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Evaluation of Lake Trout Stock Status and Abundance in Selected Lakes in the Upper Copper and Upper Susitna Drainages, 1995

by

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and

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February 1997

Alaska Department of Fish and Game — Division of Sport Fish

Symbols and Abbreviations

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
metric ton	mt
milliliter	ml
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
ounce	oz
pound	lb
quart	qt
yard	yd
Spell out acre and ton.	

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
hour (spell out for 24-hour clock)	h
minute	min
second	s
Spell out year, month, and week.	

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

All commonly accepted abbreviations.	e.g., Mr., Mrs., a.m., p.m., etc.
All commonly accepted professional titles.	e.g., Dr., Ph.D., R.N., etc.
and	&
at	@
Compass directions:	
east	E
north	N
south	S
west	W
Copyright	©
Corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
et alii (and other people)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.,
id est (that is)	i.e.,
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
number (before a number)	# (e.g., #10)
pounds (after a number)	# (e.g., 10#)
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S. state and District of Columbia abbreviations	use two-letter abbreviations (e.g., AK, DC)

Mathematics, statistics, fisheries

alternate hypothesis	H_A
base of natural logarithm	e
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	F, t, χ^2, etc.
confidence interval	C.I.
correlation coefficient	R (multiple)
correlation coefficient	r (simple)
covariance	cov
degree (angular or temperature)	°
degrees of freedom	df
divided by	÷ or / (in equations)
equals	=
expected value	E
fork length	FL
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log_2, etc.
mideye-to-fork	MEF
minute (angular)	'
multiplied by	x
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
standard length	SL
total length	TL
variance	Var

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABSTRACT

Mark-recapture experiments were conducted to estimate abundance of male lake trout *Salvelinus namaycush* on sampled spawning grounds and their survival rates and recruitment in Paxson Lake in the Copper River drainage and Lake Louise in the Susitna River drainage. Maximum sustainable yields and carrying capacities of populations in Paxson Lake, Lake Louise and Susitna Lake were estimated with thermal habitat volume (THV) measurements: the average volume of water between 8° and 12°C. The mark-recapture experiment conducted at Paxson Lake in 1995 generated an estimate of abundance for 1994 of 2,438 (SE = 94) male lake trout on the sampled spawning beds. An estimated 1,857 (SE = 88) males were present on the sampled spawning beds of Lake Louise in 1995. Estimated maximum sustainable yield of lake trout from Paxson Lake is 0.89 kg ha^{-1} y^{-1}, 0.93 kg ha^{-1} y^{-1} from Lake Louise and 0.98 kg ha^{-1} y^{-1} for Susitna Lake. Current harvests from all three lakes are below these levels.

Key words: lake trout, *Salvelinus namaycush*, population abundance, age, thermal habitat volume, yield, harvest, homing behavior, Paxson Lake, Lake Louise, Susitna River, Upper Copper drainage, Alaska.

INTRODUCTION

Lake trout *Salvelinus namaycush* are a popular target of sport anglers in Alaska. Sought in many lakes and some streams, the number of lake trout harvested annually from Alaska has averaged about 15,804 fish since 1977 (Howe et al. 1996) (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 1979-1994, Howe et al. 1995, 1996) (Figure 1b). Since 1984, harvest statistics have been available for the state's two largest lake trout sport fisheries: Paxson Lake, through which the Gulkana River flows on its way to the upper Copper River, and Lake Louise, a major source of the Tyone River, a tributary to the Susitna River (Figure 2). Together, these two lakes have produced an average of 19% of the annual statewide harvest. Harvest in both lakes has declined as a result of regulations implemented in 1994 (Figure 1a). The average annual harvest from Paxson Lake is estimated at 1,159 fish. The average harvest estimate from Lake Louise since 1984 is 1,594 lake trout. Other major sport fisheries for lake trout in the area occur at Summit Lake (near Paxson Lake), Crosswind Lake (also in the Gulkana drainage) and Susitna Lake (downstream of Lake Louise) (Figure 2). These lakes contribute between 2% and 4% of the statewide harvest of lake trout.

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

A study by the Alaska Department of Fish and Game (ADF&G) of the structure, abundance and sustainable yield of the lake trout populations in 11 interior lakes commenced in 1986. In 1987, bag limits for lake trout were reduced in the Tanana, upper Copper and upper Susitna river drainages upon determination that the harvest exceeded the maximum sustained yield by as much as seven times in some of the study lakes. A minimum harvestable size of lake trout was also established in 1987 to allow female lake trout to spawn once, on average, before they were subject to harvest. During 1994, the Board of Fisheries voted to increase the minimum size limit to 24 inches in the Tyone River drainage and in Paxson, Summit and Crosswind lakes because

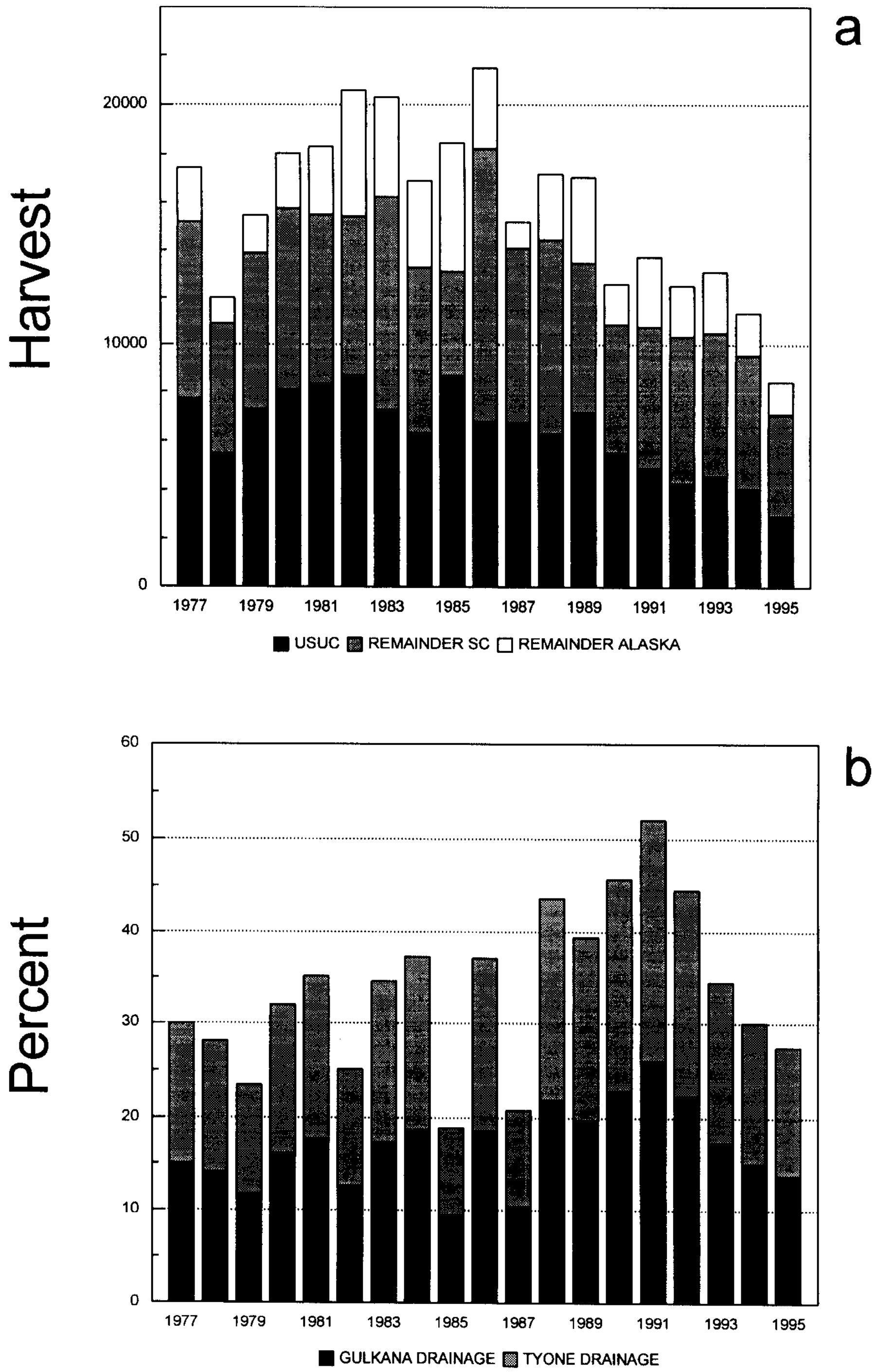

Figure 1.-Lake trout harvested from Alaska 1977-1995 with (a) number harvested from upper Copper and upper Susitna river drainages (UCUS), and remainder of Southcentral (SC), and remainder of Alaska; and (b) percent contribution of Gulkana and Tyone river drainages to the total Alaskan harvest (Mills 1977-1994, Howe et al. 1995, 1996)

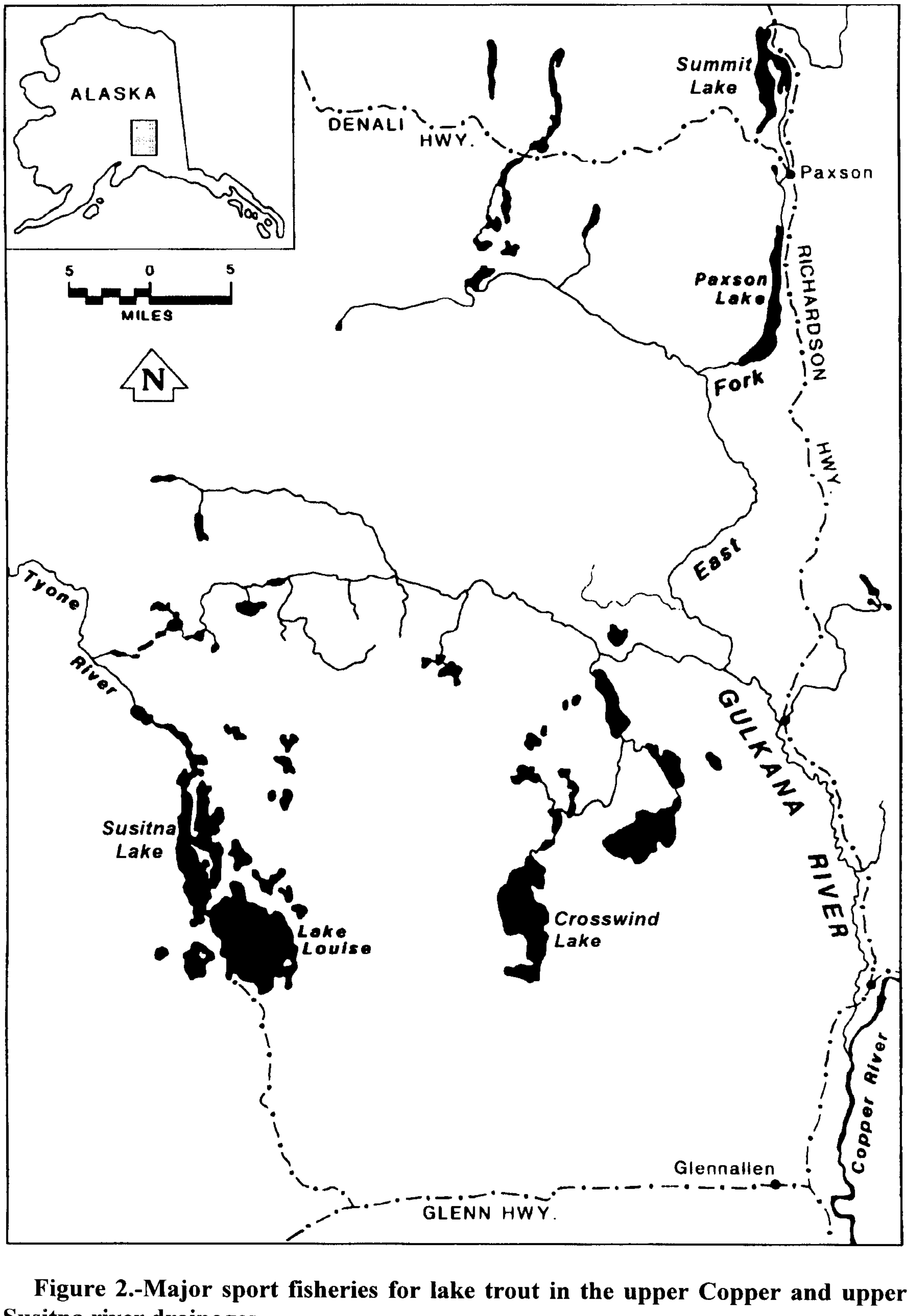

Figure 2.-Major sport fisheries for lake trout in the upper Copper and upper Susitna river drainages.

harvests exceeded sustainable levels in Paxson and Summit lakes and minimum size limits were not protecting spawners. The daily bag and possession limit was reduced from two to one lake trout in the Tyone River drainage and Crosswind Lake.

The goals of our study of lake trout are to: (1) verify that yields from several local stocks conform to historical relationships developed for populations elsewhere, and (2) monitor stocks to assure that fishing regulations sustain these yields. The specific objectives in 1995 were to:

1. Estimate abundance of mature male lake trout on sampled spawning beds in Paxson Lake and Lake Louise during fall 1994;
2. Estimate length composition of lake trout populations spawning in Paxson Lake and Lake Louise during fall 1995; and
3. Estimate the thermal habitat volume of Paxson Lake, Lake Louise and Susitna Lake in 1995.

METHODS

SITE DESCRIPTIONS

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

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.

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

ABUNDANCE ESTIMATES

Sampling during fall 1995 occurred at previously identified spawning beds in Lake Louise and Paxson Lake (Szarzi 1992, 1993). Spawning beds were numbered consecutively and sampled throughout each night between sundown and 0600 hours, when weather permitted (Table 1). A beach seine, 60 m X 3 m X 38 mm (200 ft X 10 ft X 1 in), was used to capture lake trout. Sampling began at the bed identified by a random number and proceeded in a systematic fashion around the lake. If fish were not found at the chosen spawning location, the next spawning bed was sampled. The fish captured at each bed were measured for length (in millimeters) from snout to the fork of the tail and their sex was determined by attempting to expel milt from males or observing the ovipositor (distended) and shape of fish (full belly) in females. Those fish without tags were 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 within and between seasons.

Table 1.-Sampling dates at Paxson Lake, Lake Louise and Susitna Lake, 1995.

	Paxson Lake	Lake Louise	Susitna Lake
Mark-recapture Experiment	5-8 Sep	5,7-8 Sep	
	11-16 Sep	11-15 Sep	
	18-21 Sep	17-22 Sep	
		25-29 Sep	
Thermal Sampling		7-Jun	6-Jun
	21-Jun	15-Jun	15-Jun
	29-Jun	28-Jul	28-Jun
	6-Jul		
	18-Jul	14-Jul	14-Jul
	25-Jul	26-Jul	26-Jul
	8-Aug	7-Aug	7-Aug
	15-Aug	14-Aug	14-Aug
	25-Aug	24-Aug	24-Aug

Abundance of mature lake trout has previously been estimated with a combination of two mark-recapture experiments: a mark-recapture event on the spawning beds in the fall and sampling from the harvest (1991, 1992, 1993) or the harvestable (1994) population in the spring. During 1995, only the fall mark-recapture event was conducted. Numbers of male lake trout marked and recaptured each year on the spawning beds of each lake were used to estimate abundance, survival rates, surviving recruitment and number of tagged male lake trout in the spawning population. Only males were included in the experiments because they generally spawn every year while female lake trout do not (Burr 1991). Parameters were estimated 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 estimated variances according to the procedures described in Efron (1982). Sampling events have occurred each fall in Paxson Lake since 1987. Sampling in Lake Louise began in fall 1991. Sampling at Susitna Lake began in 1992 and was discontinued in 1994. Because lake trout are faithful to their spawning beds, returning each year to the same area to spawn (Szarzi 1992, 1993 and Szarzi and Bernard 1994), the sampled spawning beds represent a unique subpopulation within each lake.

YIELD ESTIMATES

Maximum sustainable yields (MSY) in kg/ha^{-1}/yr^{-1} of lake trout were estimated for each population in our study from an empirical relationship between estimated harvests and thermal habitat volume (THV) from lakes in Ontario, Canada (Payne et al. 1990):

$$\log_{10} \text{MSY} = 2.15 + 0.714 \log_{10} \text{THV} \quad , \qquad (1)$$

$$\mathrm{THV} = \frac{(D_2 - D_1)\left(A_1 + A_2 + [A_1 \times A_2]^{1/2}\right)}{300}, \tag{2}$$

where:

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

D_2 = the average depth (m) at which water temperature is 8°C,

A_1 = the cross-sectional area (m^2) of the lake at depth D_1, and

A_2 = the cross-sectional area (m^2) of the lake at D_2.

Water temperatures are measured after each lake has reached stable, thermal stratification in the summer to estimate THV. Water temperatures were measured at 2.5 m depth intervals to the bottom of Paxson Lake, Lake Louise and Susitna Lake during June, July and August, 1995 (Table 1). A monthly temperature profile was estimated for each lake by averaging the readings at each depth interval during the month. The cross-sectional area of each lake at the depth where 12°C and 8°C temperatures were encountered was measured on a bathymetric map using a planimeter. The THV of each lake was estimated using Equation 2 with average measurements from a single month:

$$\bar{t}_{dj} = \frac{\sum_{i=1}^{p_{dj}} t_{dij}}{p_{dj}} \qquad S_j^2 = \sum_d \frac{\sum_{i=1}^{p_{dj}} (t_{dij} - \bar{t}_{dj})^2}{p_{dj} - 1}, \tag{3}$$

where t is temperature, p is the number of profiles taken, i denotes profile, d depth, and j month. Measurements used to determine D_1 and D_2 were taken in the month j' for which $S_{j'}^2$ is the minimum variance across all months. Depth D_1 = d' at which $\bar{t}_{d'j}$ = 12°C; depth D_2 is determined in the same manner.

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

$$K = \frac{(4)\mathrm{MSY}}{r}, \tag{4}$$

where r is double the instantaneous rate of natural mortality.

From Healy (1978), the instantaneous rate of natural mortality averaged over 14 Canadian populations is 0.30. Considering estimates of the instantaneous rate of total mortality derived in our mark-recapture experiments at Paxson Lake (0.41, 0.15, 0.24, 0.19, 0.25, 0.18, 0.22), 0.30 is too high. The instantaneous rate of natural mortality was calculated with estimates of harvest from the Statewide Harvest Survey (Mills 1989-1994, Howe et al. 1995), estimates of abundance of all mature males in Paxson Lake, and the Baranov catch equation. Carrying capacity was estimated with the average of instantaneous rates of natural mortality between 1988 and 1992 (0.06) for lake trout in Paxson Lake. This mortality rate was used to estimate carrying capacity for Lake Louise and Susitna Lake as well.

Actual yields (Y) in $kg/ha^{-1}/yr^{-1}$ from populations in Paxson Lake, Lake Louise and Susitna Lake in their sport fisheries were estimated from data collected during past hook-and-line sampling programs at Paxson Lake and at Lake Louise (see Szarzi and Bernard 1995) and estimates of annual harvest (H) from the Statewide Harvest Survey:

$$Y = H\overline{w}, \qquad (5)$$

where:

$\overline{w}$ = mean weight of lake trout sampled in hook and line and catch sampling programs during 1994 at Paxson Lake or from catch sampling programs at Lake Louise the same year.

The mean weight of lake trout greater than 24 inches in length captured by hook and line from Paxson Lake was used to estimate yields there. Since most harvest occurs when the hook-and-line and catch sampling occurs, growth of lake trout after completion of sampling should not have significantly biased estimates of mean weights.

RESULTS

Estimated abundance of mature male lake trout spawning on the sampled grounds in Paxson Lake during the fall, 1994, is 2,438 (Table 2). Of the 1,288 lake trout captured during fall sampling in 1995, 60% (766) had been marked in previous years (Table 3 contains tallies of all captured and recaptured male lake trout since 1987 at Paxson Lake). About 10% of all recaptured lake trout had lost their tags.

An estimated 1,857 (SE = 88) male lake trout spawned on the sampled spawning beds of Lake Louise during fall, 1994 compared to 2,004 (SE = 94) in 1993 (Table 4). Of 807 lake trout captured from Lake Louise during fall sampling in 1995, 428 had been marked previously (Table 5).

Estimates of annual survival rates of lake trout in Paxson Lake for 1987-1994 range from 0.66 to 0.86 while estimates of surviving recruitment indicate two weak and one strong year class entering the population with the estimate for 1993 to 1994 falling in between (Table 6). Rates of total instantaneous mortality range between 0.15 and 0.41. The estimated survival rate of lake trout in Lake Louise and Susitna Lake between 1993 and 1994 was 0.74 (Table 7). The instantaneous rate of mortality was estimated at 0.30 during the same period. Fishing and natural mortality rates were estimated with the Baranov catch equation and estimates of harvest from the Statewide Harvest Survey (Mills 1989-1993).

Fork lengths of 1,663 lake trout were measured from the spawning population in Paxson Lake (Table 8 and Appendix A1). Lengths were collected from 990 spawning lake trout captured in Lake Louise (Table 8 and Appendix A2). Spawning females were larger than male spawners in both lakes. On average, spawning lake trout were slightly larger in Paxson Lake. Lengths of spawning lake trout were more variable in Lake Louise.

table 2 full page

Table 2.-Updated statistics from mark-recapture experiments to estimate abundance of mature lake trout in Paxson Lake.

	Sampled Subpopulation			Total Population		
Year	Abundance[a]	Number with Marks[a]	Fraction Marked[a,b]	Abundance of Males[a,c]	Fraction Males	Abundance[a]
1987		212				
1988	2,972	947		7,340	0.5[d]	14,679
	(433)	(9)				
	(2,124;3,820)					
1989	2,619	1,383		6,468	0.5[d]	12,936
	(144)	(26)				
	(2,336;2,902)					
1990	2,120	1,381	0.4	3,422	0.5[d]	6,845
	(97)	(32)	(0.07)	(556)		(1,112)
	(1,931;2,311)					
1991	2,602	1,149	0.3	3,858	0.5	7,715
	(121)	(44)	(0.07)	(873)		(1,746)
	(2,366;2,840)					
1992	2,153	1,291	0.14	9,553	0.5	19,107
	(109)	(34)	(0.06)	(4,028)		(8,056)
	(1,939;2,368)					
1993	2,275	1,471	0.06	22,801	0.5	45,601
	(105)	(47)	(0.03)	(11,116)		(22,233)
	(2,069;2,482)					
1994	2,438	1,798				
	(94)	(35)				
	(2,253;2,623)					

Note: See Szarzi and Bernard 1995 for a description of methods to expand estimates from the sampled population to the population in Paxson Lake.

[a] Standard errors and 95% confidence intervals in parentheses.

[b] Fractions were estimated in the spring of the year following 1990-1994 in catch sampling programs.

[c] Abundance is germane to just after spawning in the fall of the listed year.

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

Table 3.-Numbers of mature male lake trout captured, marked and recaptured in Paxson Lake at sampled spawning grounds, 1987-1995.

	Year of Recapture								
	1987	1988	1989	1990	1991	1992	1993	1994	1995
Year of release:									
1987	0	39	38	8	8	3	2	3	0
1988		0	217	122	84	26	22	13	16
1989			0	214	123	55	35	33	10
1990				0	203	94	54	28	10
1991					0	108	51	54	24
1992						0	187	157	69
1993							0	290	129
1994								0	508
1995									0
Captures:									
With tags	0	39	255	344	418	286	351	578	766
Without tags	249	807	592	343	542	411	386	614	522
TOTAL	249	846	847	687	960	697	737	1,193	1,288
Releases:									
With tags	212	818	821	647	418	696	737	1,193	1,287
Without tags	0	0	0	0	542	0	0	0	0
TOTAL	212	818	821	647	960	696	737	1,193	1,287

In 1995, harvests from Paxson Lake, Lake Louise and Susitna Lake remained below the threshold of MSY as established through measurement of the THV (Figure 3). Harvest from Paxson Lake in 1995 was an estimated 507 lake trout or 0.72 kg ha^{-1} based on the average weight of 2.25 kg estimated from hook and line samples from 1994 (Szarzi and Bernard 1995). Harvest of lake trout from Lake Louise in 1995 was 946 fish or 0.42 kg ha^{-1}, based on the average weight of 2.9 kg estimated from the 1993 harvest (Szarzi and Bernard 1994). An estimated 200 lake trout were taken from Susitna Lake in 1995, a yield of approximately 0.15 kg ha^{-1} using the average weight of lake trout estimated from the harvest at Lake Louise in 1993 (2.87 kg). Estimated average MSY and carrying capacity are 747 and 21,277 lake trout in Paxson Lake (1991-1995), 2,199 and 58,734 for lake trout in Lake Louise (1991-1995) and 1,308 and 35,362 for Susitna Lake (1992-1995) (Table 9).

DISCUSSION

Estimated abundance of male lake trout on sampled spawning beds in Paxson Lake increased compared to the 1993 estimate. Abundance of this subpopulation should stabilize in the future if harvests remain at sustainable levels. The empirical relationship between estimated harvests and

Table 4.-Updated statistics from mark-recapture experiments to estimate abundance of mature lake trout in Lake Louise and Susitna Lake.

	Sampled Subpopulation			Total Population		
Year	Abundance[a]	Number with Marks[a]	Fraction Marked[a,b]	Abundance of Males[a,c]	Fraction Males	Abundance[a]
1991		669	0.14	5,020	0.5	10,040
			(0.04)	(1,413)		(2,827))
1992	1,438	905	0.11	8,146	0.5	16,292
	(77)	(14)	(0.04)	(3,165)		(6,330)
	(1,288;1,589)					
1993	2,004	1,319				
	(94)	(27)				
	(1,820;2,188)					
1994	1,857	1,448				
	(88)	(40)				
	(1,684;2,030)					

Note: See Szarzi and Bernard 1995 for a description of methods to expand estimates from the sampled population to the population in Lake Louise and Susitna Lake.

[a] Standard errors and 95% confidence intervals in parentheses.

[b] Fractions were estimated in the spring of the year following 1990-1994 in catch sampling programs.

[c] Abundance is germane to just after spawning in the fall of the listed year.

thermal habitat volume (THV) from lakes in Ontario, Canada (Payne et al. 1990) used to determine maximum sustainable yields of lake trout in our study should be verified by further sampling from the harvestable population during 1996. Samples from the harvestable population should be stratified by location of capture.

However, trends in statistics from 1988 through 1995 for lake trout in Paxson Lake are inconsistent with a perceived decline in fishing mortality in recent years. High estimated harvests in 1989 and 1990 along with poor recruitment those years drove estimated abundance in Paxson Lake down by about a third. Better recruitment after 1990 and an increased minimum size limit in 1994 has stabilized the population. As desired, estimated harvests of lake trout have declined dramatically in recent years under stricter regulations. Estimated harvest in 1994 had dropped below the estimated maximum sustainable yield from Paxson Lake for the first time since sampling began in 1988. However, estimates of annual survival rates of the sampled subpopulation of males have remained eerily stable (0.78 to 0.86) since 1988 while estimated harvests have declined by an order of magnitude.

Table 5.-Numbers of mature male lake trout captured, marked and recaptured in Lake Louise at sampled spawning grounds, 1991-1995.

LAKE LOUISE:	Year of Recapture				
	1991	1992	1993	1994	1995
Year of release:					
1991	0	210	97	55	13
1992		0	247	136	28
1993			0	332	94
1994				0	293
1995					0
Captured with tags	0	210	344	523	428
Captured without tags	699	436	510	470	379
Total captured	699	646	854	993	807
Released with tags	699	646	854	991	807
Released without tags	0	0	0	0	0
Total released	699	646	854	991	807

Possible explanations for stable survival rates and stable abundance when harvest has declined for lake trout in Paxson Lake are:

1. *Compensatory increases in natural mortality rate for a declining fishing rate.* This explanation is unlikely considering the life history of lake trout. Lake trout are a "K-selected" species whose ecological "strategy" for persistence is long life through low natural mortality at stable rates.

2. *Failure to recognize marked fish.* This explanation is viable only if failure to recognize tagged fish is a recent phenomenon to compensate for recent declines in harvest. Considering that by 1995 only 10% of recaptured fish had shed their tags over several years of stock assessment, this explanation can be discounted as well.

3. *Handling-induced mortality.* Like the explanation above, handling-induced mortality would have to be a recent phenomenon. Times and procedures of fall sampling have not changed since 1987.

4. *A shift in the pattern of effort in the fishery.* Divergence of fishing and sampling patterns in previous years is the reason that spring test fishing failed in 1994 (Szarzi and Bernard 1995). If the fishery had shifted away from the sampled subpopulation, estimated abundance and survival rates should have increased; they did not. The fishery may have shifted to the sampled population with no change in survival rates because recent regulations reduced the "fishing power" of anglers. However, harvest has fallen too far, requiring an unlikely increase in natural mortality to maintain the observed stability in estimated total mortality rates.

Table 6.-Estimates of annual harvest, survival rates, instantaneous rates and surviving recruitment for male lake trout in Paxson Lake.

Period: Fall-Fall	Estimated Harvest Males[a]	Abundance Males[b]	Survival Rate[c]	Instantaneous Rates Total[c]	Fishing[d]	Natural[d]	Surviving Recruitment[c]
1987-1988	655		0.66	0.41			
SE	(249)		(0.05)				
1988-1989	779	7,340	0.86	0.15	0.11	0.04	87
SE	(221)		(0.03)				(493)
1989-1990	1,070	6,468	0.78	0.24	0.19	0.06	89
SE	(370)		(0.03)				(115
1990-1991	518	3,442	0.83	0.19	0.17	0.02	876
SE	(88)	(556)	(0.04)				(100)
1991-1992	347	3,858	0.78	0.25	0.10	0.15	551
SE	(69)	(873)	(0.04)				(103)
1992-1993	331	9,553	0.84	0.18	0.04	0.14	473
SE	(78)	(4,028)	(0.03)				(104)
1993-1994	131	22,801	0.80	0.22	0.01	0.21	607
SE	(36)	(11,116)	(0.03)				(82)

[a] Harvests are half those reported in the Statewide Harvest Survey for years 1988 through 1995 (Mills 1989-1994, Howe et al. 1995, 1996).

[b] Estimates of abundance are germane to just after spawning in the first year listed.

[c] Estimated for males on sampled spawning ground only in the mark-recapture experiment based on the Jolly-Seber model (Seber 1982).

[d] 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.-Estimates of annual harvest, survival rates, instantaneous rates and surviving recruitment for male lake trout in Lake Louise and Susitna Lake.

Period: Fall-Fall	Estimated Harvest Males[a]	Fraction Recruited n_x/n	Abundance Males[b]	Survival Rate[c]	Instantaneous Rates			Surviving Recruitment
					Total	Fishing[d]	Natural	
1991-1992	679	0.97	4,797	0.67	0.40	0.16	0.24	
SE	(124)		(1,351)	(0.03)				
1992-1993	992	0.95	8,115	0.89	0.11	0.09	0.03	719
SE	(213)		(3,153)	(0.03)				(90)
1993-1994	732	ns[e]		0.74	0.30			370
SE	(146)			(0.04)				(66)

[a] Harvests are half those reported in the Statewide Harvest Survey for years 1988 through 1995 (Mills 1989-1994, Howe et al. 1995, 1996).

[b] Estimates of abundance are germane to just after spawning in the first year listed.

[c] Estimated for males on sampled spawning ground only in the mark-recapture experiment based on the Jolly-Seber model (Seber 1982).

[d] Estimated with the Baranov catch equation with the presumption that estimated survival rates were indicative of survival rates for all mature male lake trout in Lake Louise and in Susitna Lake.

[e] ns = no sample

5. *Unobserved mortality in lake trout caught and released by the fishery.* Fishing effort in estimated angler days from Mills (1989-1994) and Howe et al. (1995, 1996) has remained remarkably stable from 1988 through 1994 (3,890 to 4,572 days), increasing to 5,269 days in 1995. Almost all of that fishing effort is directed towards lake trout. Despite regulations, estimated catch of lake trout has remained high relative to harvest. About one fish was released for every one kept in 1990 and 1991. In 1992, 2.2 fish were released for every 1 kept, and by 1993 the ratio had increased to 3.0 to 1. In 1994, the ratio was an estimated 3.7 to 1, and in 1995, back to 2.4 to 1.

Of the possible explanations, unobserved mortality of released fish is the most likely. Loftus et al. (1988) showed that lake trout caught on artificial lures while trolling suffered high rates of mortality after release when these fish had been hooked deeply in the throat (71% died) or had not been retrieved immediately after being hooked (50% died). Most lake trout are caught at Paxson Lake by trolling anglers using artificial lures (Szarzi 1993). Some jigging occurs through the winter ice when about half the anglers use bait (Szarzi 1993). Persons and Hirsch (1994) estimated mortality of released fish caught with these techniques to be 9%, however, observed mortality was as high as 32% for fish caught deep in the throat. While these two studies do not confirm a high rate of mortality for lake trout released back into Paxson Lake, they do establish the possibility of such a loss. In contrast, other possible explanations for the contradiction in statistics from Paxson Lake remain unlikely.

Table 8.-Length statistics of spawning lake trout in Paxson Lake and Lake Louise, 1995.

	Paxson Lake			Lake Louise		
	Female	Male	All[a]	Female	Male	All[a]
LENGTH (millimeter)						
mean	557	535	539	546	525	529
mode	570	540	540	499	494	515
sample size	364	1,295	1,663	169	807	990
standard deviation	49	47	49	72	62	65
95% upper confidence interval	562	538	541	557	529	533
95% lower confidence interval	552	533	537	535	521	525
maximum	850	900	900	843	915	915
minimum	420	400	380	458	404	396

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

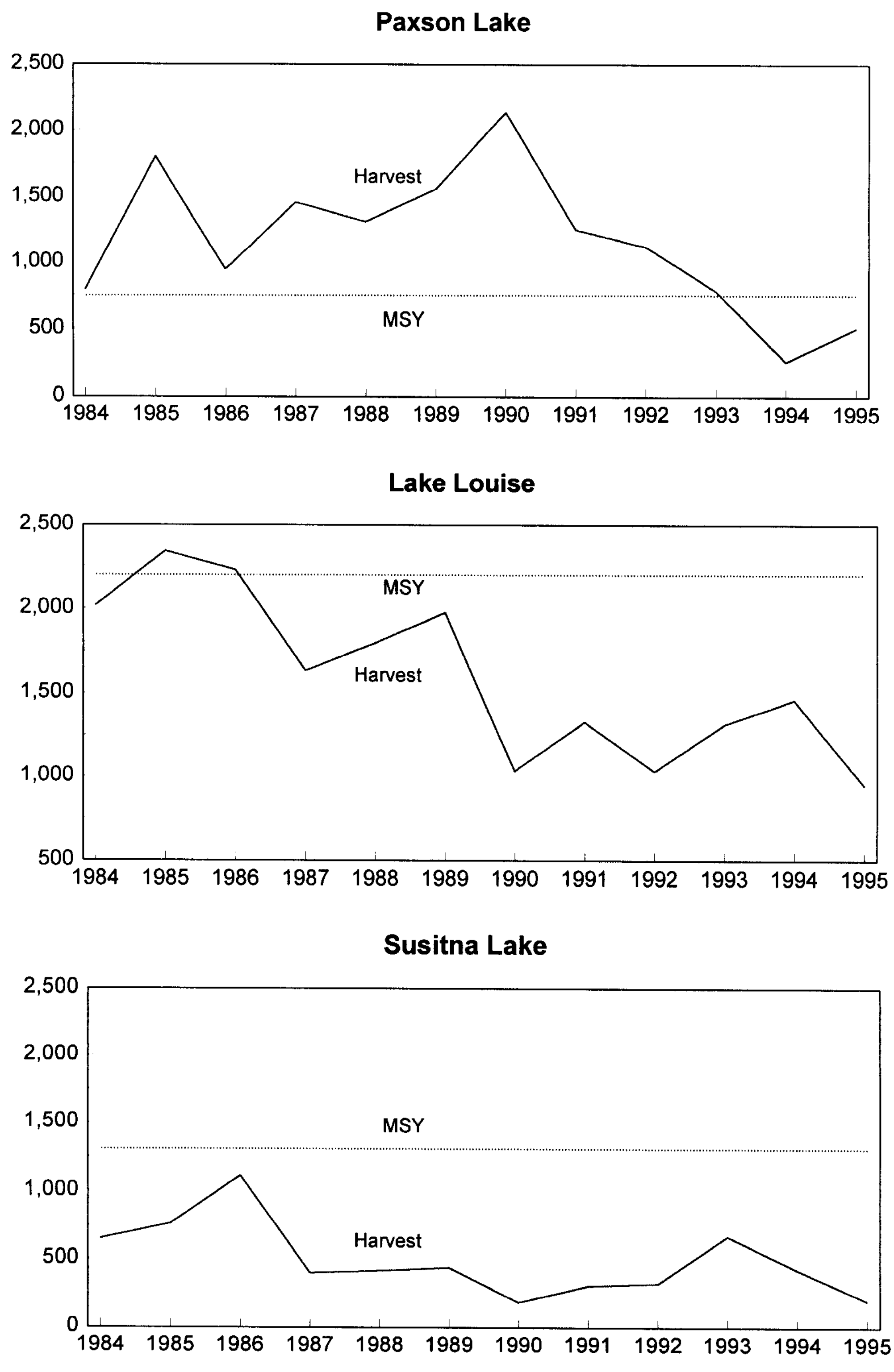

Figure 3.-Lake trout harvests compared to estimates of maximum sustainable yield (MSY) as developed through measurements of thermal habitat volume (from Payne et al. 1990).

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

	Area (ha)	Year	THV (hm^3)	Mean Weight (kg)	Maximum Sustained Yield		Carrying Capacity	
					$kg^{-1}/ha^{-1}/yr^{-1}$	Number	kg	Number
Paxson	1,575	1991	28.9	1.8	0.99	866	51,975	28,875
		1992	30.7	1.61	1.03	1,008	43,845	27,233
		1993	17.9	1.68	0.7	656	29,797	17,736
		1994	28.1					
		1995	19.4	2.25	0.75	525	31,926	14,189
		Average		1.92	0.89	747	39,767	21,277
Louise	6,519	1991	52.6	3.19	0.37	754	65,190	20,436
		1992	291.3	2.5	1.21	3,287	213,189	85,276
		1993	211					
		1994	210					
		1995	245.8	2.87	1.1	2,505	194,337	67,713
		Average		2.87	0.93	2,199	164,161	58,734
Susitna	3,816	1992	40.8	2.87	0.52	691	53,630	
		1993	97					
		1,994	130					
		1995	138.2	2.87	1.25	1,661	128,838	44,891
		Average		2.87	0.98	1,308	101,488	35,362

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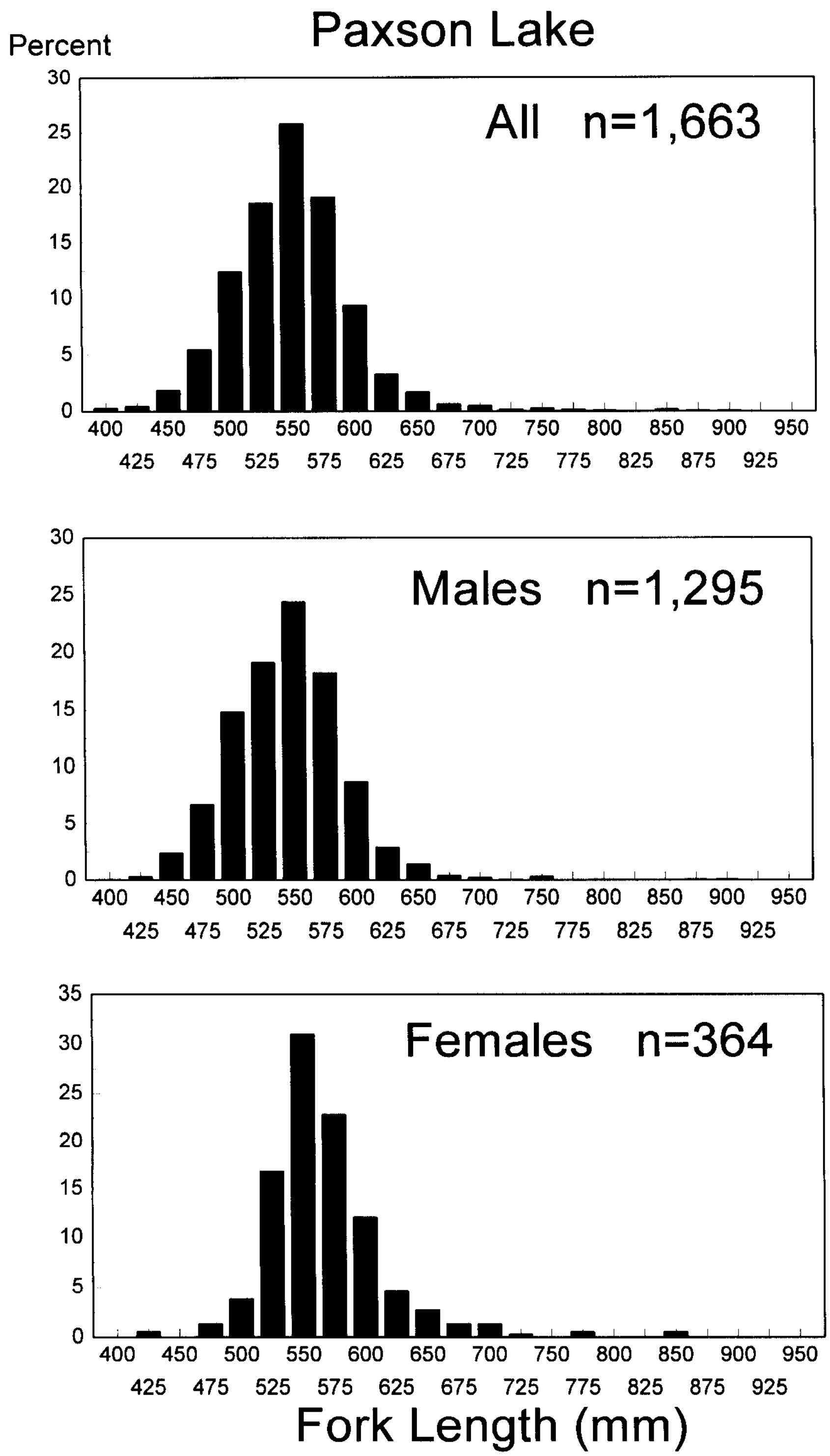
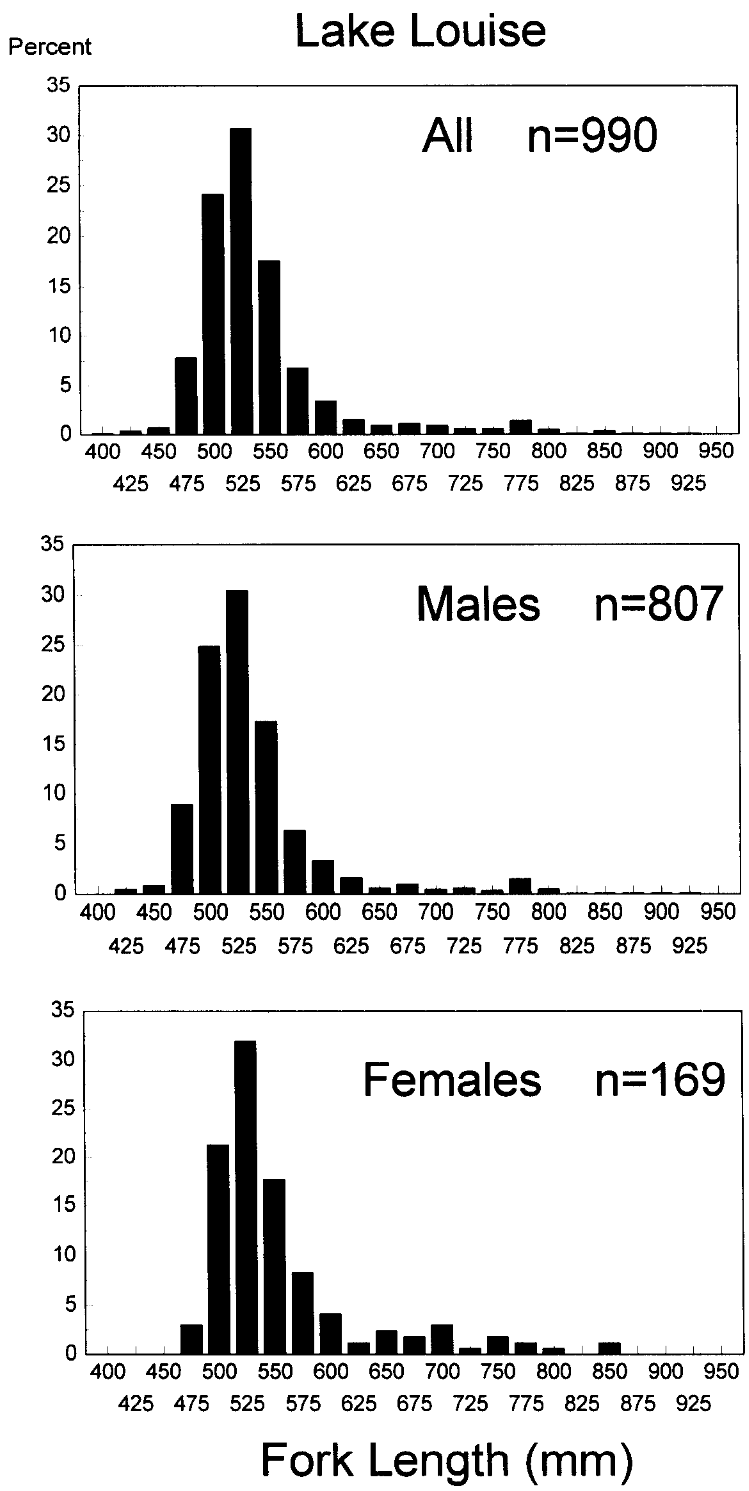
APPENDIX A. LENGTH FREQUENCIES OF LAKE TROUT SAMPLED DURING 1995



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

Appendix A1.-Fork lengths of spawning lake trout captured by beach seine from Paxson Lake, 1995.



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

Appendix A2.-Fork lengths of spawning lake trout captured by beach seine from Lake Louise, 1995.