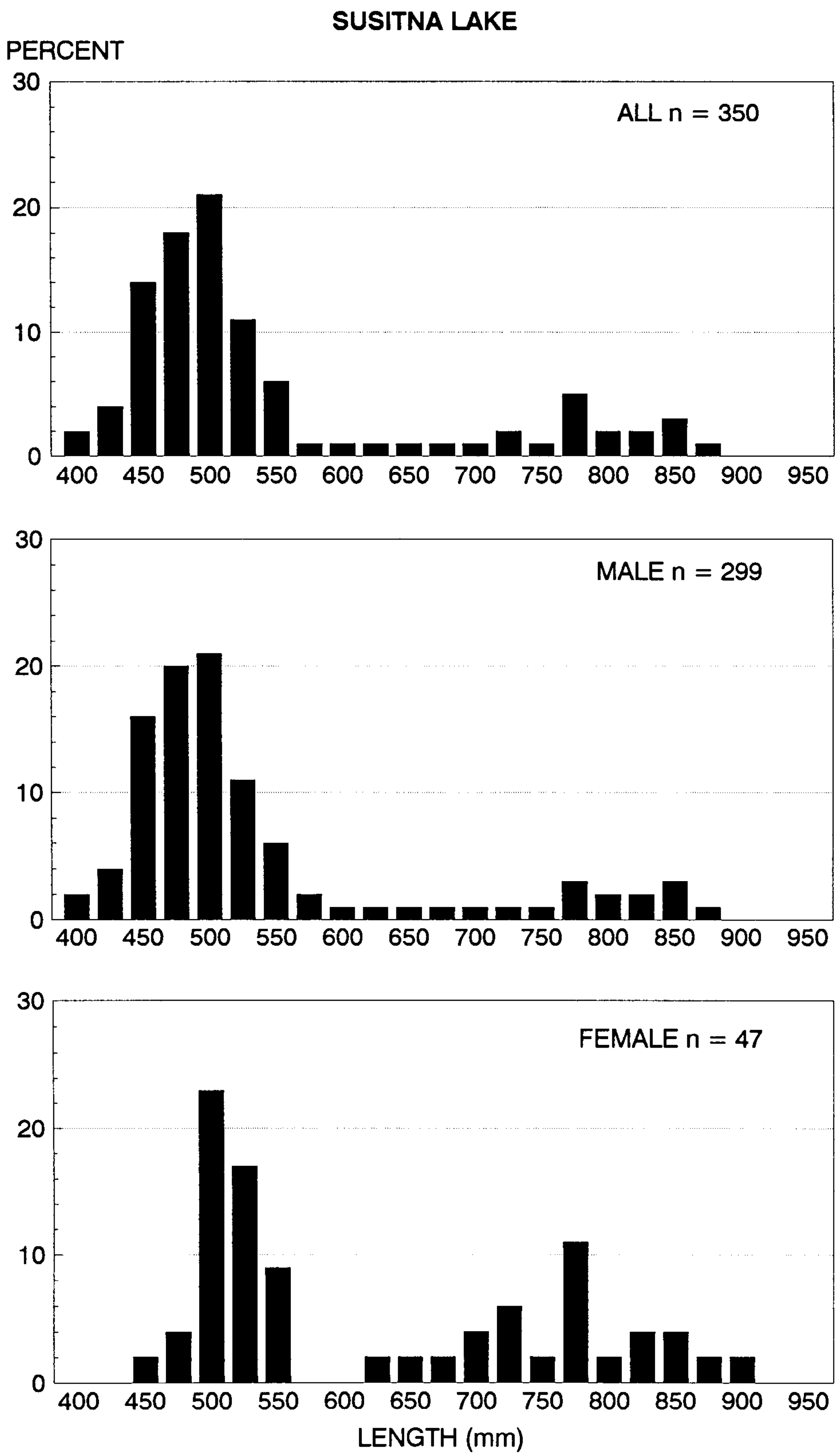

Appendix A3. Fork lengths of lake trout harvested from Susitna Lake, 1993.




Appendix A4. Fork lengths of spawning lake trout captured by beach seine from Paxson Lake, 1993.




Appendix A5. Fork lengths of spawning lake trout captured by beach seine from Lake Louise, 1993.




Appendix A6. Fork lengths of spawning lake trout captured by beach seine from Susitna Lake, 1993.