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Abundance, Composition, Sustainable Yield, and Risk Analysis of the Northern Pike Population in Harding Lake, 1998

by

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and

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November 1999

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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ABSTRACT

In 1998, estimated abundance of northern pike *Esox lucius* within Harding Lake was 1,376 fish (SE = 279) ≥ 300 mm FL, 934 fish (SE = 191) ≥ 450 mm FL, and 190 fish (SE = 43) ≥ 625 mm FL. Estimated density of northern pike ≥ 300 mm FL was 1.38 (SE = 0.28) fish per hectare. The estimated proportion of the population that was between 300 and 449 mm FL was 0.32 (SE = 0.02); between 450 and 624 mm FL was 0.54 (SE = 0.02); and, ≥ 625 mm FL was 0.14 (SE = 0.01). In 1998, estimated recruitment (abundance of age-5 fish) was 284 northern pike (SE = 58). Estimated abundance was 361 fish (SE = 73) < age-5 and 731 fish (SE = 180) > age-5. The mean error in assigning the proper incremental age from the scales of 48 northern pike recaptured in 1998 from 1997 was -0.35 years ($Z = 2.15$; $P < 0.01$); 0.40 years ($Z = 1.46$; $P = 0.14$) for 10 northern pike that were ≤ age-4 in 1997; and -0.55 years ($Z = 2.97$; $P < 0.01$) for 38 northern pike ≥ age-5 in 1997. The estimated average percent error of the scale reader in reproducing the same age twice from a Harding Lake northern pike scale in 1998 was 2.4%. For Harding Lake northern pike, the indirect value for maximum sustainable yield was estimated as 414 fish, the number of northern pike needed to produce maximum sustainable yield was estimated as 1,728 spawning size fish, and the carrying capacity of Harding Lake was estimated as 3,457 northern pike ≥ age-5. In contrast, using Ricker's stock recruitment model, maximum sustainable yield was estimated as 368 fish and the number of spawners needed to produce maximum sustainable yield was estimated as 576 spawning size fish. Risk analysis indicated that, under current regulations and fishing pressure, there is a high risk that this northern pike population will (≥ 300 mm FL) remain under 1,500 fish. A change in minimum length from 26 in (~625 mm FL) to 30 in (~725 mm FL) would reduce this risk considerably.

Key Words: Northern pike, *Esox lucius*, population abundance, age composition, length composition, Harding Lake, sustainable yield, maximum sustainable yield, mark-recapture, risk analysis, stock-recruit relationship, risk analysis.

INTRODUCTION

The Alaska Department of Fish and Game initiated northern pike *Esox lucius* studies in the Arctic-Yukon-Kuskokwim Region of Alaska (AYK) to insure that annual harvests do not exceed surplus production of northern pike. Objectives designed to obtain estimates of maximum sustainable yield (MSY) have included estimates of abundance, length composition, age composition, mortality, recruitment, and movements of northern pike within selected lakes and wetland complexes in AYK.

Objectives to estimate abundance and length and age composition of Harding Lake northern pike began in 1990. In addition, an indirect estimate of sustainable yield for northern pike in Harding Lake based on methods in Ricker (1975) and Gulland (1983) was determined by Pearse and Hansen (1993) from four years of northern pike studies (Burkholder 1991; Skaugstad and Burkholder 1992; Pearse 1994). Pearse and Hansen (1993) used the indirect method of relating natural mortality and carrying capacity to MSY instead of regression techniques because of the few years of data. This estimate of sustainable yield was updated in 1997 (Roach 1998). With the information from the current study, sustainable yield was estimated using both the indirect method and regression techniques similar to those described by Pearse and Hansen (1993).

RESEARCH OBJECTIVES

Working toward the goal of estimating surplus production and evaluating the current status of the stock, a mark-recapture experiment was conducted in Harding Lake in 1998. The research objectives were to:

1) estimate population abundance of northern pike ≥ 300 mm fork length (FL)[1] in Harding Lake such that this estimate is within 25% of the actual value 95% of the time; and,
2) estimate the age and length composition of the northern pike population ≥ 300 mm FL in Harding Lake such that these estimates of proportions are within 5 percentage points of the actual value 95% of the time.

In addition to these objectives, a risk analysis was performed on Harding Lake northern pike to estimate the likely impact of altering the length restriction on abundance and length composition (Appendix A1 – A7).

DESCRIPTION OF FISHERY

In 1991, northern pike fishing in Harding Lake was restricted by regulation to June 1 through March 31; northern pike fishing with spears or bows and arrows was prohibited; and a minimum size limit for northern pike harvested was set at 26 inches (~625 mm FL). These restrictions were designed to eliminate the harvest of northern pike during the time of spawning and reduce the harvest of smaller northern pike. The management objectives of these regulations were to prevent a harvest level that is not sustainable and to help in rebuilding the population while allowing a limited recreational fishery. The minimum size limit allows northern pike two years of spawning before reaching the legal size for harvest. In addition, it was believed that these regulations would help achieve the strategy of limiting harvest to less than 15% of northern pike ≥ 300 mm FL, which was considered a sustainable and acceptable level of harvest.

Estimated sport fishing effort at Harding Lake increased from 1,707 angler-days in 1984 to about 5,000 from 1991 through 1994 to a high of 6,743 in 1995 (Table 1; Mills 1985 - 1994; Howe et al. 1995 - 1998). Limited opportunities for fishing along the road system of the Tanana Valley and an increased angler demand for northern pike probably contributed to the increasing angler effort at Harding Lake. Despite the rise in angler effort for all species at Harding Lake, harvest of northern pike has remained relatively low since 1992 compared to 1984 through 1991 (Table 1). Harvest estimates have varied from 94 in 1997 to 2,092 northern pike in 1988. Estimates of abundance for northern pike (≥ 300 mm FL) have ranged from 1,780 (SE = 323) in 1997 to 3,768 (SE = 432) in 1993 (Burkholder 1991; Skaugstad and Burkholder 1992; Pearse 1994; Roach 1996-1998).

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[1] Five critical fork lengths are referred to in this report: 300 mm is the length that northern pike begin to recruit to the sampling gear, 450 mm is considered the smallest length of fully recruited spawners, 625 mm is the minimum size limit that can be legally harvested, and 725 mm and greater is a length category reported in the state wide harvest survey, which managers use to monitor the catch of large northern pike.

Table 1.–Estimated angler days expended, numbers (SE in parenthesis when available) of northern pike harvested and caught, and catches per angler day and harvests per catch in Harding Lake, 1984-1997 summarized by all northern pike and northern pike > 725 mm FL.

		Number Harvested		Number Caught		Catch/Angler Day		Harvest/Catch	
Year	Angler Days	All	> 725 mm	All	> 725 mm	All	> 725 mm	All	> 725 mm
1984	1,707	766	-	-	-	-	-	-	-
1985	-	-	-	-	-	-	-	-	-
1986	2,064	673	-	-	-	-	-	-	-
1987	5,125	1,886	-	-	-	-	-	-	-
1988	3,256	2,092	-	-	-	-	-	-	-
1989	4,935	1,764	-	-	-	-	-	-	-
1990	3,895	591	-	3,629	-	0.93	-	0.16	-
1991	5,155	1,888[a] (1,007)	401 (220)	5,071	476	0.98	0.09	0.37	0.84
1992	5,068	341 (128)	100 (34)	3,400	424	0.67	0.08	0.10	0.24
1993	4,885	391 (145)	238 (100)	6,041	619	1.24	0.13	0.06	0.38
1994	4,913	539 (197)	179 (72)	5,559	995	1.13	0.20	0.10	0.18
1995	6,743	502 (124)	87 (34)	3,852	753	0.57	0.11	0.13	0.11
1996	6,734	363 (123)	115 (46)	4,070	593	0.60	0.09	0.09	0.19
1997	4,100	94 (56)	94 (56)	2,234	344	0.54	0.08	0.04	0.27
Average	4,506	915	173	4,232	601	0.83	0.11	0.13	0.32

[a] The imprecision of this estimate of harvest was attributed to an extraordinarily large harvest reported by three respondents to the state wide harvest survey (Alaska Department of Fish and Game memorandum from Mike Mills to Cal Skaugstad dated November 2, 1992). The actual harvest was most likely much smaller.

DESCRIPTION OF STUDY AREA

Harding Lake is the largest road-accessible lake in the Tanana River drainage (Figure 1) with a surface area of 1,000 ha, a maximum depth of 43 m, a surface elevation of 217 m, and a shoreline circumference of 12.4 km. Harding Lake is located 54 km (69 km by road) southeast of Fairbanks, Alaska near the confluence of the Salcha and Tanana rivers. It is a circular lake with a prominent point along the southern shore and a small point along the northern shore. There are two inlets; the east inlet, which drains a 2,580 ha basin to the east of Harding Lake and enters the northeast corner of the lake, and the Little Harding Lake inlet that enters the southwest corner. There are no outlets from Harding Lake (Figure 2).

LaPerriere (1975) and Nakao (1980) described Harding Lake as oligotrophic. Most of the lake is in an open-water zone with almost all marginal vegetation (emergent grasses) found along the north and northeast shores in water < 1 m deep. However, more than half of shallow water (< 3-m depth) in the north and northeast areas of the lake is free of vegetation. There are some deep beds of *Potamageton* sp. and *Chara* sp. located sporadically at about the 5-m contour. The littoral zone (the area from zero depth to the outer margin of the deep vegetation) comprises less than 33% of the surface area of the lake. Furthermore, there are large areas within this zone that are free of vegetation. Doxey (1991) hypothesized that macrophytes are not able to colonize large areas of the littoral zone within the lake because of wave action, freeze-down, and ice-scouring. Emergent vegetation comprises less than 10% of the surface area. Shallow areas are composed of sand, sand and gravel, or silt and the deeper areas loose organic and clay sediments (Nakao 1980). In addition to northern pike, indigenous fish species that are found in Harding Lake are burbot *Lota lota*, least cisco *Coregonus sardinella*, and slimy sculpin *Cottus cognatus*. Introduced species include lake trout *Salvelinus namaycush* and Arctic char *S. alpinus*.

Access to Harding Lake is by three roads from the Richardson Highway; one that leads to a State of Alaska boat launch, and two that lead to a North Star Borough boat launch. Salchacket Drive, a perimeter road, encircles approximately three fourths of the lake (Figure 2). Approximately 75% of the shoreline is ringed by private cabins, homes, and other human development. Docks, rafts, and boatlifts dot the inhabited areas of the shoreline in the summertime. There is a State of Alaska campground on the northwestern shore near the State boat launch with a channel, swimming [illegible], campsites, parking, athletic fields, and some undeveloped areas for hiking and unstructured outdoor recreation.

METHODS

Methods for the Harding Lake northern pike mark-recapture experiment in 1998 were similar to those used from 1993 to 1997 (Pearse 1994; Roach 1996-1998) in that the two-event mark-recapture experiment was scheduled in late May and early June. The Harding Lake northern pike radiotelemetry study (Roach 1993) indicated that Harding Lake northern pike are more uniformly distributed by sex and length in June compared to May. Therefore, to help ensure a uniform sample by sex and length during at least one of the

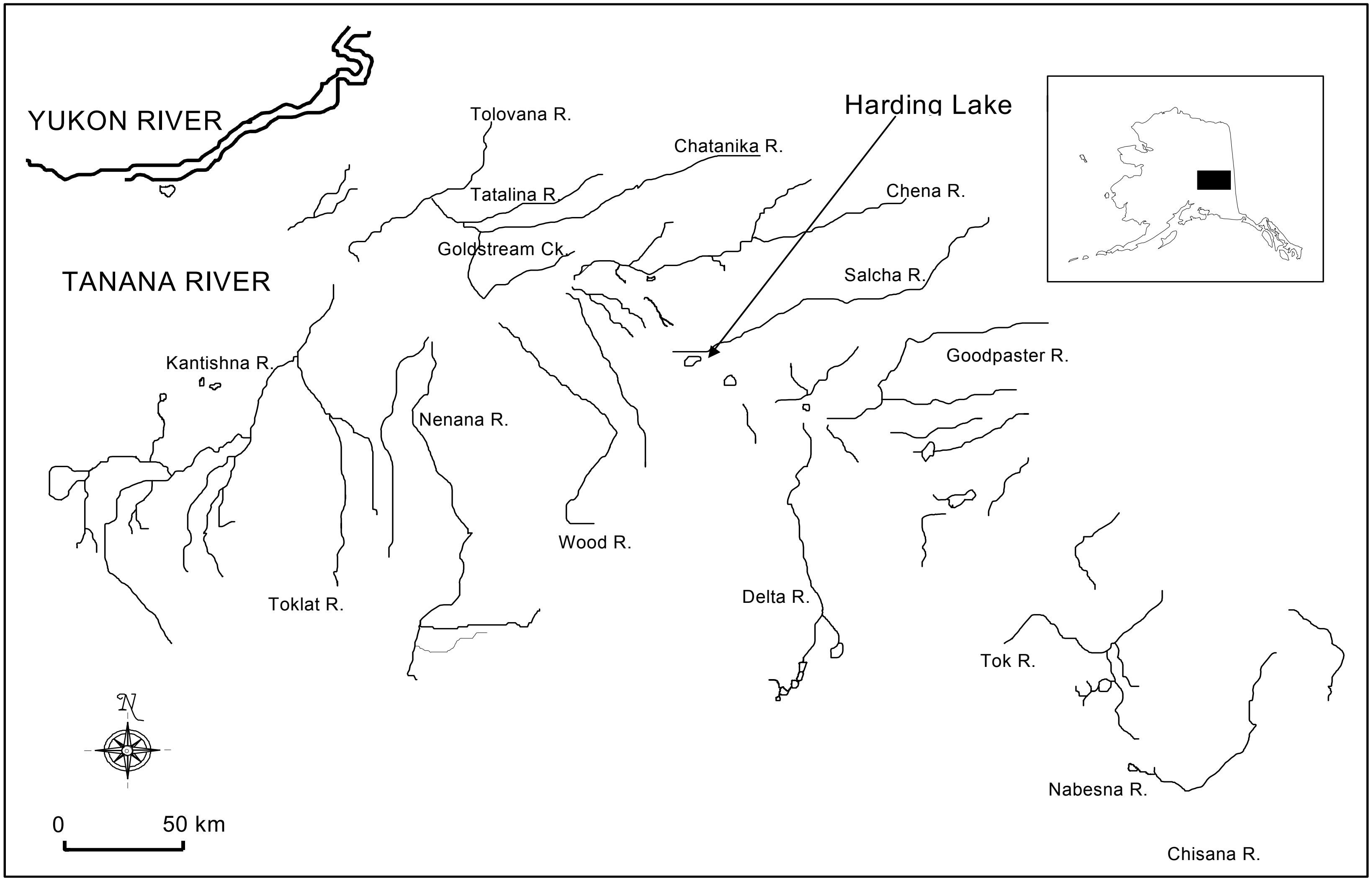

Figure 1.-Tanana River drainage.

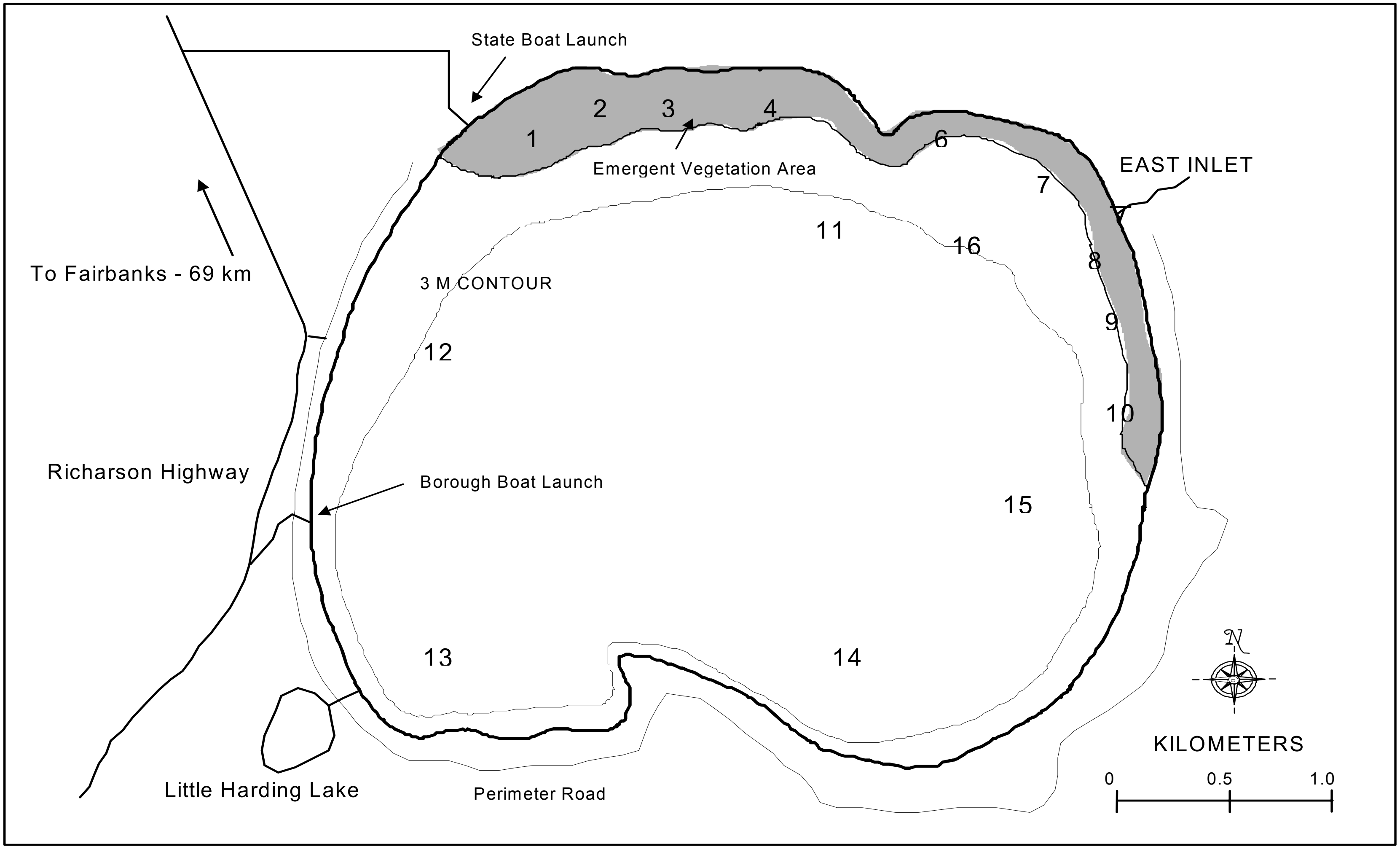

Figure 2.-Harding Lake with sampling sections (1 - 16) indicated, which were used for capture probability and movement analysis.

sampling events, the recapture event took place in early June. Unlike northern pike in other Interior lakes, Harding Lake northern pike remain in shallow water (< 3 m) during late May and early June (Roach 1993) and are susceptible to in-shore sampling techniques during this time. Methods in 1998 were different from those used from 1993 to 1997 because low water and the lack of water precluded sampling in the emergent vegetation along the north and east shores. In previous years these two areas were sampled on foot with gill nets and back-pack electrofishing gear. After a preliminary check indicated that water was too low for fish in these areas, all sampling in 1998 took place in deeper water from boats. In addition, the hiatus between the marking and recapture events was extended from three days to nine days in 1998 to allow more time for marked fish to mix with the unmarked population. The marking event (May 18 - May 22) and recapture event (June 1 – June 5) took five days each to complete with a nine-day hiatus between events (May 23 – May 31). Data files for both events were archived (Appendix B1).

SAMPLING TECHNIQUES

In previous years Harding Lake was divided into 15 sampling sections to examine movement, test for differences in catchability, and help insure uniform sampling effort (Figure 2). This was reduced to six (sections 11 – 16) since the emergent vegetation (sections 1- 10) was void of fish.

Two crews of three individuals each set gill nets from boats in open water. Each day one crew sampled in only one section of the lake. Each section, however, was sampled two consecutive days during each event, except for sections 11 and 12 which were sampled only once per event. Gill nets were deployed at the beginning of the day perpendicular to shore, checked a minimum of once every hour, and moved uniformly throughout the section. All healthy northern pike were released immediately after data collection 50 to 100 m from the capture site.

All data from northern pike captured during the mark-recapture experiment were recorded on ADF&G Tagging Length Mark-Sense Form, Version 1.0. A new form was used for each set with the date, area, and set number recorded on the description line. Locations of each set were recorded on a map each day. Scales for age determination were mounted directly to gummed cards at the time of sampling. A new gummed card was used for each set with the corresponding mark-sense litho-code, date, and water body recorded on the back. All crewmembers were aware of the importance of thoroughly examining all northern pike for Floy tags, recent tagging wounds, and recent fin clips and the importance of accurately recording data. All crewmembers performed these tasks appropriately.

During the marking event, all northern pike ≥ 300 mm FL that were captured were measured for length, examined for tags, two or more scales removed from each for age determination, and left pectoral fin slightly clipped. Length was measured and recorded to the nearest millimeter FL. Scales were taken from the preferred zone adjacent to but not on the lateral line above the pelvic fins as described by Williams (1955) and mounted on gummed scale cards. Both the left and right side of the dorsal fin were examined for the presence of a Floy tag. If a Floy tag was present, the color and number of the tag was recorded; or if not present, a new uniquely numbered Floy FD-68 internal anchor tag inserted at the left base of the dorsal fin. Northern pike killed during sampling were not tagged but all other data were recorded and the fate (K) clearly noted in the blank space after the length on the mark-sense form.

During the recapture event, the same data collection procedures were used as during the marking event except northern pike without Floy tags were not given a new Floy tag. Both the left and right side of the dorsal fin were examined closely for recent tag wounds and the left and right pectoral fins examined closely for recent clips, and then the right pectoral fin, instead of the left, was slightly clipped. Tag loss (TL) was clearly noted in the blank space after the tag number on the mark-sense forms for northern pike without a Floy tag but with a recent tag wound or recent left pelvic fin clip. Recapture (RC) was clearly noted on the mark-sense form for known recaptures from the marking event. Northern pike were not sampled more than once during the recapture event. Northern pike already sampled during the recapture event were identified by the presence of a recent right pectoral fin clip.

Upon completion of fieldwork, collected northern pike scales were processed for age determination. Scale impressions were made on 20 mil acetate sheets using a Carver press at 241,315 kPa (35,000 psi) heated to 150°C for 150 s from scales collected in the field on gummed cards. Ages were determined from scale impressions using a Micron 770 microfiche reader (32X) according to criteria established by Williams (1955), and Casselman (1967). Because scale collection was after or near the time of annulus formation, growth beyond the last annulus was only considered an additional year when the distance from the last annulus to the edge was fairly parallel in the lateral to posterior direction for fish older than age-4. In cases of age-4 and younger fish, growth beyond the last annulus was generally always considered plus growth instead of an additional year.

ABUNDANCE

The mark-recapture experiment was designed to satisfy the assumptions of a Petersen mark-recapture experiment (Seber 1982). These assumptions were that:

1) the population was closed (no change in the number or composition of northern pike during the experiment);
2) all northern pike had the same probability of capture during the marking event or the same probability of capture during the recapture event or marked and unmarked northern pike mixed completely between the marking and recapture events;
3) marking of northern pike did not affect their probability of capture in the recapture event;
4) northern pike did not lose their mark between events; and,
5) all marked northern pike were reported when recovered in the recapture event.

The validity of assumption 1 was inferred because northern pike movement into or from Harding Lake was unlikely. Mortality and growth, which may contribute to the violation of assumption 1, were assumed negligible because of the short duration of the experiment. The validity of assumptions 2 and 3 was tested by comparing recapture rates and movements of fish between events with tests of consistency designed to detect unequal catchability by area and by size of fish (Seber 1982). The validity of assumption 4 was ensured by double marking (Floy tag and fin-clip) each northern pike during the marking event. Tag loss was noted when a fish was recovered during the recapture event with the specific fin clip but without a Floy tag. In addition, Floy tag placement was standardized, which enabled the fish handler to verify tag loss by locating recent tag wounds. The validity of assumption 5 was ensured by a thorough examination of fins for fin-clips and recording Floy tag numbers for all northern pike. Floy tag numbers used for this mark-recapture experiment were archived (Appendix C1).

To reduce bias from unequal catchability by length, samples were divided into two length strata. Abundance of northern pike was estimated for both of the two groups from the number of northern pike marked, examined for marks, and recaptured in each length strata and then these were summed to estimate the total abundance. The Chapman estimator (Seber 1982) was used for each stratum:

$$\hat{N} = \frac{(M+1)(C+1)}{R+1} - 1 \tag{1}$$

where: M = the number of northern pike marked and released alive during the marking event;

C = the number of northern pike examined for marks during the recapture event;

R = the number of northern pike recaptured during the recapture event; and,

$\hat{N}$ = estimated abundance of northern pike at the time of marking.

Variance of the abundance estimate (Seber 1982) was estimated as:

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

LENGTH AND AGE COMPOSITIONS

Length and age compositions of northern pike ≥ 300 mm were estimated and adjusted for differential capture probability by length. This was accomplished by adjusting the length and age proportions according to the ratio of total abundance in each length stratum to minimize bias. Although not directly tested, it was assumed that unequal catchability of northern pike by age was correlated with length. Length and age composition data were archived (Appendix C2 and C3).

The adjusted proportion and the variance estimator approximated by the delta method were:

$$\hat{p}_k = \sum_i \frac{\hat{N}_i}{\hat{N}} \hat{p}_{ik}, \text{ and} \tag{3}$$

$$\hat{V}[\hat{p}_k] \approx \sum_i (\hat{p}_{ik} - \hat{p}_k)^2 \frac{\hat{V}[\hat{N}_i]}{\hat{N}^2} + \sum_i \left(\frac{\hat{N}_i}{\hat{N}}\right)^2 \hat{V}[\hat{p}_{ik}] \tag{4}$$

where: $\hat{N}_i$ = the abundance of northern pike in stratum *i*;

$\hat{N}$ = total abundance of northern pike; and,

$\hat{p}_{ik}$ = the conditional proportion of northern pike in stratum *i* that were of length or age class *k*.

AGE VALIDATION

Accuracy of age determinations from scales captured during the 1998 mark-recapture experiment was tested indirectly. Scales from northern pike tagged in previous years that were recaptured during the experiment were used to determine the relative accuracy of age determination. The mean error in assigning the correct incremental age from scales of these northern pike was used as a measure of bias. The mean error was determined for ages of all northern pike, northern pike ≤ age-5, and northern pike > age-5 because this age is the age of full recruitment into the spawning stock (Pearse and Hansen 1993). The Wilcoxon Signed-Rank Test was used to determine significance of the bias (Conover 1980). Probabilities of a Type I error (α) of 0.05 or lower were considered significant.

Error in assigning the correct incremental age for each fish was calculated as:

$$ERROR = AGE_{t+\Delta} - AGE_t - \Delta t \qquad (5)$$

where: $AGE_{t+\Delta}$ = age assigned when fish was recaptured;

AGE_t = age assigned at earlier capture; and,

Δt = number of years elapsed from capture to recapture.

Mean error was calculated as the sum of all the errors divided by the number of fish recaptured.

Furthermore, to evaluate the precision in age determination, ages were determined twice for a random sample of 99 scales taken during the experiment. The average percent error (APE; Beamish and Fournier 1981) of the scale reader to reproduce the same age twice from a Harding Lake northern pike scale in 1998 was calculated as:

$$APE = \frac{\sum_{i=1}^{S}\left[\frac{\sum_{j=1}^{R}\frac{\left|x_{ij}-\overline{x}_i\right|}{\overline{x}_i}}{R}\right]}{S}\cdot 100 \qquad (6)$$

where: x_{ij} = age determined from the j^{th} reading of the i^{th} scale;

$\overline{x}_i$ = average age determined from the i^{th} scale;

R = total number of readings; and,

S = total number of scales in the sample.

APE provides a means to evaluate the reproducibility of ages within a year, but should not be considered independent of age (Laine et al. 1991).

MAXIMUM SUSTAINABLE YIELD AND STOCK-RECRUIT RELATIONSHIP

Surplus production was investigated using an indirect method adopted from Pearse and Hansen (1993) which was based upon the relationship of instantaneous rate of natural mortality (M), the intrinsic rate of population increase (r), and maximum recruitment (R_{MAX}) to the number of spawners (N_{MSY}) needed to produce maximum sustainable yield (Ricker 1975; Gulland 1983):

$$N_{MSY} = \frac{R_{MAX}}{\frac{r}{2} + \left(1 - e^{-M}\right)}. \tag{7}$$

Maximum recruitment was assumed to be the greatest observed number of age-5 northern pike in Harding Lake since 1990. Natural mortality (M) was calculated using the methods of Pearse and Hansen (1993). An indirect estimate for the intrinsic rate of population increase was then determined as 1.2 times M (Gulland 1983). Following the calculations of Ricker (1975) and Gulland (1983), the carrying capacity of the environment (K) was determined as two times N_{MSY} and MSY as:

$$MSY = \frac{rK}{4}. \tag{8}$$

Surplus production was also investigated using the more direct approach of Ricker's stock-recruitment model (Ricker 1975). With the current year's data, 4 estimates of recruitment and 4 corresponding estimates of spawners were available for the necessary regression techniques. Ricker's stock-recruitment model assumes that density-dependent mortality influences early survival. This implies that there is declining recruitment at higher stock sizes. The model follows four basic properties:

1) the stock-recruitment curve should pass through the origin;

2) the curve should not fall to the abscissa at higher levels of stock abundance so that there is no point at which reproduction is completely eliminated at high densities;

3) the rate of recruitment should decrease continuously with an increase in parental stock; and,

4) recruitment must be high enough over some range of stock sizes to more than replace natural mortality losses.

The Ricker stock-recruitment model is:

$$R = \alpha N e^{-\beta N} \tag{9}$$

where: R = the number of recruits;

N = the number of spawners;

α = a dimensionless parameter often considered stock-specific and associated with density-independent factors; and,

β = a parameter with dimensions of 1/N that is usually associated with density dependent factors.

The number of spawners (N_{MSY}) needed to produce MSY was estimated by solving the Ricker equation where it's slope is parallel to the line of replacement (R = MN):

$$(1 - \beta N)\alpha e^{-\beta N} = M\,. \tag{10}$$

MSY was estimated as:

$$MSY = R_{MSY} - (MN_{MSY}) \tag{11}$$

where R_{MSY} was estimated by solving equation 9 with N_{MSY}.

RESULTS

Of the 432 northern pike handled during the mark-recapture experiment, 210 were tagged and released alive during the marking event and 222 were examined for marks during the recapture event of which 46 were recaptures from the marking event (Appendix C4). There was no observed tag loss or handling mortality during the experiment, and 156 northern pike with Floy tags from prior mark-recapture experiments (36% of unique northern pike handled) were identified.

ABUNDANCE

Estimated abundance of northern pike within Harding Lake was germane to fish ≥ 300 mm FL during late May and early June 1998. To examine tag-recovery rates by area, Harding Lake was divided into two areas in such a way that minimized the difference in recovery rates within each area but maximized the difference between the areas. A comparison of the recovery history of fish marked in these two areas indicated significantly different mixing rates between the areas (χ^2 = 15.94; 2 df; P < 0.01; Table 2). In addition, significantly different proportions of fish marked in each area were recovered (χ^2 = 3.89; 1 df; P = 0.05; Table 3). This suggested that along with unequal movement, all fish did not have a similar probability of capture during the recapture event. Recapture rates, however, were not significantly different by area (χ^2 = 1.91; 1 df; P = 0.17; Table 4), which suggested that all fish had a similar probability of capture by area during the marking event. These tests indicated that one of the "or" conditions of Assumption 2

Table 2.-Numbers of northern pike marked in areas A (sections 11, 12, 13, and 15) and B (sections 14 and 16) and recovered in area A, area B, or not recovered.

Marking	Recovery History			
Area	A	B	Not Recovered	Total
A	24	6	80	110
B	4	12	84	100
Total	28	18	164	210

Table 3.-Numbers of marked northern pike recovered and not recovered during the recapture event by areas A (sections 11, 12, 13, and 15) and B (sections 14 and 16).

	Marking Area		
History	A	B	Total
Recovered	30	16	46
Not Recovered	80	84	164
Total	110	100	210

Table 4.-Numbers of marked and unmarked northern pike captured during the recapture event by areas A (sections 11, 12, 13, and 15) and B (sections 14 and 16).

	Capture Area		
Northern Pike	A	B	Total
Marked	28	18	46
Unmarked	87	89	176
Total	115	107	222

were met, thereby satisfying the requirements of this assumption by geographic strata for a Peterson mark-recapture experiment.

To test assumptions of equal capture probability by length, length distributions of fish marked, examined for marks, and recaptured were compared. There was a significant difference between the length distributions of fish marked and fish recaptured ($D = 0.29$; $P < 0.01$; Figure 3) but there was not a significant difference between the length distributions of fish marked and fish examined for marks ($D = 0.08$; $P = 0.55$; Figure 3). This suggests that capture probability by length was not equal but, was similar during the two events. To minimize bias in the estimate of abundance, fish were divided into two groups at the length that minimized the difference within each group but maximized the difference between groups (580 mm FL; Figure 3). Abundances were estimated for each group separately and then added together for total abundance.

Estimated abundance of northern pike ≥ 300 mm FL within Harding Lake was 1,376 fish (SE = 279; CV = 20%; Table 5). The upper and lower bounds of the 95% C.I. were 996 and 2,634 northern pike ≥ 300 mm FL. Estimated abundance of northern pike ≥ 450 mm FL was 934 fish (SE = 191) and estimated abundance of northern pike ≥ 625 mm FL was 190 fish (SE = 43). Estimated density of northern pike ≥ 300 mm FL was 1.38 (SE = 0.28) fish per hectare.

LENGTH COMPOSITION

Since capture probability was similar between both events ($D = 0.08$; $P = 0.55$; Figure 3), fork lengths from both events were pooled for estimating length composition. However, since capture probability by length was not equal ($D = 0.29$; $P < 0.01$; Figure 3), length proportions were adjusted according to the ratio of total abundance in each length stratum.

Table 5.-Numbers of northern pike marked (M), examined for marks (C), recaptured (R), abundances and standard error of abundances by length stratum.

	Number of Fish				
Stratum	M	C	R	$\hat{N}$	SE($\hat{N}$)
Small (300 – 579 mm FL)	95	105	9	1,017	276
Large (≥ 580 mm FL)	115	117	37	359	39
Total	210	222	46	1,376	279

Fork lengths measured from 432 northern pike ≥ 300 mm FL in Harding Lake ranged from 300 mm to 1,050 mm (mean = 553 mm; SE = 6). The estimated abundance was 442 fish (SE = 93) for northern pike from 300 to 449 mm FL; 743 fish (SE = 153) for northern pike from 450 to 624 mm FL; and, 190 fish (SE = 43) for northern pike ≥ 625 mm FL (Figure 4). The estimated proportion was 0.32 (SE = 0.019) for northern pike from 300 to 449 mm FL; 0.54 (SE = 0.020) for northern pike from 450 to 624 mm FL; and, 0.14 (SE = 0.014) for northern pike ≥ 625 mm FL (Figure 4).

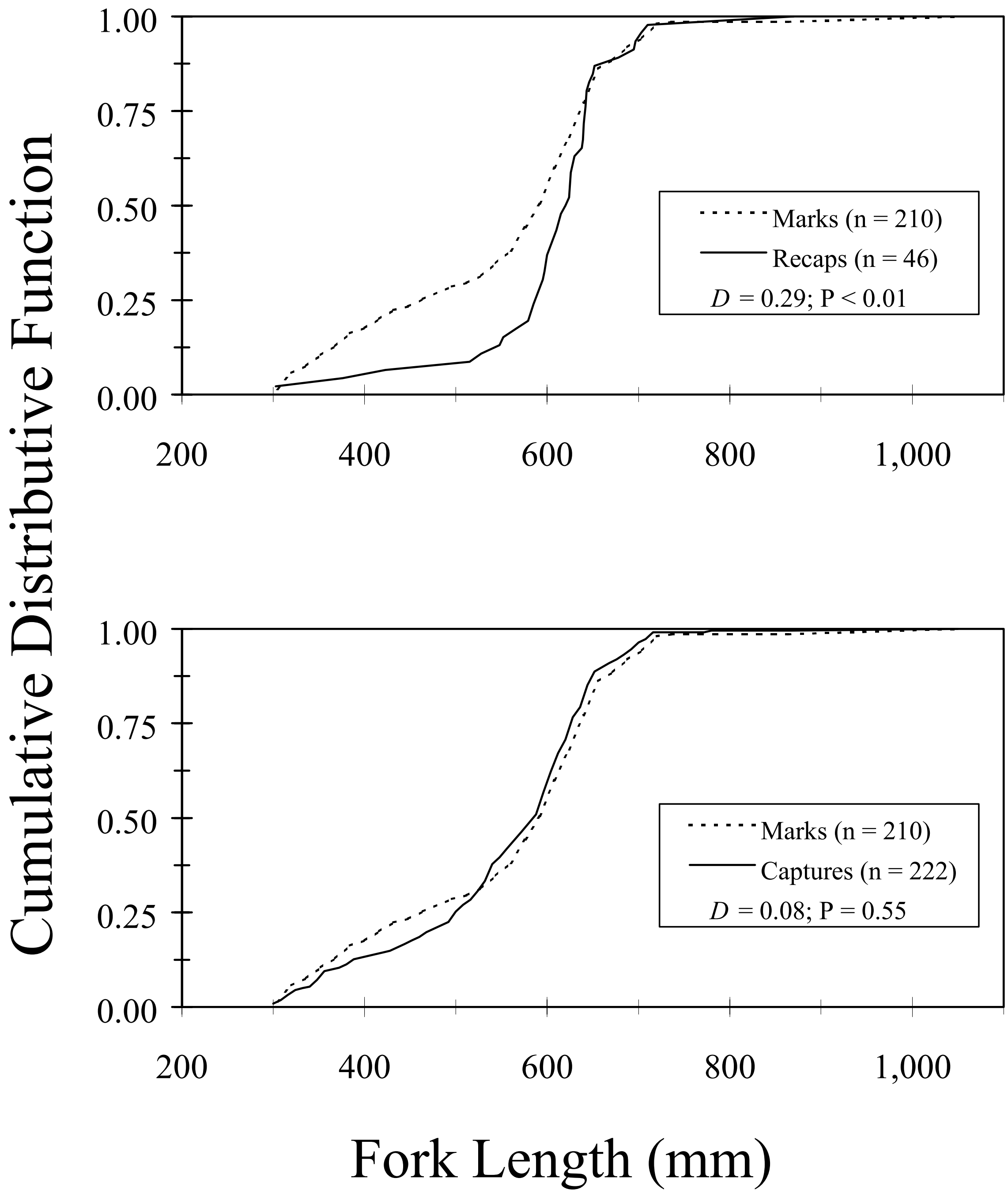

Figure 3.–Cumulative distributive functions of fork lengths of northern pike marked versus recaptured and marked versus captured in Harding Lake, 1998.

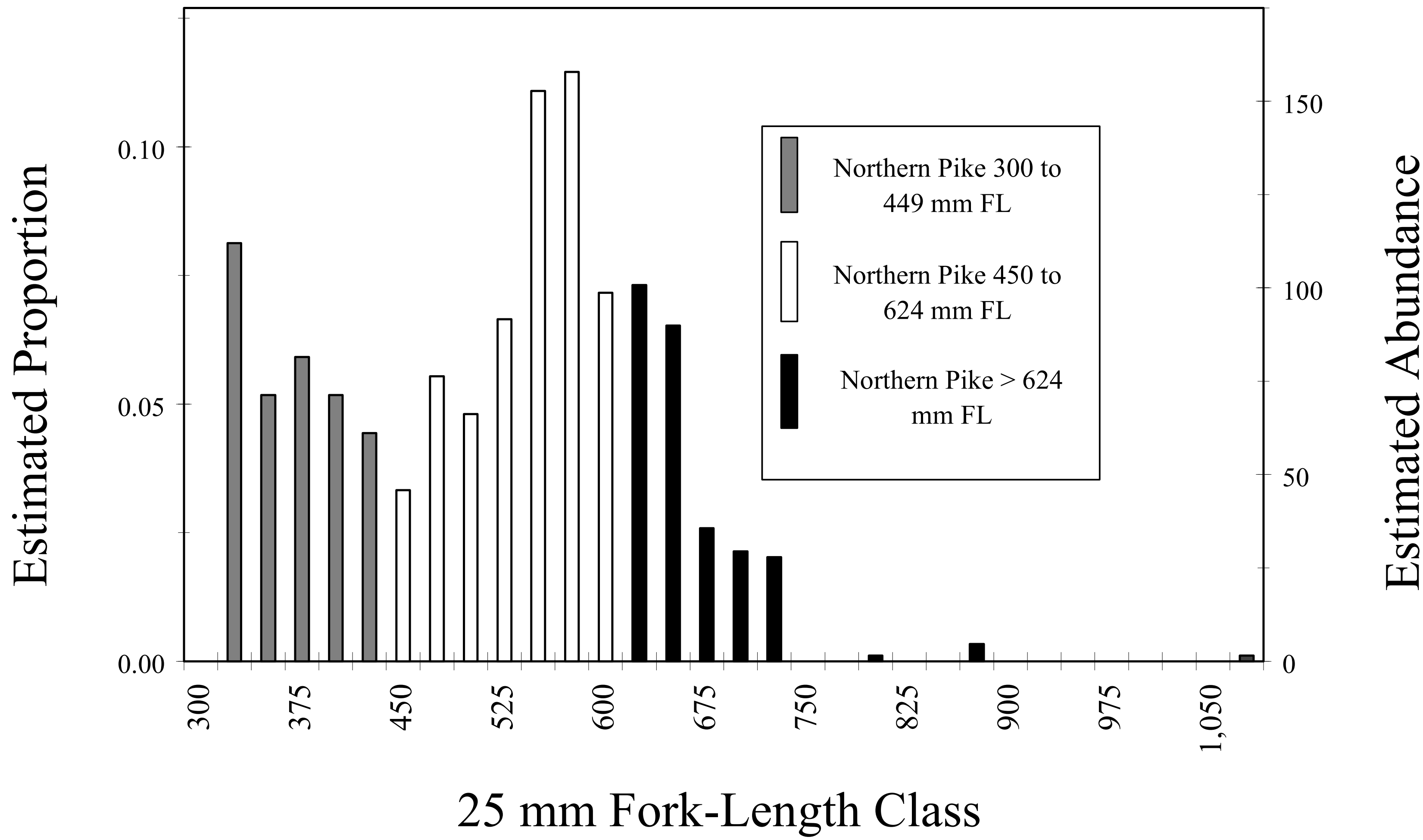

Figure 4.-Estimated proportions and abundances of northern pike ≥ 300 mm FL by 25-mm length classes within Harding Lake during late May and early June 1998.

AGE COMPOSITION

Using scales, investigators determined ages for 375 of 432 unique northern pike (≥ 300 mm FL) sampled during the mark-recapture experiment. Scales were not taken or lost from 29 fish, were not readable because of regeneration from 26 fish, and were not readable because of poor acetate impression from 1 fish. Of scales collected during the marking event, ages were determined for 190 unique northern pike. Of scales collected during the recapture event, ages were determined for 185 unique northern pike. Investigators determined ages for 48 northern pike within the sample that were also aged in 1997.

The mean error in assigning the proper incremental ages from the scales of the 48 northern pike that were recaptured in 1998 from 1997 was -0.35 years (Z = 2.15; P < 0.01); 0.40 years (Z = 1.46; P = 0.14) for 10 northern pike that were ≤ age-4 in 1997; and -0.55 years (Z = 2.97; P < 0.01) for 38 northern pike ≥ age-5 in 1997 (Figure 5). Analysis by cohort was limited to northern pike ≤ age-5 in 1998 because there was not a significant bias in relative age determination for these fish. All cohorts ≥ age-6 were lumped into one group because there was significant bias in determining the older ages. The estimated average percent error of the scale reader in reproducing the same age twice from a Harding Lake northern pike scale in 1998 was 2.4% (Figure 6).

The estimated abundances of Harding Lake northern pike ≥ 300 mm FL were 361 (SE = 73) prespawning-age fish (< age-5) and 1,015 (SE = 206) spawning-age fish (≥ age-5; Table 6). The estimated proportions of northern pike ≥ 300 mm FL were 0.26 (SE = 0.029) for prespawning-age fish (< age-5), and 0.74 (SE = 0.029) for spawning-age fish (≥ age-5; Table 6).

MAXIMUM SUSTAINABLE YIELD AND STOCK-RECRUIT RELATIONSHIP

From estimates of harvest (1990 – 1997) and abundance of northern pike ≥ age-5 and estimates of age-5 recruits (1990 – 1993 and 1995 –1998) average natural mortality (M) of Harding Lake northern pike ≥ age-5 was estimated as 0.40 and the intrinsic rate of increase (r) as 0.49. The greatest number of recruits observed from 1990 to 1998 was 982 in 1993, which was considered an estimate of maximum recruitment (R_{MAX}). Using these values and the indirect method adopted from Pearse and Hansen (1993), maximum sustainable yield (MSY) was estimated as 414 fish, the number of spawners needed to produce MSY (N_{MSY}) as 1,728 fish, ≥ 450 mm FL and the carrying capacity of the lake (K) as 3,457 fish ≥ age-5. In contrast, using Ricker's stock-recruitment model, MSY was estimated as 368 fish and the number of spawners needed to produce MSY (N_{MSY}) as 576 fish ≥ 450 mm FL (Figure 7).

DISCUSSION

In 1998, unlike 1996 and 1997, a Petersen model was used to estimate abundance of Harding Lake northern pike. The Darroch estimator was used in 1996 and 1997 because none of the "or" conditions of Assumption 2 were met for a Petersen model. In 1996, this was attributed to the late melt-off of winter ice, which resulted in the unequal distribution and movement of fish by size occurring at the time of the experiment instead of earlier in May (Roach 1997). In 1997, although the distribution and movement of fish by size was similar, sampling was not uniform during either event (Roach 1998). In 1998, there was size selectivity during both events, but since the probability of capture during the marking event was similar within each size group, a

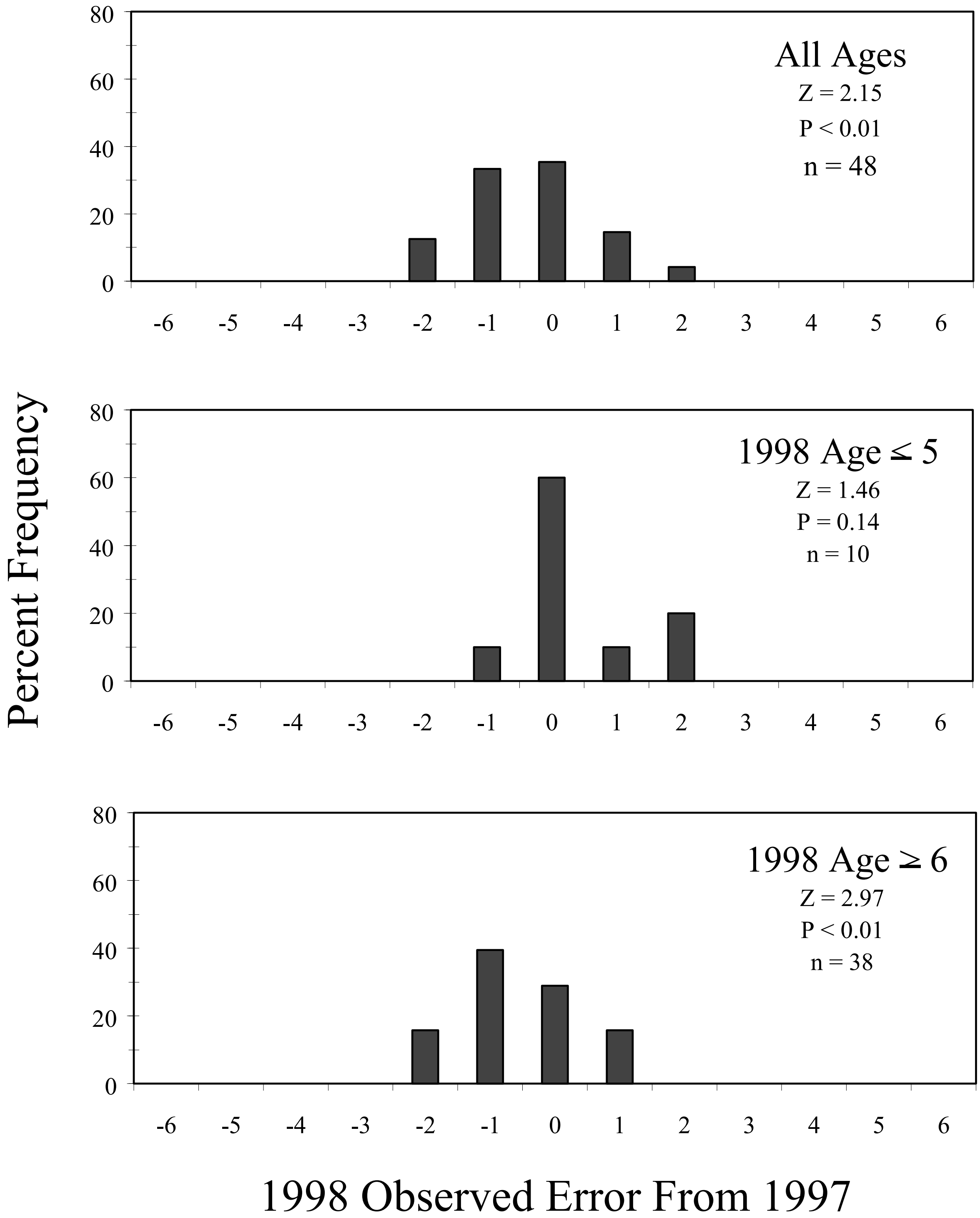

Figure 5.-Percent frequencies of observed errors in assigning the proper incremental ages to Harding Lake northern pike marked in 1997 and recaptured in 1998.

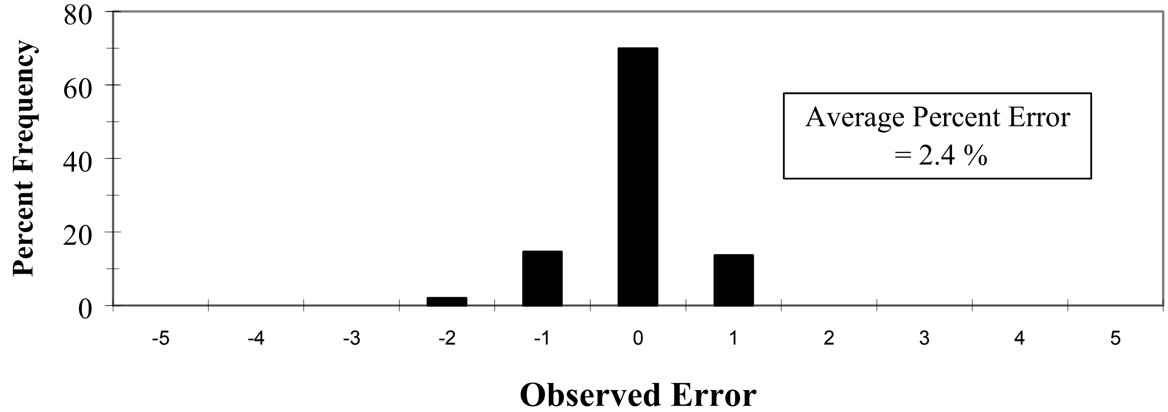

Figure 6.-Percent frequencies for observed errors in reproducing the same age twice from a Harding Lake northern pike scale in 1998.

Table 6.-Estimated proportions (p), abundances (N), and standard errors of estimates (SE) of Harding Lake northern pike that were ≥ 300 mm in late May and early June 1998 by age.

		Proportion		Abundance	
Age	n	P	SE[p]	N	SE[N]
1	-	-	-	-	-
2	8	0.02	0.009	31	6
3	34	0.12	0.020	172	35
4	53	0.12	0.019	159	32
5	85	0.21	0.024	284	58
≥ 6	222	0.53	0.036	730	148

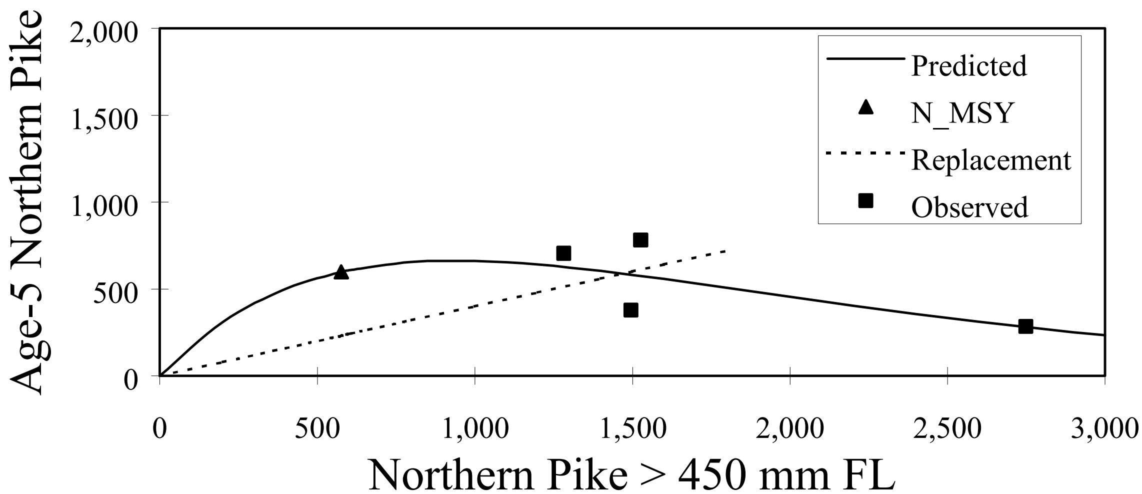

Figure 7.-Predicted Harding Lake northern pike spawner (at time t) and recruitment (at time t+5) relationship, number of spawners needed for MSY, and the line of replacement from four observed data points using Ricker's model.

stratified Petersen model was used to estimate abundance. Due to lower than normal water levels, the margins of the lake (where smaller fish are typically found) were not sampled with the same intensity as prior years. This resulted in a lower capture probability for small fish than for large fish and hence the need to stratify by size.

Once again age validation demonstrated the difficulty in determining age from the scales of interior Alaska northern pike. Unlike northern pike in warmer climates (Laine et al. 1991), age determination of interior Alaska northern pike becomes increasingly difficult after age-5 (Roach 1996; 1997; 1998). This is attributed to inconsistent growth from one year to the next and little or no growth in some years after reaching maturity. Fortunately, the age of full recruitment to the gear (age-5) was determined with relative precision and accuracy, however, it was necessary to lump older fish into one group. Age validation should be used as one component of northern pike stock assessment to safeguard against the misuse of age data.

Estimates of MSY for Harding Lake northern pike using two methods, an indirect approach and the Ricker model, were similar but estimates of N_{MSY} were not. This suggests more confidence in our understanding of MSY than in our understanding of the number or spawners that is needed to produce MSY. The estimated stock-recruitment relationship is not satisfactory yet and should be improved upon with the addition of more data points. Efforts to understand the stock-recruitment relationship, however, were improved with the 1998 mark-recapture experiment by providing the addition of an extreme data point. Recruitment estimated in 1998 was from a relatively large abundance of spawners in 1993. We will again have this opportunity for a similar data point in 2001 because in that year recruitment will be from a large abundance of spawners in 1996. This will help us understand the variability in recruitment when abundance of spawners is high. Furthermore, recruitment in 2003 will give us an opportunity to gain a data point from the relatively low number of spawners in 1998. Generally, for fitting these kinds of curves, middle range data points predominant and extreme data points are rare. We will need to take advantage of these opportunities in 2001 and 2003 by conducting mark-recapture experiments to provide information about these extremes in spawner and recruit abundances.

The current Harding Lake regulations have the effect of providing a yearly harvest between 10% (SE = 4%; 1992) and 19% (SE = 5%; 1995) of the yearly average abundance of northern pike ≥ 300 mm FL but do not provide for increasing the stock as initially desired and may contribute to the stock falling below 1,500 fish (Appendix A4). Given the relatively high number of angler days at Harding Lake (Table 1), the 26 inch TL (~625 mm FL) minimum size limit has resulted in a recruitment fishery in which some years there are more legal-size fish harvested than are present at the beginning of the fishing season. This type of fishery results in a reduction of the average length of fish harvested and a reduction in the abundance of fish greater than the minimum size limit (Appendix A5). In view that the current point estimate of abundance is below 1,500 fish (95% C.I. 996 – 2,634; Figure 8), consideration should be given to adopting more restrictive regulations. The initial goal of increasing the population is not likely under the current regulation regime. If no action is taken to restrict regulations, population assessment of Harding Lake northern pike must be continued to monitor this highly exploited small stock of fish.

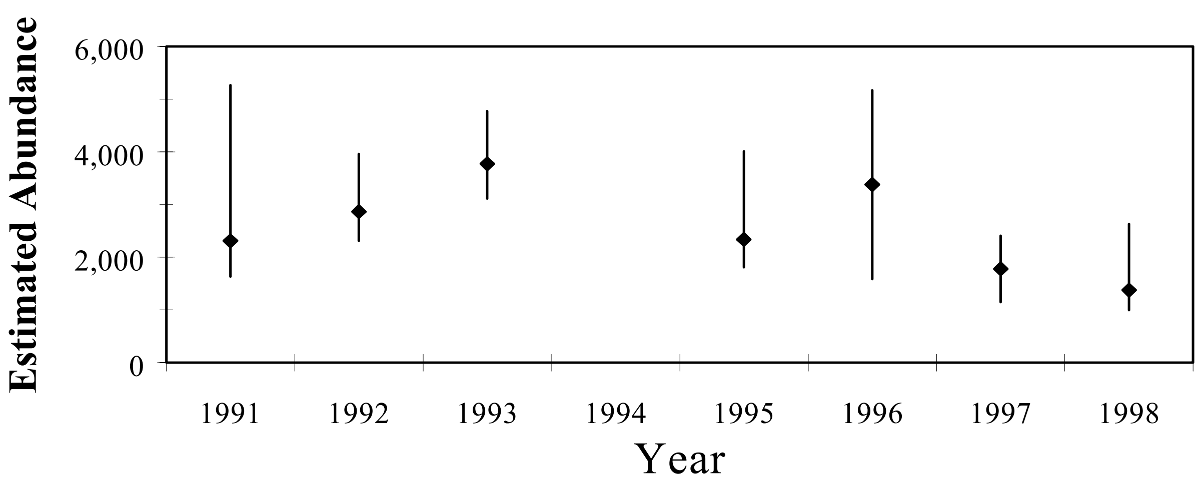

Figure 8.-Estimated abundance and 95% C.I. for Harding Lake northern pike, 1991 - 1998.

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APPENDIX A
Risk Analysis

Appendix A1.-Description of risk analysis on changing the Harding Lake northern pike minimum length limit.

Risk analysis was performed on the Harding Lake northern pike fishery to examine the likely impact on abundance and length composition by altering the length restriction on harvest. The unacceptable risk was defined as the assessed population falling below 1,500 fish and the number of fish ≥ 625 mm FL falling below 250 fish. The simulation model (Appendix A2) was structured around a simple relationship describing the change in total abundance from one year to the next:

$$N_{i+1} = N_i - M_i - F_i + R_i \quad \text{(A1.1)}$$

where: N_i = total abundance in year *i*;

M_i = total natural mortality in year *i*;

F_i = total harvest in year *i*; and,

R_i = total recruitment in year *i*.

Three harvest restrictions were chosen for simulation: the current minimum length of 625 mm FL, a minimum length of 725 mm FL, and closed to harvest. A Monte Carlo program was used to simulate the population under each harvest regime (Appendix A3). The program calculated probability of abundance and projected length composition after 20 years based on 200 iterations (Appendix A4 and A5).

The population was initialized with a starting value based on the abundance and variance of abundance in 1998 (Appendix A6). Fish were apportioned to each length category based on the 1998 proportions and adjusted for gear vulnerability (Appendix A7). The dynamics of the population were then simulated on a monthly basis with the assumption that the population after a period (t) was proportional to the number of fish at the beginning of the period (N_0) and the instantaneous rate of population growth *k*:

$$N_t = N_0 e^{kt}. \quad \text{(A1.2)}$$

The probability of survival for fish smaller than the minimum length was estimated as:

$$S = e^{-Mt} \text{, and} \quad \text{(A1.3)}$$

the probability of survival for fish larger than the minimum length was estimated as:

$$S = e^{-(M+F)t}. \quad \text{(A1.4)}$$

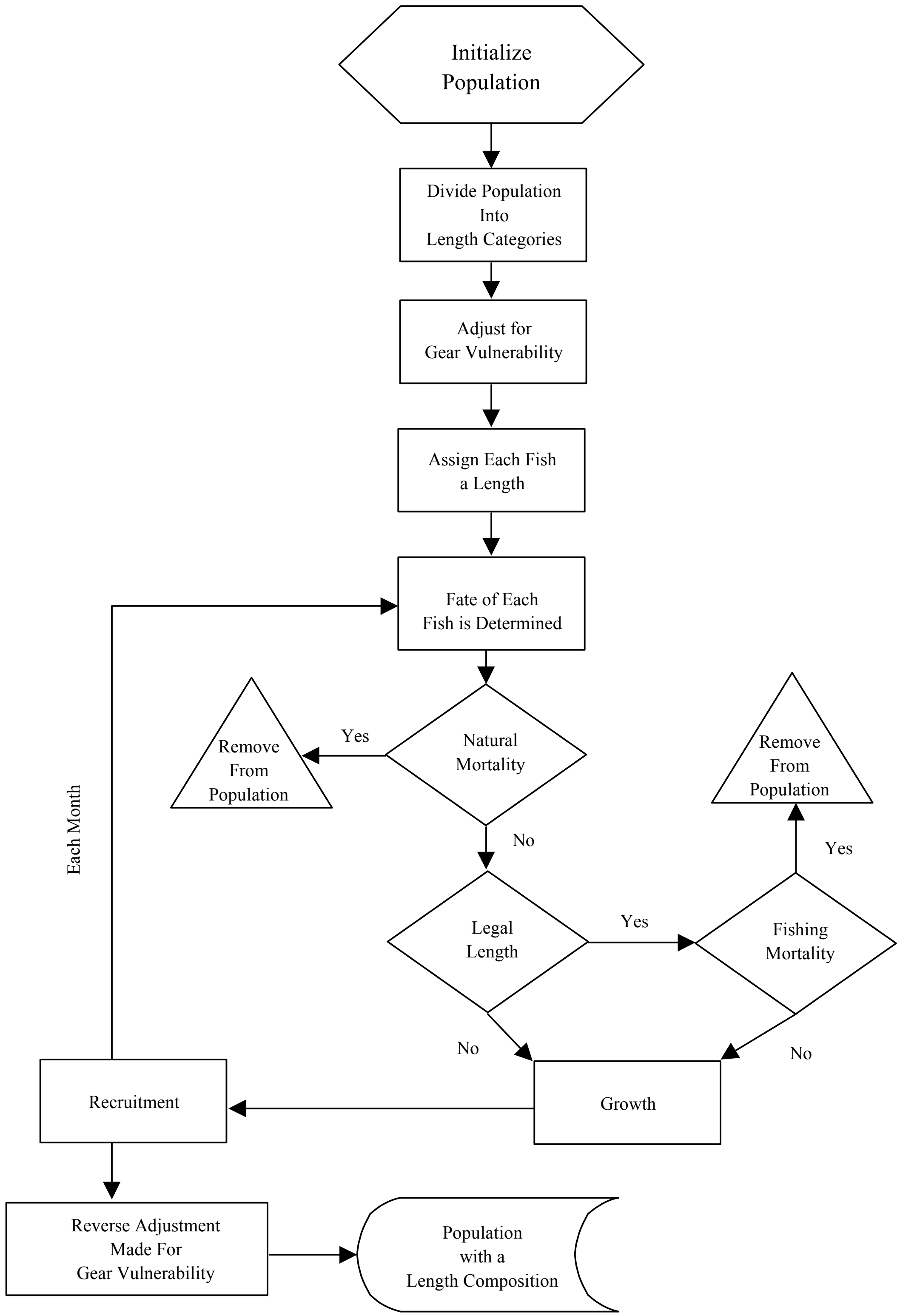
Growth of surviving fish was calculated from the Von Bertalanffy growth curve:

$$L_t = L_\infty(1-e^{-K(t-t0)}), \quad \text{(A1.5)}$$

where L_∞, K, and t_0 were parameters of the fitted curve (Appendix A6).

Recruitment was based on a density-dependent relationship that assumed there was a carrying capacity and that recruitment to the 300 mm FL category was proportional to the abundance of fish three years prior to recruitment. Recruits were added to the population and were assigned lengths within the smallest length class.

Appendix A2.-Flow chart of simulation program for risk analysis on changing the Harding Lake northern pike minimum length limit.



Appendix A3.-Monte Carlo simulation program for risk analysis on changing the Harding Lake northern pike minimum length limit.

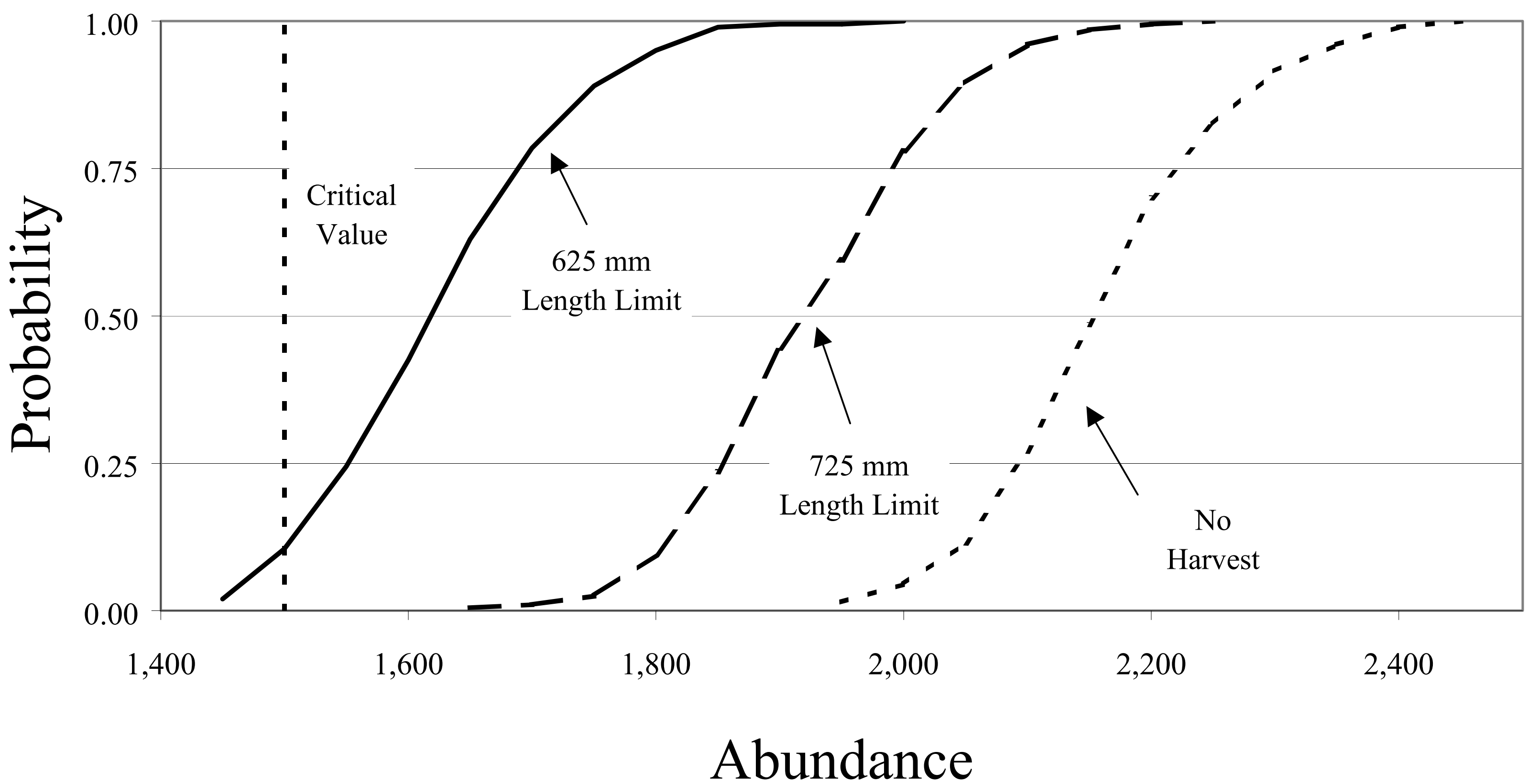
```
Harding.sim<-function(nreps, nmonths, h.rest, muN, sdN, len.prop, low.len, up.len, vulnerability,
        mu.nmort, sd.nmort, mu.harv, sd.harv, mu.linf, sd.linf, mu.K, sd.K, mu.tzero, sd.tzero,
        ccap, krec.low, krec.high, lags)

{

#nreps = number of realizations
#nmonths = number of months for simulation
#h.rest = harvest length restriction
#len.prop = vector of proportions of fish in each length class; sum(len.prop) = 1
#low.len = vector of minimum lengths for the k length classes
#up.len = vector of maximum lengths for the k length classes
#vulnerability = vector of gear vulnerability estimates for each length class
#mu.nmort, sd.nmort = mean and standard deviation of rate of natural mortality
#mu.harv, sd.harv = mean and standard deviation of rate of fishing mortality
#mu.linf, sd.linf, (K, tzero) = distribution of parameters of VB growth curve
#ccap = carrying capacity, maximum population
#krec.low = low bound for recruitment parameter
#krec.high = upper bound for recruitment parameter
#lags = vector of initial annual abundances for calculating recruitment with lag

        Nfinal <- matrix(NA, nreps * trunc(nmonths/12), length(up.len))for(k in 1:nreps){
#choose the starting overall population

        Nzero <- rnorm(1,muN, sdN)

#calculate number in each length class, including non-vulnerable

        n.len <- round((Nzero * len.prop)/vulnerability)

#choose a length for each fish in the population

        lpop <- runif(n.len[1], low.len[1], up.len[1])
                for(i in 2:length(nlen))
                        lpop <- c(lpop, runif(n.len[i], low.len[i], up.len[i]))
#begin monthly loop
                for(i in 1:nmonths) {
#choose mortality and harvest rates
#(note F=annual harvest rate for 10-month fishery, M=annual rate of natural mortality)
#calculate survival probability from: s=exp(-(F+M)*t)
#select and remove fish that die (binomial: 1=live and 0=die)
```

-continued-

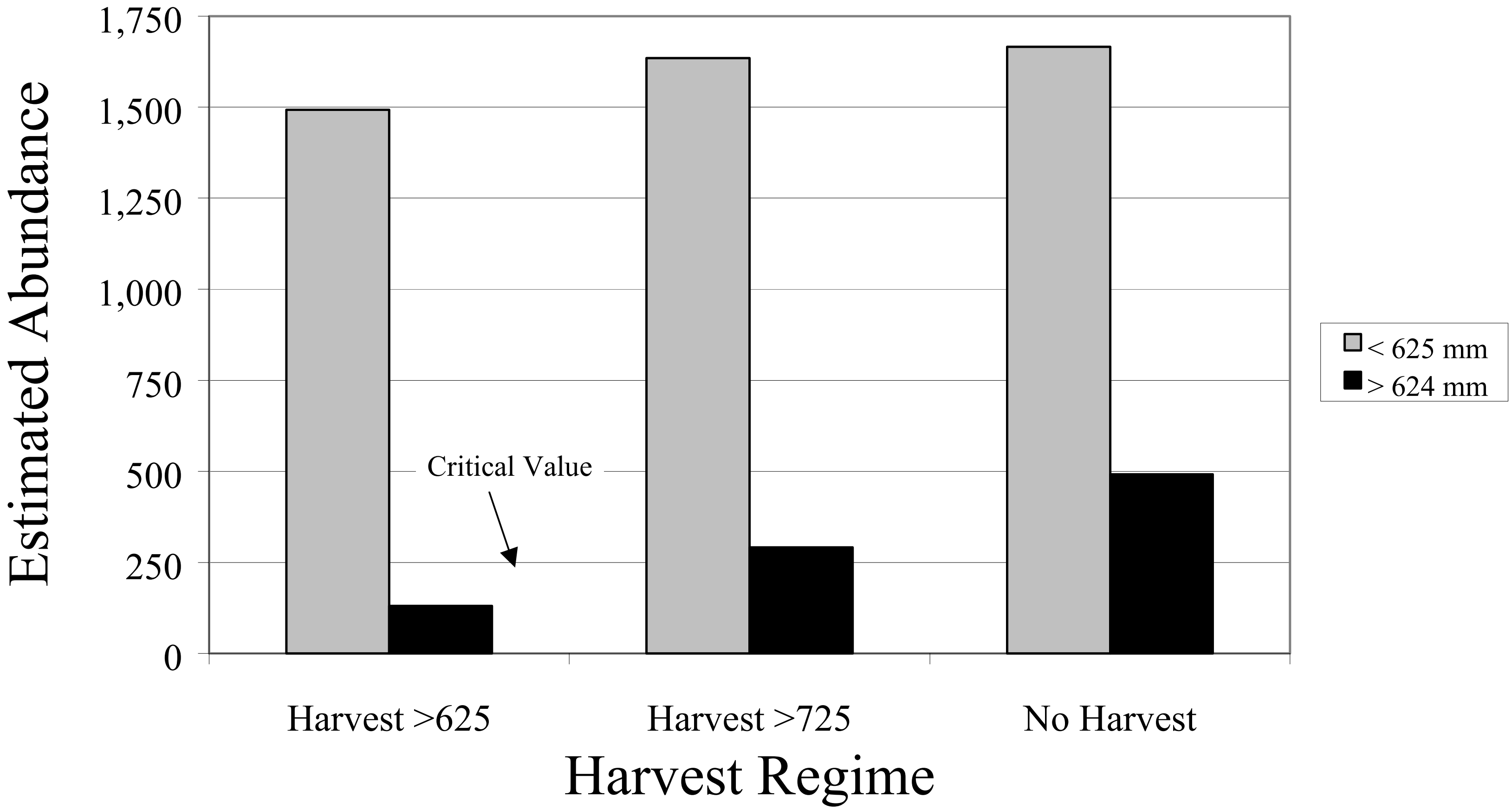
```
                    Mrate <- abs(rnorm(1, mu.nmort, sd.nmort))
                    Frate <- abs(rnorm(1, mu.harv, sd.harv))
                    morts <- rep(NA, length(lpop))
                    if(i %% 12<3)
                            morts <- rbinom(length(lpop), 1, exp(-Mrate/12))
                    else {
                            avail <- seq(along = lpop)[lpop >= h.rest]
                            not <- seq(along = lpop)[lpop < h.rest]
                            morts[avail] <- rbinom(length(avail), 1,
                                    exp((-Mrate – 1.2 * Frate)/12))
                            morts[not] <- rbinom(length(not), 1, exp(-Mrate/12))
                    }
                    lpop <- lpop * morts
                    lpop <- lpop[lpop > 0]
#select VB growth parameters and add growth to each fish in population
#total annual growth occurs in 5 months
                    if(i %% 12 < 6) {
                            linf <- rnorm(1, mu.linf, sd.linf)
                            K <- rnorm(1, mu.K, sd.K)
                            tzero <- rnorm(1, mu.tzero, sd.tzero)
                            y <- seq(along = lpop)[lpop < linf]
                            lpop[y] <- linf + (lpop[y] – linf) * exp(-K/5)

#add recruitment proportional to abundance 3 years earlier,
#total annual recruitment occurs in 5 months
#assign recruits length in smallest length class

                            k.recruit <- runif(1, krec.low, krec.high)
                            lpop <- c(runif((lags[1] * ccap)/(lags[1] +
                                    (ccap – lags[1]) * exp(( -ccap * k.recruit)/5)) –
                                            lags[1], low.len[1], up.len[1]), lpop)
                    }

#prepare output of yearly abundance
                if(i %% 12 == 0) {
#calculate new population, remove non-vulnerable fish from estimate
                            preN <- rep(NA, length(up.len) – 1)
                            for(j in 1:length(up.len) – 1)
                            preN[j] <- length(lpop[lpop <= up.len[j]])
                            preN <- c(preN, length(lpop))
```

-continued-

```
#cumulative abundance by length class

                                        x <- preN[1]
                                        for(k in 2:length(preN))
                                        x <-c(x, preN[k] – preN[k – 1])

#total abundance by length class

                                        lags <- c(lags[-1], sum(x * vulnerability))
                                        Nfinal[(k – 1) * trunc(nmonths/12) + (i/12),] <- x * vulnerability


                              }
                    }
          }
}
```



Appendix A4.-Probability of abundance after 20 years estimated from risk analysis on changing the Harding Lake northern pike minimum length limit.



Appendix A5.-Projected abundance of northern pike less than and greater than 625 mm FL after 20 years estimated from risk analysis on changing the Harding Lake northern pike minimum length limit.

Appendix A6.-Parameters used for performing the risk analysis on changing the Harding Lake northern pike minimum length limit.

Parameter	Value	SE
N_0	1,780	323
$F_{>625}$	0.60	0.02
$F_{>725}$	0.68	0.04
M	0.37	0.015
L_∞	920.28	22.100
K	0.159	0.009
t_0	-0.256	0.093

Appendix A7.-Vulnerability of Harding Lake northern pike to sampling gear estimated from 5 years of mark-recapture data and standardized to the 600 to 649 mm FL category.

Length Category	Vulnerability to Sampling Gear
300 – 349	0.18
350 – 399	0.50
400 – 449	0.63
450 – 499	0.72
500 – 549	0.75
550 – 599	0.80
600 – 649	1.00
> 649	0.70

APPENDIX B

Data File Listing

Appendix B1.–Data files used to estimate parameters of the Harding Lake northern pike populations, 1998.

Data file[a]	Description
U18900L011998.DTA	Population and marking data for Harding Lake northern pike captured during the marking event, May 18 through May 22, 1998.
U18900Lo21998.DTA	Population and recapture data for Harding Lake northern pike captured during the recapture event, June 1 through June 5, 1998.

[a] Data files were archived at and are available from the Alaska Department of Fish and Game, Sport Fish Division, Research and Technical Services, 333 Raspberry Road, Anchorage, Alaska 99518-1599.

APPENDIX C

Historical Data Summaries

Appendix C1.–Floy tag numbers used for Harding Lake northern pike mark-recapture experiments by year and color, 1990-1997.

	Tag Color			
Year	White	Blue	Gray	Red
1990		62,765-62,999		
		63,550-63,984		
1991		64,000-64,099		
		64,400-64,415		
		64,700-64,999		
1992	351-900			
	1,001-1,053			
1993			48,000-48,868	
1994				
1995			40,000-40,783	
1996		53,000-53,271		
		53,750-53,894		
1997			4,425-4,774	
1998				22,001-22,270

Appendix C2.–Sample sizes, estimated abundances, and standard errors by length category for Harding Lake northern pike, 1995 – 1998 (adjustments made in sample sizes and abundances for unequal capture probabilities in 1995, 1996, 1998).

	1995			1996		
Length	n	$\hat{N}$	SE	n	$\hat{N}$	SE
300-324	23	101	18	16	126	34
325-349	23	77	13	3	28	8
350-374	23	77	14	19	155	42
375-399	33	94	16	14	112	30
400-424	32	75	13	16	126	34
425-449	53	119	21	31	253	69
450-474	32	115	20	26	211	57
475-499	52	138	24	31	253	69
500-524	72	203	36	31	253	69
525-549	60	154	27	55	450	122
550-574	88	283	50	52	421	114
575-599	101	250	44	62	506	137
600-624	74	190	33	20	164	44
625-649	64	143	25	14	116	31
650-674	37	83	15	9	76	21
675-699	24	62	11	4	30	8
700-724	20	42	8	2	18	5
725-749	13	28	5	1	9	3
750-774	8	20	4	1	12	3
775-799	4	10	2	2	14	4
800-824	8	20	3	1	9	3
825-849	3	5	1	1	12	3
850-874	2	3	1	0	2	1
875-899	2	6	1	1	7	2
900-924	7	27	5	1	7	2
925-949	-	-	-	1	7	2
950-974	2	7	1	-	-	-
975-999	1	3	0	-	-	-
1,000-1,024	1	3	0	-	-	-
1,025-1,049	-	-	-	-	-	-
> 1,050	-	-	-	-	-	-
Totals	862	2,338	-	600	3,377	-

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Length	1997			1998		
	n	$\hat{N}$	SE	n	$\hat{N}$	SE
300-324	10	37	12	35	112	23
325-349	10	37	12	22	71	14
350-374	22	82	21	26	81	17
375-399	9	34	11	22	71	14
400-424	20	74	19	19	61	12
425-449	27	101	24	14	46	9
450-474	37	138	31	24	76	15
475-499	50	186	40	21	66	13
500-524	38	142	32	29	92	19
525-549	36	134	30	48	153	31
550-574	49	182	39	49	158	32
575-599	60	223	47	31	99	20
600-624	44	164	36	32	101	20
625-649	31	115	27	28	90	18
650-674	9	34	11	11	36	7
675-699	2	7	5	9	29	6
700-724	6	22	9	9	28	6
725-749	4	15	7	-	-	-
750-774	0	0	0	-	-	-
775-799	4	15	7	<1	2	<1
800-824	3	11	6	-	-	-
825-849	5	19	8	-	-	-
850-874	0	0	0	1	5	1
875-899	1	4	3	-	-	-
900-924	-	-	-	-	-	-
925-949	-	-	-	-	-	-
950-974	-	-	-	-	-	-
975-999	-	-	-	-	-	-
1,000-1,024	1	4	3	-	-	-
1,025-1,049	-	-	-	-	-	-
> 1,050	-	-	-	<1	2	<1
Totals	478	1,780	-	432	1,376	279

Appendix C3.–Sample sizes, estimated abundances, and standard errors by age for Harding Lake northern pike ≥ 300 mm FL, 1990-1998 (adjustments made in sample sizes and abundances for unequal capture probabilities in 1995, 1996, and 1998).

	1990[a]			1991[a]			1992[a]			1993[a]			1994[b]		
Age	n	$\hat{N}$	SE	n	$\hat{N}$	SE	n	$\hat{N}$	SE	n	$\hat{N}$	SE	n	$\hat{N}$	SE
2	1	11	11	---	---	---	---	---	---	16	71	19	---	---	---
3	15	160	48	11	126	56	51	538	111	128	571	80	---	---	---
4	47	484	106	15	171	72	87	892	164	254	1,134	143	---	---	---
5	88	657	125	30	343	131	75	609	97	220	982	126	---	---	---
≥ 6	324	973	140	192	1,668	482	133	829	174	226	1,007	185	---	---	---
Totals	475	2,285	---	248	2,308	---	519	2,868	---	581	3,765	---	---	---	---

-continued-

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	1995[c]			1996[d]			1997[e]			1998		
Age	n	$\hat{N}$	SE	n	$\hat{N}$	SE	n	$\hat{N}$	SE	n	$\hat{N}$	SE
2	5	15	3	-	-	-	8	35	13	8	31	6
3	46	185	32	29	244	66	34	151	35	47	172	35
4	128	431	76	34	289	78	53	235	50	43	159	32
5	225	704	124	92	781	212	85	377	75	77	284	58
≥ 6	357	1,003	177	242	2,063	560	222	982	183	200	730	148
Totals	761	2,338	---	397	3,377	916	402	1,780	---	375	1,376	---

[a] From Pearse (1994).

[b] Data were not collected in 1994.

[c] From Roach (1996).

[d] From Roach (1997).

[e] From Roach (1998).

Appendix C4.–Number of northern pike ≥ 300 mm FL marked (M), examined for marks (C), and recaptured with marks (R) by section during Harding Lake two-event mark-recapture experiments, 1995 - 1998.

Section	1995			1996			1997			1998		
	M	C	R	M	C	R	M	C	R	M	C	R
1	45	56	7	48	46	6	23	26	3	--	--	--
2	22	15	1	10	9	0	0	2	0	--	--	--
3	5	3	0	1	10	1	0	0	0	--	--	--
4	116	46	18	55	50	7	62	54	8	--	--	--
6	3	5	2	0	5	2	5	0	0	--	--	--
7	28	15	3	8	19	4	4	8	1	--	--	--
8	32	53	15	24	19	3	45	19	3	--	--	--
9	60	71	25	45	33	9	21	27	11	--	--	--
10	15	32	10	33	15	5	17	24	7	--	--	--
11	1	9	3	11	0	0	0	0	0	4	--	--
12	3	4	1	1	0	0	0	1	0	24	9	3
13	31	37	3	23	26	1	11	18	1	57	50	13
14	34	25	4	14	25	3	3	31	4	39	63	10
15	25	15	5	5	13	2	30	25	2	25	56	12
16	26	26	8	26	43	8	7	15	5	61	44	8
Totals	446	412	105	304	313	51	228	250	45	210	222	46