Fishery Data Series No. 96-8

Abundance and Composition of the Northern Pike Population in Harding Lake, 1995

by

Stafford M. Roach

April 1996

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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by

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ABSTRACT

Abundance and composition of the northern pike *Esox lucius* population within Harding Lake in early June 1995 was described using mark-recapture techniques. Future strength of the population was discussed in view of year-class strength, percent harvest, estimated maximum sustainable yield, and past history of the fishery. Since 1991 estimated abundances of northern pike ≥ 300 mm FL have ranged from 2,308 fish (SE = 563) in 1991 to 3,768 fish (SE = 432) in 1993. In 1995, estimated abundance of northern pike ≥ 300 mm FL was 2,338 fish (SE = 411 and CV = 24%) and for northern pike ≥ 450 mm FL was 1,554 fish (SE = 170 and CV = 11%). Estimated density of northern pike ≥ 300 mm FL was 2.3 (SE = 0.04) fish per hectare. The estimated abundances of northern pike were 543 fish (SE = 95) from 300 to 449 mm FL; 1,333 fish (SE = 234) from 450 to 624 mm FL; and, 464 fish (SE = 82) ≥ 625 mm FL. The estimated proportion of northern pike from 300 to 449 mm FL was 0.23 (SE = 0.04); from 450 to 624 mm FL was 0.57 (SE = 0.07); and, ≥ 625 mm FL was 0.20 (SE = 0.01). The estimated abundances of northern pike ≥ 300 mm FL were 631 fish (SE = 111) < age-5 and 1,707 fish (SE = 300) ≥ age-5. The estimated proportions of northern pike ≥ 300 mm FL were 0.27 (SE = 0.02) for fish < age-5, and 0.73 (SE = 0.02) for fish ≥ age-5.

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

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 estimating abundance, length composition, age composition, mortality, recruitment, and movements of northern pike within selected lakes and wetland complexes in AYK.

Harding Lake northern pike research objectives to estimate abundance and length and age composition of northern pike began in 1990. An indirect estimate of sustainable yield for northern pike in Harding Lake based on 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). An indirect method was used because population data were available for only four years. However, to directly estimate sustainable yield using the methods described by Pearse and Hansen (1993), a minimum of two estimates of surplus production are needed. For Harding Lake, this translates to a data series that includes two estimates of abundance for fully recruited northern pike, followed by estimates of abundance for their respective progeny at full recruitment.

1995 Research Objectives

Working toward the goal of estimating surplus production and evaluating the current status of the stock, a northern pike mark-recapture experiment was conducted in Harding Lake in 1995. 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.

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 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 intent was 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 also allows Harding Lake northern pike two spawning years before reaching the legal size for harvest. In addition, it was believed that these regulations would restrict harvest to 15% of northern pike ≥ 300 mm FL, which was considered by managers as an acceptable level of harvest.

Estimated sport fishing effort at Harding Lake increased from 1,707 angler-days in 1984 to about 5,000 angler-days from 1991 through 1994 (Table 1; Mills 1985 - 1994; Howe et al. 1995). Limited availability of northern pike fisheries along the road system of the Tanana Valley and an increased angler demand for northern pike probably contributed to the increasing angler effort. Despite the rise in angler effort, since 1992 harvest has remained at relatively low levels (Table 1). Harvest estimates of northern pike have varied from 341 in 1992 to 2,092 northern pike in 1988. Estimates of abundance of northern pike (≥ 300 mm FL) have ranged from 2,308 (SE = 563) in 1991 to 3,768 (SE = 432) in 1993 (Table 2; Burkholder 1991; Skaugstad and Burkholder 1992; Pearse 1994).

In 1993, estimated abundance of fully recruited spawners (northern pike ≥ 450 mm FL) was 2,749. This was less than estimated N_{MSY} (3,383 northern pike ≥ 450 mm FL) for Harding Lake (Pearse and Hansen 1993). Harvest of 391 (SE = 140) northern pike ≥ 625 mm FL in 1993, however, was similar to the estimate of MSY (390 fully recruited spawners; SE = 60). There was not an estimate of northern pike abundance in 1994, but the estimated harvest during 1994 was 539 (SE = 197) northern pike ≥ 625 mm FL.

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[1] Four 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, 1984-1994 summarized by all northern pike and northern pike > 725 mm FL.

		Number Harvested				Number Caught		Catch/AnglerDay		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
Average	4,100	1,093		229		4,740	628	0.99	0.13	0.16	0.41

[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.

Table 2.-Abundance and SE of northern pike ≥ 300 mm and ≥ 450 mm in Harding Lake by year.

	≥ 300 mm		≥ 450 mm	
Year	Abundance	SE	Abundance	SE
1990[a]	-	-	1,283	145
1991	2,308	563	1,527	313
1992	2,868	353	1,496	160
1993	3,768	432	2,749	307

[a] Abundance was not estimated for northern pike < 450 mm FL in 1990 due to the absence of recaptured northern pike < 450 mm FL.

DESCRIPTION OF STUDY AREA

Harding Lake is the largest road accessible lake in the Tanana River drainage (Figure 1). It has 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 Harding Lake is in an open-water zone with almost all of the marginal vegetation (emergent grasses) found along the north and northeast shores in water < 1 m deep. However, more than half of the shallow water (< 3 m depth) in the north and northeast area of the lake is free of vegetation. There are some deep weed 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 weed-beds) comprises less than 33% of the surface area of the lake. However, there are large areas within this zone that are free of vegetation. The emergent vegetation comprises less than 10% of the surface area of the lake. In addition to northern pike, the 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 provided 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 is a perimeter road that 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 shoreline near the State boat launch with a channel, swim beach, campsites, parking, athletic fields, and some undeveloped areas for hiking and unstructured outdoor recreation.

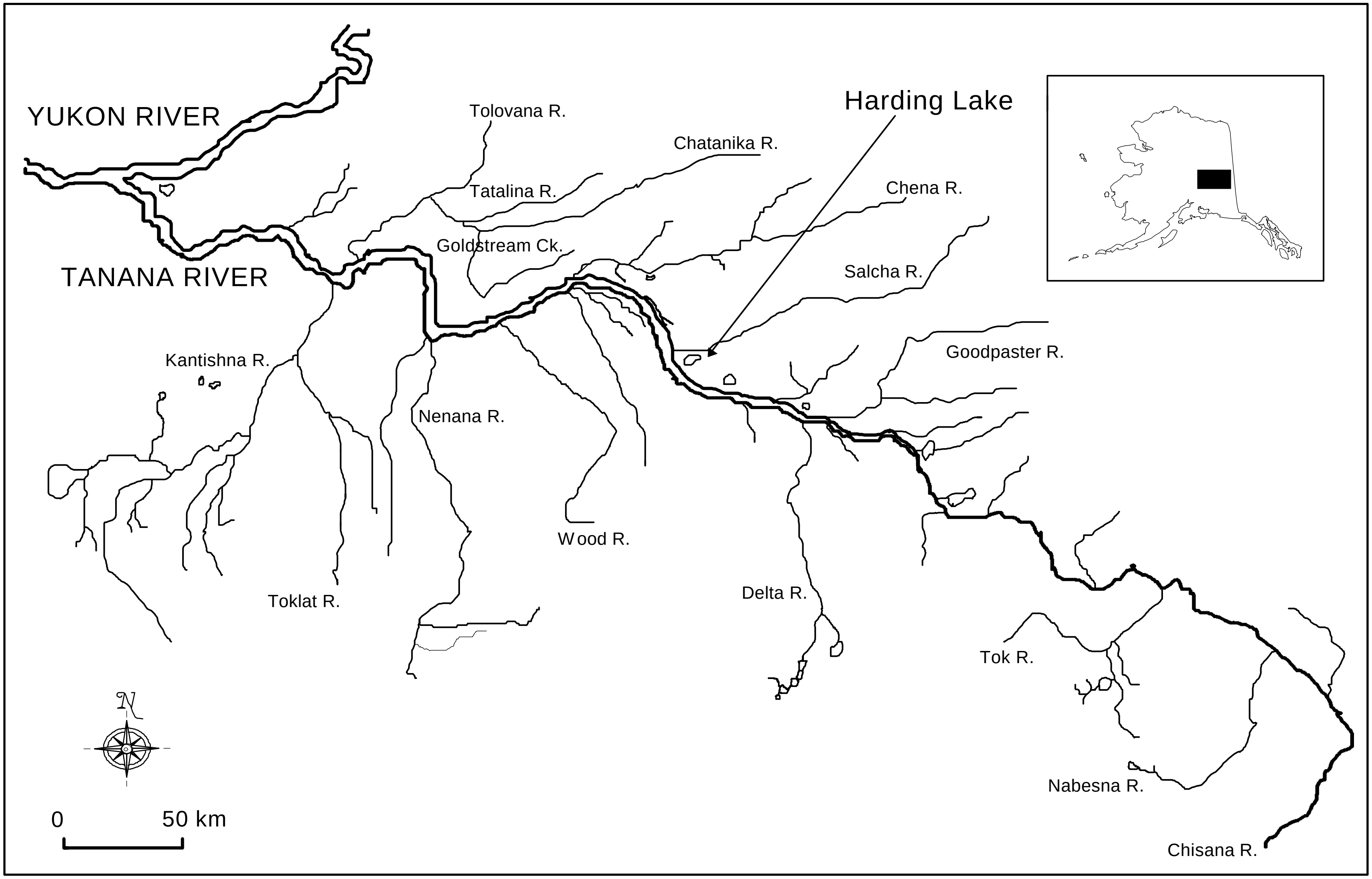

Figure 1.-Tanana River drainage.

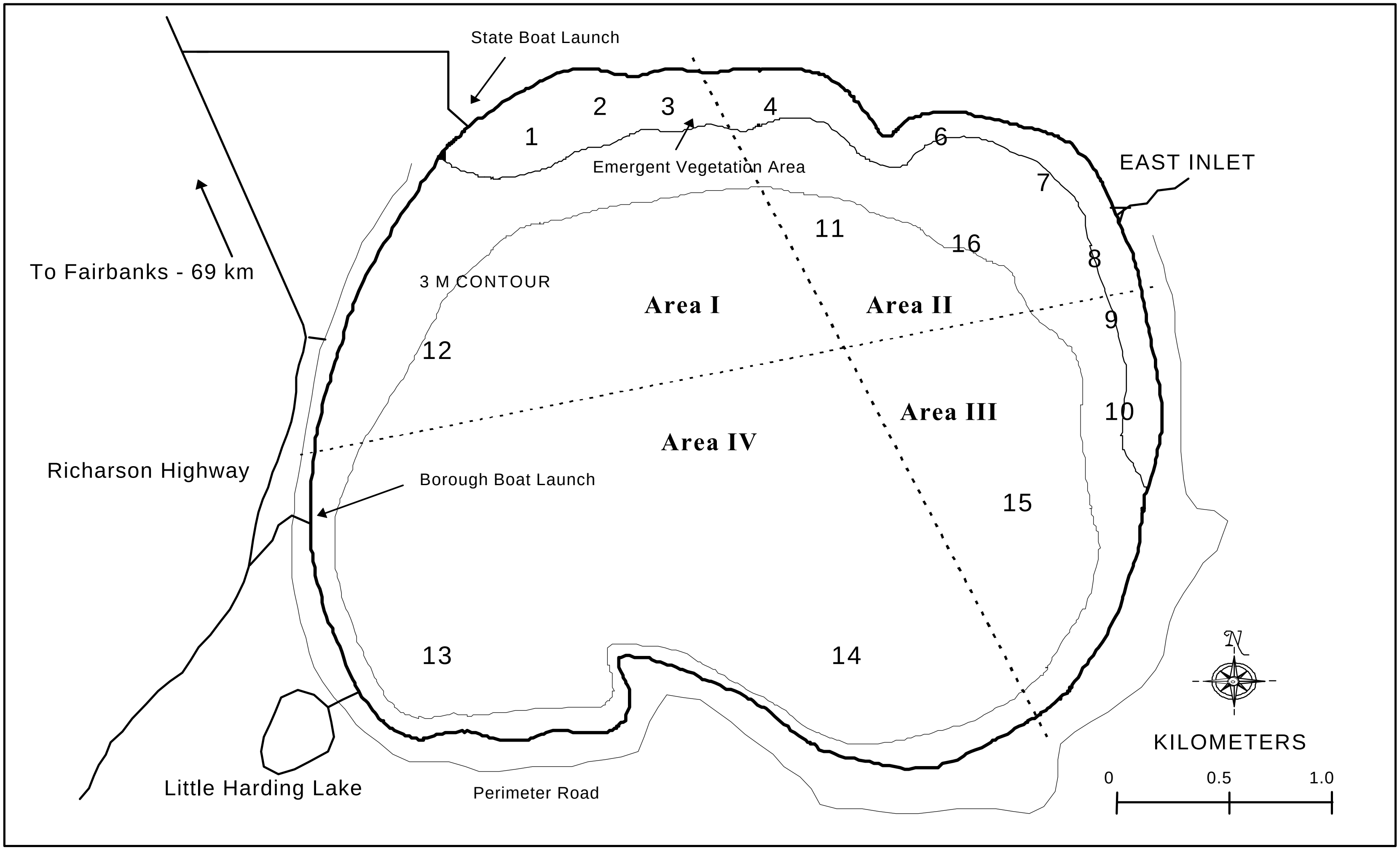

Figure 2.-Harding Lake with sampling sections (1 - 16) indicated and dashed line showing where the lake was divided into four areas for capture probability and movement analysis.

METHODS

The 1995 Harding Lake northern pike mark-recapture sampling methods were similar to the methods used in 1993 (Pearse 1994) due to the relative success of the mark-recapture experiment in that year compared to previous years. The 1993 mark-recapture sampling took place in early June, two to three weeks later than in other years and contrary to previous years, length distributions between marking and capture events were similar. In addition, Pearse (1994) concluded, from recapture to capture (R/C) ratios from three sections of Harding Lake, that fish marked in the 1993 sample mixed completely with unmarked fish between events or that there was equal probability of capture for northern pike throughout the lake. Furthermore, the results of the Harding Lake northern pike radio-telemetry study indicated that by June, Harding Lake northern pike are distributed more uniformly by sex and length compared to May and 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). Based on these studies, the 1995 mark-recapture experiment was scheduled for late May and early June. The marking event (May 30 - June 2) and recapture event (June 6 - June 9) took four days each with a three-day hiatus between events (June 3 - June 5). Data files for both events were archived (Appendix A1).

SAMPLING TECHNIQUES

In 1995, Harding Lake was divided into 15 sections in order to examine movement, test for differences in catchability, and help insure uniform sampling effort (Figure 2). Two methods were used to capture northern pike, one in sections of emergent vegetation and the other in sections of open water.

Two crews of three individuals used a combination of gill nets and backpack electrofishing to sample sections of emergent vegetation. In sections one through four, one set consisted of three gill nets set within the emergent vegetation, parallel to shore, parallel to each other, and spaced about 10 m apart. Northern pike were actively moved into the nets by electroshocking and splashing. At the completion of each set, the gill nets were pulled parallel to shore a distance equal to the length of the gill nets and the process repeated. In sections six through ten, sets were similar to sections one through four except only one gill net was used instead of three and it was placed at the outer margin of the emergent vegetation instead of within the emergent vegetation. In this manner sampling effort uniformly covered the emergent vegetation area of Harding Lake. All healthy northern pike were released immediately after data collection approximately 25 m from the capture site and in the opposite direction from the next set.

A crew of two individuals set gill nets from a boat in sections of open water. These gill nets were deployed at the beginning of the day perpendicular to shore and checked a minimum of once every hour. 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 Harding Lake 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 waterbody recorded on the back. All crew members 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 crew members performed these tasks appropriately.

During the marking event, all northern pike ≥ 300 mm FL that were captured were measured for length, a scale removed for age determination, examined for previous tag, if not tagged then tagged with a uniquely numbered Floy tag, the upper caudal fin slightly clipped, and sex determined. Length was measured and recorded to the nearest millimeter FL. A minimum of two scales was 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; and if present, the color and number of the tag recorded; or if not present, a new Floy FD-68 internal anchor tag inserted at the left base of the dorsal fin and the number recorded. Northern pike killed during the sampling procedure 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. When possible, the sex of each northern pike was determined by the presence of milt or eggs and recorded.

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, but instead, both the left and right side of the dorsal fin were examined closely for recent tag wounds and the upper and lower caudal fin examined closely for recent clips, and then the lower caudal fin, instead of the upper, 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 upper caudal 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 recaptured event. Northern pike already sampled during the recapture event were identified by the presence of a recent lower caudal fin clip.

Upon completion of field work, 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). Since 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 and there were more than eight circuli on the anterior edge of the scale.

ESTIMATION OF ABUNDANCE

Investigators estimated abundance using a Petersen mark-recapture experiment (Seber 1982). The assumptions of the experiment 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.

Testing of Assumptions

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 (eleven days from beginning to end).

The validity of assumption 2 and 3 were evaluated with a series of tests designed to detect unequal catchability and length selectivity, both of which violate these two assumptions. These tests included a chi-square contingency table test that compared catchability by area, inspection of movement, and two Kolmogorov-Smirnov two-sample tests that compared catchability by length. The results of these tests, in combination, determined the methods used to compensate for bias in the abundance estimation.

Specifically, the chi-square tests compared catchability among sections during the recapture event (the frequency of fish with marks to the frequency of fish without marks). Inspection of movement was an empirical comparison of fish with marks that moved from one area of the lake to another area between events to fish with marks that stayed in the same area. Movement was determined significant if more than 10% of fish marked in one area were recaptured in another area. Using the results of these tests, Appendix B1 outlines the methodology used to determine stratification by area and choice of abundance estimators. The dividing point of the strata was chosen as the point that resulted in the maximum difference in catchability between the strata. The maximum difference was determined as the greatest chi-square value from a series of chi-squared tests that compared the frequency of fish marked in each stratum to the frequency of fish recaptured in each stratum.

After evaluating equal catchability by area, equal catchability by length was addressed for each stratum separately. Kolmogorov-Smirnov two-sample tests were used to compare: 1) the cumulative length frequency distributions of recaptured northern pike with all northern pike captured during the marking event; and 2) the length frequency distributions of northern pike captured during the marking event with those captured in the recapture event. Using the results of these tests, Appendix B2 outlines the methodology used to determine stratification by length. In cases when stratification by length was necessary the fish were divided into two strata by length. The dividing point of the two strata was chosen as the point that resulted in the maximum difference in catchability between the two strata. The maximum difference was determined as the greatest chi-square value from a series of chi-squared tests that compared the frequency of marked fish not recaptured in each length stratum to the frequency of fish recaptured in each length stratum. The number of size classes used for chi-square tests was restricted to two because further stratification reduced overall precision while only minimally reducing bias.

The validity of assumption 4 was insured 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 insured by a thorough examination of fins for fin-clips and the recording of fin clips and Floy tag numbers for all northern pike.

Abundance Calculations

To reduce bias from unequal catchability by area, it was necessary to divide the lake into two area strata to estimate abundance. In addition, to reduce bias from unequal movement by length, it was necessary to divide the fish into two length strata within one of the areas. Estimated abundance of northern pike was calculated from the number of northern pike marked, examined for marks, and recaptured for each stratum and summed. The Chapman estimator (Seber 1982) was used for each stratum:

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

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:

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

ESTIMATION OF LENGTH COMPOSITION

Length compositions of northern pike ≥ 300 mm were estimated for each area stratum of Harding Lake and adjusted for differential capture probability by length when necessary.

Testing of Assumptions

The integrity of estimates of length composition relies on the same assumptions as estimates of abundance. Unequal movement by length and gear selectivity by length violate these assumptions. Validity of these assumptions for length-based bias from unequal catchability and gear selectivity were included in the tests for the assumptions of abundance estimation. Methodology to determine how to compensate for bias from violation of these assumptions is outlined in Appendices B1 and B2.

Length Composition Calculations

Length proportions were estimated for each of two area strata within Harding Lake. In one area it was necessary to adjust the length proportions according to the ratio of each length group to total abundance in that area to minimize length bias.

The proportion and variance estimator used when no adjustments were needed was:

$$\hat{p}_k = \frac{x_k}{n}, \text{ and} \tag{3}$$

$$\hat{V}[\hat{p}_k] = \frac{\hat{p}_k(1-\hat{p}_k)}{n-1} \tag{4}$$

where: $\hat{p}_k$ = the proportion of northern pike that were length *k*;

x_k = the number of northern pike sampled that were length *k*; and,

n = the number of northern pike sampled that were measured.

The proportion and variance estimator used when adjustments were needed was:

$$\hat{p}_k = \sum_{i=1}^{j} \frac{\hat{N}_m}{\hat{N}} \hat{p}_{mk}, \text{ and} \tag{5}$$

$$\hat{V}[\hat{p}_l] \approx \sum_{m=1}^{j} (\hat{p}_{mk} - \hat{p}_k)^2 \frac{\hat{V}[\hat{N}_m]}{\hat{N}^2} + \sum_{m=1}^{j} \left(\frac{\hat{N}_m}{\hat{N}}\right)^2 \hat{V}[\hat{p}_{mk}] \tag{6}$$

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

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

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

ESTIMATION OF AGE COMPOSITION

Age compositions of northern pike ≥ 300 mm were estimated for each area stratum of Harding Lake and adjusted for differential capture probability by length when necessary. Although not directly tested, it was assumed that unequal movement and unequal catchability of northern pike by age was correlated with length. The age composition was calculated using the same equations for proportions and variances of the proportions as with length composition except ages were substituted for lengths.

Age Validation

Accuracy of age determination from scales of Harding Lake northern pike captured during the 1995 mark-recapture experiment was tested indirectly. Scales from northern pike that were recaptured during the experiment from prior years were used to determine the relative accuracy of age determination. The mean error in assigning the correct incremental age from the scales of these northern pike was used as a measure of bias. The mean error was determined for the ages of all northern pike, northern pike < age-5, and northern pike ≥ age-5. Age-5 was used because previous studies used age-5 as the age of 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. Significant bias in assigning the proper incremental age was the criteria used to determine whether or not the age composition would be used for cohort analysis.

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

$$ERROR = AGE_{t+\Delta} - AGE_t - \Delta t \tag{7}$$

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 of Harding Lake northern pike, ages were determined twice for a random sample of 108 scales taken during the experiment. The average percent error (Beamish and Fournier 1981) of the scale reader to reproduce the same age twice from a Harding Lake northern pike scale in 1995 was calculated as:

$$APE = \frac{\sum_{i=1}^{S}\left[\frac{\sum_{j=1}^{R}\frac{\left|x_{ij}-\bar{x}_i\right|}{\bar{x}_i}}{R}\right]}{S}\cdot 100 \tag{8}$$

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

$\bar{x}_i$ = 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).

RESULTS

Investigators handled 752 unique northern pike ($\geq$ 300 mm FL) during the Harding Lake mark-recapture experiment. During the marking event, 445 northern pike were tagged and released alive (one fish without length was ignored). During the recapture event, 412 northern pike were examined for marks. Of these, 307 were unique and 105 were recaptured from the marking event. During the mark-recapture experiment all northern pike were released alive and there was no tag loss from the marking event to the recapture event (as determined by examination of fin clips of all northern pike captured during the recapture event). Investigators identified 243 northern pike with Floy tags from prior mark-recapture experiments (32.3% of unique northern pike handled).

Abundance

Estimated abundance of northern pike within Harding Lake was germane to fish ≥ 300 mm FL during early June 1995. Recapture rates of northern pike within the study area were significantly different among four areas ($\chi^2 = 21.62$; 3 df; $P < 0.01$). The bias associated from differential catchabilities was minimized by dividing the lake into two strata in a way that minimized the differences of catchability within each strata by maximizing the differences in catchability between the strata (Stratum I = sections 1, 2, 3, 13, and 14 and Stratum II = sections 4, 6, 7, 8, 9, 10, 11, 12, 15, and 16; Figure 2; $\chi^2 = 21.57$; 1 df; $P < 0.01$). The recapture rate (fish recaptured divided by fish examined for marks in the recapture event; R/C) for Stratum I was 0.11 and for Stratum II was 0.33 (Figure 3).

Comparison of areas where northern pike were marked with areas where the fish were recaptured indicated movement between areas (Table 3). Thirty-six of 105 northern pike (34.3%) moved from one area to another between events. However, movement between area strata and different catchability between area strata indicated that marked fish did not mix completely with unmarked fish between area strata. In this situation the methodology outlined in Appendix B1 (Case IV) was followed, abundance estimates were calculated for each area stratum separately and summed using the Chapman estimator and for all area strata combined using the Darroch (1961) estimator. The two estimates were compared. The Chapman estimate of abundance was similar to the Darroch estimate (< 1% difference); and estimated variance of the Chapman estimate was less than the estimated variance of the Darroch estimate. No difference in these two estimates implied that mixing was sufficient within each area stratum, therefore, the Chapman estimator was chosen to estimate abundance of northern pike ≥ 300 mm FL within each stratum.

There was no statistically significant difference between the length distributions of northern pike marked and northern pike recaptured within Stratum I ($D = 0.29$; $P = 0.17$; Figure 4-A), or Stratum II ($D = 0.06$; $P = 0.97$; Figure 4-A). A visual inspection of Figure 4-A along with the large test statistic, however, suggested that the sample size may not have been sufficient to detect size-selective sampling within Stratum I. Therefore, length-stratified estimated abundance was

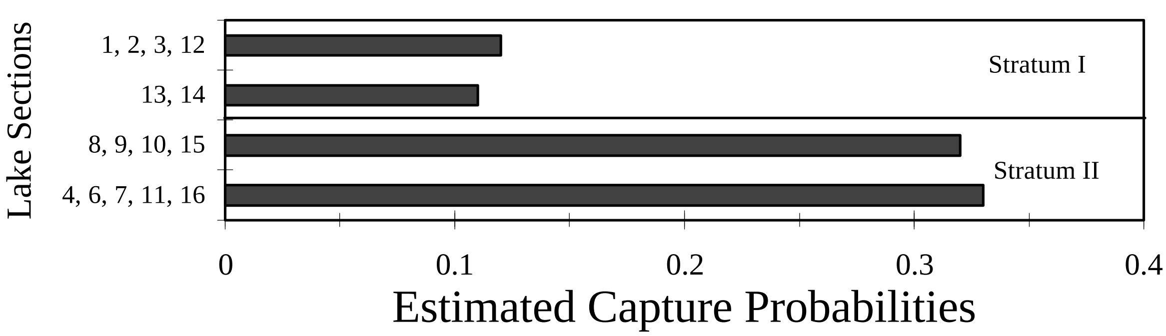

Figure 3.-Estimated capture probabilities (number of fish marked in the marking event and recaptured in the recapture event divided by the total number of fish captured in the recapture event) by sections and areas.

Table 3.-Numbers of northern pike recaptured in areas (n = 105) and numbers of northern pike that moved between areas of Harding Lake summarized by the areas in which the fish were marked.

	Number Recaptured				Number That
	Recapture Areas				Moved
Mark Areas	I	II	III	IV	Between Areas
I	5	3	0	1	4
II	1	21	15	1	17
III	0	8	38	0	8
IV	3	2	2	5	7
Totals	9	34	55	7	36

compared to estimated abundance without length stratification. Summed length-stratified estimated abundance was not similar to estimated abundance without length stratification (21% difference), which supported the hypothesis that there was length selectivity during the recapture event. Therefore, a length stratified abundance estimate was used to estimate northern pike abundance within Stratum I (Appendix B2). Maximal difference in catchability by length was obtained by dividing the fish into two length strata at 580 mm FL (small-fish stratum = 300 mm to 580 mm FL and large-fish stratum > 580 mm FL; $\chi^2 = 12.56$; 1 d.f.; $P < 0.01$). In Stratum II, there was not length selectivity during the recapture event, therefore, an unstratified abundance estimate was used for this area stratum (Appendix B2).

Estimated abundance of northern pike ≥ 300 mm FL within Harding Lake was 2,338 fish (SE = 411; CV = 24%; Table 4). Estimated abundance of northern pike ≥ 450 mm FL was 1,554 fish (SE = 170; CV = 11%; Table 4). Estimated density of northern pike ≥ 300 mm FL was 2.3 (SE = 0.04) fish per hectare.

LENGTH COMPOSITION

There was no significant difference between the length distributions of northern pike marked and northern pike examined for marks during the recapture event within Stratum I ($D = 0.10$; $P = 0.45$; Figure 4-B). This along with a difference between length distributions of northern pike marked and northern pike recaptured in Stratum I indicated that there was size selectivity during both events in Stratum I. To estimate length composition in Stratum I, fork lengths of northern pike captured during the marking and recapture events were pooled and adjusted for different capture probabilities by length (Appendix B2).

There was no significant difference between the length distributions of northern pike marked and northern pike examined for marks during the recapture event within Stratum II ($D = 0.06$; $P = 0.73$; Figure 4-B). This along with no difference between the length distributions of northern pike marked and northern pike recaptured in Stratum II indicated that no size selectivity was

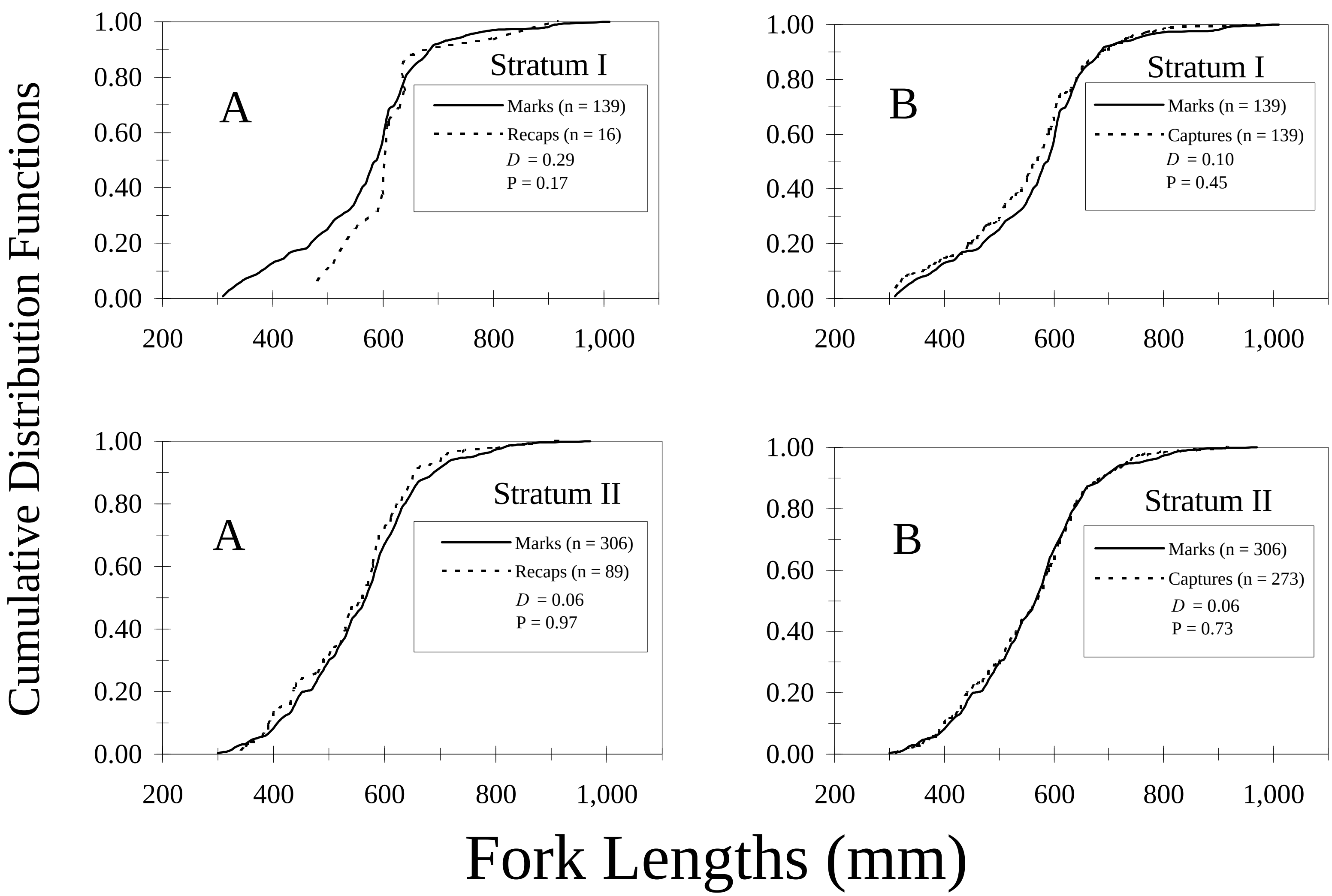

Figure 4.-Cumulative distribution functions of fork lengths of northern pike (A) marked versus recaptured and (B) marked versus examined for marks in Harding Lake (Stratum I and II).

Table 4.-Numbers of Harding Lake northern pike ≥ 300 mm FL marked (M), examined for marks (C), recaptured with marks (R), capture probabilities, estimated abundances (N), and standard errors of estimated abundances SE[N] summarized by area strata and lengths.

Strata	Length (FL)	M	C	R	R / C	R / M	$\hat{N}$	$SE[\hat{N}]$
I	300 to 580 mm	67	76	4	0.05	0.06	1,046	398
I	≥ 581 mm	72	63	12	0.19	0.17	358	78
I	≥ 300 mm	139	139	16	0.11	0.11	1,404	405
II	≥ 300 mm	306	273	89	0.33	0.29	934	68
I & II	≥ 300 mm	445	412	105	0.25	0.24	2,338	411
I	≥ 450 mm	115	114	16	0.14	0.14	784	158
II	≥ 450 mm	249	215	69	0.32	0.28	770	64
I & II	≥ 450 mm	364	329	85	0.26	0.23	1,554	170

detected for either events in Stratum II. To estimate length composition in Stratum II, fork lengths of northern pike captured during the marking and recapture events were pooled with no adjustment necessary (Appendix B2).

Fork lengths measured from 857 northern pike ≥ 300 mm FL in Harding Lake ranged from 300 mm to 1,001 mm (mean = 560 mm; SE = 4 mm). The length compositions of northern pike ≥ 300 mm FL was different by area of the lake (Figure 5). The estimated abundances of northern pike were 543 (SE = 95) fish from 300 to 449 mm FL; 1,333 (SE = 234) fish from 450 to 624 mm FL; and, 464 (SE = 82) fish ≥ 625 mm FL. The estimated proportions of northern pike were 0.23 (SE = 0.04) from 300 to 449 mm FL; 0.57 (SE = 0.07) from 450 to 624 mm FL; and, 0.20 (SE = 0.01) ≥ 625 mm FL.

AGE COMPOSITION

Investigators determined ages from the scales from 674 of 752 unique northern pike (≥ 300 mm FL) sampled during the Harding Lake mark-recapture experiment. Of scales collected during the marking event, ages were determined for 405 unique northern pike. Of scales collected during the recapture event, ages were determined for 269 unique northern pike. Investigators determined ages for 108 northern pike within the sample that were also aged in 1993. Of the 752 unique northern pike (≥ 300 mm FL) sampled, ages were not determined for 78 (scales were not taken or lost from 11 fish, not readable because of regeneration from 43 fish, and not readable because of poor acetate impression from 24 fish).

The mean error in assigning the proper incremental ages was -0.81 years (Z = 5.87; $P < 0.01$) from the scales of the 108 northern pike that were recaptured from 1993; -0.14 years (Z = 1.30;

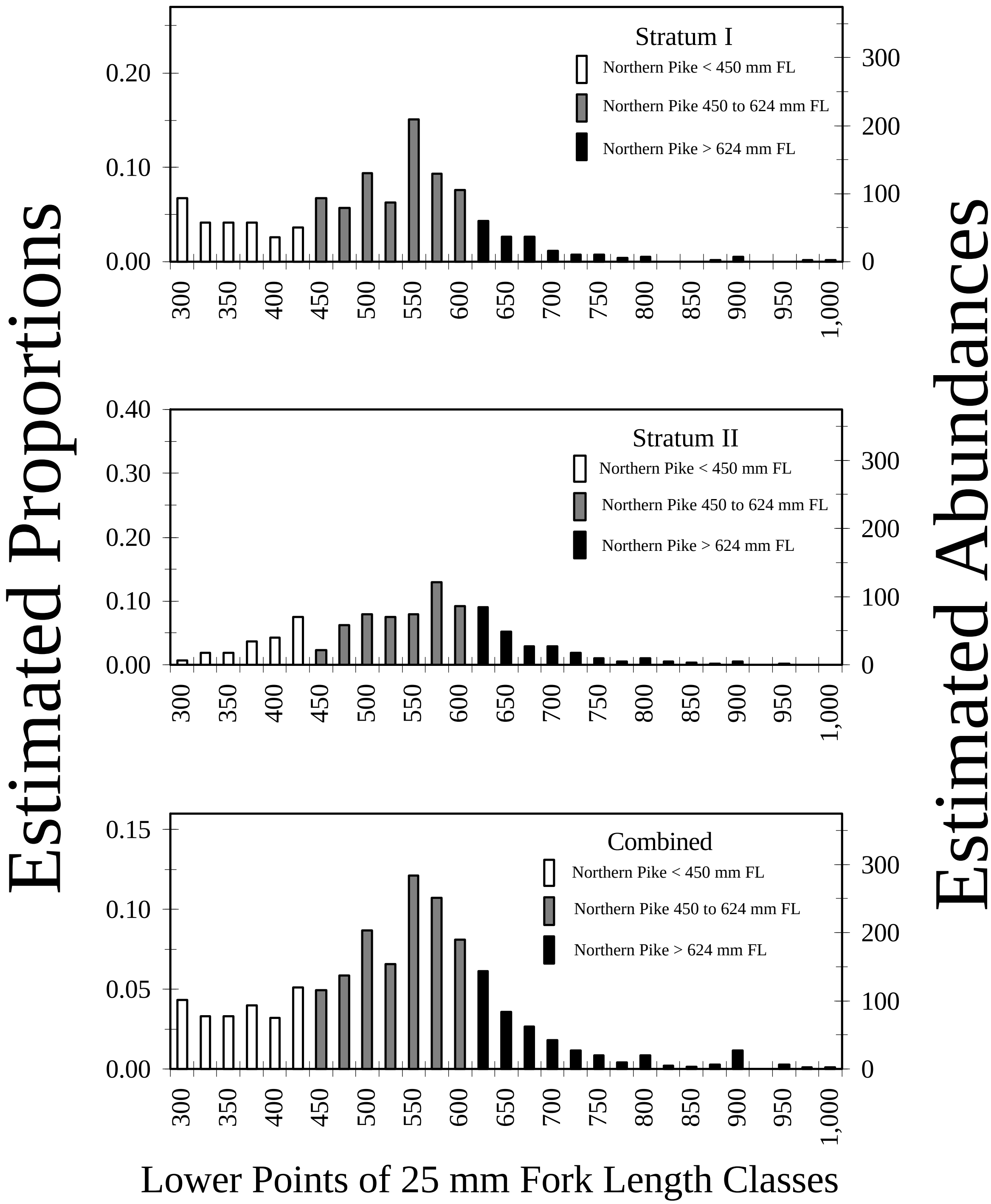

Figure 5.-Estimated proportions and abundances of northern pike ≥ 300 mm FL by 25-mm length classes within Stratum I, Stratum II, and combined areas of Harding Lake during early June 1995 (adjusted for different capture probabilities by length and area).

P = 0.19) for 58 northern pike that were < age-5; and -1.60 years (Z = 5.78; P < 0.01) for 50 northern pike ≥ 5 (Figure 6). Since there was significant bias in determining ages of northern pike ≥ age-5, all age groups ≥ 5 were lumped into one group.

The estimated average percent error of the scale reader in reproducing the same age twice from a Harding Lake northern pike scale in 1995 was 3.18%.

The estimated abundances of northern pike ≥ 300 mm FL in Harding Lake were 631 (SE = 111) fish < age-5 and 1,707 (SE = 300) fish ≥ age-5. The estimated proportions of northern pike ≥ 300 mm FL were 0.27 (SE = 0.02) for fish < age-5, and 0.73 (SE = 0.02) for fish ≥ age-5. The estimated proportions of northern pike ≥ 300 mm FL were different by area of the lake (Table 5).

DISCUSSION

Harding Lake northern pike regulations have provided a harvest within the 15% range of abundance of northern pike ≥ 300 mm FL. These levels of harvest, however, may not contribute to an increase in abundance. The 1995 estimated abundance of northern pike ≥ 300 mm FL was similar to the 1991 estimate (Figure 7).

MAXIMUM SUSTAINABLE YIELD

The estimated abundance of northern pike in 1995 (1,544 fish ≥ 450 mm FL) was less than that needed to provide MSY as calculated by Pearse and Hansen (1993; N_{MSY} 3,383 northern pike ≥ 450 mm FL; Figure 8). In fact, not once since abundance estimates were initiated in 1991 has the spawning population estimate reached the level required for $N_{MSY.}$ Furthermore, estimated harvest of northern pike in Harding Lake exceeded MSY in eight of the last 10 years. Despite the apparent low numbers of fish and excesses of harvest, estimated abundance has remained relatively stable (Figure 7). One would expect that if harvests have been exceeding MSY that the population would be decreasing, but this has not been observed at Harding Lake. One reason may be that the estimates of N_{MSY} were indirect estimates based on only four years of data, and thus may not be accurate. Compounding the short time series of the information is the poor relative precision of age determination. The average error in assigning the proper incremental age to a recaptured northern pike from Harding Lake was 1.52 years (Z = 6.40; P < 0.01) in 1991 and -1.99 years (Z = 7.42; P < 0.01) in 1992 (Skaugstad and Burkholder 1992). In methods used by Pearse and Hansen (1993), errors in age determination would result in biased estimates of recruitment and survival, the basis of the model.

Abundance, harvest equilibrium, and constant survival rates are primary assumptions of logistic surplus production models. Pearse and Hansen (1993) suggested that these assumptions may not be valid for some interior northern pike populations. Craig and Kipling (1983) observed that northern pike populations cannot respond sufficiently to environmental conditions to prevent wide fluctuations in recruitment with a given number of spawners. Furthermore, they reported that except in cases of very low numbers of eggs, the relationship between number of eggs and number of fish recruited at age 2 was not discernible at Windermere Lake. Also, Franklin and Smith (1963) did not determine a direct relationship between recruitment and adult abundance in Minnesota lakes. Factors other than number of spawners may have a greater influence on recruitment and cause fluctuations in abundance for some northern pike populations.

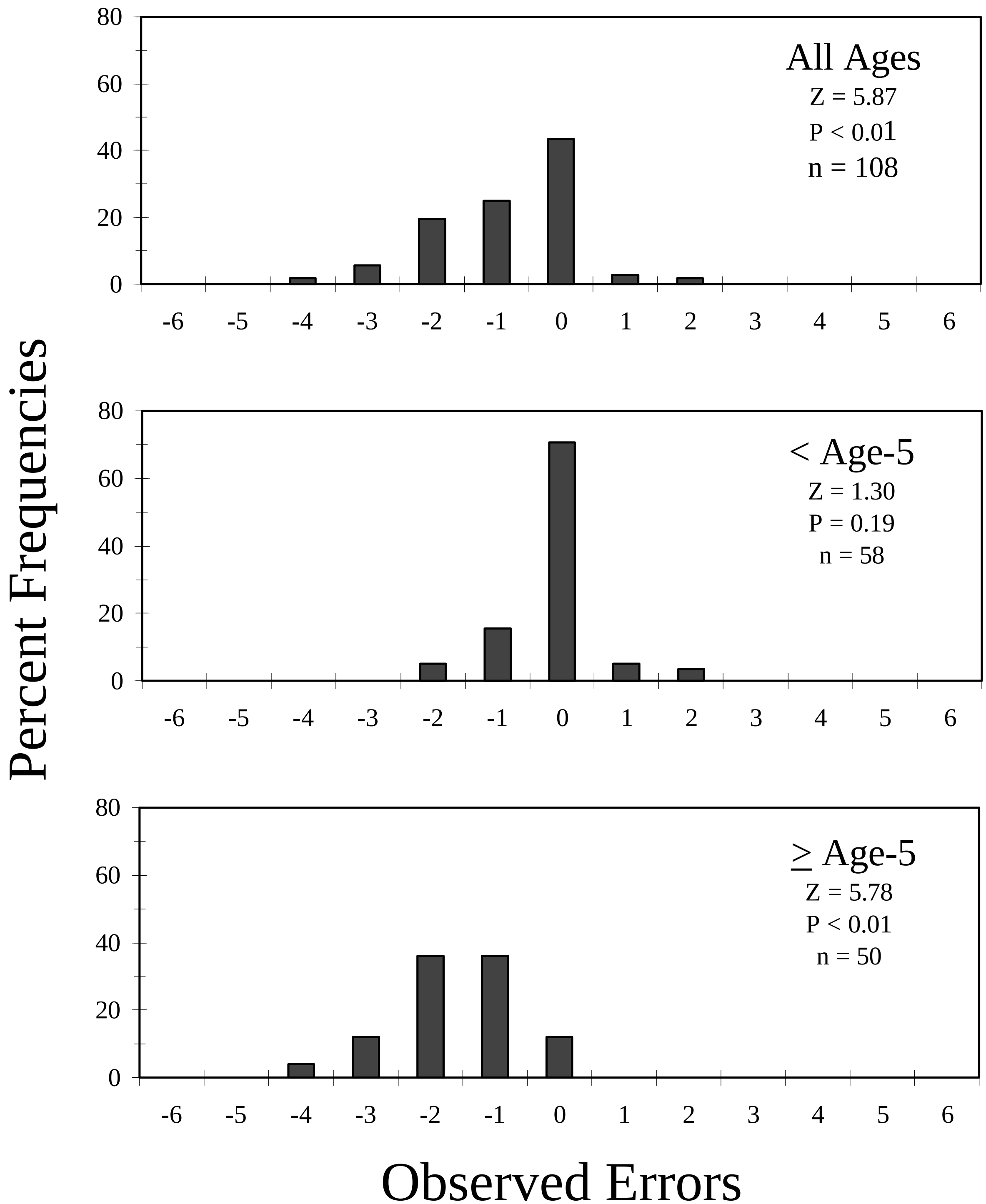

Figure 6.-Percent frequencies of observed errors in assigning the proper incremental ages to Harding Lake northern pike marked in 1993 and recaptured in 1995.

Table 5.-Estimated proportions (p), abundances (N), and standard errors of estimates (SE) of Harding Lake northern pike that were ≥ 300 mm in early June 1995 by age, area strata, and totals (adjusted for different capture probabilities by length and area).

	Stratum I				Stratum II				Totals			
Age	p	SE[p]	N	SE[N]	p	SE[p]	N	SE[N]	p	SE[p]	N	SE[N]
1	-	-	-	-	-	-	-	-	-	-	-	-
2	0.01	0.006	8	2	0.01	0.004	7	1	0.01	0.003	15	3
3	0.11	0.026	149	43	0.04	0.008	35	3	0.08	0.013	185	32
4	0.21	0.037	294	85	0.15	0.016	137	10	0.18	0.017	431	76
< Age-5	0.32	0.029	451	130	0.19	0.018	180	13	0.27	0.016	631	111
≥ Age-5	0.68	0.029	953	275	0.81	0.018	754	55	0.73	0.016	1,707	300
All Ages	1.00	-	1,404	405	1.00	-	934	68	1.00	-	2,338	411

YEAR-CLASS STRENGTH

Wide fluctuations in year-class strength appear to have contributed to recent fluctuations in Harding Lake northern pike abundances. These fluctuations may be due more to variable survival rates during the early life of one year-class compared to another and less to spawner abundance. Carbine (1941), Kipling and Frost (1970), and Latta (1971) reported mortality rates from egg to fingerling greater than 99% for northern pike in Michigan lakes and Windermere. At these high

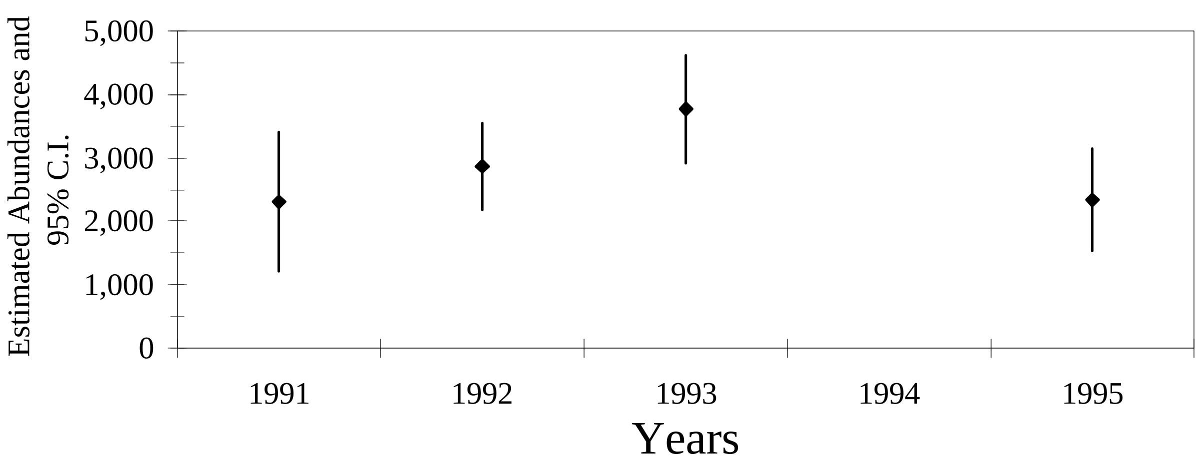

Figure 7.-Estimated abundances of Harding Lake northern pike ≥ 300 mm FL and 95% confidence intervals by year.

rates of mortality, small changes in mortality rates result in large changes in the number that survive. For example, if the mortality rate decreases by 1% from one year to the next, the number of fish that survive doubles. In addition to density dependent factors such as food competition and cannibalism, water level and temperature fluctuations contribute to mortality of northern pike within the first year of life (Franklin and Smith 1963; Hassler 1970; Giles et al. 1986).

Cohort examination indicated that the abundance of Harding Lake northern pike in 1993 was influenced by the strengths of year-classes 1988, 1989, and 1990. The strength of these year classes were seen in the sampled populations in 1993 (age-3, age-4, and the increase in number of fish ≥ age-5 from the previous year) and in 1995 (the continued strength of fish ≥ age-5; Figure 9). In contrast, the estimated abundances of age-3 and age-4 northern pike that were ≥ 300 mm FL in 1995 suggest that year-classes 1991 and 1992 are not as strong and helps to explain the disparity in abundance between 1993 and 1995. Relative to the 1993 and 1995 estimates of abundance, these year-classes may reflect low abundances of northern pike ≥ age-5 in 1996 and 1997. Abundance of legal-sized northern pike (~≥ 625 mm FL), however, should remain similar or increase in 1996 and 1997 compared to 1993 and 1995 due to the strong year classes remaining in this length-class.

PERCENT HARVEST

The Harding Lake northern pike minimum length limit regulation (~625 mm FL) was designed, in part, to reduce the harvest of northern pike while at the same time allowing a harvest of 15% of northern pike ≥ 300 mm FL. At the time the regulation was enacted managers believed that 15% of the estimated abundance of northern pike ≥ 300 mm FL could be exploited without harming the population. The upper 95% C.I. for northern pike harvested was contained in the recommended harvest of 15% of abundance of northern pike ≥ 300 mm FL two of the three years that both sets of data were available (Figure 10). Furthermore, the estimated abundances of northern pike ≥

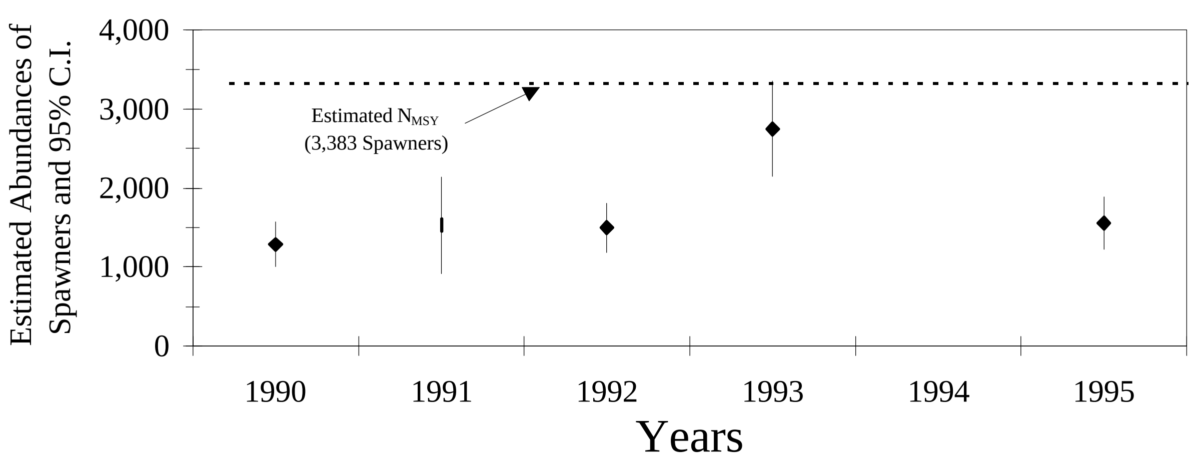

Figure 8.-Estimated abundances of Harding Lake northern pike ≥ 450 mm FL and 95% confidence intervals by year. (Dashed line indicates estimated N_{MSY}).

625 mm FL indicated that there were sufficient numbers of legal size northern pike to provide a harvest of 15% of the population (Figure 10).

The abundance of Harding Lake northern pike was not estimated in 1994. However, if it is assumed that the 1994 abundance was between the 1993 and 1995 estimate of abundance, estimated percent harvest of northern pike in 1994 was in the range of 14 to 23% of northern pike ≥ 300 mm FL. In comparison, the estimated percent harvest of northern pike in 1993 was in the range of 4% to 18% of the estimated abundance of northern pike ≥ 300 mm FL.

MANAGEMENT AND RESEARCH RECOMMENDATIONS

The current Harding Lake regulations have provided a harvest near the 15% level as anticipated by managers, but the data do not indicate the anticipated increase in abundance of northern pike since the enactment of these regulations. The 1995 estimated abundance of northern pike was similar to 1991 estimated abundance (Figure 7). Given the lack of increase in abundance, at minimum the regulations should remain in place that protects Harding Lake northern pike < 625 mm FL and all northern pike in Harding Lake during the time of spawning. In addition, Harding Lake northern pike should be monitored closely through continued population assessment with particular attention to a decrease in abundance or an increase in harvest. Furthermore, if managers desire the current population abundance of northern pike to increase then consideration may need to be given to regulations that would reduce the current harvest level.

Given the weaknesses of estimating MSY from Harding Lake northern pike age data, this northern pike population is a good candidate for exploring length-based population assessment, as described by Schnute (1987), Fournier and Doonan (1987), Zheng et al. (1995), and Pauly (1983; 1984), with future research. Under length-based population assessment, recruitment to a length class and survival of fish within a length class is estimated using growth data. Length-based

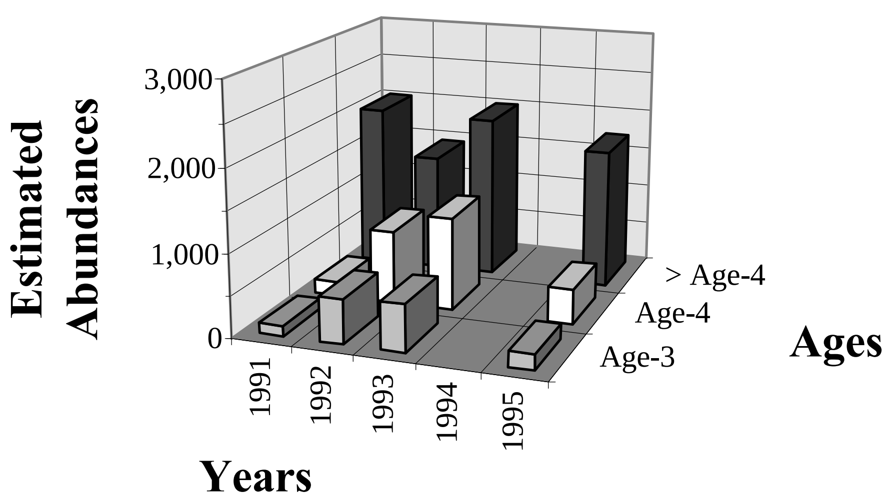

Figure 9.-Estimated abundances of Harding Lake northern pike ≥ 300 mm FL by year and age.

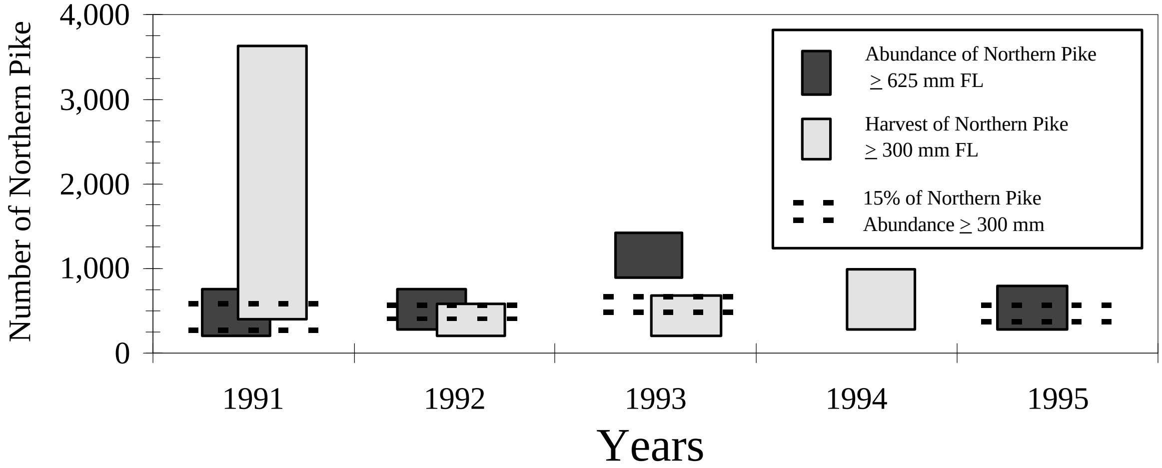

Figure 10.-Ninety-five percent confidence intervals for Harding Lake northern pike > 625 mm FL, number of northern pike harvested ≥ 300 mm FL, and 15% of estimated abundance ≥ 300 mm FL.

information may improve stock assessment of northern pike because northern pike reach critical stages of life at different ages. Northern pike mature, recruit to gear, and recruit to certain size limits (set by regulation) by length and not by age. Along with looking into length-based population assessment, the traditional age-based population assessment should not be abandoned but continue, at least initially, with emphasis on improving the relative precision of age determination through age validation techniques and to further evaluate the logistic surplus production model calculated by Pearse and Hansen (1993).

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APPENDIX A

Data File Listing

Appendix A1.-Data files used to estimate parameters of the Harding Lake northern pike populations, 1995.

Data file[a]	Description
U1890LA5.DTA	Population and marking data for Harding Lake northern pike captured during the marking event, May 30 through June 2, 1995.
U1890LB5.DTA	Population and recapture data for Harding Lake northern pike captured during the recapture event, June 6 through June 9, 1995.

[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 B

Statistical Methodology

Appendix B1.-Methodology to compensate for bias due to unequal catchability by lake section .

Case	Result of χ^2 Test[a]	Inspection of Fish Movement[b]	Inferred Cause
I[c]	Fail to reject H_o	No movement between sections	There is no differential capture probability by lake section or marked fish completely mixed with unmarked fish within each lake section.
II[d]	Fail to reject H_o	Movement between sections	There is no differential capture probability by lake section or marked fish completely mixed with unmarked fish across lake sections.
III[e]	Reject H_o	No movement between sections	There is differential capture probability by lake section or marked fish did not mix completely with unmarked fish within at least one lake section.
IV[f]	Reject H_o	Movement between sections	There is differential capture probability by lake section or marked fish did not mix completely with unmarked fish across lake sections.

[a] The chi-squared test compares the frequency of marked fish recaptured during the second event in each lake section with the frequency of unmarked fish examined in the second event in each lake section. H_o for this test is: capture probability of marked fish in the second event is the same in all lake sections.

[b] Inspection of fish movement is a visual comparison of the frequency of marked fish recaptured in the second event that moved from one lake section to another with the frequency of unmarked fish examined in the second event in each lake section.

[c] Case I: Calculate one unstratified abundance estimate using the Chapman estimator (Seber 1982).

[d] Case II: Calculate one unstratified abundance estimate using the Chapman estimator (Seber 1982).

[e] Case III: Completely stratify the experiment by lake section, calculate abundance estimates for each using the Chapman estimator (Seber 1982)., and sum abundance estimates.

[f] Case IV: Completely stratify the experiment by lake section. Calculate abundance estimates for each using the Chapman estimator (Seber 1982) and sum estimates. Calculate abundance with the partially stratified model of Darroch (1961) and compare with the sum of the Chapman estimates. If estimates are dissimilar, discard the sum of the Chapman estimates and use the Darroch estimate as the estimate of abundance. If estimates are similar, discard the estimate with the largest variance.

Appendix B2.- Methodologies to compensate for bias due to unequal catchability by length.

Case	Result of First K-S Test[a]	Result of second K-S test[b]	Inferred Cause
I[c]	Fail to reject H_o	Fail to reject H_o	There is no size-selectivity during either sampling event.
II[d]	Fail to reject H_o	Reject H_o	There is no size-selectivity during the second sampling event, but there is during the first sampling event.
III[e]	Reject H_o	Fail to reject H_o	There is size-selectivity during both sampling events.
IV[f]	Reject H_o	Reject H_o	There is size-selectivity during the second sampling event; the status of size-selectivity during the first event is unknown.

[a] The first K-S (Kolmogorov-Smirnov) test is on the lengths of fish marked during the first event versus the lengths of fish recaptured during the second event. H_o for this test is: The distribution of lengths of fish sampled during the first event is the same as the distribution of lengths of fish recaptured during the second event.

[b] The second K-S test is on the lengths of fish marked during the first event versus the lengths of fish captured during the second event. H_o for this test is: The distribution of lengths of fish sampled during the first event is the same as the distribution of lengths of fish sampled during the second event.

[c] Case I: Calculate one unstratified abundance estimate, and pool lengths and ages from both sampling events for size and age composition estimates.

[d] Case II: Calculate one unstratified abundance estimate, and only use lengths and ages from the second sampling event to estimate size and age composition.

[e] Case III: Completely stratify both sampling events and estimate abundance for each stratum. Add abundance estimates across strata. Pool lengths and ages from both sampling events and adjust composition estimates for differential capture probabilities.

[f] Case IV: Completely stratify both sampling events and estimate abundance for each stratum. Add abundance estimates across strata. Also calculate a single abundance estimate without stratification.

Case IVa: If stratified and unstratified estimates are dissimilar, discard unstratified estimate and use lengths and ages from second event and adjust these estimates for differential capture probabilities.

Case IVb: If stratified and unstratified estimates are similar, discard estimate with largest variance. Use lengths and ages from first sampling event to directly estimate size and age compositions.