Fishery Data Series No. 93-48

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Nicole J. Szarzi

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[1] This information was partially financed by the Federal Aid in Sport Fish Restoration Act (16 U.S.C. 777-777K) under Project F-10-8, Job No. R-2-2.

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ABSTRACT

Mark-recapture experiments were conducted to estimate the abundance of spawning lake trout *Salvelinus namaycush* in Paxson Lake in the Copper River drainage, and Lake Louise and Susitna Lake in the Susitna River drainage. Total abundance of mature fish was estimated by applying the sex ratio from the harvest to the estimated number of spawning males. The experiments focused on males because females do not spawn every year.

The experiment conducted at Paxson Lake in 1992 generated an estimate of abundance for 1991 of 5,828 (SE = 396) mature lake trout. Spawning lake trout were found to return to the same locations to spawn each year, therefore population size estimated from mark-recapture experiments was considered a minimum estimate. An alternate estimate was derived from the mark-unmarked ratio of lake trout sampled from the harvest. The estimate from this method for 1991 was 9,124 (SE = 1,707) mature lake trout. A significant increase in the number of mature lake trout in Paxson Lake occurred from 1990 to 1991.

The potential yield, estimated from the average volume of water between 8° and 12° C, was 1.01 kg ha^{-1} y^{-1} for Paxson Lake, 0.9 kg ha^{-1} y^{-1} for Lake Louise and 0.5 kg ha^{-1} y^{-1} for Lake Susitna.

In each lake with significant lake trout harvests, an estimate of sustainable yield was compared to estimated harvest. Harvests from Paxson and Summit lakes, in the upper Copper drainage, may exceed sustainable levels.

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 annual statewide lake trout harvest 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; 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, an upper Susitna tributary (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 1,405 fish. The average harvest from Lake Louise since 1984 is 1,796 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 3% and 5% 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 (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.

An Alaska Department of Fish and Game (ADF&G) study 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 drainage, upper Copper and upper Susitna 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. The ultimate goal of the study is to improve our understanding of the population dynamics of lake trout in selected lakes in the upper Copper and upper Susitna drainages to establish regulations which will maintain stocks while providing opportunities to anglers.

The specific objectives in 1992 were to:

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

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

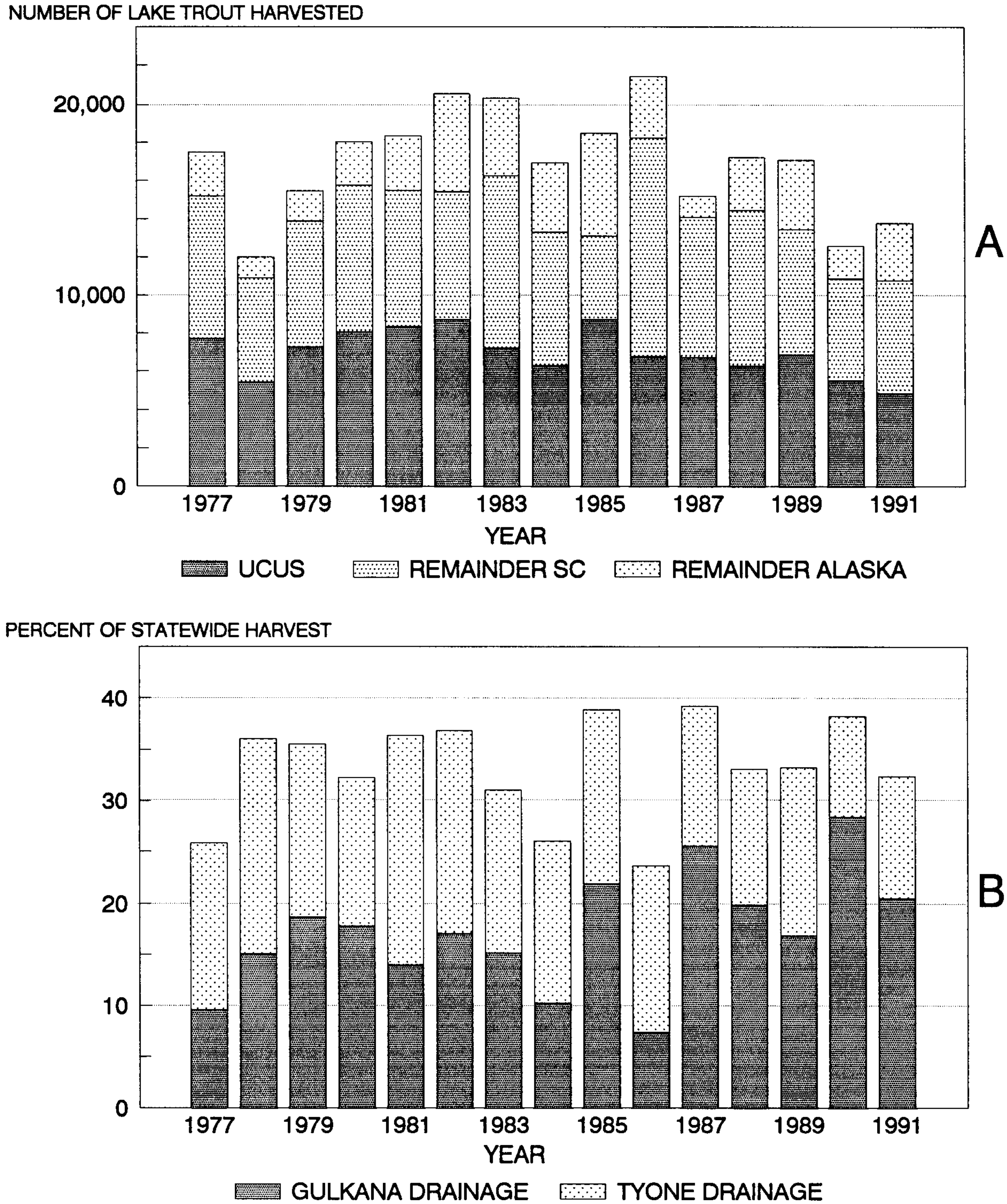

Figure 1. Lake trout harvests in Alaska 1977-1991 with (a) contribution of upper Copper and upper Susitna river drainages (UCUS) and Southcentral (SC) harvests, and (b) contribution of Gulkana and Tyone harvests to the statewide harvest (Mills 1979-1992).

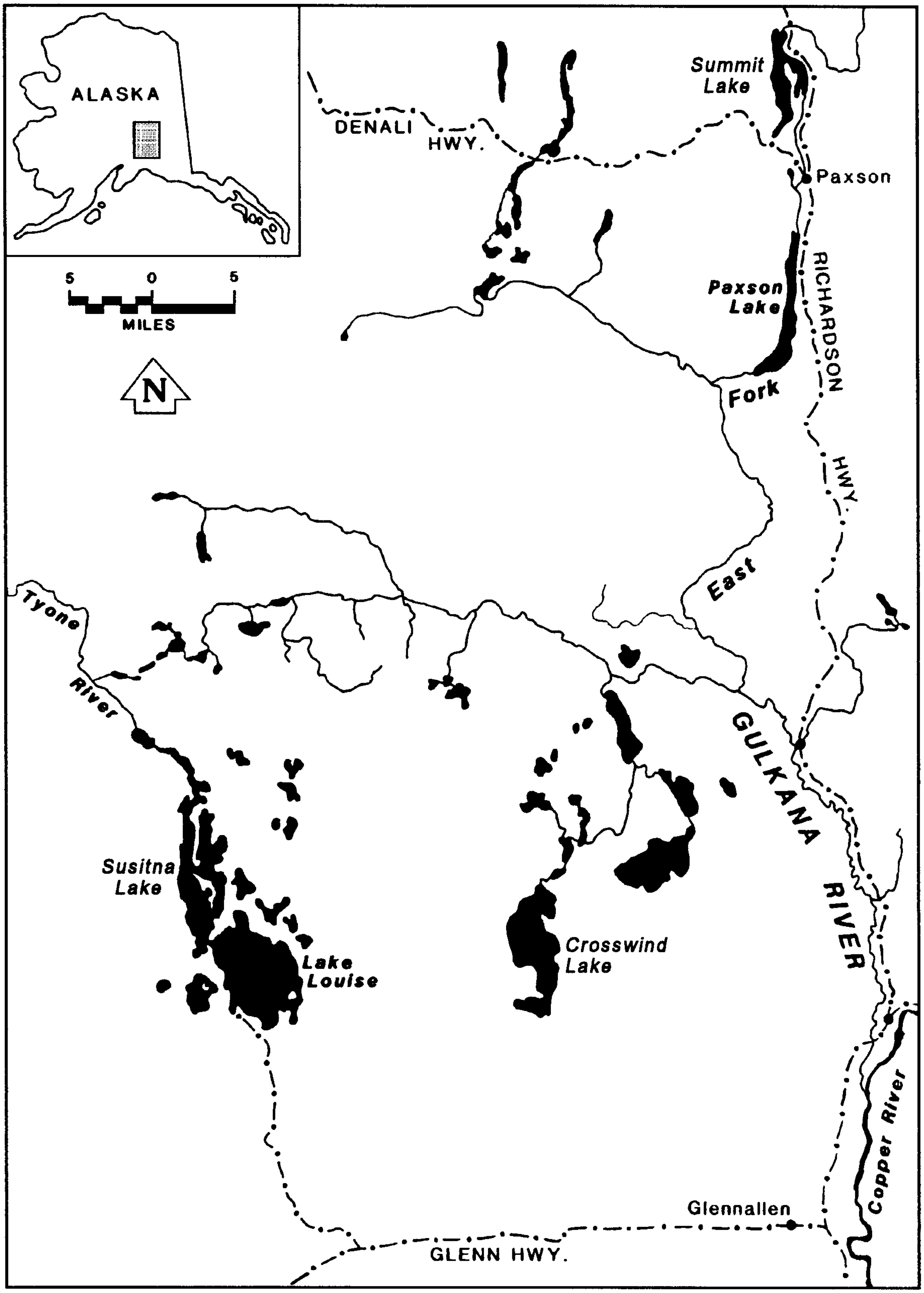

Figure 2. Populations of lake trout in the stock assessment program in the upper Copper and upper Susitna drainages, 1992.

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 length and mean weight of lake trout from the sport harvest at Paxson Lake, Lake Louise and Susitna Lake;

6. estimate the fraction of anglers that harvest one, two, more than two or no lake trout during an angler day in early summer (breakup to July) from Paxson Lake, Lake Louise and Susitna Lake;

7. estimate the fraction of angler-trips on Paxson Lake, Lake Louise and Susitna Lake during the early summer in which bait is used; and

8. estimate the thermal habitat volume of Paxson Lake, 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) is part of a complex of lakes in the Tyone River drainage which ultimately flows into the upper Susitna River. The lake 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 (62°25' N, 146°38' W) is immediately downstream of Lake Louise. The lake is 3,816 ha with a maximum depth of 37 m and an elevation of 720 m. It is accessed through a channel from Lake Louise.

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 lake trout in Paxson Lake was estimated with a combination of two mark-recapture experiments and a catch sampling program on its fishery. Sampling events in the first experiment have been conducted each fall from 1987 through 1992. Spawning male lake trout were captured with beach seines in 1992 and were marked with individually identifiable tags. Only males were included in this experiment because males generally spawn every year; females do not (Burr 1991a). Numbers of male lake trout marked and recaptured since 1987 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).

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, 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 in Paxson Lake. The abundance of all spawning males in the lake in year i (N_{mi}) was estimated as:

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

where:

M_i = number of marked, male lake trout in Paxson Lake 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 in Paxson Lake 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 was restricted to older fish to remove bias in the estimate of abundance from growth recruitment. The variance of the estimate of abundance of males in year i was approximated according to the delta method:

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

$V[\hat{M}_i]$ came from the first mark-recapture experiment while $V[q_{(i+1)}]$ was estimated from the catch sampling program as follows:

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

where:

n_x = the number of male lake trout 6-years old and older sampled from the creel in the spring, 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) and to expand estimates of abundance to 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:

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

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

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

where:

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

Abundance estimates for Lake Louise and Susitna Lake will be generated following the sampling in the fall of 1993 and 1994, respectively.

Sampling during the fall occurred at previously identified spawning beds in Lake Louise and Paxson Lake (Scott Meyer, ADF&G, Anchorage, personal communication; John Burr, ADF&G, Fairbanks, personal communication) and at beds discovered during reconnaissance of Lake Susitna in 1992 (Table 1). Spawning beds were numbered consecutively and sampled throughout each night between sundown and 0600 hours, when weather permitted. 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.

	Paxson Lake	Lake Louise	Susitna Lake
Mark-recapture Experiment	3-4 Sep	2-4 Sep	1-4 Sep
	7-11 Sep	7-12 Sep	7-8 Sep
	16-18 Sep	14-30 Sep	10-11 Sep
	21-25 Sep		14-18 Sep
			22-24 Sep
Catch Sampling	18-19 Apr	3-7 Jun	3-7 Jun
	25-26 Apr	10-14 Jun	10-14 Jun
	2-3 May	17-21 Jun	17-21 Jun
	9-10 May	24-28 Jun	24-28 Jun
	16-17 May	1-5 Jul	1-5 Jul
	23-24 May	8-13 Jul	8-13 Jul
	4-28 Jun	17-19 Jul	17-19 Jul
	1-11 Jul	24-25 Jul	24-25 Jul
Thermal Sampling	2 Jul[a]	28 Jun	28 Jun
	21 Jul[a]	13 Jul[a]	13 Jul[a]
	6 Aug[a]	28 Jul[a]	28 Jul[a]
	19 Aug[a]	11 Aug[a]	11 Aug[a]
		26 Aug[a]	26 Aug[a]
			31 Aug

[a] Profile used to estimate thermal habitat volume (THV) of the lake.

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. 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 in season and between seasons. Recaptured fish were noted, sexed and measured.

During the latter part of the ice fishing season and the spring fishery in 1992, harvested lake trout were sampled from Paxson Lake, Lake Louise and Susitna Lake. Successful anglers were contacted during two randomly selected 3.5-hour periods, 5 to 7 days per week. Collection boxes were placed to obtain lake trout heads and sex information. 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). Each interviewed angler was asked: (1) if they had completed their fishing trip that day, (2) what they had used for bait, (3) how many lake trout they had caught, and (4) how many lake trout had they kept.

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) of lakes in Ontario, Canada (Payne et al. 1990):

$$\log_{10}MSY = 2.15 + 0.714 \log_{10}THV \tag{7}$$

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

where:

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

D_2 = the deepest 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. Water temperatures measured at 2.5 m depth intervals to the bottom of Paxson Lake, Lake Louise, and Susitna Lake during 2 days in July and 2 days in August 1992 (Table 1) were used to generate the average temperature profile from which the THV was estimated.

Carrying capacities (K) of Lake Louise and Paxson Lake were estimated 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):

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

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, no estimated yields are reported for 1992.

RESULTS

Abundance Estimates

Estimated abundance of mature male lake trout spawning on the sampled grounds in Paxson Lake during the fall, 1991, is 2,914; estimated abundance of all mature males spawning during the fall throughout Paxson Lake in 1991 is 4,562; and estimated abundance of all mature lake trout in the fall, 1991, is 9,124 (Table 2 contains SEs and 95% CIs for these statistics and for statistics for previous years). Six hundred ninety-five male lake trout were captured during fall sampling in 1992 of which 51% (355) had been marked in previous years (Table 3 contains tallies of all captured and recaptured male lake trout since 1987 at Paxson Lake and at Lake Louise since 1991). An estimated 1,178 (SE = 75) male lake trout were extant with marks just prior to sampling during the fall, 1991 (Table 2) and 1,747 (SE = 75) just after (569 newly marked males were released during sampling in 1991). During catch sampling in the spring, 1992, 162 lake trout were sampled of which 89 were $\geq$ 7 years. Of these 89 fish, 47 were males of which 18 were marked, making $q = 0.38$ and $SE[q] = 0.07$. Since the proportion of male lake trout $\geq$ 7 years in the catch sample (0.53) is not significantly different than 0.50 ($\chi^2 = 0.88$, $P > 0.25$, $df = 1$), estimated abundance of all lake trout 7 years of age or older is double that estimated for males alone.

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

Year	Sampled Population	Number w/ Marks (M)	Fraction Marked (q)	Abundance Males (N_m)	Fraction Males (p)	Abundance (N)
1987	-----	213	-----	-----	-----	-----
1988	3,316 (308) (2,362;3,535)	921 (11)	0.39[a]	5,033	0.5	10,067
1989	2,540 (162) (2,294;2,932)	1,321 (31)	0.39[a]	4,077	0.5	8,154
1990	1,944 (111) (1,746;2,221)	1,272 (40)	0.40 (0.06)	3,201 (520)	0.5	6,402 (1,040)
1991	2,914 (198) (2,563;3,348)	1,747 (75)	0.38 (0.07)	4,562 (894)	0.5	9,124 (1,707)
1992	-----	>695	-----	-----	-----	-----

[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 and 1991; fractions prior to 1990 are assumptions based on later sampling.

Table 3. Numbers of mature male lake trout captured, marked and recaptured in Paxson Lake and Lake Louise at sampled spawning grounds, 1987-1992.

PAXSON LAKE:	Year of Recapture					
	1987	1988	1989	1990	1991	1992
Year of release:						
1987	0	40	38	8	8	3
1988		0	213	122	68	23
1989			0	213	115	50
1990				0	195	85
1991					0	194
1992						0
Captured with tags	0	40	251	343	386	355
Captured without tags	250	803	595	348	569	340
Total captured	250	843	846	691	955	695
Released with tags	213	813	819	652	954	695
Released without tags	0	0	0	0	1	0
Total released	213	813	819	652	955	695

LAKE LOUISE:	Year of Recapture					
	1987	1988	1989	1990	1991	1992
First marked in:						
1991					0	179
1992						0
Captured with tags					0	179
Captured without tags					695	423
Total captured					695	602
Released with tags					695	602
Released without tags					0	0
Total released					695	602

Rates of recapture in 1992 of lake trout in Paxson Lake that had been marked in 1991 were consistent with (1) fish using the same spawning grounds each year and (2) probability of capturing a fish in 1991 had been equal across spawning grounds. Capture histories of lake trout were segregated according to two clusters of smaller spawning grounds (Figure 3). One hundred ninety-one of 200 males (95.5%) and 17 of 18 females (94.4%) were recaptured in the same cluster in 1992 as captured in 1991 (Table 4). The proportions of lake trout recaptured in 1992 were similar across both clusters of spawning grounds for males ($\chi^2 = 0.95$, $P > 0.25$, df = 1) and females ($\chi^2 = 0.02$, $P > 0.90$, df = 1) (Table 5).

Since 1987, estimated annual survival rates of male lake trout in Paxson Lake have varied from 70% to 92%; meaningful numbers of male lake trout were recruited to the spawning population in only 1 of the 3 years for which there are estimates (Table 2). Estimates of the annual instantaneous natural mortality rate between 1988 and 1991 were 0.06, 0.09, and -0.27. Instantaneous rates were calculated with estimates of harvest from the Statewide Harvest Survey (Mills 1989-1992) (Table 6), estimates of abundance of all mature males in Paxson Lake (Table 2) and the Baranov catch equation. Since almost all fishing for lake trout at Paxson Lake occurs between March and September, 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 (as between 1990 and 1991). Since there was little recruitment from 1988 to 1990, estimates of the annual instantaneous rates of natural mortality for these years are probably not biased. 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.

Lake trout were found to home to spawning beds in Lake Louise from sampling conducted during 1990 and 1991 (Szarzi 1992). The analysis was not repeated for the 1991 and 1992 capture histories.

Three hundred thirty-seven male lake trout were captured in Susitna Lake and released with tags in 1992. Abundance estimates were not generated for Susitna Lake in 1992.

<u>Length and Weight Information</u>

The fork lengths of 169 lake trout were measured from the harvest from Paxson Lake, 18 April to 11 July (Table 7 and Appendix A1). The lengths of 198 and 55 lake trout, respectively, were measured from the harvests from Lake Louise and Susitna Lake, 3 June to 25 July (Table 7 and Appendices A2 and A3). Sampled lake trout from Lake Louise were generally intermediate in size falling between the Paxson Lake fish and fish in Susitna Lake. There was no significant change in the average length of harvested fish between 1991 and 1992 for either Paxson Lake or Lake Louise (Szarzi 1992).

The fork lengths of 846 lake trout were measured from the spawning population in Paxson Lake (Appendix A4). Lengths were collected from 910 spawning lake trout captured in Lake Louise (Appendix A5) and 461 spawners from Susitna Lake (Appendix A6). Sampled females were larger than sampled males in both Paxson Lake and Lake Louise (Table 8). Similar to the length data from the spring

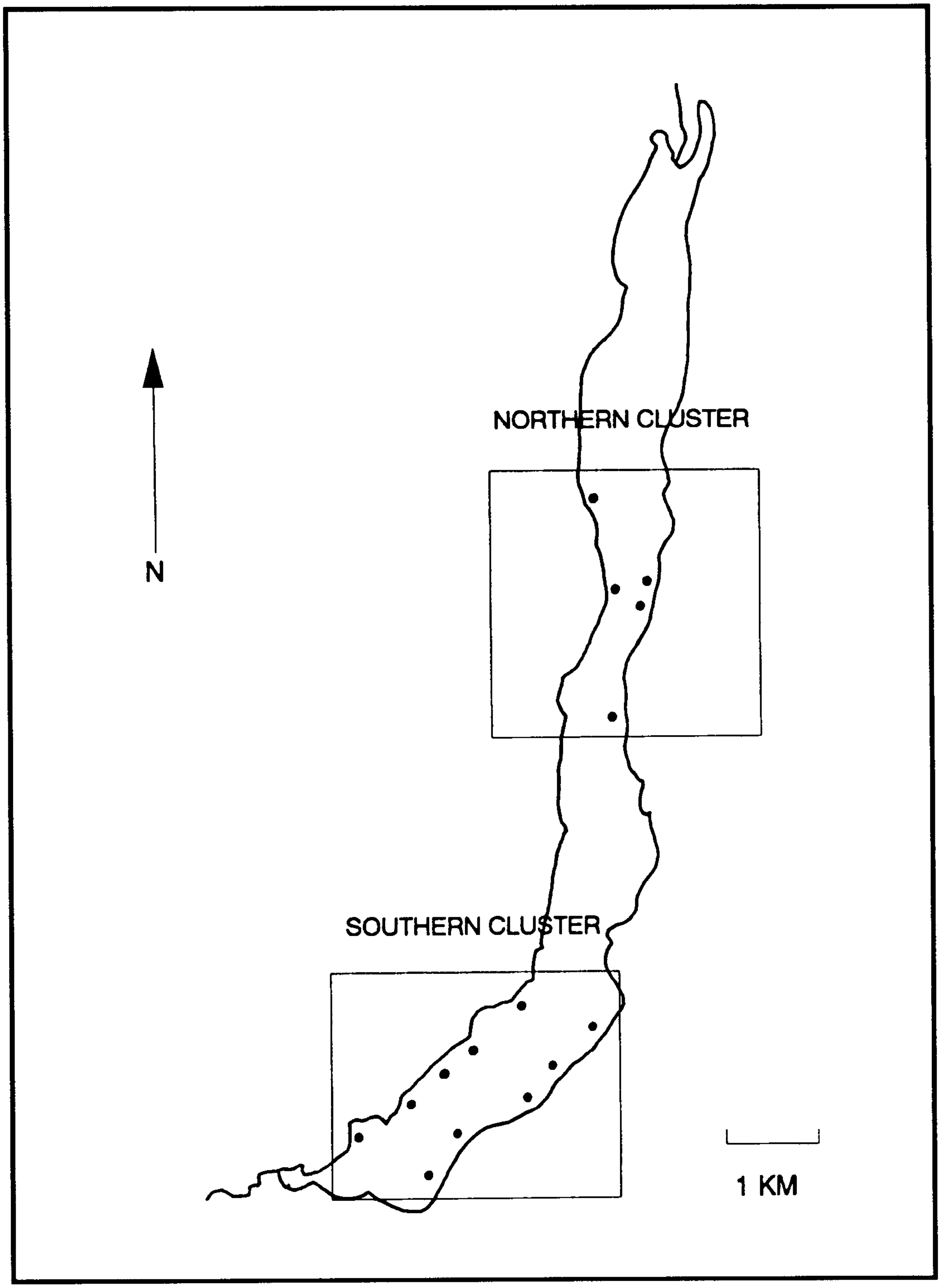

Figure 3. Location of sampled spawning areas (dots) of lake trout in Paxson Lake.

Table 4. Frequency of marked lake trout released in 1991 and recaptured in 1992 by clustered spawning grounds in Paxson Lake.[a]

MALES:

RELEASED 1991:	RECAPTURED IN 1992: SOUTHERN CLUSTER	RECAPTURED IN 1992: NORTHERN CLUSTER
SOUTHERN CLUSTER	166	5
NORTHERN CLUSTER	4	25

FEMALES:

RELEASED 1991:	RECAPTURED IN 1992: SOUTHERN CLUSTER	RECAPTURED IN 1992: NORTHERN CLUSTER
SOUTHERN CLUSTER	16	0
NORTHERN CLUSTER	1	1

[a] See Figure 3 for description of clusters.

Table 5. Numbers of lake trout captured over two clustered spawning grounds[a] in Paxson Lake in 1992 with recaptures being those fish that had been released with tags in 1991.

CLUSTER	MALE		FEMALE		MALE	FEMALE
	Recapture	Capture	Recapture	Capture	Recap./Cap.	Recap./Cap.
SOUTHERN	174	604	17	123	0.29	0.14
NORTHERN	22	92	4	27	0.24	0.15

[a] See Figure 3 for description of clusters.

Table 6. Estimates of annual harvest, survival rates, instantaneous rates, and surviving recruitment for males in Paxson Lake.[a]

Period: Fall-Fall	Harvest	Survival Rate	Instantaneous Rates: Total	Fishing	Natural	Surviving Recruitment
1987-1988	729 (328)	0.70 (0.06)	0.36	----	----	----
1988-1989	655 (249)	0.82 (0.04)	0.20	0.14	0.06	1 (181)
1989-1990	779 (221)	0.73 (0.05)	0.31	0.22	0.09	109 (84)
1990-1991	1,155 (370)	0.92	0.08	0.35	-0.27	1,153 (139)
1991-1992	624 (106)	----	----	----	----	----

[a] Harvests are half those reported in the Statewide Harvest Survey for years 1988 through 1991 (Mills 1989-1992). Surviving recruitment and survival 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 Paxson Lake.

Table 7. Length, weight and age statistics of lake trout from harvest samples from Paxson Lake, Lake Louise and Susitna Lake, 1992.

	Paxson Lake			Lake Louise			Susitna Lake		
	Female	Male	All[a]	Female	Male	All[a]	Female	Male	All[a]
LENGTH (mm)									
mean	527	504	516	572	562	567	648	592	614
mode	508	495	507	534	536	540	635	584	584
sample size	75	74	169	89	104	198	21	31	55
standard deviation	67	51	65	98	89	92	130	105	116
95% upper confidence interval	543	516	526	593	579	580	704	629	644
95% lower confidence interval	512	492	507	552	545	554	592	555	583
maximum	860	650	864	889	870	889	889	838	889
minimum	407	407	407	432	444	432	458	457	457
WEIGHT (kg)									
mean	1.78	1.42	1.61	2.83	2.08	2.50	----	4.65	----
sample size	21	16	40	20	16	36	----	2	----
standard deviation	1.51	0.62	1.17	1.87	1.11	1.60	----	4.60	----
95% upper confidence interval	2.43	1.72	1.97	3.65	2.62	3.02	----	11.02	----
95% lower confidence interval	1.14	1.12	1.25	2.01	1.53	1.97	----	0.00	----
maximum	8.00	3.00	8.00	7.90	4.50	7.90	----	7.90	----
minimum	0.70	0.80	0.70	1.30	1.10	1.10	----	4.65	----
AGE (yr)									
mean	10	9	9	10	10	10	11	11	11
sample size	59	60	135	51	78	137	15	22	40
standard deviation	3.2	3.0	3.7	3.3	3.1	3.2	2.6	3.6	3.1
95% upper confidence interval	11	10	10	11	11	11	12	12	12
95% lower confidence interval	9	8	9	9	9	10	10	9	10
maximum	27	20	27	22	20	22	17	22	22
minimum	6	5	5	6	6	6	7	6	6

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

Table 8. Length statistics of spawning lake trout in Paxson Lake, Lake Louise and Susitna Lake, 1992.

	Paxson Lake			Lake Louise			Susitna Lake		
	Female	Male	All[a]	Female	Male	All[a]	Female	Male	All[a]
LENGTH (mm)									
mean	535	497	504	528	509	515	594	574	574
mode	520	510	500	514	500	505	530	510	513
sample size	147	695	846	312	589	910	114	337	461
standard deviation	64	53	57	62	50	55	134	133	137
95% upper confidence interval	545	501	507	534	513	519	619	589	587
95% lower confidence interval	524	494	500	521	505	512	570	561	562
maximum	816	933	933	843	830	843	901	904	904
minimum	453	370	370	419	404	404	412	311	311

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

fishery, spawning males in Lake Louise were intermediate in size between those in Paxson Lake and Susitna Lake. Lengths of sampled females were greatest in Susitna Lake followed by Paxson Lake and Lake Louise. There was no significant change in the average length of spawning lake trout between years for either Paxson Lake or Lake Louise (Szarzi 1992).

The lengths of both males and females sampled from the harvest were significantly larger than samples from the spawning population in Lake Louise.

No meaningful difference in weight was evident between harvested male and female lake trout (Table 7). Lake trout from Lake Louise weighed more than males from Paxson Lake. The average weight did not change significantly between 1991 and 1992 for either lake (Szarzi 1992).

Age Structure

The widest range of ages was found in the harvest from Paxson Lake (Table 7, Appendix A7). Sampled lake trout harvested from Lake Louise and Susitna Lake were generally older than fish from Paxson Lake (Table 7, Appendices A8 and A9). The average age of lake trout harvested from both Paxson Lake and Lake Louise was younger in 1992 than in 1991 (Szarzi 1992).

Relatively large numbers of male lake trout age 11 were observed in harvest samples from Paxson Lake. In 1991, this age class was predominant in harvest samples and in 1990 was evident in the spawning population (John Burr, ADF&G, Fairbanks, personal communication).

Yield Estimates

Estimates of MSY and carrying capacity are 940 and 18,739 for lake trout in Paxson Lake, 2,021 and 39,092 for lake trout in Lake Louise and 625 and 12,519 for Susitna Lake (Table 9). Statistics on THV and mean weight of harvest lake trout varied little at Paxson Lake from 1991 and 1992. All calculations of THV at Paxson Lake were based on the more stable measurements in July. In contrast, measured THV in 1992 was almost six times higher than that measured in 1991 at Lake Louise. Calculation of THV at Lake Louise in 1991 was based on the more stable measurements in July, while calculation of THV in 1992 was based on an average of the equally variable estimates across July and August.

The harvest from Paxson Lake in 1991 was 1,248 lake trout or 1.4 kg ha^{-1} based on the average weight of 1.8 kg estimated from harvest samples from 1991 (Szarzi 1992). The 1991 harvest of lake trout from Lake Louise was 1,332 fish or 0.65 kg ha^{-1}, based on the average weight of 3.2 kg estimated from the 1991 harvest (Szarzi 1992). An estimated 308 lake trout were taken from Susitna Lake in 1991, a yield of approximately 0.25 kg ha^{-1} using the average weight of lake trout estimated in Burr (1987) (3.2 kg). Estimates of carrying capacity could not be determined from the mark-recapture experiments because of the instability of fishing mortality estimates.

Harvest Methods and Angler Characteristics

Bait was the predominant tackle in 4%, 3% and 2% of angler trips on Paxson Lake, Lake Louise and Susitna Lake, respectively (Table 10). Bait was used in

Table 9. Estimates of maximum sustained yield for mature lake trout and the carrying capacity for these fish in Paxson and Susitna lakes and Lake Louise.

	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
		Average			1.01	940	31,815	18,739
Louise	6,519	1991	52.6	3.19	0.37	754	48,241	15,080
		1992	291.3	2.50	1.21	3,287	157,760	63,103
		Average		2.86	0.79	2,021	103,001	39,092
Susitna	3,816	1992	40.8	3.17	0.52	625	39,686	12,519

Table 10. Terminal tackle use by lake trout anglers at Paxson Lake, Lake Louise and Susitna Lake, late spring and early summer, 1992.

	Bait	Lures	Both	TOTAL
Paxson Lake (Angler-trips)[a]				
Ice	12	13	0	25
Shore/boat	3	305	15	323
TOTAL	15	318	15	348
Lake Louise (Angler-trips)				
Shore/boat	5	153	9	167
Susitna Lake (Angler-trips)				
Shore/boat	1	34	6	41

[a] The fishing done by an angler in one 24-hour period.

conjunction with lures on 4% of angler-trips to Lake Louise and 15% of angler-trips to Susitna Lake. Approximately half of the anglers interviewed who were ice-fishing on Paxson Lake used bait. Lures were the most prevalent terminal tackle used during the open water period in all three lakes. Most anglers accessed the lakes with boats after ice out.

The greatest proportion of anglers in Paxson Lake and Lake Louise did not harvest any fish (Table 11) and the greatest proportion of anglers fishing at Paxson Lake did not catch any fish. Anglers fishing on Lake Louise and Susitna Lake were more successful; more than half of the anglers caught at least one lake trout. The data suggest that anglers were more likely to catch a lake trout at Lake Louise or Lake Susitna but more likely to keep a fish from Paxson Lake.

Of the lake trout harvested from Paxson Lake, 82% of the harvest was accounted for by the first fish taken on an angler-trip (Table 12). The remaining 18% of the harvest was taken by anglers that had already killed one lake trout. In Lake Louise and Susitna Lake, 77% and 79% of the harvest was accounted for by the first fish.

The average harvest-per-angler at Paxson Lake was 0.33 fish; the average catch was 0.52. An average of 0.54 fish were harvested from Lake Louise and 1.42 were caught. The average harvest and catch from Susitna Lake was 0.70 and 1.60, respectively.

DISCUSSION

The current length and bag limits governing lake trout harvests from lakes in the upper Copper and upper Susitna drainages since 1987 are inadequate to protect most of these populations from overharvest. The estimated harvest from Paxson Lake in 1991 is not significantly lower than estimates since 1987 and continues to exceed estimates of sustainable yields (Figure 4). Although the abundance of mature lake trout in Paxson Lake in 1991 was significantly higher than in 1990, the overall decline from 1988 levels is expected to continue at present harvest rates. Few of the spawners captured during our sampling have been less than the 18 inch minimum size limit.

The current harvests at Lake Louise probably do not exceed sustainable levels (Figure 4). Recruitment is evident in length and age samples (Appendices A2, A5 and A8) but minimum size limits are probably ineffective at protecting first time spawners or preventing overharvest. No spawning female lake trout were less than 18 in TL (416 mm FL) and 3% were less than 20 in TL (460 mm FL) in 1992 samples (Appendix A5). Because harvests have exceeded that calculated with the method of Healy (1978) since 1977, that estimate of MSY (2,021) is probably too low.

The sustainable yield of Susitna Lake is estimated to be 629 fish from Healy (1978). The average harvest since 1985 is 535 fish (Mills 1986-1992). Recent harvests have been below sustainable levels but have increased since 1990 (Figure 4). Current minimum size limits are protecting few first time spawners. Less than 1% of spawning females are smaller than 18 in TL; 6% of spawning females are smaller than 20 in TL.

Table 11. Angler success in catching lake trout, spring and early summer, 1992.

	Paxson Lake		Lake Louise		Susitna Lake	
	Number	Percent	Number	Percent	Number	Percent
Harvest (fish)						
0	285	0.77	106	0.61	19	0.46
1	66	0.18	48	0.28	16	0.39
2	18	0.05	20	0.11	6	0.15
TOTAL	369	1.00	174	1.00	41	1.00
Catch (fish)						
0	251	0.68	78	0.45	10	0.24
1	82	0.22	54	0.31	13	0.32
2	20	0.05	25	0.14	8	0.20
3+	16	0.04	16	0.09	10	0.24
TOTAL	369	1.00	174	1.00	41	1.00

Table 12. Proportion of the harvest from Paxson Lake, Lake Louise and Susitna Lake comprised of the first and second fish harvested.

	Paxson Lake		Lake Louise		Susitna Lake	
	Number	Percent	Number	Percent	Number	Percent
Harvest (fish)						
1st	84	0.82	68	0.77	22	0.79
2nd	18	0.18	20	0.23	6	0.21
TOTAL	102	1.00	88	1.00	28	1.00

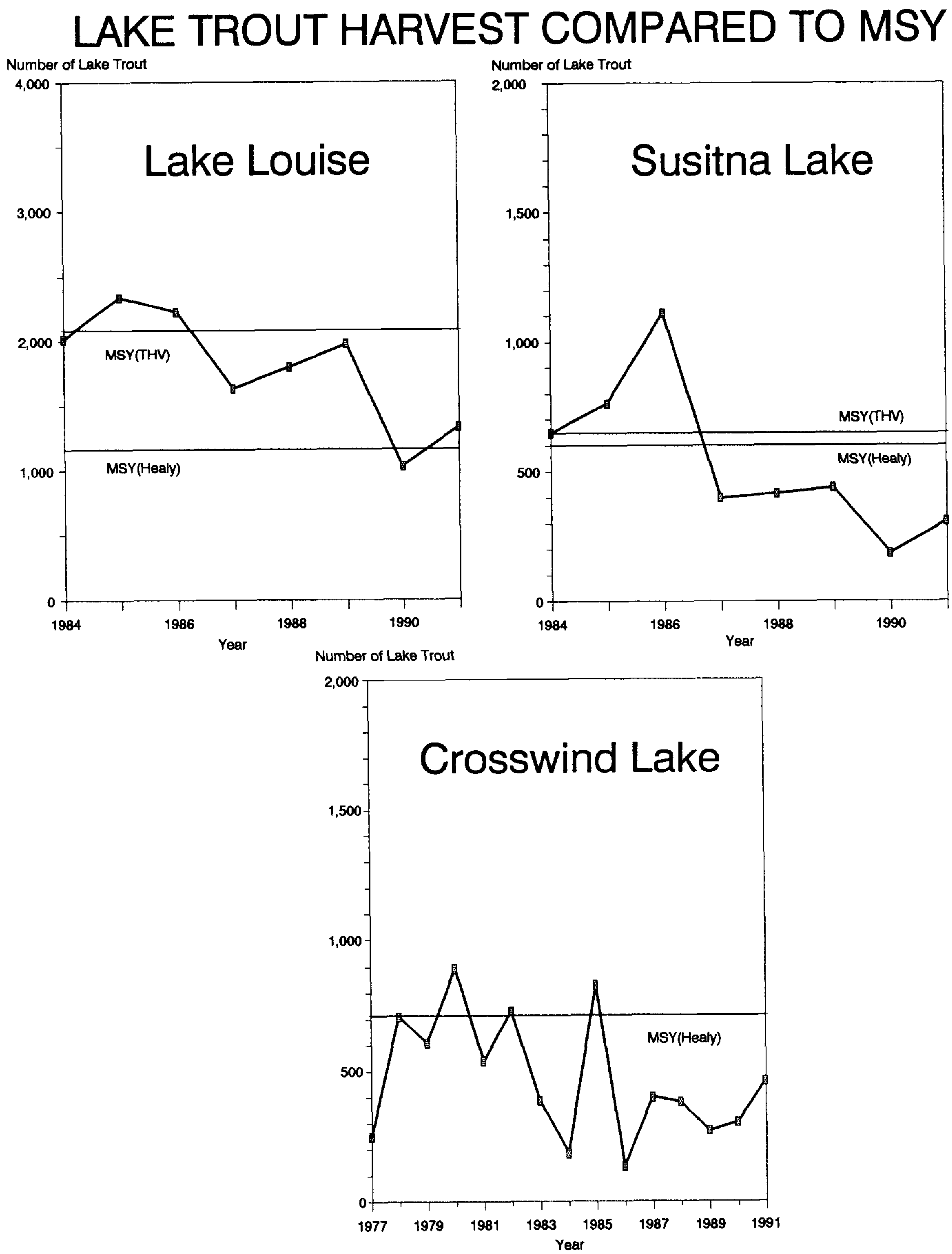

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Figure 4. Lake trout harvests compared to estimates of maximum sustainable yield (MSY) for five major fisheries.

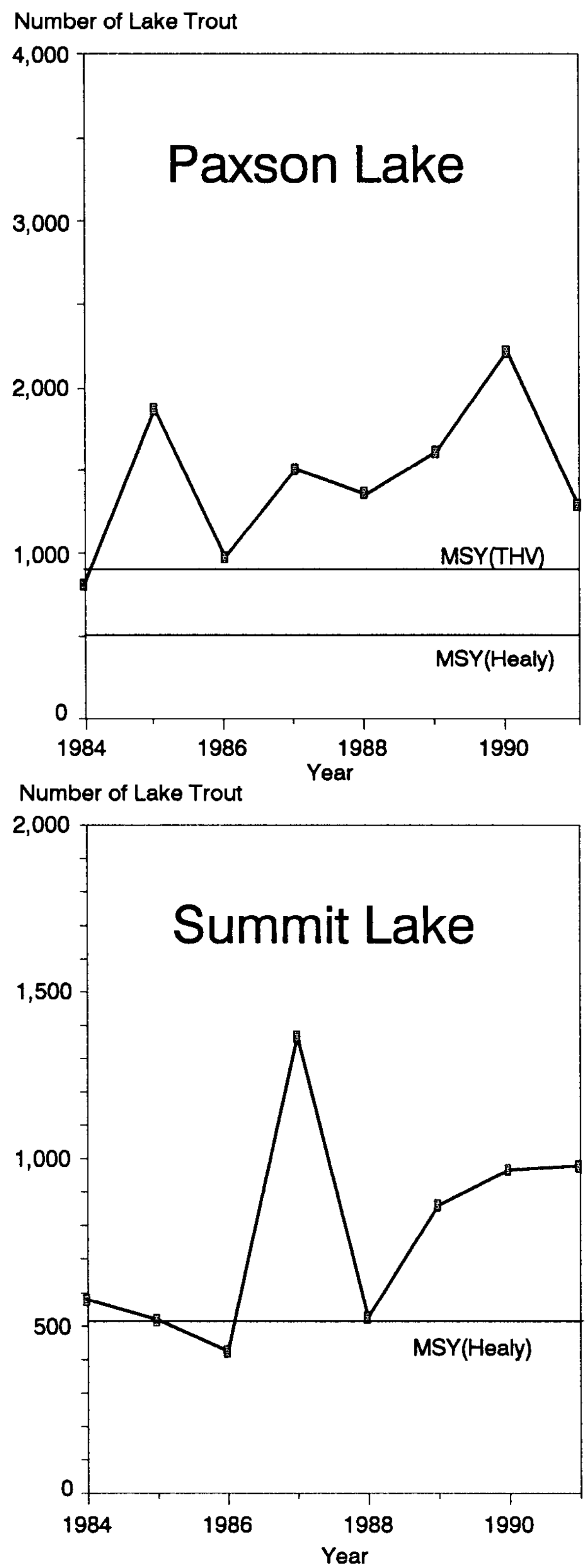

Figure 4. (Page 2 of 2).

The two other lakes in the upper Copper and upper Susitna drainages which support significant lake trout fisheries are Crosswind and Summit lakes. Lake trout harvests from Summit Lake have exceeded sustainable levels estimated from Healy (1978) during 7 of the past 8 years (Figure 4). Harvests from Crosswind Lake have generally been below sustainable levels since 1977 (Figure 4). Recent estimates of angler-days fished on Crosswind Lake are not available but anecdotal information indicates that interest in fishing at the lake is increasing.

Management Options for Paxson Lake

The increase in abundance of mature lake trout in Paxson Lake in 1991 is partly the result of the large number of new recruits to the spawning population which are evident not only from the results of the mark-recapture experiment (Table 6) but from the large number of 6-year-olds in the harvest samples (Appendix A7). The presence of this strong year class from spawning which occurred in 1986, and an earlier strong year class which is present in the harvest samples for 1992 as 11 year olds, suggests that the recruitment into the lake trout population in Paxson Lake is variable. Although 5-year-old males are not fully recruited into the harvest, the relative lack of them in harvest samples in 1992 compared to 1991 may indicate that recruitment was low in 1992 (Szarzi 1992) (actual estimates of recruitment in 1992 will not be available until the fall of 1993).

Due to the variable recruitment into the spawning population at Paxson Lake, surplus production models are of limited use in predicting population parameters. Although surplus production models used in Szarzi (1992) may be too simplistic to describe the dynamics of the lake trout population in Paxson Lake, they may help managers approximate actual trends in abundance at given levels of harvest.

The abundance of mature lake trout in Paxson Lake was modeled (Table 13). The maximum sustainable yield of 884 fish, estimated from the average July THV in 1991 and 1992 (1.01 kg h^{-1} y^{-1}) and the average weight lake trout harvested from Paxson Lake in 1991 (1.8 kg), was used in the model. The estimate of carrying capacity (K) is 17,675, assuming that M is 0.10 from Pauly (1980).

Estimates of overall hooking mortality reported in the literature range from 7% to 15% (Falk et al. 1974, Olver 1988, Nadeau and Lapointe 1991). It is unlikely that lake trout in Paxson Lake experience a significant amount of hooking mortality; an average of almost one of every two lake trout captured in Paxson Lake are released. The abundant recruitment experienced in 1991 would be unlikely in the face of such a release rate if hooking mortality was excessive. Therefore, an average hooking mortality of 10% was chosen to model abundance.

Although the abundance estimates and trends from the mark-recapture experiments cannot be mimicked exactly, the downward trend in the modeled abundance to 1992 probably reflects the true trend in abundance. It is not possible to estimate the exact reduction in the harvest necessary to arrest the projected decline in abundance and return the population to a level where the sustainable harvest is maximized; population parameter estimates for a complete cycle from hatching to maturity are needed for a more reliable estimate. According to the model, removals from Paxson Lake must be reduced

Table 13. Projected trends in abundance of lake trout from Paxson Lake with the imposition of a 62% reduction in the harvest in 1994.

Year	Abundance	Harvest	Hooking Mortality
1984	12,500		
1985	11,427	1,803	155
1986	11.287	944	81
1987	10,589	1,457	125
1988	10,052	1,310	113
1989	9,246	1,557	134
1990	7,808	2,139	184
1991	7,263	1,248	107
1992	6,458	1,494	128
1993	5,686	1,494	128
1994	5,766	568	221
1995	5,861	568	221
1996	5,944	568	221
1997	6,012	568	221
1998	6,044	568	221

by approximately 60% to arrest the decline in the abundance of the modeled population. The model does not account for any reduction in effort although some reduction is likely if further restrictions are imposed (Olver 1988).

The minimum length limit, implementation of a protected slot limit, further restriction of bag limits, seasonal closures and bait restrictions can be used to reduce harvest to within sustainable levels at Paxson Lake.

A change in the length limit could be an effective tool to reduce harvest while protecting more spawners. The minimum size limit in place for Paxson Lake was established to allow female lake trout to spawn at least once before they are exploited. Burr found that 50% of females in Paxson Lake were mature at a fork length of 426 mm (18.6 in TL). Theoretically, the length limit is achieving the stated goal. In practice, few female spawners under this size were captured in seine samples in 1991 (Szarzi 1992) and no females under this size were captured in 1992 (Appendix A4).

Sublegal fish which reached legal size following the imposition of the minimum length limit did not contribute significantly to the harvest from Paxson after 1988 (Figure 4). Whether the length limit protected enough spawners to increase the number of recruits into the fishery at Paxson Lake will not be known until 1993 when those recruits reach maturity. The relatively small number of 5 year olds in the harvest in 1992 indicates that the length limit did not add a significant number of recruits to the fishery.

Burr (1991b) states that a minimum length limit of 22 in TL (511 mm FL) would protect females in Paxson Lake through two spawning seasons and be more effective than the present size limit at reducing harvest. In 1992, 42% of spawning females in seine samples were under 511 mm FL while 39% of harvested females was less than 511 mm FL (Figure 5). The modal length of the harvest samples from Paxson Lake for 1991 and 1992 is also 22 in TL (508 mm FL). An increase in the minimum size limit to 22 in TL may not produce an adequate reduction in the harvest. A size limit larger than 22 inches or a size limit in concert with some other regulation may be necessary.

More restrictive size limits would increase the number of fish that were released and consequently the amount of hooking mortality. This added source of mortality might be offset by a decrease in effort, however.

Increasing the minimum length limit would disenfranchise anglers who like to keep small lake trout to eat. Protected slot limits would serve these anglers and might be successful at increasing the abundance of lake trout in Paxson Lake. Burr (1991b) states that the lake is a likely candidate due to its high productivity and high density of lake trout. He suggests a slot range where lake trout between 16 in TL and 30 in TL are protected. The proportion of the lake trout harvest less than 16 in TL in 1986 (36%) and the proportion of lake trout over 30 in TL (1%) indicate that this would also be a viable alternative for reducing harvest. A slot limit is probably not appropriate at this time because the abundance of immature lake trout has not been estimated. Increasing effort on this element of the population might reduce abundance by removing too much of the potential spawning stock needed to rebuild the population.

The elimination of bait could offset some of the increase in lake trout killed due to hooking, although its affect on harvest levels would be minimal.

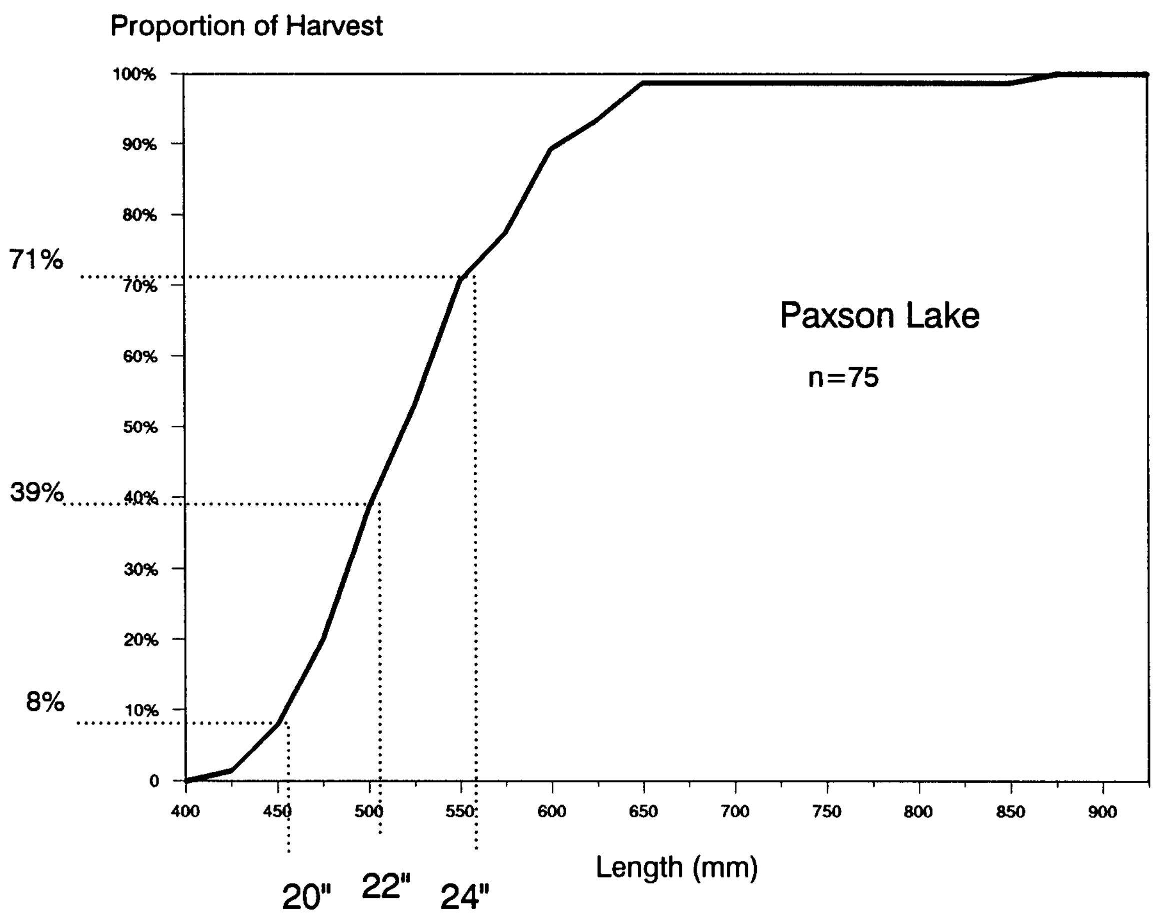

Figure 5. Cumulative frequency of lengths of female lake trout in harvests from Paxson Lake during 1992.

Anglers used bait or bait in combination with lures on only 9% of angler-trips on Paxson Lake.

A reduction in the bag limit to one fish would also do little to reduce the harvest; anglers kept two lake trout on 5% of angler-trips to Paxson Lake during 1992. A bag limit reduction could reduce the additional pressure which might be directed towards bigger lake trout if their abundance increases in the future.

An unknown but perhaps significant reduction in the harvest might be achieved by closure of the fishery in the spring until the lake stratifies. The largest portion of the fishery at Paxson Lake occurs as the ice melts away from the shoreline in the spring until the lake stratifies in early July. This alternative would accommodate those anglers who like to eat small fish but place a hardship on local businesses who benefit from the large influx of anglers during ice out through the July 4th holiday.

ACKNOWLEDGEMENTS

The author wishes to thank the technicians and biologists who assisted with field data collection and data entry: Kathy Adler, Shelley Peck, Ed Peck, Roger Jacobson, Suzanne McCarron, Rick Conklin, Pat Houghton, Dave Vozka, John Snow, Ben Tillotson, Randy Bachman, Mike Cross and Wade Willis. Thanks are due to the owners of the lodges at Lake Louise for their cooperation with the tag recovery program and the tagging operation. Thanks also to Dinty Bush Services for their assistance. The author is especially grateful to John Burr for his cooperation and Dr. Dave Bernard and Doug McBride for their guidance.

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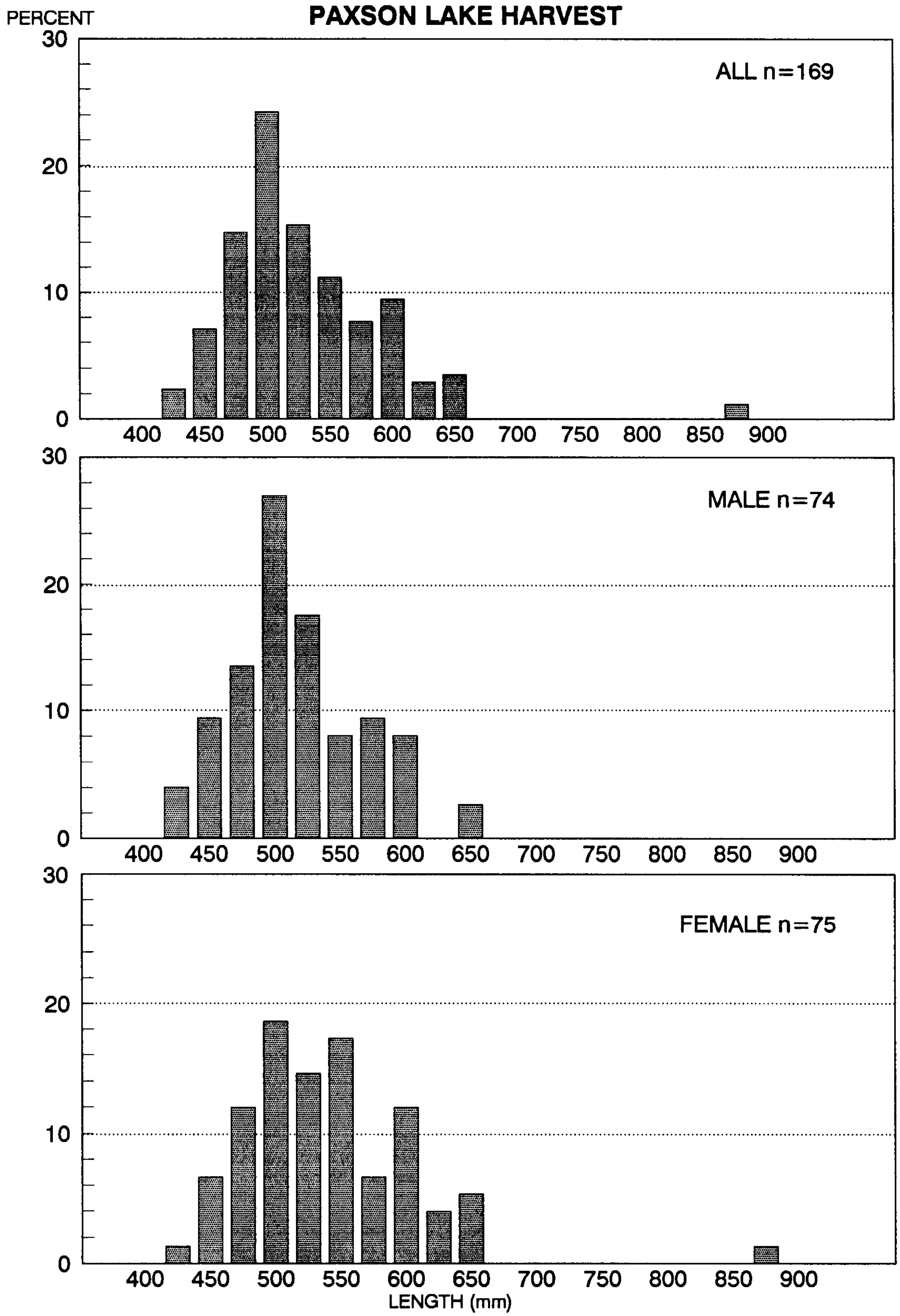
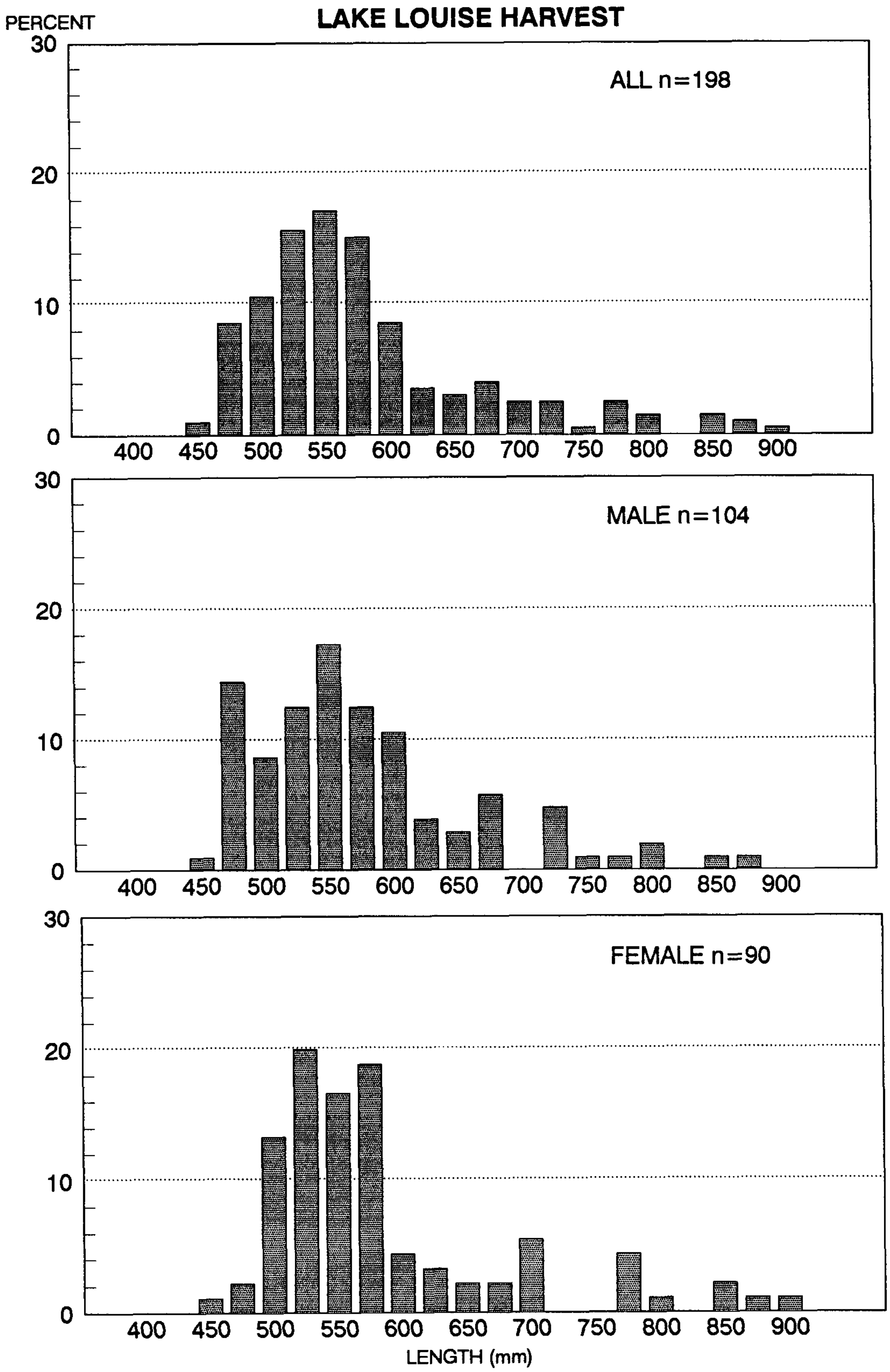
APPENDIX A

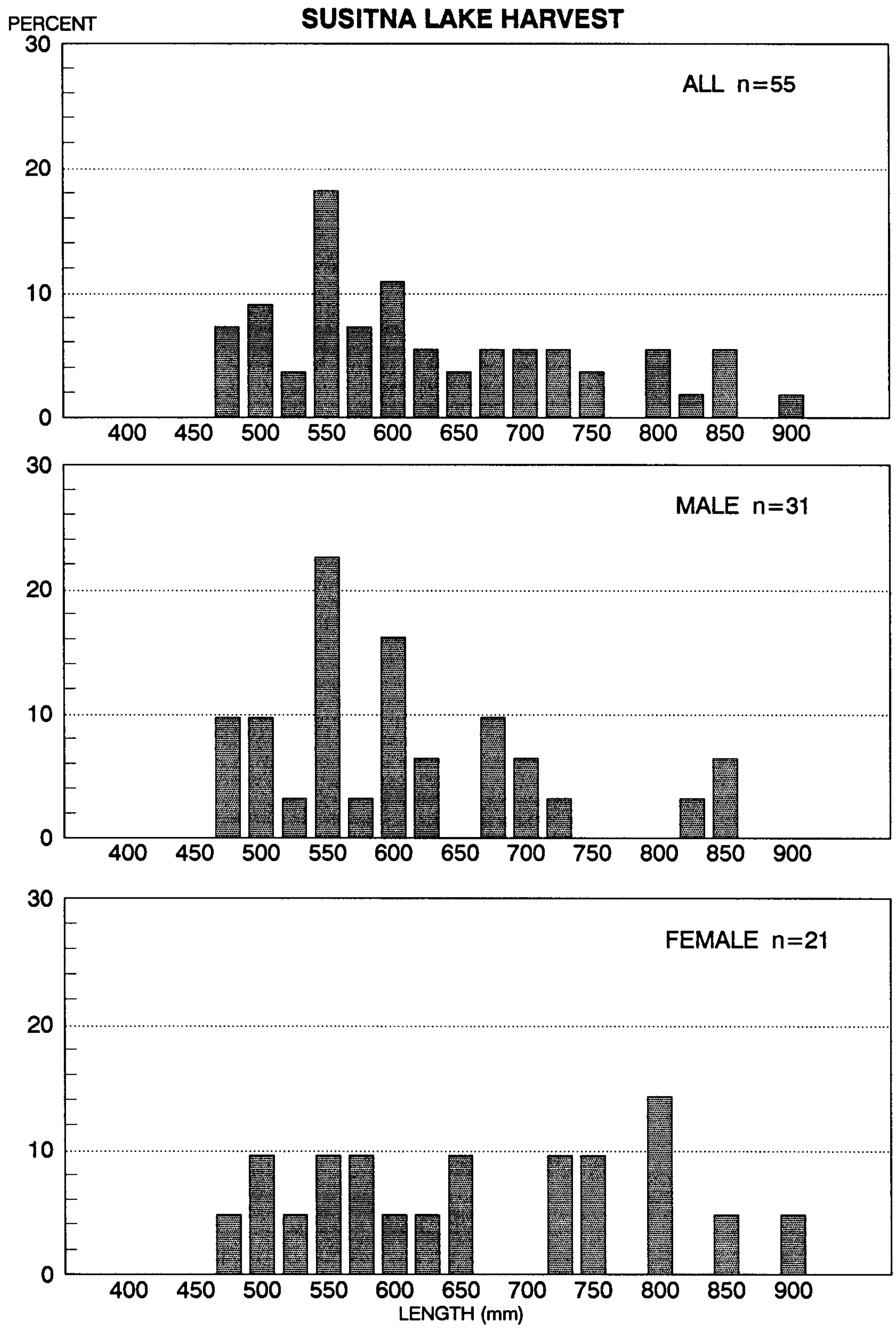
Length and age frequencies of harvested lake trout and length frequencies of spawning lake trout.



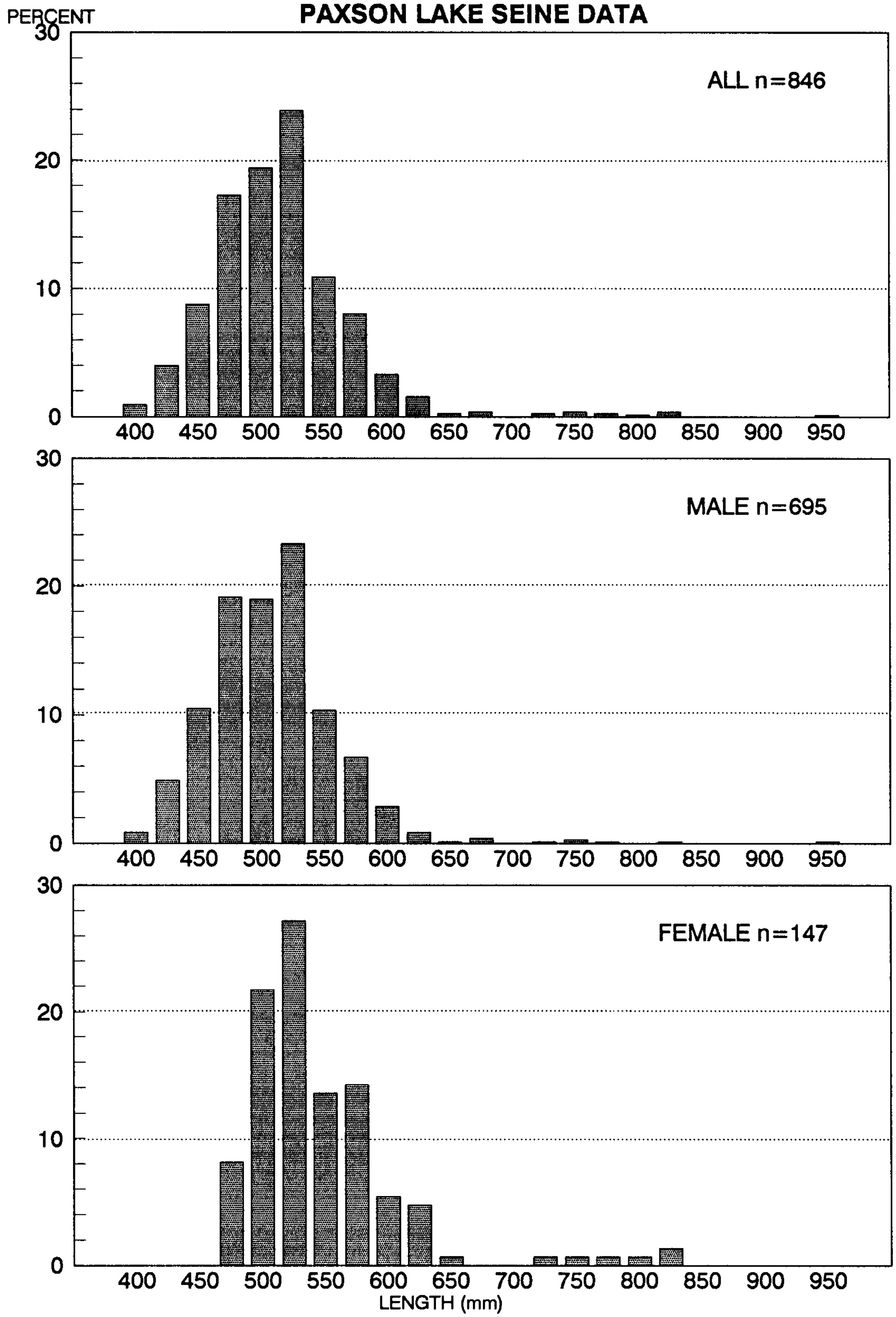
Appendix A1. Fork lengths of lake trout harvested from Paxson Lake, 1992.



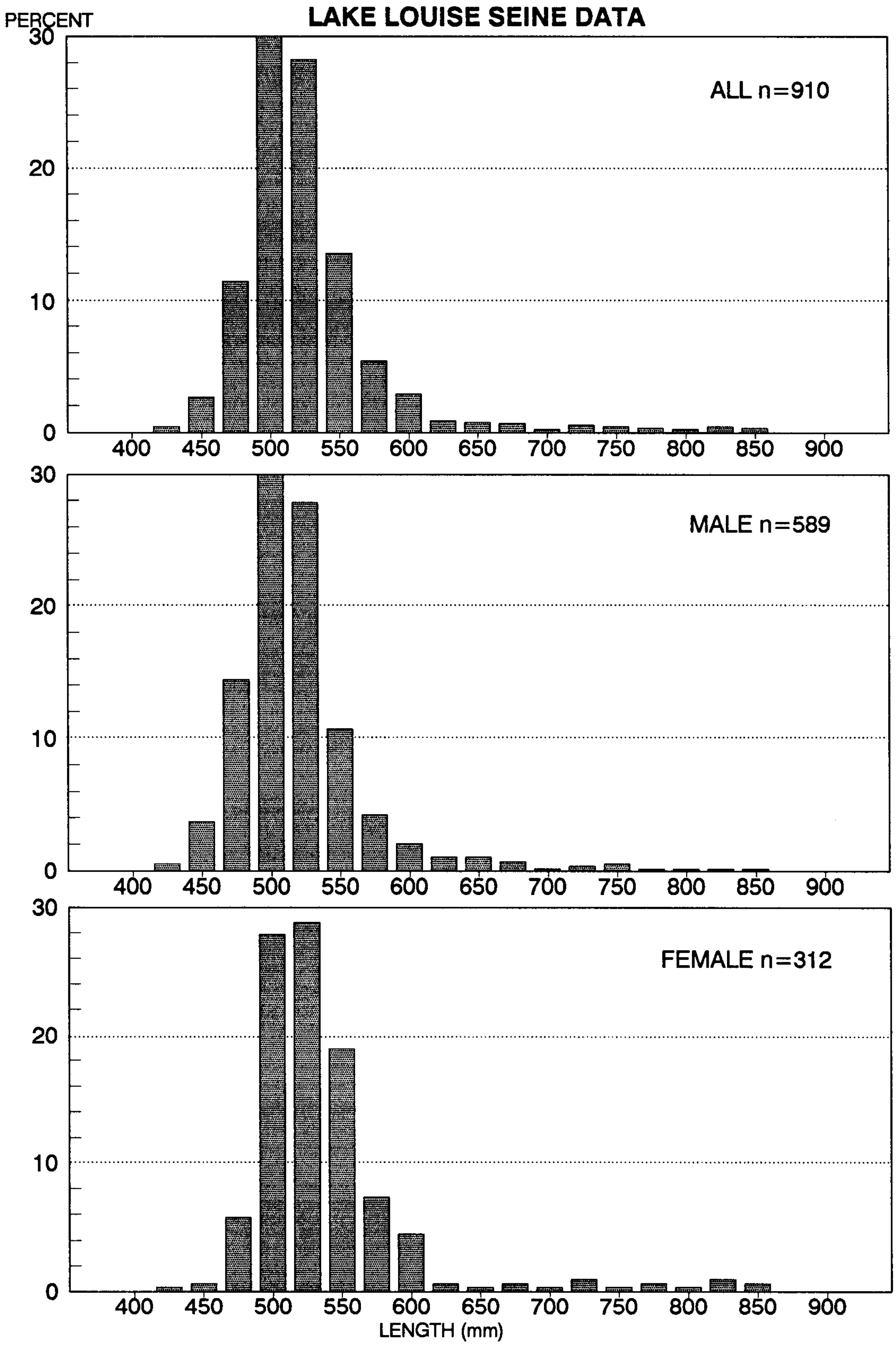
Appendix A2. Fork lengths of lake trout harvested from Lake Louise, 1992.



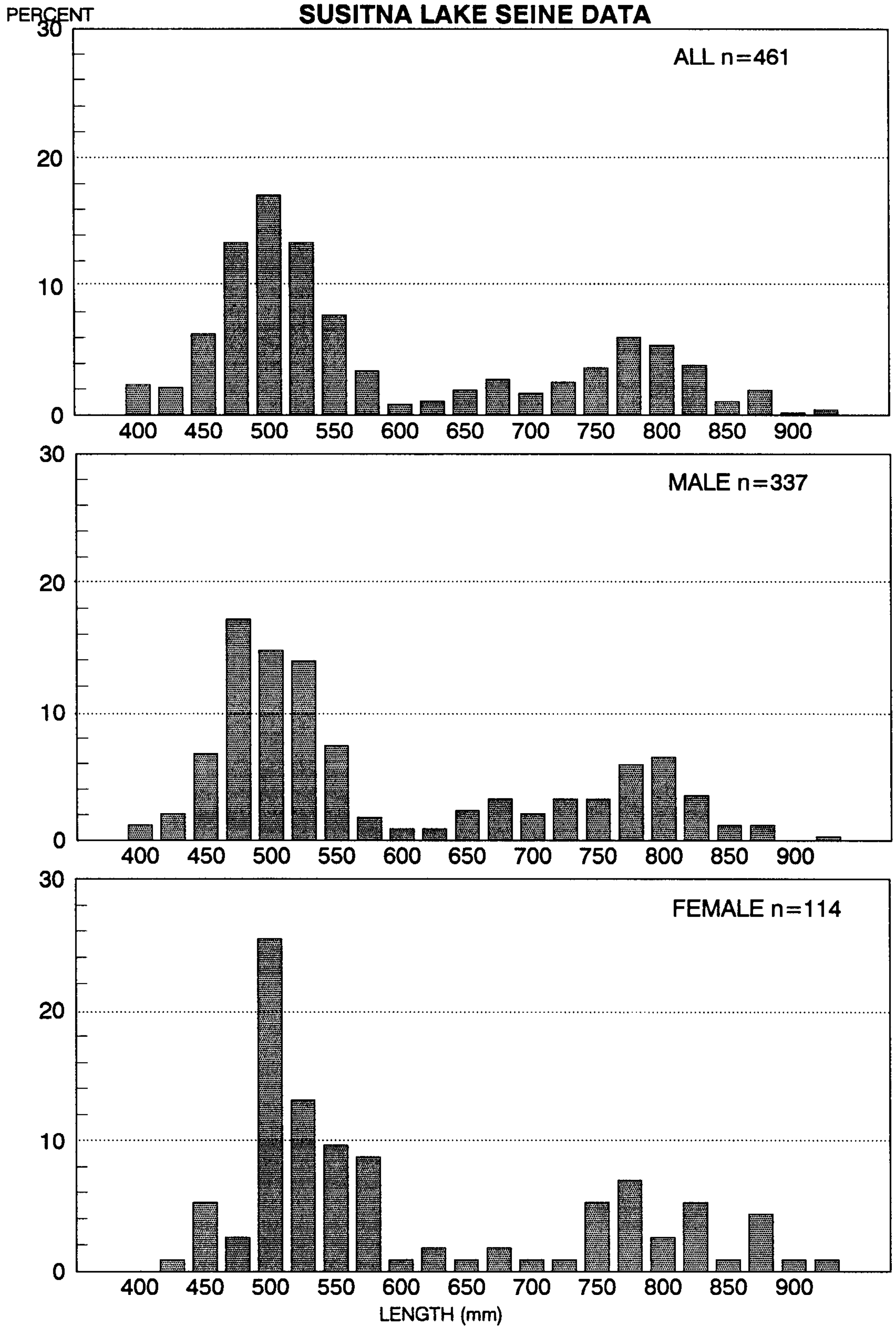
Appendix A3. Fork lengths of lake trout harvested from Susitna Lake, 1992.



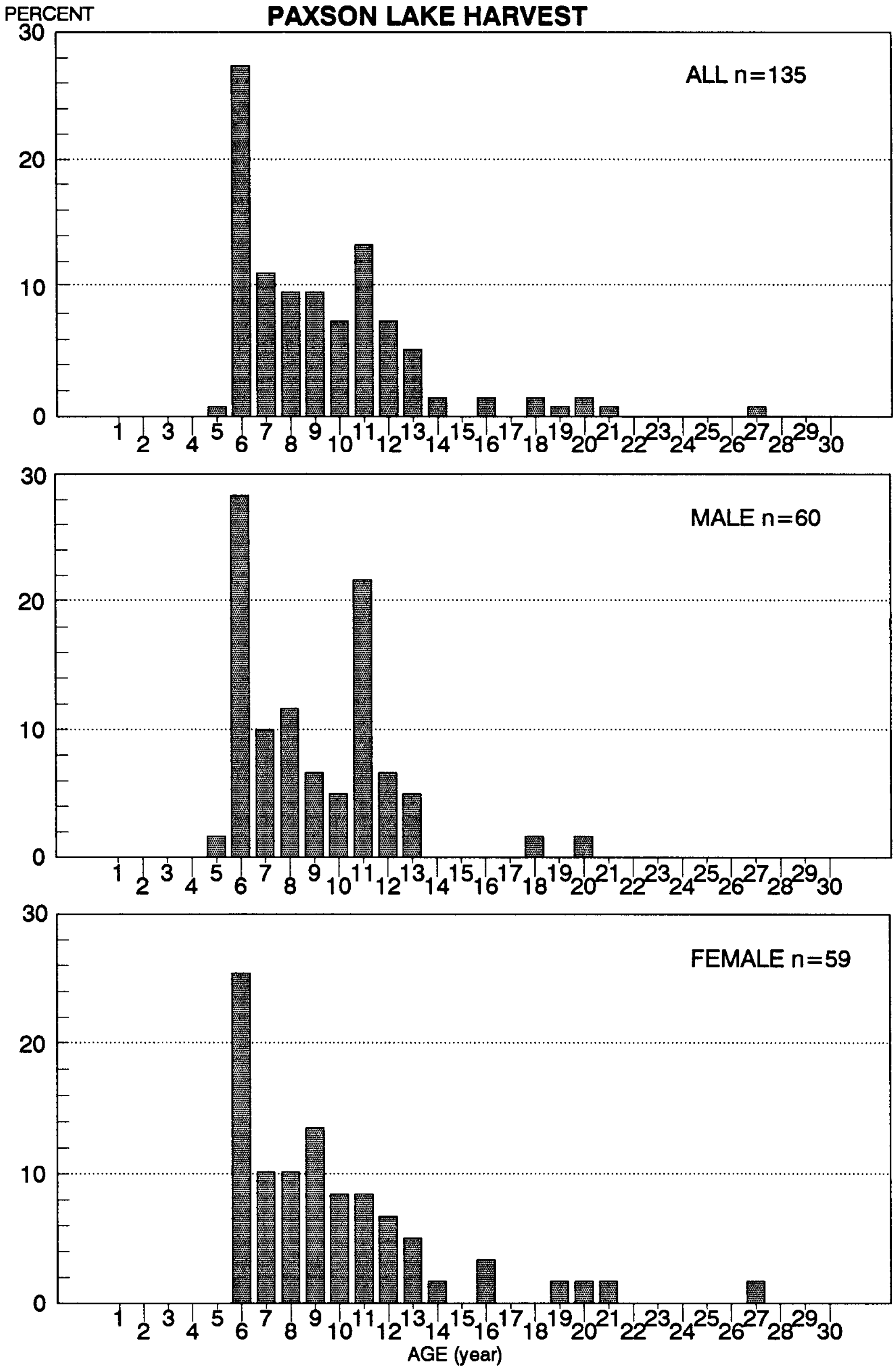
Appendix A4. Fork lengths of spawning lake trout captured by beach seine from Paxson Lake, 1992.



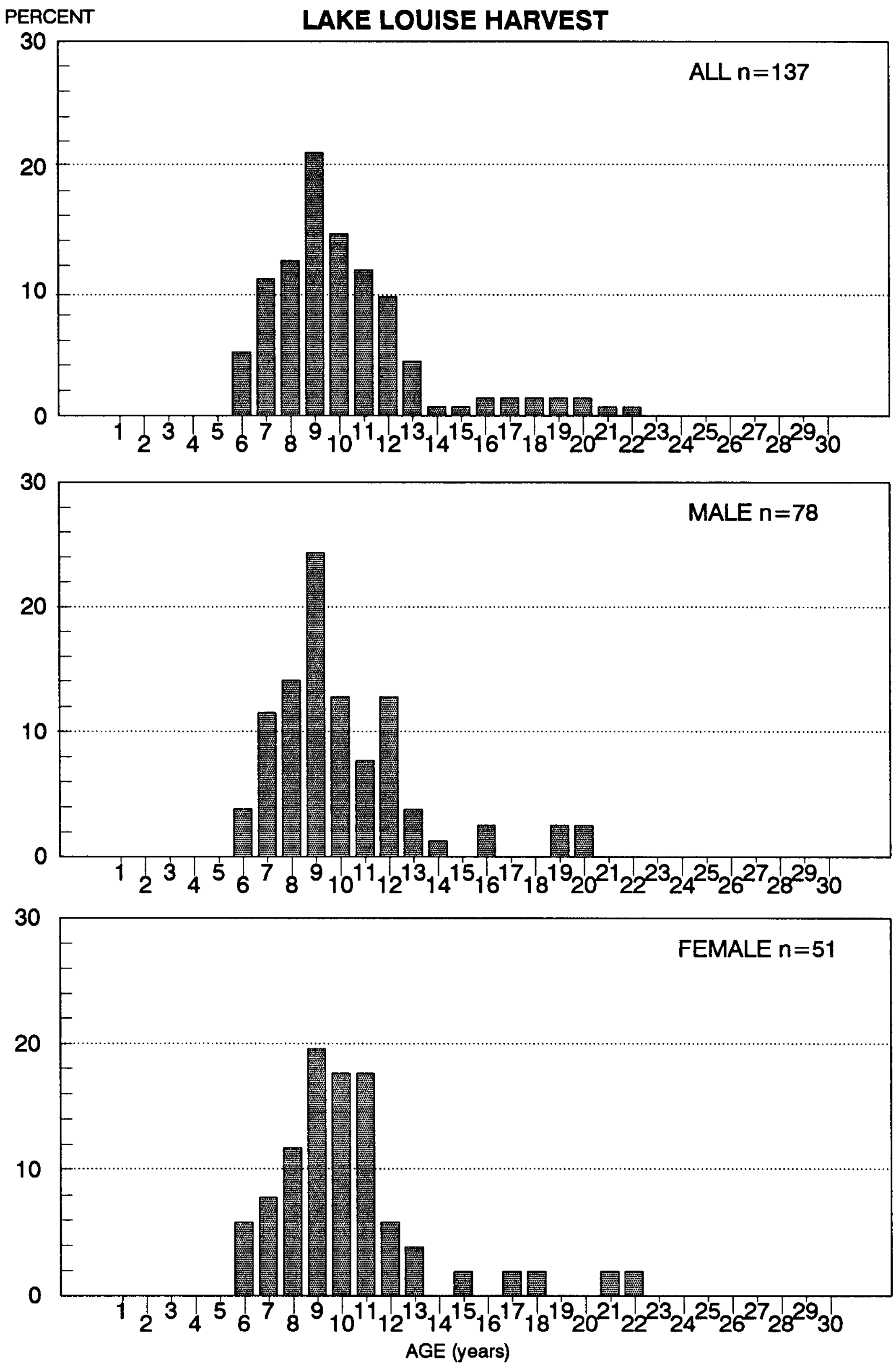
Appendix A5. Fork lengths of spawning lake trout captured by beach seine from Lake Louise, 1992.



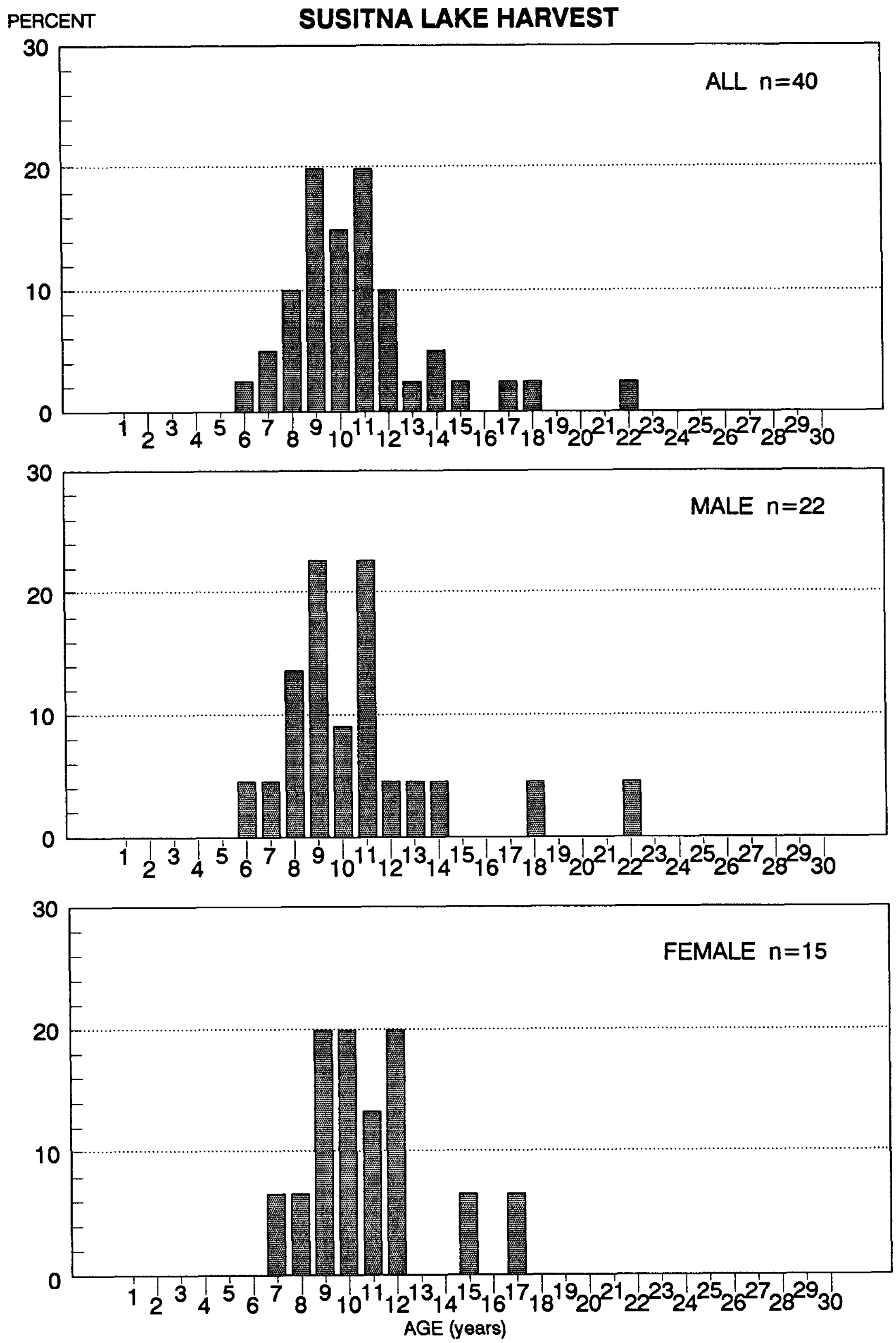
Appendix A6. Fork lengths of spawning lake trout captured by beach seine from Susitna Lake, 1992.



Appendix A7. The proportion of the harvest sampled from Paxson Lake in age categories, 1992.



Appendix A8. The proportion of the harvest sampled from Lake Louise in age categories, 1992.



Appendix A9. The proportion of the harvest sampled from Susitna Lake in age categories, 1992.