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by

Nicole Szarzi

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ABSTRACT

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

The experiment conducted at Paxson Lake in 1991 generated an estimate of abundance for 1990 of 3,817 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 marked-unmarked ratio of lake trout sampled from the harvest. The estimate from this method for 1990 is 6,686 mature lake trout. A significant decline in the number of mature lake trout in Paxson Lake occurred from 1988 to 1990.

The potential yield, estimated from the volume of water between 8° and 12° centigrade, was 1.74 kilogram hectare^{-1} year^{-1} for Paxson Lake and 0.4 kilogram hectare^{-1} year^{-1} for Lake Louise, based on an average weight from the harvest at each lake of 1.8 kg and 3.2 kg, respectively. The carrying capacity of Paxson Lake was estimated to be 30,000 lake trout with a maximum surplus production of 1,500 fish per year. Trends in the abundance in Paxson Lake were modeled using different regulatory options. Closure or a limit of one fish and no bait allowed the population to rebuild.

Lake trout were found to recruit into the fishery and into the spawning population a year later in Lake Louise than in Paxson Lake. Males harvested from Lake Louise weighed more than either males or females from the harvest at Paxson Lake.

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

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 1979 to 1991). Over 40% of the annual statewide harvest has been taken from the lakes and streams which drain into the upper Copper and upper Susitna rivers. Since 1984, harvest statistics have been available for the state's two largest lake trout sport fisheries, Paxson Lake and Lake Louise. Together, these two lakes have produced an average of 20% of the annual statewide harvest (Figure 1a). The annual harvest of lake trout from these two lakes has varied since 1984 (Figures 1b and 1c). The average annual harvest from Paxson Lake is estimated at 1,430 fish. The average harvest from Lake Louise since 1984 is estimated at 1,860 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 1987a). Age at maturity averages from 7 to 20 years in Alaska; maturity is later at more northerly latitudes (Burr 1987a). Lake trout do not generally 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, upper Copper and upper Susitna drainages upon determination that the harvests in some lakes exceeded guidelines for maximum sustained yield (Healy 1978) by as much as seven fold in the study lakes. A minimum harvestable size of lake trout was also established in 1987 which was intended to allow 50% of the population to spawn once before they were subject to harvest.

This study continues previous research into the structure, abundance, and sustainable yield of lake trout in Paxson Lake and extends research into lakes in the upper Susitna drainage. 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 in order to establish regulations which will maintain stocks while providing opportunities to anglers.

The specific objectives in 1991 were to:

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

2. estimate the abundance of spawning male lake trout in Lake Louise and Paxson Lake;

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

4. estimate the sex composition of lake trout in Lake Louise and Paxson Lake; and

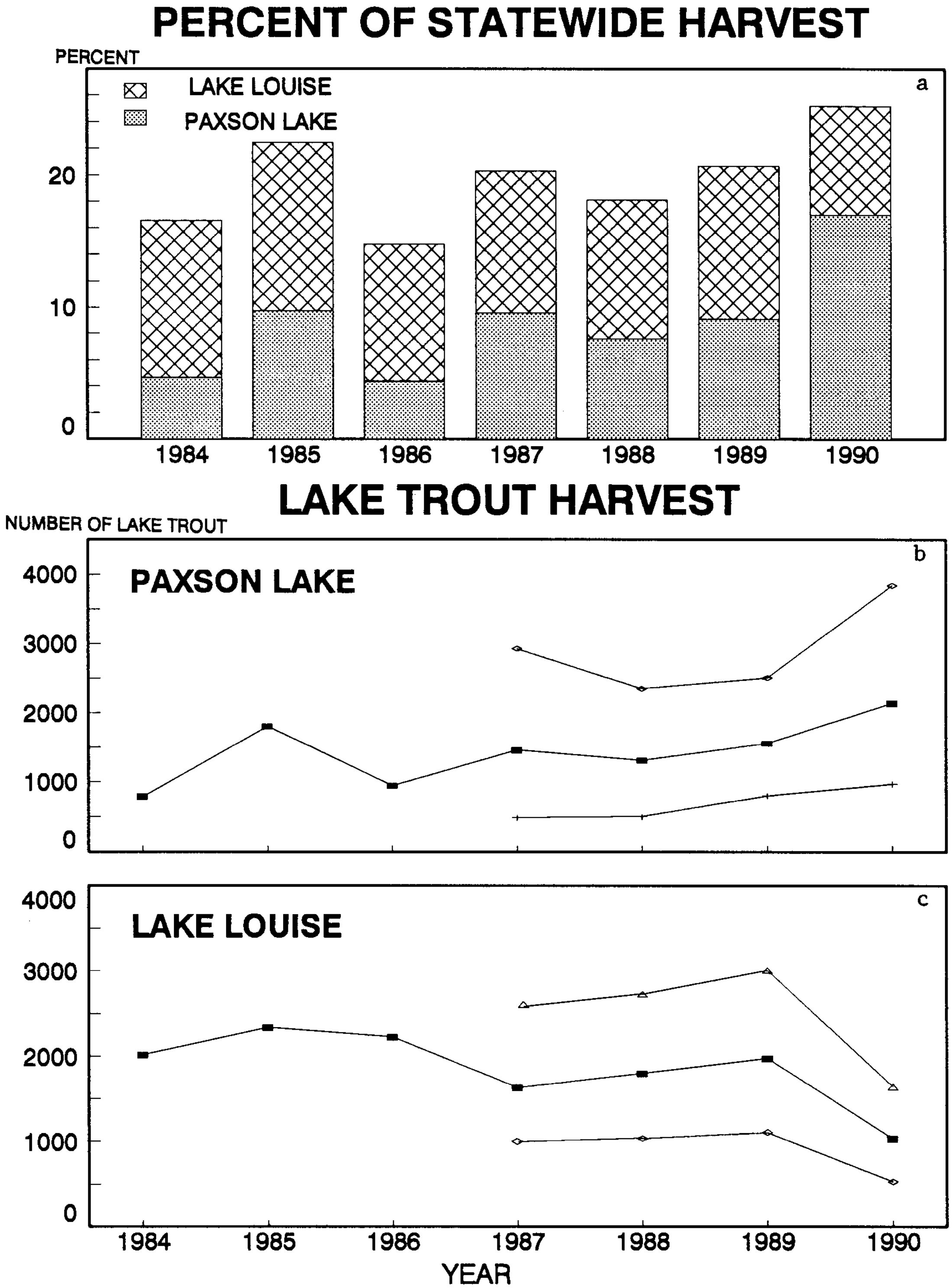

Figure 1. (a) Contribution of harvests from Lake Louise and Paxson Lake to the statewide harvest, (b) harvest of lake trout from Paxson Lake, 1984-1990, with 95% confidence interval, (c) harvest of lake trout from Lake Louise, 1984-1990, with 95% confidence interval.

5. estimate the mean length and mean weight of lake trout from the sport harvest at Lake Louise and Paxson Lake.

METHODS

Site Descriptions

Information was collected from two lake trout populations in Southcentral Alaska (Figure 2):

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 hectares 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.

Paxson Lake (62°50′ N, 145°35′ W) is located along the Gulkana River, 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 hectares with a maximum depth of 29 m and an elevation of 625 m. Numerous cabins are located along its shore. The Bureau of Land Management maintains a campground and boat launch on the lake.

Abundance Estimates

In the fall, lake trout gather on rocky lake shoals to spawn (Healy 1978, Martin and Olver 1980, Burr 1988). Previous department researchers have found adequate numbers of spawning fish to estimate population parameters using mark-recapture techniques (Burr 1989, 1990, 1991a).

The abundance, survival, and recruitment of spawning male lake trout in Paxson Lake were estimated with the Jolly-Seber model (Seber 1982). The model is based on the assumptions that there is complete mixing of marked and unmarked fish, equal mortality between marked and unmarked fish, and no loss of marks. Violations of closure are accommodated; mortality and recruitment may occur between sampling events. Large sample sizes are required and at least two prior annual sampling events are needed to generate estimates.

A year elapses between marking and recapturing spawning lake trout which is considered sufficient time to allow complete mixing to occur. Large numbers of fish can be captured and recaptured from spawning beds, fulfilling model requirements for large sample sizes. Sufficient numbers of fish have been marked in Paxson Lake each year since 1987 to generate estimates for 1988 through 1990. In 1991, large numbers of spawning fish from Lake Louise were marked for the first time. Abundance estimates for Lake Louise will be generated following sampling in 1993.

The number of spawning male lake trout is estimated by:

$$\hat{M}_i = \frac{z_i R_i}{r_i} + m_i \qquad (1)$$

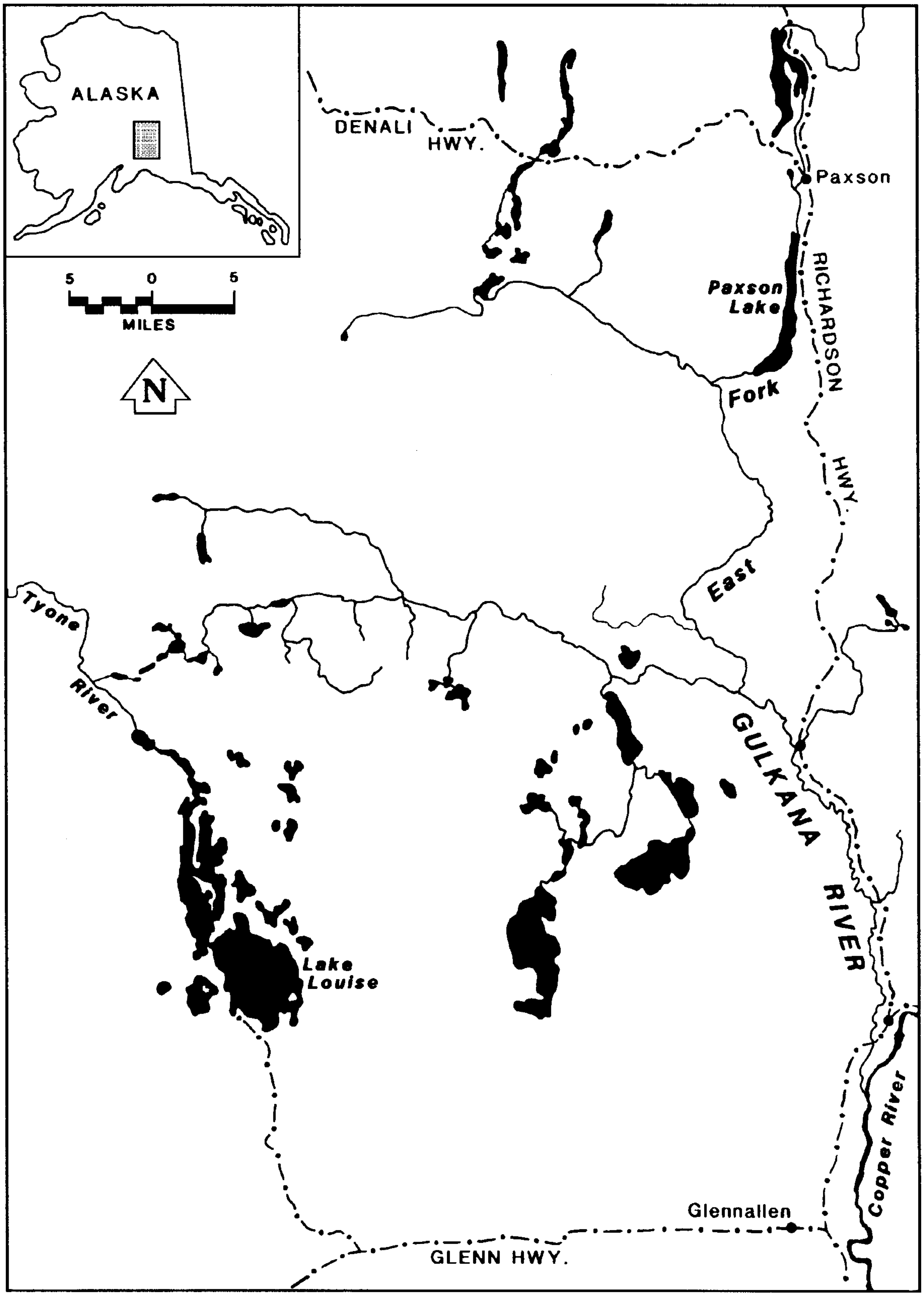

Figure 2. Location of lake trout study lakes, 1991.

where M_i = number of fish in the population just prior to the start of the i^{th} sampling event, z_i = number of marked fish in the population not recaptured during the i^{th} sampling event but recaptured in subsequent events, r_i = number of marked fish released during the i^{th} event that were subsequently recaptured, R_i = number of marked fish released during the i^{th} sampling event, and m_i = number of marked fish recaptured during the i^{th} sampling and released alive. The abundance of the population just before the i^{th} sampling event is estimated as:

$$\hat{N}_i = \hat{M}_i \frac{(m_i + u_i)}{m_i} \qquad (2)$$

where u_i = the number of unmarked fish in the sample. The estimated survival rate of marked fish between the i^{th} and (i+1) sampling events is:

$$\hat{S}_{i,i+1} = \frac{\hat{M}_{i+1}}{\hat{M}_i - m_i + R_i} . \qquad (3a)$$

Because the number of marked fish in the population just after the first sampling event is known, not estimated, the survival rate of marked fish between the first and second sampling events is estimated as:

$$\hat{S}_{1,2} = \frac{\hat{M}_2}{R_1} . \qquad (3b)$$

Recruitment to the population from any source (growth or immigration) between the i^{th} and (i+1) sampling events that are still alive just before the (i+1) event is calculated as:

$$\hat{A}_{i,i+1} = \hat{N}_{i+1} - \hat{S}_{i,i+1} \{\hat{N}_i - m_i - u_i + R_i\} . \qquad (3c)$$

The term $(m_i + u_i - R_i)$ adjusts the abundance estimate for any fish that are killed during a sampling event.

The variances of the parameters are calculated by bootstrapping the 1987-1991 capture histories of lake trout 400 times according to the procedures of Efron (1982) and Buckland (1980, 1982).

In 1987, fish were captured with gill nets and a beach seine in Paxson Lake. Since 1988, all lake trout have been captured by beach seine. All seining was conducted after dark and before 0600 hours.

The spawning population at Lake Louise was first sampled with beach seines in 1990 as part of a preliminary study to assess the feasibility of capturing spawning fish for marking and recapturing. A sample of 300 fish was tagged during the 19 to 21 September sampling period.

Beginning 4 and 5 September 1991, lake trout were observed on spawning beds in Lake Louise and Paxson Lake, respectively. Beds were sampled throughout each night when weather permitted until 23 September on Lake Louise and 17 September on Paxson Lake. 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. Fish were captured from Paxson Lake with a 46 m X 3 m X 9.5 mm (150 ft X 10 ft X 3/8 in) seine.

Previously identified spawning beds (Scott Meyer, Alaska Department of Fish and Game, Anchorage, personal communication; John Burr, Alaska Department of Fish and Game, Fairbanks, personal communication) were numbered consecutively. Sampling began at the bed identified by a random number and proceeded in a systematic fashion each evening. 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 fork length, 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 from the Lake Louise population and a hole was punched in the left ventral fin of fish from Paxson Lake 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.

Sex Composition of the Harvest

Annual recapture rates of female lake trout from Paxson Lake between 1987 and 1990 indicate that females were not present during the entire spawning season or that females do not spawn every year (Burr 1991a). In either case, the assumption of equal probability of capture for spawning female lake trout is violated in Paxson Lake. To correct for this bias, the sex ratio in Paxson Lake was assumed to be 1:1 and estimates of abundance of male lake trout were doubled to determine the population size and mortality parameters for 1988 and 1989 (Burr 1991a).

During the latter part of the ice fishing season and the spring fishery, lake trout were sampled from the harvest at Lake Louise and Paxson Lake to estimate the sex composition of the population.

The estimated sex ratio was applied to the abundance of males determined from the mark-recapture experiments to predict the total size of the spawning population. Abundance of all mature lake trout was estimated by dividing the number of males by the fraction of males in the population:

$$N_t = \frac{N_m}{p} \tag{4}$$

where N_t is the estimated abundance of mature fish, N_m is the estimated abundance of males only, and p is the estimated fraction of the population comprised of males. The variance for N_t is approximated by the delta method:

$$V[N_t] \approx N_t^2 \left[\frac{V[N_m]}{N_m^2} + \frac{V[p]}{p^2} \right] = N_t^2 \{CV^2 [N_m] + CV^2 [p]\}. \tag{5}$$

Other Population Parameters

Age, weight, and fork length data were obtained from the sport harvest from Lake Louise and Paxson Lake. Mean length, weight, and age were estimated with standard normal procedures.

Sustainable Yield

Summer temperature regimes are thought to limit lake trout abundance. In a study of 15 large lakes in Canada, 10-day averages of the volume of the water between 8° and 12° C were summed over a summer. This thermal habitat volume (THV) explained 86% of the variability in lake trout harvests (Christie and Regier 1988). Payne et al. (1990) developed a relationship between the THV measured in July and harvest. The model is effective for lakes >100 hectares which have fairly stable temperature regimes with an historically stable harvest and moderate to high fishing pressures. One to two temperature profiles were required to estimate the depth of the lens of water 8° to 12° C.

Measurements of the water temperature were taken at four locations on Lake Louise during 1 day in July and at three locations during 2 days in August. At Paxson Lake, water temperature profiles were measured at five locations during 2 days in July and two locations during 2 days in August. Measurements were made at 2.5 m intervals to the bottom of the lake at each sample location. An average temperature at each 2.5 m depth interval was calculated for each month.

The volume of the lake where the depth contours are intersected by the water lens that is between 8° and 12° C is determined from the formula:

$$V = \frac{(D_2 - D_1)(A_1 + A_2 + (A_1 \times A_2)^{.5})}{300} \qquad (6)$$

where D refers to depth and A refers to area.

The potential MSY in kg gr^{-1} was calculated from:

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

Estimates of MSY from knowledge of THV along with estimates of the intrinsic rates of increase (r) were used to estimate carrying capacity (K) of each lake and subsequently the sustainable yield of lake trout. Equations taken from Gulland (1983) of surplus production (SP) as a function of biomass (B) were used:

$$SP = rB\left(1 - \frac{B}{K}\right) \qquad (8)$$

where:

$$MSY = \frac{rK}{4} \qquad (9)$$

and:

$$r = 1.2\ M \tag{10}$$

where M is an estimate of this instantaneous rate of natural mortality.

The biomass of the harvest was estimated from the mean weight of fish sampled from the sport fishery.

RESULTS

Sex Ratios

A sample of 138 lake trout was collected from the harvest at Paxson Lake; 75 were males. Of 145 fish collected from the harvest at Lake Louise, 68 were males. The proportion of male lake trout in Paxson Lake, estimated from the harvest, was 0.54. The estimated proportion of male lake trout in Lake Louise was 0.47.

A test that the sex ratios from Paxson Lake and Lake Louise were not significantly different from 50:50 was accepted ($X^2_{Paxson} = 1.04$, $X^2_{Louise} = 0.56$, $P<0.05$, $df = 1$).

Abundance Estimates

The abundance of spawning male lake trout in Paxson Lake in 1990 was estimated to be 2,061 (95% confidence interval: 1,817 to 2,412) (Table 1).

It is estimated that there were 3,130 (95% confidence interval: 2,455 to 3,500) males prior to sampling in 1988 and 2,619 (95% confidence interval: 2,353 to 2,979) males prior to sampling in 1989. In 1987, 251 males were captured; 214 were released with tags (Table 2). Of 842 male lake trout captured in 1988, 813 were released with tags. During sampling in 1989, 847 males were captured and 819 were released with tags. In 1990, 693 males were captured, and 654 were released with tags; and in 1991, 961 males were tagged and 960 were released with tags.

The estimates of abundance for spawning male lake trout (Table 1) were significantly lower in 1990 (2,061) than in 1988 (3,130).

The abundance of mature lake trout in Paxson Lake in 1990 was extrapolated from the number of males divided by the proportion of males present in the harvest. The estimated abundance of mature lake trout was 3,817 fish (Table 1).

The proportion of males in the population was assumed to be 0.5 for 1988 and 1989 (Burr 1991a). The abundance of mature lake trout in Paxson Lake, before sampling in 1988, was estimated to be 6,260 fish. For 1989, the estimate was 5,238 mature fish.

The assumption that random mixing occurs between sampling events was tested in Lake Louise by examining recapture ratios of fish first tagged in 1990 and recaptured in 1991. The spawning beds in the southern end of Lake Louise were

Table 1. Population parameter estimates and their standard errors for lake trout from Paxson Lake, 1987-1990.

	Abundance		Harvest			Instantaneous Rates			
	Males	Total	Males	Total	Percent (males)	Survival S	Total Mortality Z	Fishing Mortality F	Recruits (males)
1987	----	----	729[a]	1,457	0.50[a]	0.68	0.39	----	----
			(328)	(655)		(0.06)			
1988	3,130	6,260	655[a]	1,310	0.50[a]	0.84	0.17	0.23	0
	(284)	(568)	(249)	(498)		(0.04)			(181)
1989	2,619	5,238	779[a]	1,557	0.50[a]	0.76	0.27	0.34	94
	(158)	(316)	(221)	(441)		(0.05)			(84)
1990	2,061	3,817	1,155	2,139	0.54	----	----	----	-----
	(141)	(398)	(370)	(740)	(0.042)				

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

Table 2. Male lake trout captured, marked, and recaptured in Paxson Lake, 1987-1991.

	Number of Lake Trout				
	1987	1988	1989	1990	1991
First marked in:					
1987	0	39	38	8	8
1988	0	0	214	212	77
1989	0	0	0	214	120
1990	0			0	198
1991	0				0
Captured with tags	0	39	252	343	403
Captured without tags	251	803	595	350	558
Total captured	251	842	847	693	961
Released with tags	214	813	819	654	960
Released without tags	0	0	0	0	1
Total released	214	813	819	654	961

grouped because of their proximity to one another (Figure 3). A second grouping consisted of the beds in the west-central part of the lake. A test of the hypothesis that the recapture ratios of lake trout were the same for each group of spawning beds was accepted ($Z = -0.35$ $P<0.05$, df = 1) (Table 3).

There is evidence that lake trout return to the same areas where they have previously spawned. The location of recapture in 1991, for fish first captured in 1990, was the same for 159 out of 168 males in Lake Louise (Table 4). Of 19 female trout first captured in 1990, 18 were recaptured in the same spawning area in 1991.

The spawning areas in Paxson Lake were grouped according to their location in the southern or northern end of the lake (Figure 4). Recaptures of lake trout from the same spawning area occurred 461 of 465 times during the 1987 to 1990 time periods.

Survival, Mortality, and Recruitment

Survival rates (S) were estimated for male lake trout in Paxson Lake between 1987 and 1988, 1988 and 1989, and between 1989 and 1990 (Table 1). The estimates did not differ significantly (^{L} = 0.05) from one another.

Instantaneous total mortality rates (Z) were estimated and used, along with catches from the statewide harvest survey (Mills 1988-1991), to estimate fishing mortality rates (F) (Table 1). Estimated fishing mortality rates were larger than total mortality rates.

No male lake trout recruited into the spawning population between 1988 and 1989. Male recruits numbered 94 fish between 1989 and 1990. The estimates were not significantly different (^{L} = 0.05).

Length and Weight Information

The fork lengths of 132 lake trout from the harvest at Paxson Lake were measured during the period 27 April to 7 July (Table 5 and Figure 5). A total of 149 fish were measured from the harvest at Lake Louise between 10 May and 2 July (Table 5 and Figure 6). The average male lake trout from Paxson Lake was smaller in length than the average female (^{L} = 0.05). Conversely, the mean length of male lake trout from Lake Louise was greater than the lengths of males or females from Paxson Lake (^{L} = 0.05).

The fork lengths of 1,224 lake trout were measured from the spawning population in Paxson Lake (Figure 7). Lengths were collected from 862 lake trout captured in Lake Louise (Figure 8). Female spawners from Paxson lake were larger, on average, than males in Paxson Lake and males in Lake Louise (^{L} = 0.05) (Table 6).

Lake trout from the harvest at Paxson lake weighed 1.83 kg on average (Table 6). The mean weight of the catch sample from Lake Louise was 3.19 kg. Harvested males from Lake Louise weighed significantly more than either males or females from the harvest at Paxson Lake (^{L} = 0.05).

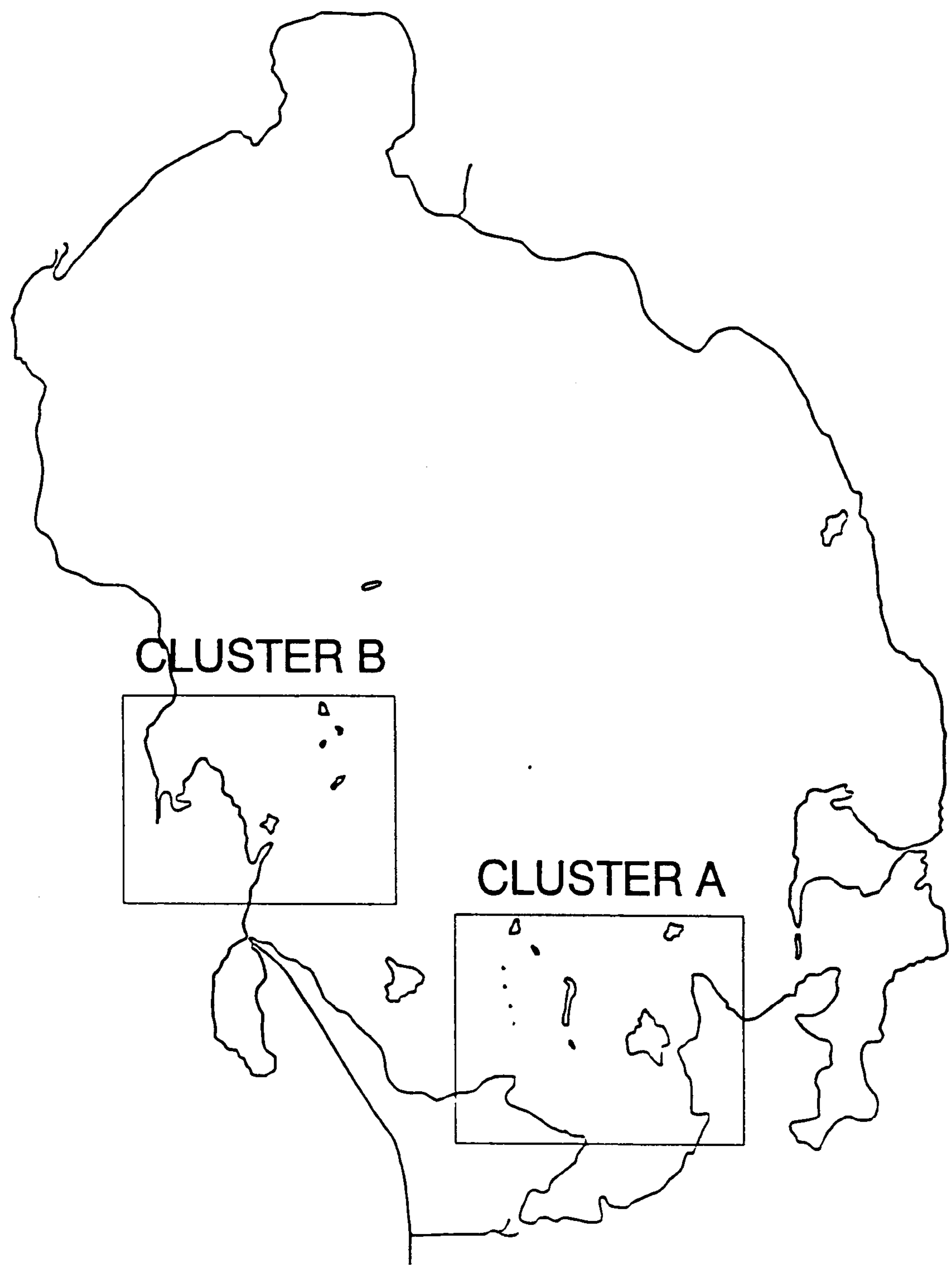

Figure 3. Location of spawning area clusters in Lake Louise.

Table 3. Recapture rates of fish tagged in 1990 and recaptured in 1991 in Lake Louise.

	Male		Female		Male	Female
Cluster	r_i[a]	c_i[b]	r_i	c_i	r_i/c_i	r_i/c_i
A	23	188	1	60	0.12	0.02
B	69	494	8	118	0.14	0.07

[a] r = Number of lake trout recaptured.

[b] c = Number of lake trout caught.

Table 4. Inseason capture and recapture of lake trout at spawning areas in Lake Louise, 1991.

	MALES	
	RECAP A	RECAP B
TAGGED A	32	9
TAGGED B	0	127
	FEMALES	
	RECAP A	RECAP B
TAGGED A	2	0
TAGGED B	1	16

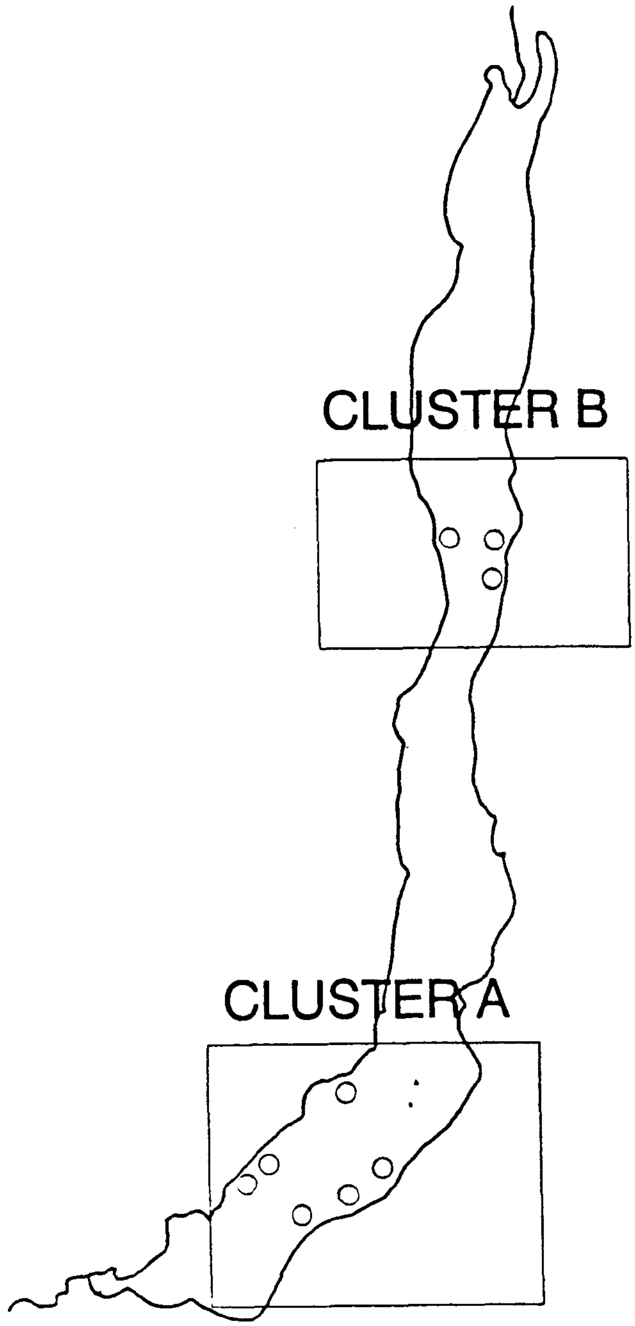

Figure 4. Location of spawning area clusters in Paxson Lake.

Table 5. Length, weight and age characteristics of harvest samples from Paxson Lake and Lake Louise, 1991.

	Paxson Lake			Lake Louise		
	Female	Male	All	Female	Male	All
LENGTH (mm)						
mean	550	511	532	563	594	585
sample size	60	71	132	72	65	149
standard deviation	63.1	85.2	62.1	85.6	111.0	110.8
95% upper confidence interval	566	532	543	583	621	603
95% lower confidence interval	534	492	522	543	567	568
maximum	737	660	737	860	918	940
minimum	445	419	419	465	456	400
WEIGHT (kg)						
mean	2.01	1.64	1.83	2.66	3.12	3.19
sample size	45	52	98	21	20	48
standard deviation	0.85	0.72	0.77	1.89	2.30	2.34
95% upper confidence interval	2.26	1.84	1.98	3.47	4.13	3.86
95% lower confidence interval	1.77	1.45	1.68	1.85	2.11	2.53
maximum	5.50	4.10	5.50	8.00	8.70	8.80
minimum	1.00	0.80	0.80	1.30	1.35	1.05
AGE (yr)						
mean	12	11	11	13	11	12
sample size	39	51	91	50	55	110
standard deviation	7.2	5.4	6.1	4.3	3.4	4.0
95% upper confidence interval	15	12	13	14	12	13
95% lower confidence interval	10	9	10	12	10	11
maximum	30	25	30	22	20	22
minimum	6	5	5	7	6	7

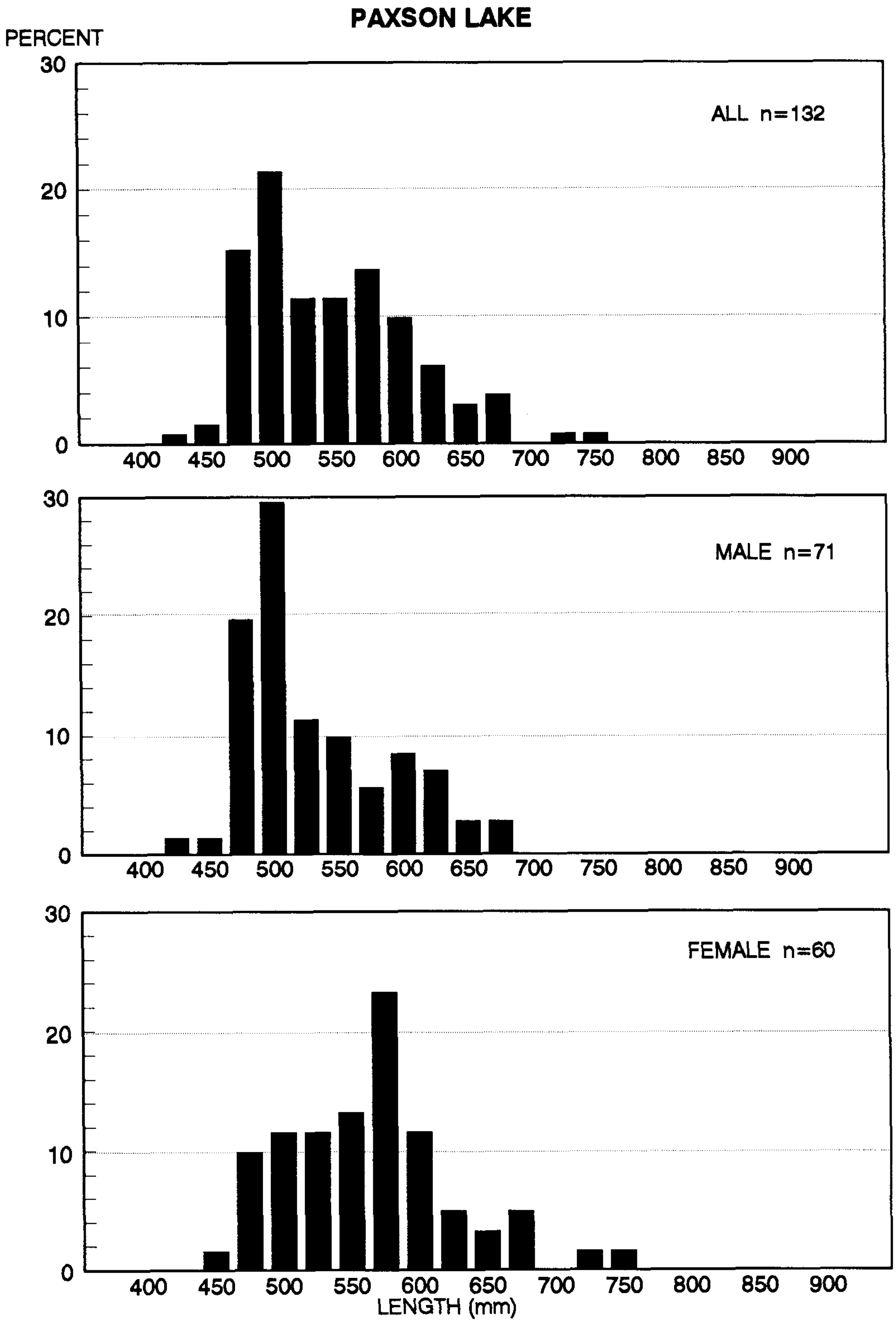

Figure 5. Fork lengths of lake trout harvested from Paxson Lake, 1991.

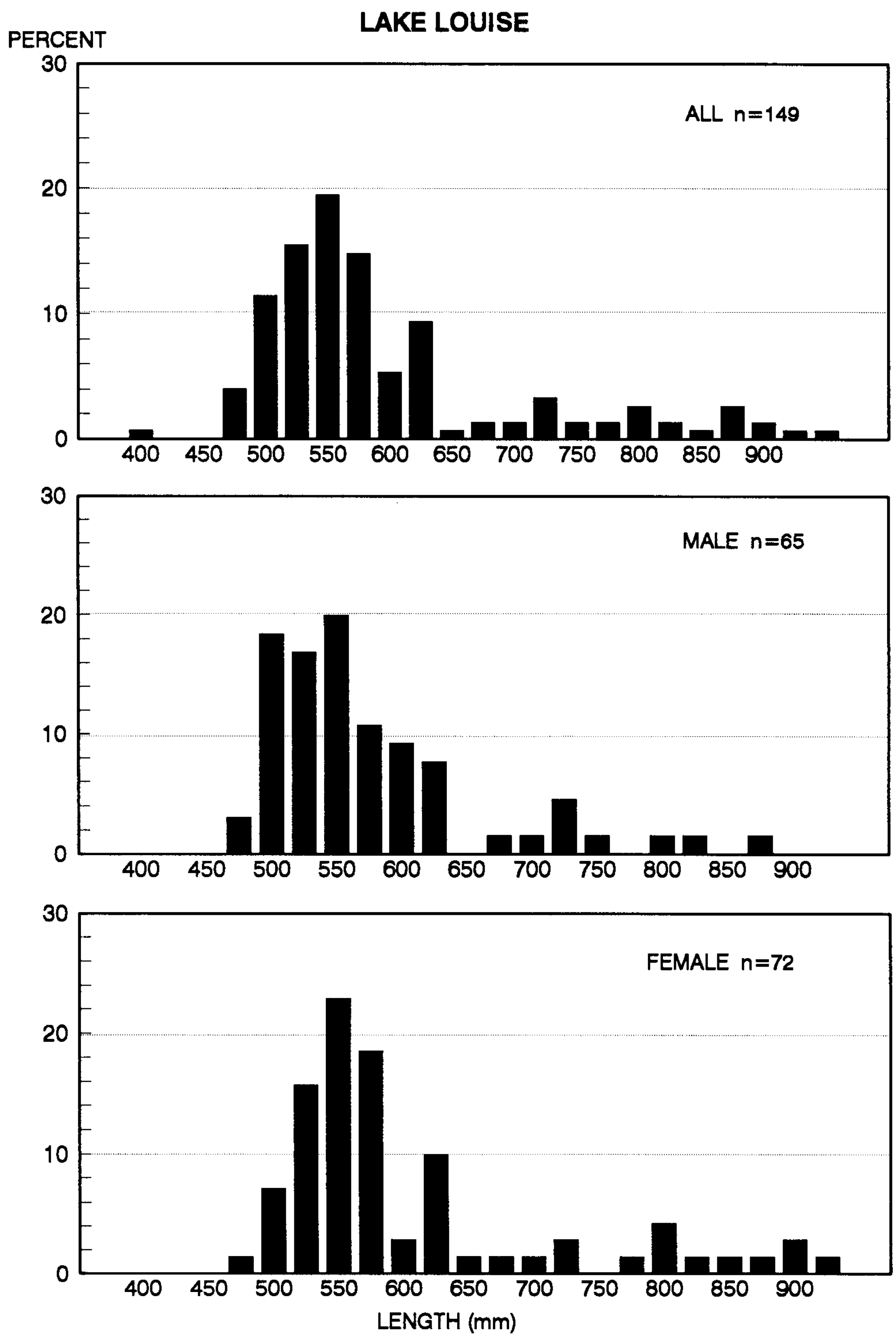

Figure 6. Fork lengths of lake trout harvested from Lake Louise, 1991.

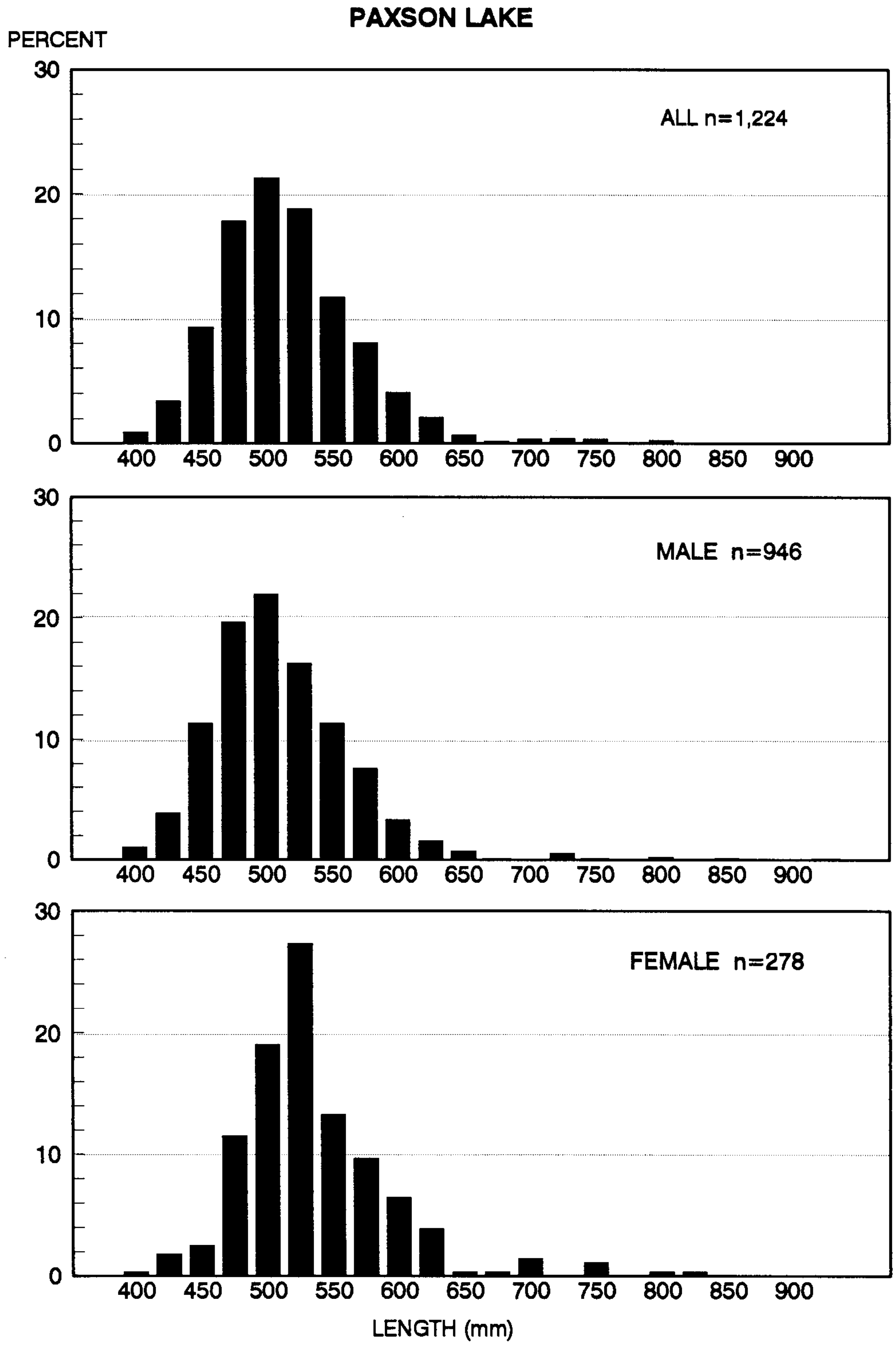

Figure 7. Fork lengths of spawning lake trout captured by beach seine from Paxson Lake, 1991.

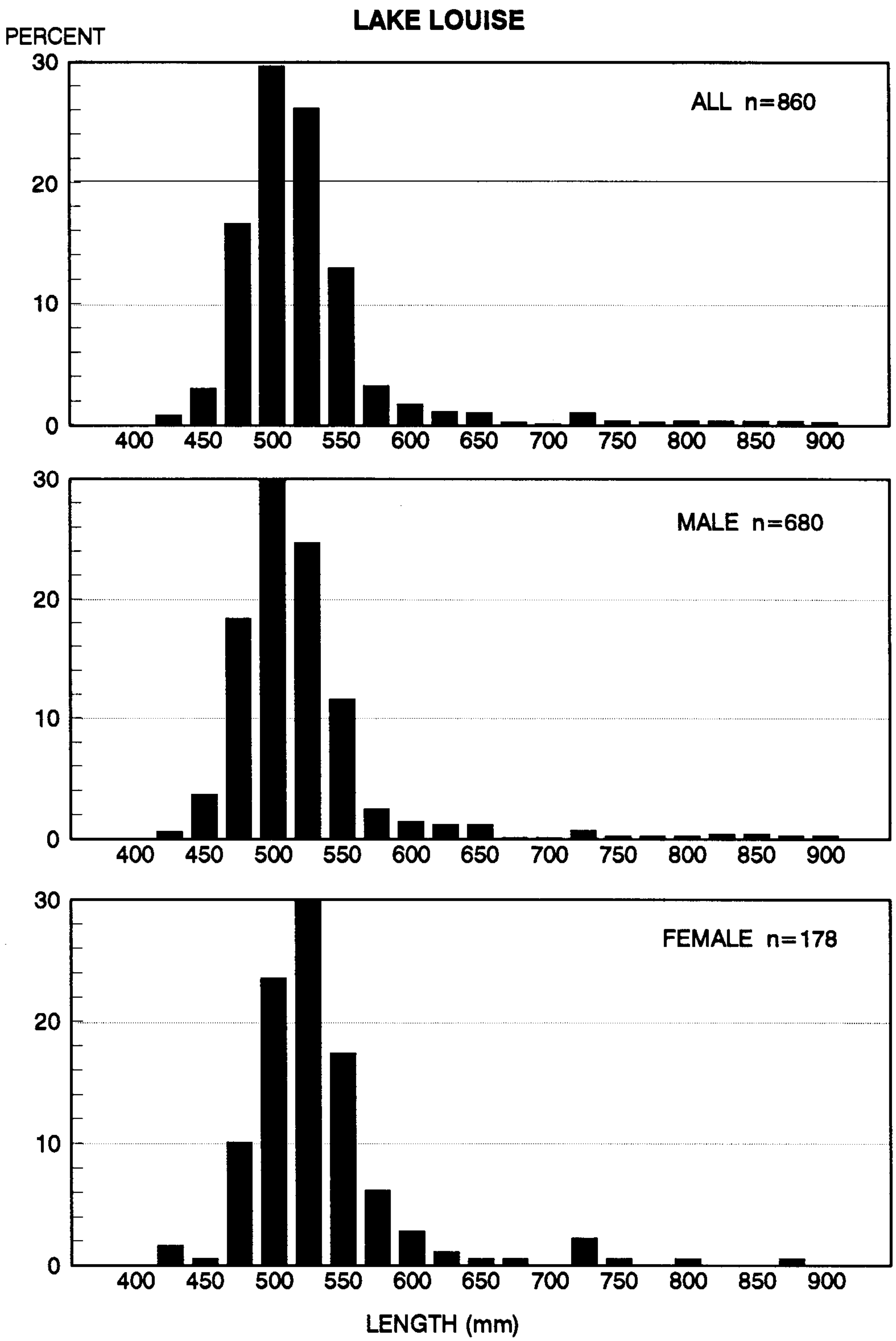

Figure 8. Fork lengths of spawning lake trout captured by beach seine from Lake Louise, 1991.

Table 6. Length characteristics of spawning lake trout from seine samples from Paxson Lake and Lake Louise, 1991.

	Paxson Lake			Lake Louise		
	Female	Male	All	Female	Male	All
LENGTH (mm)						
mean	524	498	510	521	509	512
sample size	278	946	1,224	178	683	862
standard deviation	58.8	55.2	57.0	58.9	63.1	62.4
95% upper confidence interval	530	510	514	530	513	516
95% lower confidence interval	517	495	508	512	504	508
maximum	804	918	918	857	897	897
minimum	399	382	399	521	408	406

Age Structure

Otoliths were used to age lake trout sampled from the harvest at Paxson Lake and Lake Louise (Figures 9 and 10). A wider range of ages was found in the harvest from Paxson Lake (Table 5). Mean ages of harvested lake trout from the two lakes did not differ significantly ($\alpha = 0.05$). Lake trout appear to recruit into the harvest a year earlier in Paxson Lake than in Lake Louise. Females appear to recruit a year later than males in both populations.

Yield Estimates

The data from July from both lakes yielded the least variable mean temperature measurement over all depths and were used to calculate the THV. The THV was 63.8 cubic hectometers (hm^3) for Paxson Lake and 52.6 hm^3 for Lake Louise. The potential harvest, estimated from equation (7), is 2,747 kg y^{-1} or 1.74 kg h^{-1} y^{-1} for Paxson Lake. For Lake Louise, the estimate was 2,393 kg y^{-1} or 0.4 kg h^{-1} y^{-1}. The harvest from Paxson Lake in 1990 was 3,850 kg or 2.4 kg h^{-1} based on the average weight of 1.8 kg estimated from the harvest in 1991. The 1990 harvest of lake trout from Lake Louise was 1,036 fish, 3,324 kg or 0.51 kg h^{-1}, based on the average weight of 3.2 kg estimated from the harvest. Estimates of carrying capacity could not be determined because of our inability to estimate fishing mortality.

DISCUSSION

Paxson Lake

The abundance estimate for 1990 was significantly lower than the estimate for 1988 at $\alpha = 0.05$ while harvests increased 63% from 1,310 lake trout in 1988 to 2,139 lake trout in 1990. Recruitment into the spawning population was low. Harvest is above the yields recommended by Healy (1978) and estimated from the thermal habitat volume of the lake. Minimum size limits, coupled with a two fish bag and possession limit, are not protecting the lake trout population at Paxson Lake from overharvest.

Minimum Size Limits:

Minimum size limits have been used by fishery managers as a tool to regulate the exploitation of lake trout. Limits were established to allow 50% of female lake trout to spawn at least once before they are exploited. Female lake trout in Paxson Lake mature at a larger size than males (Burr 1991b). Lake trout grow quickly and mature early in Paxson Lake compared to many Alaskan lake trout populations (Burr 1991b). Burr (1991b) estimated that 50% of female lake trout in Paxson Lake were mature at a fork length of 426 mm (18.3 in total length; 6 yr) and 95% of females were mature when they reached a fork length of 467 mm (20 in total length; 8 yr). Of female lake trout captured in seine samples from Paxson Lake in 1991, approximately 5% were under the 18 inch minimum size limit; 16% of spawning females were under 20 inches in length. Two percent of the females harvested from Paxson Lake were smaller than 20 inches.

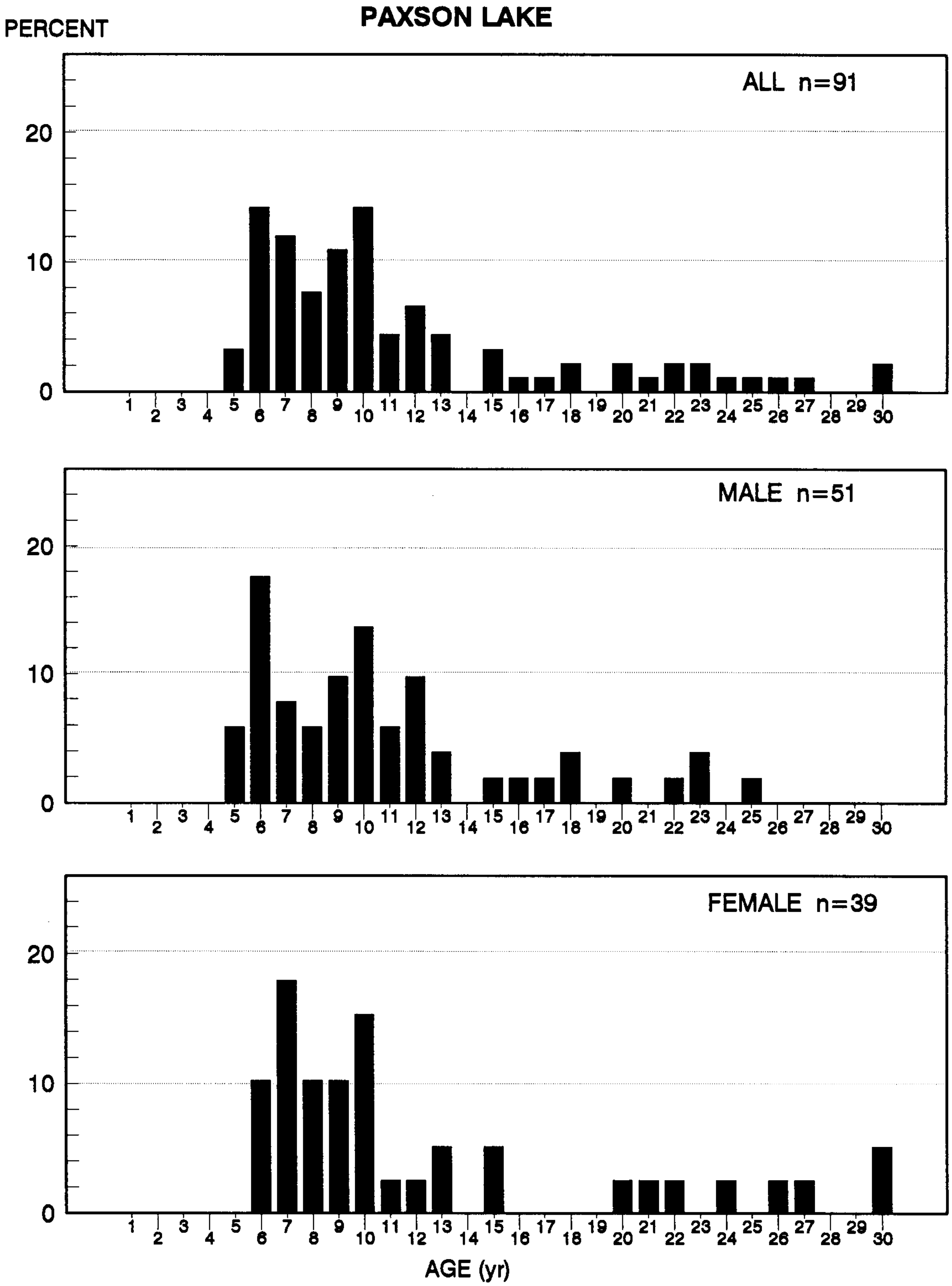

Figure 9. Age composition of lake trout in the harvest sampled from Paxson Lake, 1991.

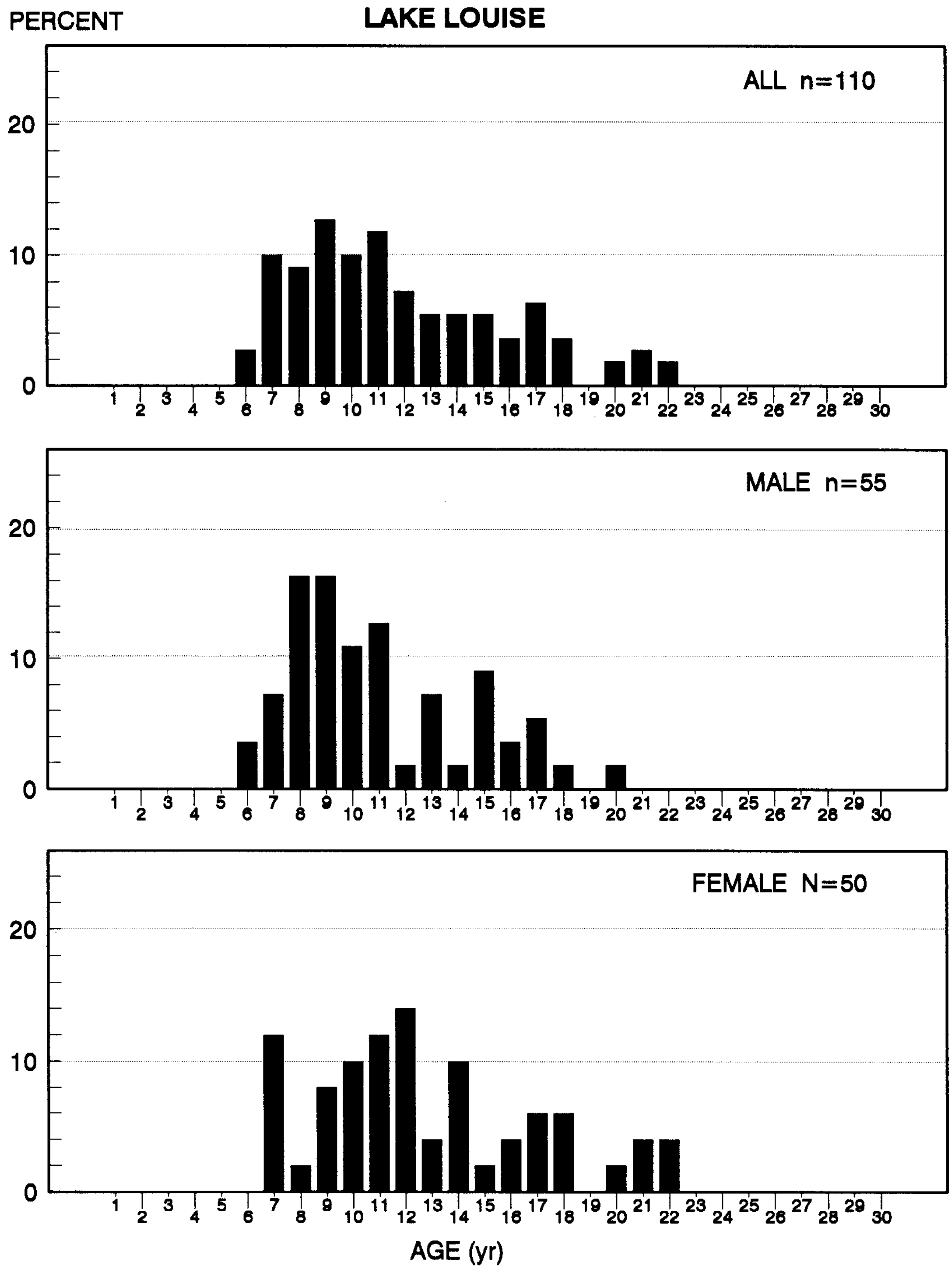

Figure 10. Age composition of lake trout in the harvest sampled from Lake Louise, 1991.

Adjusted Abundance Estimates:

Negative values for the instantaneous rates of natural mortality (M) result when F > Z which is an impossibility (Z = F + M). Since precision in the mark-recapture experiment is excellent (almost half the fish in the experiment are marked), this impossibility is due to either the harvest of many immature fish or the presence of spawning populations other than those sampled in the mark-recapture experiment. Since catch sampling of the harvest showed only mature fish being taken, there is strong inferential evidence that there are spawning areas other than those included in the mark-recapture experiment. Evidence shows fidelity of lake trout to specific spawning beds in this lake and in Lake Louise. The presence of these other spawning areas and the faithful return of lake trout to the same areas to spawn means that direct estimates of abundance from the mark-recapture experiment are too low.

Expanding estimated abundance from the mark-recapture experiment to encompass all spawning populations in the lake involves the fraction of marked fish observed in the catch sampling program in spring 1991. Of the fish 7+ years old sampled from the creel in Paxson Lake, 57 were male, and of these 23 were marked. The estimated number of tagged males in the mark-recapture experiment just prior to sampling in 1990 was thus 1,020. Twenty of these were killed for biopsy in 1990 and another 349 were marked. Since marked fish in 1990 were 6+ years, growth recruitment was removed from the sample taken in 1991 by restricting the data to males 7+ years. The quotient (3,343) of the number of tagged males in the population in 1990 (1,349) divided by the fraction marked in 1991 (23/57 or 0.40) is an estimate of abundance for males for the entire population in 1990. This estimated abundance of males when doubled produces an estimate for both sexes: 6,686 lake trout spawning in Paxson Lake in 1990. This new estimate of abundance is 160% of the estimate from the mark-recapture experiment. If this same ratio applies to other years, the adjusted estimates of abundance for both sexes were 10,152 in 1988 and 8,496 in 1989.

Statistics from the catch sampling program also show that harvest as reported in Mills (1985-1991) is accurate but is too high for determination of mortality rates. Estimated survival rates from the mark-recapture experiment pertain to fish that are fully recruited to the spawning population. Since new recruits in the spring (age 6 and younger) comprise a significant percentage of the harvest before they have a chance to recruit to the mark-recapture experiment, survival rates from the mark-recapture experiment are relevant to only part of the harvest, not all. The consequence of this situation is that the estimated harvest (Mills 1985-1991) can not be used to partition total mortality into fishing and natural mortality.

Statistics from the catch sampling program along with recruitment as measured in the mark-recapture experiment indicate considerable hook-and-release mortality. Approximately a quarter of all fish caught in spring 1991 were new recruits (age 6 and younger). Although recruitment to the spawning population in 1991 is yet to be estimated, recruitment to the spawning populations in 1989 and 1988 was nil. If recruitment to the spawning population is again negligible in 1991, it will be because younger, smaller fish had a considerably higher mortality rate than did post recruits. About one fish was released for every fish kept in the fishery in 1990 (4,466 caught and 2,139 kept; Mills 1991); undoubtedly, most of those released were younger, smaller fish, many or most of them newly recruited to the fishery. During a study on hooking mortality of lake trout caught on artificial lures (Loftus et al. 1988), 71% of the lake trout that swallowed hooks subsequently died from the experience. Since the use of baited hooks is common, there may be a high rate of hooking mortality for those fish that are released.

Surplus production:

The dynamic relationship between surplus production, harvest, and biomass is:

$$B_{i+1} = B_i + SP_i - W_i \quad (11)$$

with W being the harvest in weight. The average weight of lake trout harvested in 1991 was 1.8 kg and was the same for lake trout sampled in 1986 in the fishery and from the population (Burr 1987b). Since there is little evidence of growth compensation in lake trout, the average size of 1.8 kg is considered a constant across the years. Equation (11) can then be rewritten as:

$$N_{i+1} = N_i + SP_i - H_i \quad (12)$$

with SP now measured in fish. Surplus production in the years 1988 through 1990 can be estimated from information available from Mills (1985-1991) and mark-recapture experiment:

$$SP_i = N_{i+1} - N_i + H_i. \quad (13)$$

From 1988 to 1989, the estimated surplus production was -100 fish (= 8,496 - 10,152 + 1,557); from 1989 to 1990 the estimated surplus production was -166 (= 6,191 - 8,496 + 2,139). These near zero levels of surplus production indicate that abundance could be near carrying capacity since surplus production is negligible at this value. However, the long history of harvest makes it unlikely that abundance was near carrying capacity. Since mortality of released fish is indicated from other statistics, this source of mortality is a likely cause for the observed dissipation of surplus production.

The estimate of maximum surplus production (MSY) is predicated on the empirical relationship between the volume of water 8° through 12° C in a lake and its maximum sustainable productivity as reported in Payne et al. 1990. Measurements of water temperatures at Paxson Lake in July and August produced an estimate of SP_{max} of 1.74 kg/hectare or 2,741 kg for the 1,575 hectare surface area of the lake. Dividing SP_{max} by 1.8 kg per fish gives the maximum surplus production in fish: about 1,500 fish per year.

Abundance Model:

The logistic model of surplus production (SP) as a function of the intrinsic rate of increase (r), the carrying capacity B_∞, and the annual biomass (B) is:

$$SP_{t+6} = r\, B_t\, (1 - B_t/B_\infty) \quad (14)$$

where t is the year. Since sampling in the mark-recapture experiment at Paxson Lake is of the spawning population during spawning and since lake trout in Paxson Lake mature in 5 to 6 years (Burr 1991b), potential surplus production in year t becomes realized surplus production in year t+6. Maximum sustained yield or the maximum surplus production in the logistic model occurs when the $B = B_\infty/2$ and is:

$$SP_{max} = \frac{r\ B_\infty}{4} \ . \tag{15}$$

From this relationship and the empirical relationship between SP_{max} and M in Gulland (1983, p. 56) ($SP_{max} = 0.5MB_\infty$):

$$r = 2.0\ M. \tag{16}$$

From Healey (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 (0.39, 0.17, 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 growth model at water temperature; the growth coefficient came from Payne et al. (1990). Considering the results of Pauly's method and statistics from Yaremchuk (1986), M at 0.10 was chosen for this model.

The estimate of carrying capacity B_∞ is predicated on equating SP_{max} from the logistic model with SP_{max} calculated from the methods of Payne et al. 1990. Plugging SP_{max} into Equation (11) and solving for carrying capacity gives B_∞ = 54,820 kg or 30,000 fish at 1.8 kg apiece.

Before biomass and sustained yield can be projected with the model described above, modeled time must be rolled back to 1984. Because there is a 6-year lag between spawning and recruitment to the population, surplus production from 1991 through 1996 resulted from the abundance of spawners in 1985 to 1990. That surplus production must be estimated.

Estimate of past abundance (and hence the surplus production for the next few years) were derived by manipulating added mortality of hooked and released fish and by manipulating abundance in 1984 until biomass predicted by the model for 1988, 1989, and 1990 reflected that measured in the actual stock assessment program. Harvests in 1984 through 1990 were taken from Mills (1985-1991) with added mortality from hooking and releasing fish. Hook-induced mortalities with bait were set at 71% of the estimated number released and 14% without bait. The relationship between caught and kept fish reported for 1990 was used as a guide to the number released. Surplus production entering the population from 1984 to 1989 was set at 1,500 and abundance in 1984 was set at 14,000 to produce a fit with the model (Figure 11). The specific results for each projection are listed in Appendix A.

Recommendations for Management:

Because of a somewhat arbitrary assignment of mortality rates of fish hooked then released, the specific consequences of the projections should be treated as trends. Immediate closure of the fishery resulted in the most rapid rebound in the abundance of the modeled population. A delay in the closure to

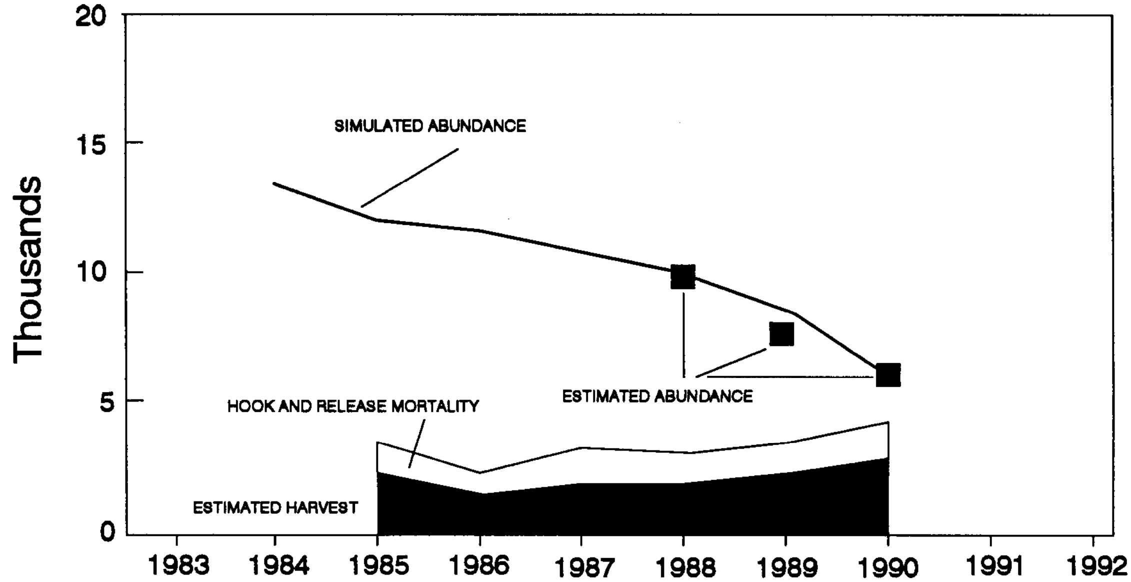

Figure 11. Predicted abundance of lake trout at harvest levels estimated by Mills (1985-1991) with a hooking mortality of 71%.

1994 would delay recovery but stocks would eventually rebound. Recovery would be effected and the population would stabilize if the harvest was limited to one fish and bait was eliminated.

The benefits from allowing the fishery to continue another season may outweigh the loss of recovery time of the population. The harvest and/or hooking mortality of potential recruits to the spawning population could be documented more conclusively. The fishery could be further characterized and regulations further developed which would be more effective at maintaining fishing opportunity while assuring sustained yields over the long term. This strategy would also provide for the opportunity to see if the recruitment evident in the 1991 fishery samples from Paxson Lake also recruited into the 1991 spawning population or if fishing mortality effectively cropped this recruitment off.

Lake Louise Yields and Population Structure

Within the constraints created by using fewer than the recommended number of water temperature profiles and a regression equation formulated for lake trout populations in Ontario to estimate THV, it can be stated that the lake trout population in Lake Louise is likely being harvested at or above its maximum sustainable level.

Lake trout first enter the harvest and seine samples at a larger size in Lake Louise than in Paxson Lake. Lake trout also enter the harvest a year later in Lake Louise than in Paxson Lake.

Although no estimates of length or age at maturity are available, recruitment is evident from length and age data. Fish may recruit into the spawning population in Lake Louise at as much as 450 mm in length. Later age at recruitment into samples from Lake Louise may also be a result of missing size/age classes due to overfishing in the past. Minimum lengths of spawners captured in 1990 are less than in 1991.

Sufficient data are not yet available to characterize the health of the lake trout population at Lake Louise. Female lake trout appear to recruit into the spawning population at a larger size than males. Females also recruit into the harvest at an older age than males. Current length limits are not protecting a significant proportion of spawners in Lake Louise; in 1991, only 1% of the harvest of females was under 20 inches.

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APPENDIX A

Appendix A. Projected trends in abundance of lake trout from Paxson Lake for different management strategies.

No Regulation Change

Year	Abundance	Harvest	Hooking Mortality[a]
1984	14,000		
1985	12,314	1,803	1,382
1986	12,146	944	723
1987	11,072	1,457	1,117
1988	10,257	1,310	1,004
1989	9,007	1,557	1,193
1990	6,721	2,139	1,640
1991	5,460	1,535	1,177
1992	4,194	1,535	1,177
1993	2,879	1,535	1,177
1994	1,517	1,535	1,177
1995	66	1,535	1,177

[a] Hooking mortality rate set at 71% from Loftus et al. 1988.

-continued-

Immediate Closure

Year	Abundance	Harvest	Hooking Mortality[a]
1984	14,000		
1985	12,314	1,803	1,382
1986	12,146	944	723
1987	11,072	1,457	1,117
1988	10,257	1,310	1,004
1989	9,006	1,557	1,193
1990	6,721	2,139	1,640
1991	5,460	1,535	1,177
1992	6,906	0	0
1993	8,303	0	0
1994	9,653	0	0
1995	10,914	0	0
1996	11,957	0	0
1997	12,850	0	0
1998	13,914	0	0
1999	15,115	0	0

[a] Hooking mortality rate set at 71% from Loftus et al. 1988.

-continued-

1994 Closure

Year	Abundance	Harvest	Hooking Mortality[a]
1984	14,000		
1985	12,314	1,803	1,382
1986	12,146	944	723
1987	11,072	1,457	1,117
1988	10,257	1,310	1,004
1989	9,006	1,557	1,193
1990	6,721	2,139	1,640
1991	5,460	1,535	1,177
1992	4,194	1,535	1,177
1993	2,879	1,535	1,177
1994	4,229	0	0
1995	5,490	0	0
1996	6,533	0	0
1997	7,426	0	0
1998	8,148	0	0
1999	8,669	0	0
2000	9,395	0	0
2001	10,292	0	0
2002	11,315	0	0
2003	12,432	0	0
2004	13,619	0	0
2005	14,852	0	0
2006	16,143	0	0

[a] Hooking mortality rate set at 71% from Loftus et al. 1988.

-continued-

Hook & Release 1992 - 100% effort.

Year	Abundance	Harvest	Hooking Mortality[a]
1984	14,000		
1985	12,314	1,803	1,382
1986	12,146	944	723
1987	11,072	1,457	1,117
1988	10,257	1,310	1,004
1989	9,006	1,557	1,193
1990	6,721	2,139	1,640
1991	5,460	1,535	1,177
1992	4,640	0	2,266
1993	3,771	0	2,266
1994	2,855	0	2,266
1995	1,850	0	2,266
1996	627	0	2,266

[a] Hooking mortality rate set at 71% from Loftus et al. 1988.

-continued-

Hook & Release 1992 - 50% Effort

Year	Abundance	Harvest	Hooking Mortality[a,b]
1984	14,000		
1985	12,314	1,803	1,382
1986	12,146	944	723
1987	11,072	1,457	1,117
1988	10,257	1,310	1,004
1989	9,006	1,557	1,193
1990	6,721	2,139	1,640
1991	5,460	1,535	1,177
1992	5,573	0	1,333
1993	5,637	0	1,333
1994	5,654	0	1,333
1995	5,582	0	1,333
1996	5,292	0	1,333
1997	4,852	0	1,333
1998	4,427	0	1,333
1999	4,010	0	1,333
2000	3,595	0	1,333
2001	3,170	0	1,333
2002	2,709	0	1,333
2003	2,190	0	1,333
2004	1,611	0	1,333
2005	973	0	1,333

[a] Hooking mortality rate set at 71% from Loftus et al. 1988.

[b] Half the number of fish handled if fishing effort drops to 2,000 angler days per year.

-continued-

Appendix A. (Page 6 of 11).

No Bait 1992

Year	Abundance	Harvest	Hooking Mortality[a]
1984	14,000		
1985	12,314	1,803	1,382
1986	12,146	944	723
1987	11,072	1,457	1,117
1988	10,257	1,310	1,004
1989	9,006	1,557	1,193
1990	6,721	2,139	1,640
1991	5,460	1,535	1,177
1992	5,139	1,535	232
1993	4,769	1,535	232
1994	4,352	1,535	232
1995	3,846	1,535	232
1996	3,122	1,535	232
1997	2,248	1,535	232
1998	1,333	1,535	232
1999	369	1,535	232

[a] Hooking mortality rate set at 14% from Loftus et al. 1988.

-continued-

Hook & Release 1994 - 100% effort

Year	Abundance	Harvest	Hooking Mortality[a,b]
1984	14,000		
1985	12,314	1,803	1,382
1986	12,146	944	723
1987	11,072	1,457	1,117
1988	10,257	1,310	1,004
1989	9,006	1,557	1,193
1990	6,721	2,139	1,640
1991	5,460	1,535	1,177
1992	4,194	1,535	1,177
1993	2,879	1,535	1,177
1994	1,963	0	2,266
1995	958	0	2,266

[a] Hooking mortality rate set at 71% from Loftus et al. 1988.

[b] Hooking mortality rate set at 14% from Loftus et al. 1988.

-continued-

Hook & Release 1994 - 50% Effort

Year	Abundance	Harvest	Hooking Mortality[a,b]
1984	14,000		
1985	12,314	1,803	1,382
1986	12,146	944	723
1987	11,072	1,457	1,117
1988	10,257	1,310	1,004
1989	9,006	1,557	1,193
1990	6,721	2,139	1,640
1991	5,460	1,535	1,177
1992	4,194	1,535	1,177
1993	2,879	1,535	1,177
1994	2,896	0	1,333
1995	2,824	0	1,333
1996	2,534	0	1,333
1997	2,094	0	1,333
1998	1,483	0	1,333
1999	671	0	1,333

[a] Hooking mortality rate set at 71% from Loftus et al. 1988.

[b] Half the number of fish handled if fishing effort drops to 2,000 angler days per year.

-continued-

Limit 1 - No Bait 1992

Year	Abundance	Harvest	Hooking Mortality[a,b]
1984	14,000		
1985	12,314	1,803	1,382
1986	12,146	944	723
1987	11,072	1,457	1,117
1988	10,257	1,310	1,004
1989	9,006	1,557	1,193
1990	6,721	2,139	1,640
1991	5,460	1,535	1,177
1992	5,746	714	446
1993	5,983	714	446
1994	6,173	714	446
1995	6,274	714	446
1996	6,157	714	446
1997	5,890	714	446
1998	5,660	714	446
1999	5,458	714	446

[a] Hooking mortality rate set at 14% from Loftus et al. 1988.

[b] Same number handled but harvest is halved.

-continued-

Limit 1 - No bait 1994

Year	Abundance	Harvest	Hooking Mortality[a,b]
1984	14,000		
1985	12,314	1,803	1,382
1986	12,146	944	723
1987	11,072	1,457	1,117
1988	10,257	1,310	1,004
1989	9,006	1,557	1,193
1990	6,721	2,139	1,640
1991	5,460	1,535	1,177
1992	4,194	1,535	1,177
1993	2,879	1,535	1,177
1994	3,069	714	446
1995	3,170	714	446
1996	3,053	714	446
1997	2,786	714	446
1998	2,348	714	446
1999	1,709	714	446
2000	1,100	714	446
2001	507	714	446

[a] Hooking mortality rate set at 14% from Loftus et al. 1988.

[b] Same number handled but harvest is halved.

-continued-

Appendix A. (Page 11 of 11).

Closure 1992 - limit 1 and no bait 1994

Year	Abundance	Harvest	Hooking Mortality[a,b]
1984	14,000		
1985	12,314	1,803	1,382
1986	12,146	944	723
1987	11,072	1,457	1,117
1988	10,257	1,310	1,004
1989	9,006	1,557	1,193
1990	6,721	2,139	1,640
1991	5,460	1,535	1,177
1992	6,906	0	0
1993	8,303	0	0
1994	8,493	714	446
1995	8,594	714	446
1996	8,477	714	446
1997	8,210	714	446
1998	8,114	714	446
1999	8,155	714	446
2000	8,213	714	446
2001	8,279	714	446

[a] Hooking mortality rate set at 14% from Loftus et al. 1988.

[b] Same number handled but harvest is halved.