Fishery Data Series No. 06-74

Abundance and Composition of the Northern Pike Population in Minto Lakes, 2003

by
Brendan Scanlon

December 2006

Alaska Department of Fish and Game Divisions of Sport Fish and Commercial Fisheries

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
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

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

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
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
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Measures (fisheries)

fork length	FL
mideye-to-fork	MEF
mideye-to-tail-fork	METF
standard length	SL
total length	TL

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
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	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
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.
minute (angular)	'
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
variance	
population	Var
sample	var

FISHERY DATA REPORT NO. 06-74

ABUNDANCE AND COMPOSITION OF THE NORTHERN PIKE POPULATION IN MINTO LAKES, 2003

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ABSTRACT

Abundance and composition of the northern pike *Esox lucius* population within the Minto Lakes study area was estimated using mark-recapture techniques during middle to late July 2003 to determine if estimated harvests within a specified reporting area exceed 20% of the estimated abundance as prescribed in the management plan. The mean estimated total harvest of northern pike from the sport and subsistence fishery for the period 2001-2003 represented 5% (1,362 fish; SD = 752) of the estimated abundance of northern pike ≥ 400 mm FL (25,227 fish; SE = 4,529; 90% CI = 17,755-32,699). Fork lengths of 1,679 northern pike ≥ 400 mm FL sampled within the study area ranged from 400 mm to 940 mm (mean = 567 mm; SE = 3 mm). Of the 1,285 northern pike ≥ 400 mm FL that were aged in 2003, 41% (SE = 1%) were assigned age-3, and 22% (SE = 4%) were assigned age 6+. For comparison to three previous (1996, 1997, and 2000) abundance estimates of northern pike ≥ 600 mm FL from within the study area that ranged from 3,251 (SE = 174) to 7,616 (SE = 883), abundance in 2003 was 7,683 (SE = 2,347) northern pike ≥ 600 mm FL.

Key Words: Northern pike, *Esox lucius*, population abundance, age composition, length composition, Minto Flats, Minto Lakes, mark-recapture.

INTRODUCTION

The Alaska Department of Fish and Game (ADF&G) conducts studies of northern pike *Esox lucius* in the Arctic-Yukon-Kuskokwim (AYK) region of Alaska to ensure that annual harvests by subsistence and sport anglers do not exceed surplus production of northern pike. Objectives designed to meet this goal have included estimates of abundance, length composition, age composition, mortality rates, recruitment, and movements of northern pike within selected lakes and wetland complexes in the AYK region. For northern pike in the Minto Flats wetland complex (200,000 ha; Figure 1), the Minto Flats Northern Pike Management Plan (5 AAC 01.244, 2001) dictates that the maximum exploitation rate of northern pike in a defined harvest reporting area (Figure 2) by all users (i.e., sport and subsistence) may not exceed 20% annually. The reporting area is defined as the lower Chatanika River and the Minto Lakes/Goldstream Creek area and these boundaries were chosen because it is where almost all of the sport fishing and some subsistence effort occur. The Minto Lakes index or study area, which contains an estimated 6,000 ha of summer habitat for northern pike (Figure 3), serves as a surrogate for abundance of northern pike within the entire Minto Flats wetland complex (Roach 1998a). The boundaries for the study area are the same as the reporting area except that the former does not include the lower Chatanika River or Goldstream Creek because inclusion of these streams in a stock assessment greatly increases the size of the study area and requires a large increase in resources to accurately assess the population. The Minto Flats Northern Pike Management Plan specifies management options available if the harvest is greater than 20% of this abundance.

ADF&G conducted mark-recapture experiments in Minto Flats from 1987 through 1991 (Burkholder 1989, 1990, 1991; Hansen and Burkholder 1992). These experiments were designed as two-event, closed-system experiments, with long hiatuses between events (2-3 months for within-year experiments and 11 months for between-year experiments). Due to the long hiatuses in these experiments, the estimates of abundance and composition were considered germane to the time of the first event, and growth recruitment was culled using the methods described in Robson and Flick (1965). The times of year that the sampling events occurred (just after breakup in spring and just before freeze-up in the fall) were chosen to maximize catches because they coincided with periods when northern pike were congregated and were making mass-movements to spawning or overwintering areas.

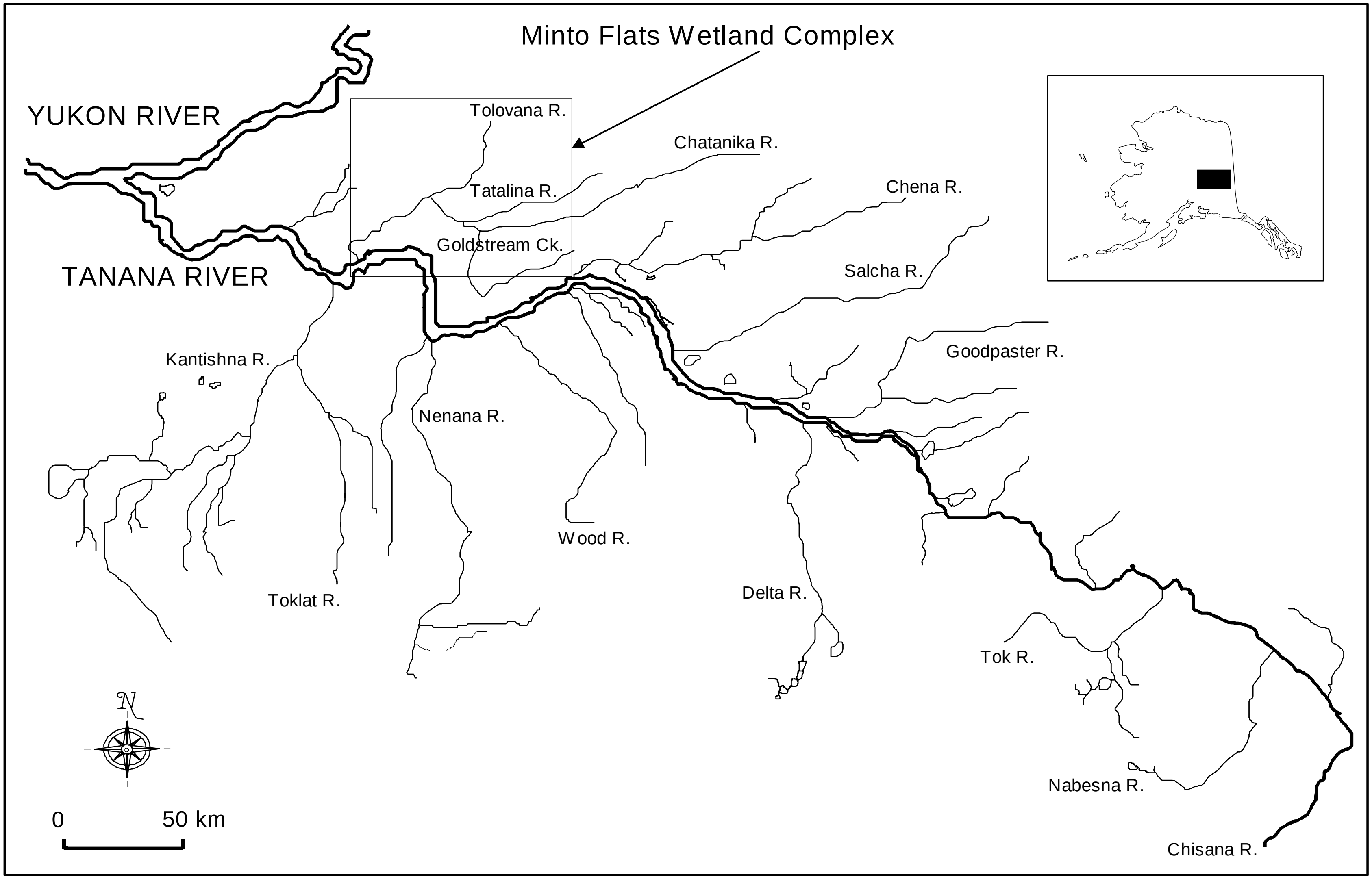

Figure 1.–Tanana River drainage and the demarcation of the Minto Flats wetland complex**.**

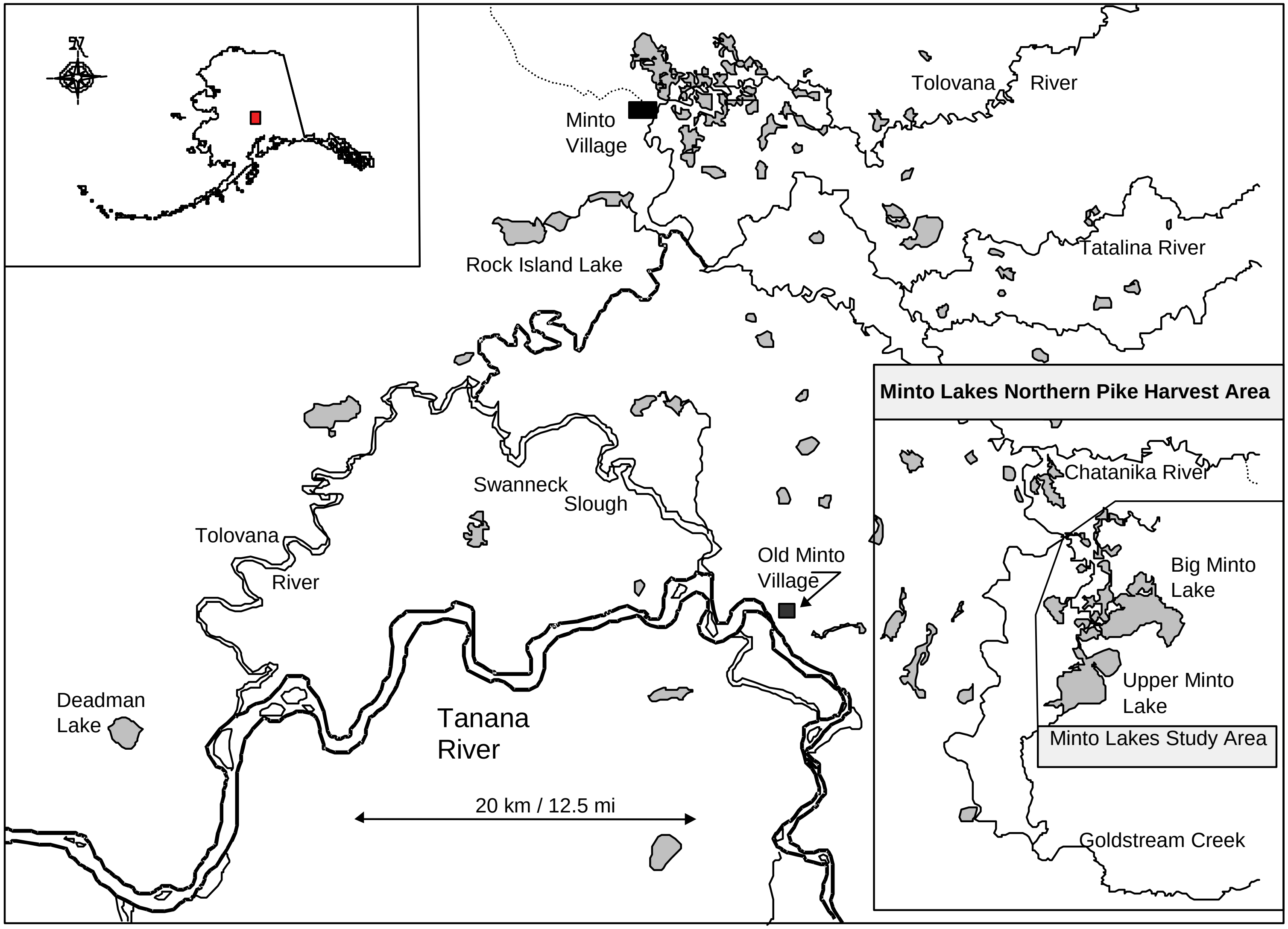

Figure 2.–Minto Flats wetland complex with Minto Lakes Harvest reporting area and 2003 study area designated.

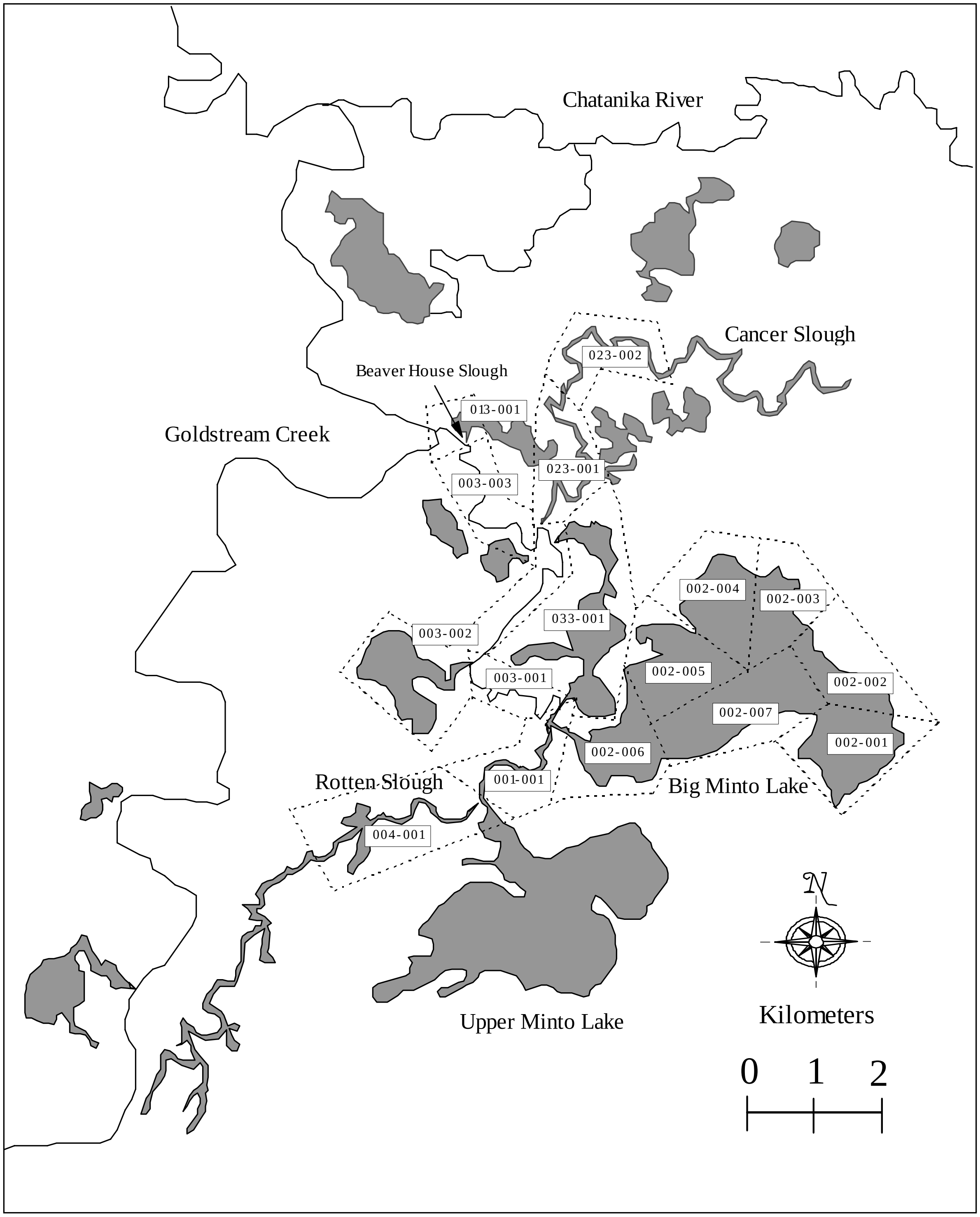

Figure 3.–Minto Lakes Study Area with demarcated sampling areas (area-subarea designation), 2003.

Prior to 1991, these experiments were designed to estimate the abundance of northern pike in an area that included not only the defined Minto Lakes study area but also parts of the Tolovana, Tatalina, and Chatanika rivers, as well as Goldstream Creek and Swanneck Slough (Figure 2). Generally, these experiments were fraught with low sample sizes, incomplete mixing, size and sex biases, a need to cull growth recruitment, and high water during the spring events (Burkholder 1989, 1990 and 1991). Bias in sex and length compositions in these samples were likely because of sex-specific movement patterns where males generally move into and out of spawning areas sooner than females, and females grow to be much larger than males. Casselman (1975) also reported that male and female northern pike exhibited biannual peaks of availability to sampling gear, resulting in inherent bias.

In 1991, an experiment was conducted focusing on estimating abundance of northern pike in the Minto Lakes study area only because, using radiotelemetry, Burkholder (1989) determined that the Minto Lakes study area was the major spawning area for northern pike in Minto Flats complex, and it would therefore be easy to capture fish in the spring and fall because Goldstream Creek was the only migratory channel (Figure 2). However, spring and fall sampling events were used, and problems associated with the long hiatus (growth) and sampling in the spring (high water) were not rectified. It was then hypothesized that it might be possible to perform a within-season experiment with a short hiatus during the summer to estimate of abundance for the Minto Lakes area of Minto Flats and that this approach would reduce potential for bias (Roach 1998b).

The results from a radiotelemetry study in 1995 and 1996 suggested that it was feasible to use a single-season two-event mark-recapture experiment for a closed population to estimate abundance and composition of northern pike in the Minto Lakes area during the summer (Roach 1998b). The mark-recapture experiment conducted within the Minto Lakes study area in 1996 (Roach 1997), incorporated a number of design changes. The hiatus between the marking event and the recapture event was reduced from months to several days, sampling took place in June (a period that radiotelemetry data indicated negligible movement into and out of the area) instead of early May or September, and the study area was uniformly sampled instead of sampling only a limited number of locations. The reduction in the hiatus eliminated the need to adjust estimates of abundance because of mortality or growth recruitment between events, and reduced the opportunity for fish to leave or enter the study area.

Even though the 1996 mark-recapture experiment was viewed a success in that estimates of abundance were obtained, low catch rates resulted in relatively large standard errors (Table 1). Improving upon the 1996 experiment, in which only gillnets were used as a capture method, the 1997 experiment was designed to increase catch rates by adding hoop traps as an additional capture method and sampling during the cooler hours of the day to enable the use of more gear and longer soaks. The number of crewmembers (four two-person crews) and duration (two eight-day sampling events) of the experiment stayed the same as in 1996. Consequently, the number of fish sampled in both events went from 899 in 1996 to 2,289 in 1997 and the precision of the estimates was improved (Roach 1997, 1998b; Table 1). In 2000, methods (gear types and hours of sampling effort per crew) similar to those in 1997 were used, but the number of two-person crews was reduced from four to two (it was believed that with the use of hoop traps, two crews of two people each would be sufficient effort to reach the desired precision). However, abnormally heavy rains raised the water level considerably and rendered the capture gear less effective because of the large increase in area and depth of the wetland complex. This rise in water level, along with the reduction in the number of sampling crews, resulted in catches that were lower than anticipated (879 fish in both events combined; Scanlon 2001).

Table 1.–Abundance estimates of northern pike in the Minto Lakes study area during 1996, 1997, and 2000. Data obtained from Roach (1997, 1998b) and Scanlon (2001).

	Year		
Length	1996	1997	2000
≥ 400 mm FL	23,850 (SE = 7,799)	16,546 (SE = 1,754)	N/A
≥ 600 mm FL	7,616 (SE = 883)	3,251 (SE = 174)	5,331 (SE = 1,152)

DESCRIPTION OF MINTO FLATS NORTHERN PIKE FISHERY

Minto Flats and the lower Chatanika River/Goldstream Creek area supported the largest sport fishery for northern pike in Alaska in 19 of the last 21 years (Mills 1980 - 1994; Howe et al. 1995, 1996; Howe et al. 2001a-d; Walker et al. 2003; Jennings et al. 2004, 2006 a-b). From 1979-1984, the average sport harvest in this combined area was 2,466 northern pike. In 1985, however, a new sport fishery developed on a concentration of over-wintering northern pike in the lower Chatanika River upstream from the mouth of Goldstream Creek (Figure 2). This fishery resulted in an increase in the estimated sport harvest from 2,349 northern pike in 1984 to 4,665 fish in 1985, and 4,903 in 1986 (Table 2). Angler reports and limited creel survey data indicated that a large proportion of the harvest from this new fishery was prespawning females (Holmes and Burkholder 1988; W. Busher, Commercial Fisheries Biologist, ADF&G, Fairbanks; personal communication). Prespawning females are known to feed heavily in the months prior to spawning (Craig 1996).

Due to the increased winter harvest of northern pike, which may concentrate in only a few locations and are easily caught if located, ADF&G closed the Minto Flats winter sport fishery for northern pike by emergency order in January 1987. In the spring of 1988 the Alaska Board of Fisheries restricted the sport-fishing season to June 1 through October 14 and reduced the bag limit to five northern pike per day, only one of which can be over 30 inches TL (≈ 725 mm FL). This regulation has remained in effect and the estimated sport-fish harvest of northern pike in Minto Flats has fluctuated between 266 in 2000 and 8,438 in 1994, and estimated angler days has fluctuated between 699 in 1989 and 6,267 in 1994 (Mills 1988 - 1994; Howe et al. 1995, 1996 and Howe et al. 2001a-d; Walker et al. 2003; Jennings et al. 2004; 2006 a-b; Table 2). These widely varying levels of effort and harvest emphasized the need for periodic assessments the Minto Flats northern pike population.

A subsistence fishery for northern pike occurs near the present village site (New Minto) and at historically used sites in the eastern portions of Minto Flats (Andrews 1988). Gillnets are used to catch northern pike throughout the open-water period and hook-and-line techniques are primarily used to capture fish through the ice. From 1994 to 2003, the subsistence harvest ranged from a high of 1,616 northern pike in 1996 to 214 in 2001, annual harvests averaged 771 fish (SE = 498; Table 2), and the number of subsistence fishers ranged from 13 to 57 (ADF&G *Unpublished*).

Table 2.–Estimated angler days expended; number of northern pike harvested and caught by sport anglers; and, subsistence harvests during 1979-2003 summarized by all northern pike and northern pike > 725 mm FL[a].

	Sport Fishery[b]					Subsistence Fishery[c]		Total Harvest
Year	Angler Days	Total Harvest	Harvest > 725 mm FL	Total Catch	Catch > 725 mm FL	Number of Fishers	Total Harvest	All Fish
1979	2,709	3,209						
1980	2,727	3,909						
1981	2,045	2,009						
1982	1,791	1,886						
1983	1,281	1,825						
1984	1,829	1,960						
1985	2,011	3,902						
1986	3,318	3,621						
1987	1,539	1,161						
1988	1,564	1,128						
1989	699	872						
1990	932	1,182		3,967				
1991	1,532	1,754	297	4,907	535			
1992	2,401	1,247	131	5,765	808			
1993	3,911	2,076	170	19,536	5,238			
1994	6,267	8,438	1,943	47,248	5,408	24	995	9,433
1995	6,260	3,126	594	21,823	2,463	20	1,023	4,149
1996	3,973	2,078	659	12,495	1,408	24	1,616	3,694
1997	4,372	1,702	290	14,712	1,935	41	1,344	3,046
1998	1,414	731	142	4,138	550	32	431	1,162
1999	2,431	908	528	3,261	904	24	400	1,308
2000	1,230	266	29	1,402	95	13	352	618
2001	1,118	641	256	2,849	500	19	214	855
2002	2,349	483	187	8,806	1,636	13	521	1,004
2003	2,023	1,260	1,175	8,706	4,511	57	966	2,226
Average	2,459	2,007	492	11,401	1,999	27	786	2,369

a Current daily fishing regulations within Minto Flats are such that only one northern pike over 30 inches TL (≈725 mm FL) may be retained or in possession.

b Data from Statewide Harvest Survey (Mills 1988 - 1994; Howe et al. 1995, 1996 and Howe et al. 2001a-d; Walker et al. 2003; Jennings et al. 2004; 2006 a-b).

c Subsistence effort and harvest data from ADFG (*Unpublished*); data not available prior to 1994.

In December 1997, the Alaska Board of Fisheries adopted more restrictive regulations to ensure that the Minto Flats subsistence and sport-fishing harvest remain sustainable. Given the potential for the over harvest of overwintering northern pike, the board restricted subsistence and sport-fish anglers to the use of single-hook gear within the Chatanika River overwintering area between the mouth of Goldstream Creek and the Murphy Dome Road Extension. The board also put in place measures to restrict the entire Minto Flats northern pike sport fishery to a daily bag and possession limit of one northern pike once the reported winter subsistence harvest from the Chatanika River overwintering area reaches 750 northern pike. Furthermore, the Chatanika overwintering area will be closed to subsistence fishing once the reported winter harvest from this area reaches 1,500 northern pike.

OBJECTIVES

To evaluate the criteria in the management plan of annual exploitation rates not exceeding 20 percent[1], a mark-recapture experiment was conducted in 2003 to estimate abundance and stock composition of northern pike in the Minto Lakes study area.

The research objectives in 2003 were to:

1) estimate the population abundance of northern pike ≥ 400 mm FL in Minto Lakes study area during July 2003 such that the estimate was within 25% of the actual value 90% of the time; and,
2) estimate the age and length composition of the northern pike population ≥ 400 mm FL in Minto Lakes study area during July 2003 such that the estimates of proportions were within 5 percentage points of the actual value 95% of the time.

METHODS

DESCRIPTION OF MINTO LAKES STUDY AREA

Minto Flats wetlands complex is located approximately 50 km west of Fairbanks, Alaska within the Tanana River drainage (Figure 1). This area (200,000 ha) of marshes, lakes, and boreal forests is interconnected by numerous sloughs and five rivers: Goldstream Creek and the Chatanika, Tatalina, Tolovana, and Tanana rivers (Figure 2). Except for the Tanana River, these rivers are slow flowing and meandering. The Tanana River is a large glacial river that delineates the southern boundary of the flats and is the primary water source for Swanneck Slough. The lakes of Minto Flats are generally shallow and contain large areas of dense aquatic vegetation. Summer habitat within the study area for northern pike covers approximately 6,000 ha (Holmes and Pearse 1987). In addition to northern pike, least cisco *Coregonus sardinella*, humpback whitefish *C. pidschian*, broad whitefish *C. nasus*, round whitefish *Prosopium cylindraceum*, sheefish *Stenodus leucichthys*, Arctic grayling *Thymallus arcticus*, burbot *Lota lota*, longnose sucker *Catostomus catostomus*, blackfish *Dallia pectoralis*, slimy sculpin *Cottus cognatus*, and lake chub *Couesius plumbeus* are found in Minto Flats. Chinook salmon *Oncorhynchus tshawytscha*, chum salmon *O. keta*, and coho salmon *O. kisutch* pass through parts of Minto Flats during migrations to riverine spawning areas.

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[1] This area is also referred to in some reports as Minto Flats Area I (see Figure 3).

EXPERIMENTAL AND SAMPLING DESIGN

The study was designed to estimate abundance and length and age composition of northern pike within the Minto Lakes study area using a two-event mark-recapture experiment. The assumptions of the experiment were that:

1) the population was closed (northern pike do not enter the population, via growth or immigration, or leave the population via death or emigration, during the experiment);

2) all northern pike had a similar probability of capture in the first event or in the second event, or marked and unmarked northern pike mixed completely between the first and second events;

3) marking of northern pike in the first event did not affect the probability of capture in the second event;

4) marked northern pike were identifiable during the second event; and,

5) all marked northern pike were reported when examined during the second event.

The abundance estimator used was derived from the general form of the Petersen estimator:

$$\hat{N} = \frac{n_1 n_2}{m_2}; \qquad (1)$$

where:

n_1 = the number of northern pike marked and released during the first event;

n_2 = the number of northern pike examined for marks during the second event; and,

m_2 = the number of marked northern pike recaptured during the second event.

The specific form of the estimator was determined from the experimental design and the results of diagnostic tests performed to evaluate if the assumptions were met. The sampling design allowed the validity of these assumptions to be insured or tested.

The Minto Lakes study area was divided into seven areas and 16 subareas (one to seven subareas per area; Figure 3). Subareas were sampled using a combination of gillnets and hoop traps so that sampling effort was not concentrated in a small portion of the study area but evenly distributed throughout. Within a subarea, hoop traps were placed in areas to maximize catches while gillnets were deployed to distribute effort throughout the subarea attempting to subject all northern pike to a similar probability of capture. Water bodies within the study area that were identified using radiotelemetry as not used by northern pike ≥ 400 mm FL (Roach 1998a) were not sampled in 1996, 1997 and 2000, and were not sampled in 2003 (e.g., Upper Minto Lake and the upper reaches of Rotten and Cancer sloughs). The first event (July 3 – 10) and second event (July 17 - 28) were separated by a six-day hiatus.

Because it was possible for northern pike to enter or exit the study area during the mark-recapture experiment the validity of Assumption 1 was ensured by completing the experiment during a period of least movement. A radiotelemetry study indicated that during the open water period, northern pike within the Minto Flats study area are least active from the middle of June until the end of July (Roach 1998b). The duration of the study was also kept short to render growth recruitment and mortality insignificant.

The study was designed to ensure that Assumption 2 was met by attempting to subject all fish, within each sampling event, to the same probability of capture by using the systematic sampling design that was used in 1997. Movement during the experiment was not expected to be sufficient to result in complete mixing of northern pike ≥ 400 mm FL within the study area (Roach 1998a). Size-selective sampling of northern pike ≥ 400 mm FL using a combination of gillnets and hoop traps was not anticipated based on the 1997 results (Roach 1998a). Diagnostic tests to identify heterogeneous capture probabilities and methods to correct for potential biases are presented under in the Data Analysis section.

Relative to Assumptions 4 and 5, northern pike captured during the first event were double marked with an individually-numbered Floy™ FD-94 internal anchor tag and partial finclip. All fish caught in the second event were given an identifying finclip to prevent resampling, and were carefully examined for marks.

CAPTURE METHODS

During the first event, two two-person crews rotated within their assigned areas sampling two subareas daily for eight days, resulting in each subarea being sampled twice. Due to higher water levels in the second event and a commensurate reduction in capture efficiencies, sampling was conducted for 12 days (eight days were planned), resulting in each subarea being sampled three times.

Each crew fished four hoop traps (two in each area per day), moving them at the beginning and end of each workday. Hoop traps had a 4-ft diameter opening and were 8-ft long. Each hoop trap had a 25-ft wing on one side and a 50 ft-wing on the other, and traps were placed parallel to the shoreline with wings deployed in a funnel-shaped pattern to capture northern pike moving along shorelines. In some locations where the sloughs were narrow and shallow enough, two hoop traps were sewn together at the wings facing opposite directions and placed across the slough, which effectively blocked-off the slough and caught fish moving in either direction.

Between times when hoop traps were moved, crews fished 80-ft by 6-ft floating and sinking variable-mesh multifilament gillnets (1-, 1.5-, 2-, and 2.5-in bar mesh) within their designated subareas. Nets were allowed to soak for 10 – 20 min before being checked, depending on catch rates and condition of captured fish. All healthy northern pike were released immediately 150 to 300 ft from the capture site after data collection and tagging.

DATA COLLECTION

All data from northern pike captured during the Minto Flats mark-recapture experiment were recorded on ADF&G Tagging Length Mark-Sense Forms, Version 1.0. A new form was used for each day and each subarea with the date, area, and gear type recorded on the description line. Scales taken for age determination were mounted directly to gummed cards at the time of sampling. Gummed cards were labeled with the corresponding mark-sense form litho-code, date, species, and study subarea. The importance of thoroughly examining all northern pike for Floy tags, recent tagging wounds and recent finclips, and accurately recording data was stressed to all crewmembers.

During the marking event, all captured northern pike were measured for length, had at least two scales removed for age determination, and were examined for a previous tag or finclip. Fork lengths were measured and recorded to the nearest millimeter. A minimum of two scales were taken from the preferred zone adjacent to the lateral line above the pelvic fins as described by Williams (1955). 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 tag was inserted at the left base of the dorsal fin and the number and color recorded. The new Floy tags were gray in color and numbered between 5,119 and 5,573 and between 46,000 and 46,299 (Appendix B1). In addition, all sampled fish received a left-pelvic finclip. Northern pike killed during the sampling procedure were not tagged but all other data were recorded. Northern pike with tags and finclips from previous years were treated as fish unique to the 2003 experiment, and counted as recaptures only if sampled in the first event and second events.

During the second event, the same data collection procedures were used for all northern pike as during the marking event. In addition, both the left and right sides of the dorsal fin were examined closely for recent tag wounds and the left and right pectoral fin examined closely for recent clips. All sampled fish in the second event received a right-pelvic finclip to prevent double counting during the second event.

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 an Eyecom® 3000 microfiche reader (32X) according to criteria established by Williams (1955).

Mark sense forms were optically scanned and converted to an electronic ASCII file. The ASCII file was imported into an Excel spreadsheet for analysis and archival (Appendix A).

DATA ANALYSIS

Abundance Estimation

Diagnostic tests were performed to evaluate the validity of Assumption 2 and determine the appropriate abundance estimator. Violations of Assumption 2 relative to size-selective sampling were tested by using two Kolmogorov-Smirnov (K-S) tests. There were four possible outcomes of these two tests relative to evaluating size selectivity (either one of the two samples, both, or neither of the samples could be biased) and two possible actions for abundance estimation (stratify estimates by length or not). The tests and possible actions for data analysis are outlined in Appendix C1. If stratification by size was required, capture probability by location were examined for each stratum, and total abundance and its variance estimate were calculated by summing strata estimates.

Spatial violations of Assumption 2 were tested within identified size strata using consistency tests described by Seber (1982; Appendix C2). If all three of these tests rejected the null hypothesis, then a partially or completely stratified estimator must be used. If movement of marked fish between strata was observed (incomplete mixing), the methods of Darroch (1961) would be used to compute a partially stratified abundance estimate. If no movements of marked fish between geographic strata were observed, a completely stratified abundance estimate would be computed using the methods of Chapman (Seber 1982) or Darroch (1961). Otherwise, at least one of the three consistency tests will fail-to-reject the null hypothesis and it will be concluded that at least one of the conditions in Assumption 2 was satisfied.

For evaluating Assumption 2, the documentation of release location for each fish permitted the examination of multiple geographic stratification schemes at the scale of sampling areas or subareas that were established by the sampling design.

Age and Length Compositions

Length and age compositions of the population were estimated using the procedures outlined in Appendices C1 and C4. Length composition was estimated for 10-mm FL incremental size classes.

Age Validation

Scales from northern pike that were captured from previous experiments (i.e., 1996, 1997, and 2000) that were also captured in 2003 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 to be considered as a measure of bias. Based upon initial ages and time elapsed since initial capture, all incremental ages were expected to be ≥ 3. The Wilcoxon Signed Rank Test (Conover 1980) was used to determine significance of the bias at the 95% confidence level.

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

$$\text{ERROR} = \text{AGE}_{t+\Delta} - \text{AGE}_t - \Delta t \qquad (2)$$

where: $\text{AGE}_{t+\Delta}$ = 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 from previous experiments and successfully aged.

Furthermore, to evaluate the precision in age determination, ages were determined twice for a simple random sample of 100 scales taken from those collected during the experiment. The average percent error (Beamish and Fournier 1981) assigned to the scale reader was calculated as:

$$\text{APE} = \frac{\sum_{i=1}^{S}\left[\frac{\sum_{j=1}^{R}\frac{\left|x_{ij}-\bar{x}_i\right|}{\bar{x}_i}}{R}\right]}{S}\cdot 100 \qquad (3)$$

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 successfully aged.

RESULTS

CATCH STATISTICS

Of the 1,652 unique northern pike ≥ 400 mm FL handled during the mark-recapture experiment, 832 were tagged and released alive during the first event (n_1), 847 were examined during the second event (n_2), and 27 were recaptures from the first event (m_2). All fish sampled ranged in size from 228 to 940 mm FL (Appendix B3). The smallest recaptured fish was 458 mm FL and the largest was 903 mm FL. During the experiment 63 northern pike (< 4% of all fish handled) were inadvertently killed, there was no observed tag loss, and 23 northern pike with Floy tags from prior mark-recapture experiments (< 2% of unique northern pike handled) were identified.

ABUNDANCE

The sampling design and the results of the diagnostic testing procedures (Appendices C1 and C2) indicated that there was no need to stratify the data by length or by area. Therefore, the unstratified Chapman estimator (Appendix C3) was used to estimate the abundance of northern pike ≥ 400 mm FL in the Minto Lakes study area.

For fish ≥ 400 mm FL, stratification by size was not necessary because results from the K-S tests indicated that the length composition did not vary between fish captured in the first event and fish examined in the second event (D = 0.05; P-value = 0.18; Figure 4) nor did it vary between those captured in the first event and those recaptured in the second event (D = 0.12; P-value = 0.85; Figure 4).

Heterogeneity in capture probabilities due to spatial factors was tested using three geographic stratification scenarios. The first examined the previously-defined seven areas (001, 002, 003, 004, 013, and 033; Figure 3), the second examined the 16 subareas, and the third was between the center (002, 003, 023, and 033) and the outer margins (001, 004, and 013) of the study area to detect evidence of movement of fish into or out of the study area. This last set of tests was performed in the previous three abundance experiments conducted on northern pike in the Minto Flats (Roach 1997 and 1998; Scanlon 2001).

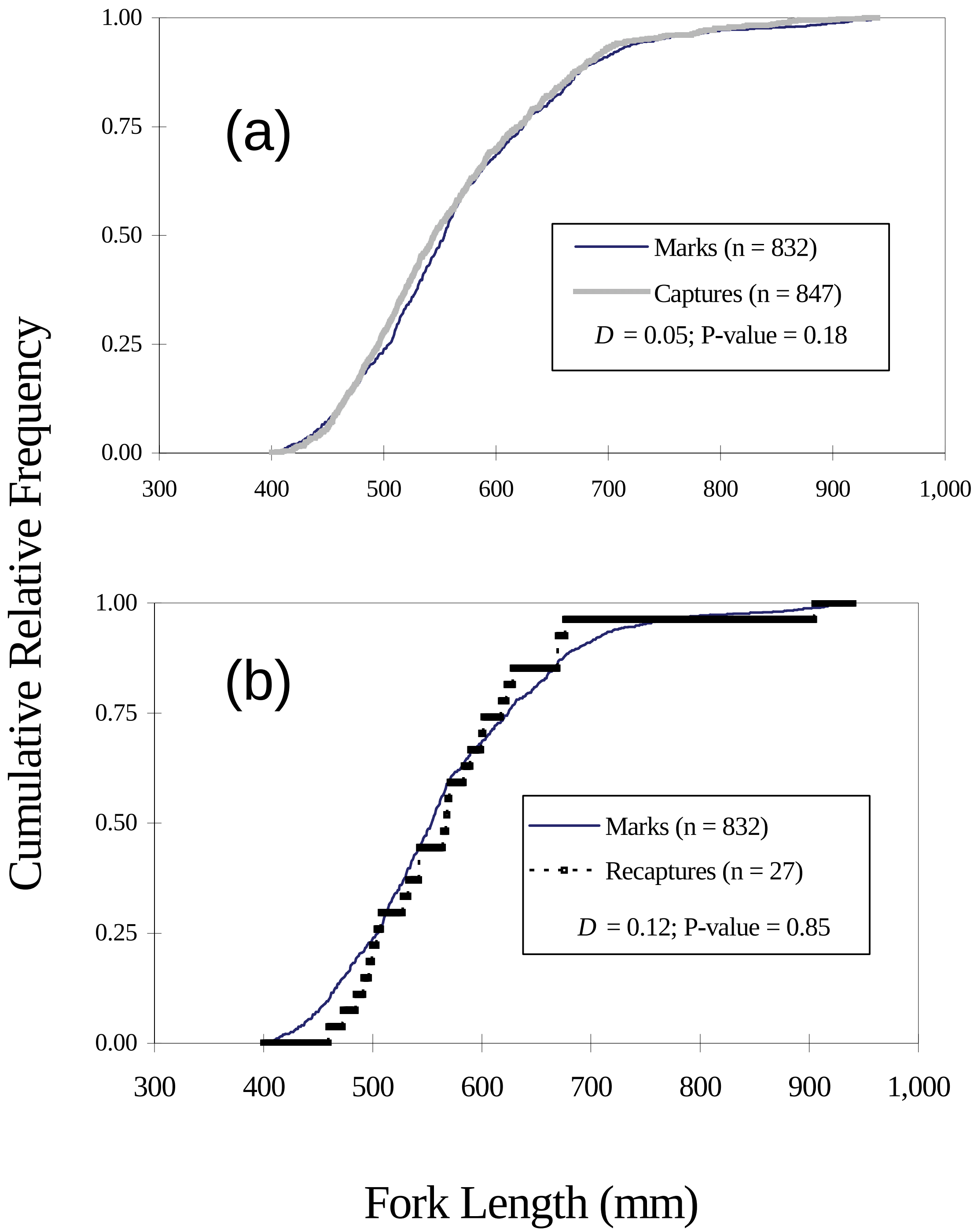

Figure 4.–Cumulative distribution functions of lengths of (a) marks (n_1) versus examined (n_2) and (b) marks (n_1) versus recaptures (m_2) in the Minto Lakes study area in 2003.

The results from the first scenario failed to reject the hypothesis of equal probability of capture of fish during the first event (P-value = 0.92; Table 3) and second event (P-value = 0.19; Table 4), but that mixing of fish among the areas was incomplete (P-value < 0.01; Table 5). The results from the second stratification scenario also failed to reject the hypothesis of equal probability of capture in the first (P-value = 0.99) and second (P-value = 0.73) events, however the test for complete mixing at this scale could not be conducted because seven subareas were pooled due to having either no fish marked or no fish recaptured in them. Consistency tests for the third movement scenario (between the center and outer margins of the study area) also failed to reject the hypothesis of equal probability of capture in the first (P-value = 0.79) and second (P-value = 0.54) events, and provided some evidence for complete mixing of fish between center and out margins of the study area (P-value = 0.11). Examination of the movement of recaptured fish from this third scenario indicated that 55% (six of 11) of fish marked in the outer margins (001, 004, and 013) were recaptured in the center (002, 003, 023, and 033), while 13% (two of 16) marked in the center were recaptured in the outer margins.

Based on the results of the consistency tests the abundance was estimated using the unstratified Chapman's modification of the Petersen estimator (Appendix C3). Estimated abundance of northern pike ≥ 400 mm FL within Minto Lakes was 25,227 fish (SE = 4,529; 90% CI = 17,755 – 32,699; relative precision at the 90% confidence level = 30%).

Although the smallest recaptured fish was 458 mm FL, the 400 mm FL lower boundary was selected because: 1) it is the smallest length at which previous estimates of northern pike in Minto Lakes were calculated in 1996 and 1997 (Roach 1997 and 1998b); 2) fish as small as 228 mm FL were captured in both events, demonstrating that above this boundary northern pike were recruited to the gear; and, 3) the absence of smaller-sized recaptures (i.e., < 458 mm FL) during the second event was a function of their relatively low density in the population. One hundred and thirty-three northern pike or 16% of those marked were within the three smallest length categories (400 - 474 mm FL), and given the estimated average probability of capture during the second event (3.2%) approximately four recaptures in this size interval were expected. There were three recaptures of in these size categories and the probability of recapturing three or less marks when four are expected was relatively high (~20%).

Similarly, while only one recaptured fish was > 699 mm FL (903 mm FL), only 8.2% of all fish sampled were of this size and therefore this was not unexpected. The proportion of northern pike > 699 mm FL was 0.09 in the first event sample and 0.07 in the second event sample. Based on the low number of fish > 699 mm FL marked in the first event and the estimated probability of capture during the second event (3.2%), the expected number of recaptures of this size was two fish. Again, the probability of recapturing one mark when two are expected was relatively high. Consequently, no upper length boundary was needed on the abundance estimate of northern pike ≥ 400 mm FL in 2003.

Table 3.-Test for equal probability of capture during the first event for northern pike ≥ 400 mm FL. Numbers of marked and unmarked northern pike captured during the recapture event by area (1, 4, 13, 2, 3, 23, and 33).

	Area							
Category	001	002	003	004	013	023	033	Total
Marked (m_2)	4	3	9	0	3	6	2	27
Unmarked (n_2-m_2)	128	115	248	37	67	151	74	820
Examined (n_2)	132	118	257	37	70	157	76	847
$P_{capture}$ 1st Event (m_2/n_2)	0.03	0.03	0.04	0.00	0.04	0.04	0.03	0.03

χ^2 = 2.02, df = 6, P-value = 0.92, fail to reject H_o.

Table 4.-Test for equal probability of capture during the second event for northern pike ≥ 400 mm FL. Numbers of marked northern pike recaptured and not recaptured during the recapture event by area (1, 4, 13, 2, 3, 23, and 33).

	Area							
Category	001	002	003	004	013	023	033	Total
Recaptured (m_2)	4	1	9	2	5	3	3	27
Not Recaptured (n_1-m_2)	71	139	240	136	75	94	50	805
Marked (n_1)	75	142	249	140	80	97	53	836
$P_{capture}$ 2nd Event (m_2/n_1)	0.05	0.01	0.04	0.01	0.06	0.03	0.06	0.03

χ^2 = 8.72, df = 6, P-value = 0.19, fail to reject H_o.

Table 5.-Test for complete mixing. Number of northern pike ≥ 400 mm FL marked in each area (1, 4, 13, 2, 3, 23, and 33) and recaptured or not recaptured in each area (areas 3 and 4 combined for this test to remove column of zeros found in 4).

Area Where Marked	Area Where Recaptured						Not Recaptured	Total Marked
	001	002	003&4	013	023	033	(n_2-m_2)	(n_1)
001	**1**	1	2	0	0	0	71	75
002	0	**1**	0	0	0	0	139	142
003&4	2	1	**5**	0	2	1	376	249
013	1	0	1	**3**	0	0	75	140
023	0	0	0	0	**3**	0	94	97
033	0	0	1	0	1	**1**	50	53
Total	4	3	9	3	6	1	805	836

χ^2 = 58.18, df = 30, P-value = 0.002, reject H_o.

LENGTH COMPOSITION

For northern pike ≥ 400 mm FL, the K-S test results indicated that inferences about the composition of the population can be based upon the lengths of fish sampled during both events (Case I, Appendix C1 and C4). Fork lengths measured from 1,652 northern pike ≥ 400 mm FL ranged from 400 mm to 940 mm (mean = 567 mm; SD = 95 mm; Figure 5). The estimated proportion of northern pike ≥ 400 mm FL that were ≥ 725 mm FL (30 in TL) was 0.06 (SE < 0.01) and the abundance of northern pike in this size category was estimated as 1,405 fish (SE = 288; Appendix B3).

AGE COMPOSITION

Age was determined for 1,285 northern pike (≥ 400 mm FL) sampled during mark-recapture experiment, 704 from the first event and 581 from the second event. Of the 1,656 unique northern pike sampled, ages were not determined for 371 fish (scales were not taken, lost or inadvertently destroyed from 299 fish, not readable because of regeneration from 40 fish, and not readable because of poor acetate impression from 32 fish).

Because a large number of fish (n = 371) were not aged in this experiment and those without ages could not be considered removed at random, comparison of length composition of all aged and all non-aged fish ≥ 400 mm FL was conducted using a K-S test. In addition, the length composition of the aged fish was compared to the length composition of the fish captured with regenerated scales (n = 40) to see if the incidence of collecting regenerated scales was related to fish size. Results from these two K-S tests indicated that the length compositions were not significantly different between the treatment groups (P-values ≥ 0.24); therefore, the age composition analysis using the 1,285 northern pike ≥ 400 mm FL that were aged in 2003 did not appear biased by the missing or regenerated scales. The estimated proportion of northern pike in the Minto Flats study area that were age-3 was 0.41 (SE = 0.01) and the proportion that was age-6+ was 0.17 (SE = 0.01; Figure 6, Appendix B4).

Ages were determined for 12 northern pike for which ages had been determined in previous years (four fish from 2000, eight from 1997). The mean error in assigning the proper incremental ages from the scales of these 12 fish was -1.75 years, a bias found to be significant using the Wilcoxon signed rank test (T = -2.61, P < 0.01; Figure 7). The estimated average percent error (Beamish and Fournier 1981) of the scale reader in reproducing the same age twice in 2003 was 4.3% (Figure 8).

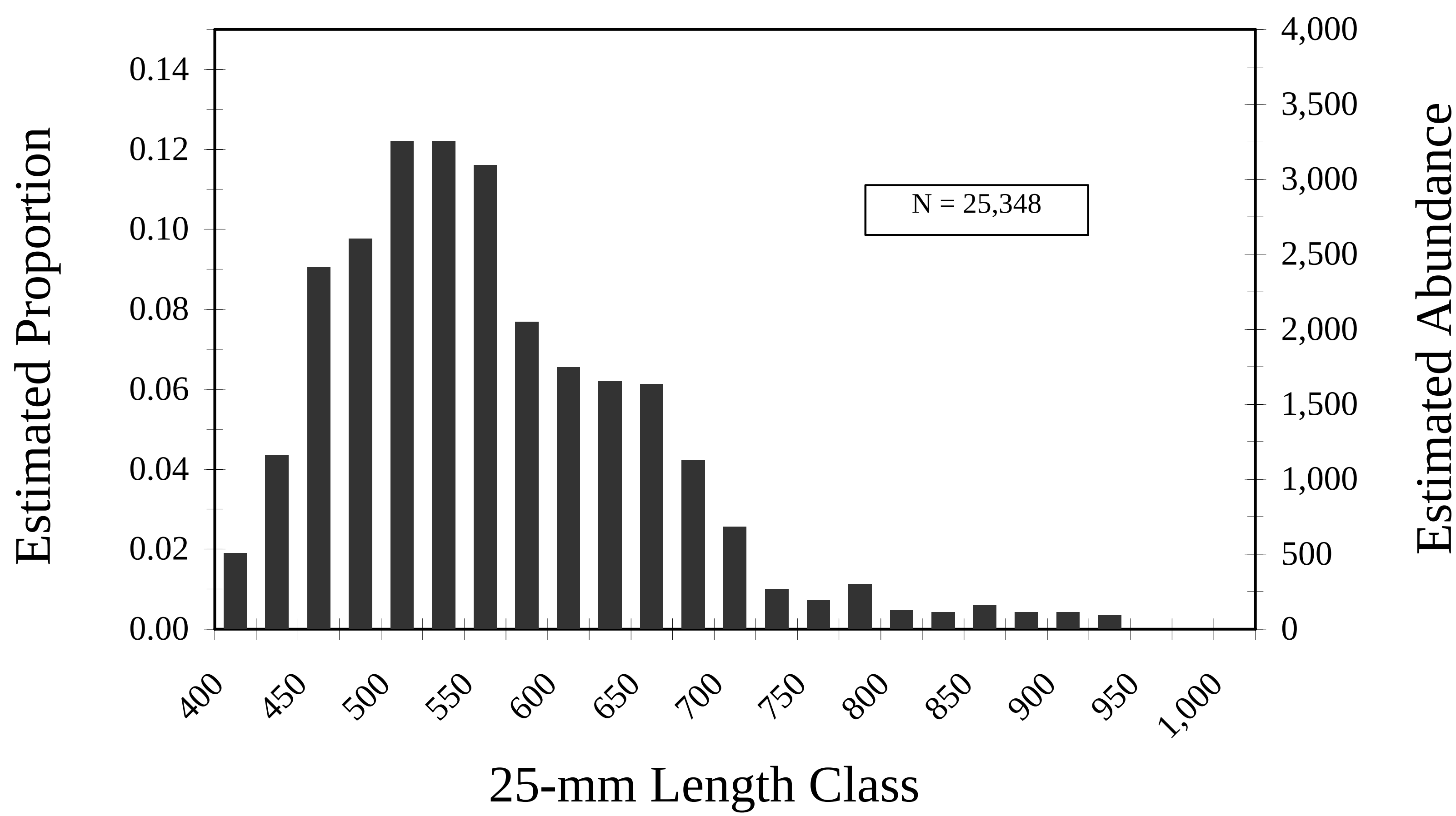

Figure 5.-Estimated proportions and abundances of northern pike ≥ 400 mm FL by 25-mm length classes within the Minto Lakes study area during middle to late July 2003.

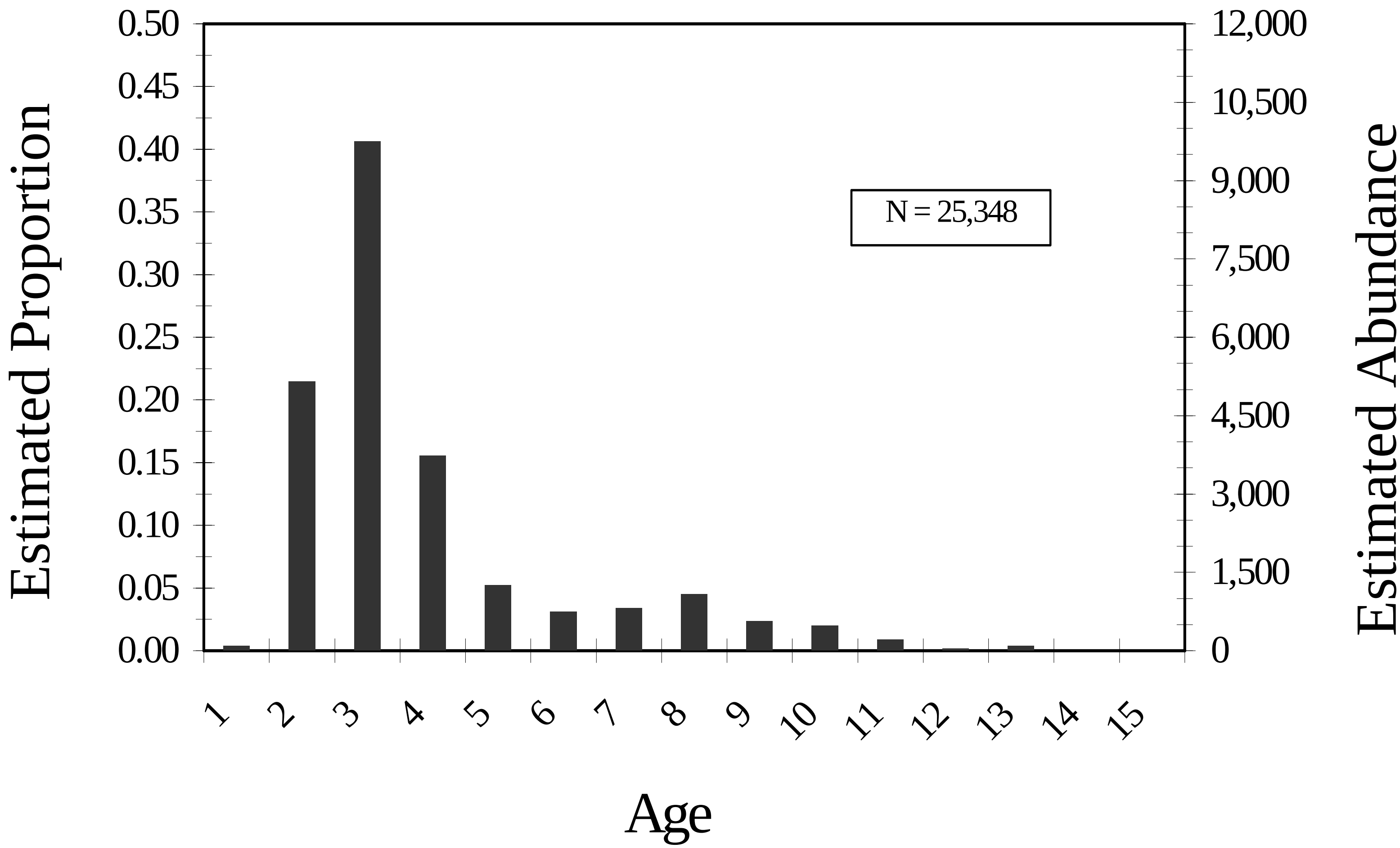

Figure 6.-Estimated proportions and abundances of northern pike ≥ 400 mm FL by ages within Minto Lakes study area, 2003.

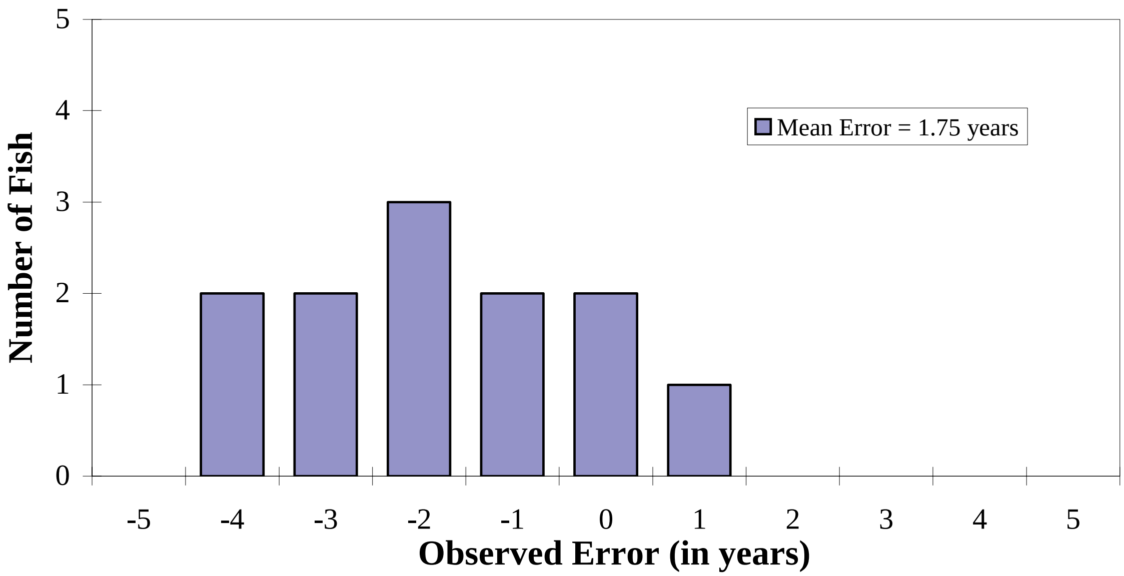

Figure 7.-Observed error in assigned incremental ages northern pike initially sampled and aged in 1997 or 2000 and aged again in 2003 from the Minto Lakes study area.

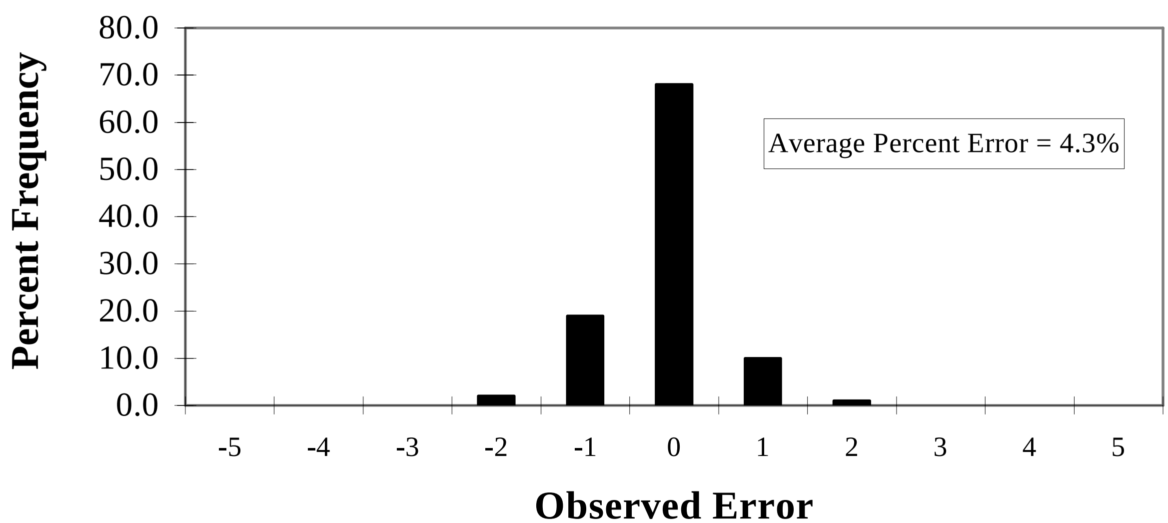

Figure 8.-Observed error in reproducing the same age twice from a sample of scales (n = 100) collected from northern pike in the Minto Lakes study area, 2003.

DISCUSSION

The mean estimated total harvest of northern pike from the sport and subsistence fishery for the period 2001-2003 represented 5% (1,362 fish; SD = 752) of the estimated abundance of northern pike ≥ 400 mm FL in 2003 (25,227 fish; SE = 4,529; 90% CI = 17,755-32,699), far below the management objective of not exceeding 20% exploitation annually. The estimated abundance of northern pike ≥ 400 mm FL in the Minto Lakes study area in was not significantly different (at 90% confidence level) than previous estimates (1996, 1997, and 2000; Table 1). Given that the abundance of northern pike ≥ 400 mm FL in the Minto Lakes in 2003 was within the range of recent estimates of abundance (Table 1) and exploitation was well below 20%, a more restrictive sport fishing regulation is not warranted. In addition, the abundance of large northern pike (≥ 30 inches or 725 mm FL) in 2003 (1,405, SE = 288) is within the range of previous estimates (between 672 fish (SE = 48) in 1997 and 2,971 fish (SE = 1,003) in 1996; Appendices B2 and B3).

The results from the examination of the movement of recaptured fish indicated that 55% (six of 11) of fish marked in the outer margins (001, 004, and 013) were recaptured in the center (002, 003, 023, and 033), while 13% (two of 16) marked in the center were recaptured in the outer margins, suggested that there may have been some movement into and possibly minimal movement out of the study area between events (Figure 3). The limited potential for emigration was presumed to introduce minimal bias and the greater potential for immigration led to interpreting the abundance estimate as germane to the second event.

The inability to estimate abundance of northern pike in 2003 within the desired precision criteria (± 25% of the true abundance 90% of the time vs. ± 30% attained) was likely because of inadequate planned sampling effort. Despite the favorable sampling conditions in 2003 (water level lower than normal, which contributed to high catch rates by reducing the ability of fish to avoid the gear), it is unlikely that two crews of two persons each could have attained the sample sizes needed without either increasing the amount of hoop traps used or increasing the duration of the experiment. However, both of these solutions can have deleterious effects. By increasing the number of hoop traps deployed by each crew, the time between checking traps and sampling fish increases, which in turn can lead to increased mortality of northern pike induced by prolonged exposure to stresses (e.g., overcrowding). By increasing the duration of the experiment (three or four passes through each subarea per event instead of two), the potential for significant movements in and out of the study area increases and commensurate with this, potential biases.

A solution would be to increase the number of two-person sampling crews from two to four, which in turn can double the amount of sampling gear or effort deployed. In 1997, four two-person crews using identical gear (hoop traps and gillnets) over a similar duration captured a substantially higher proportion of the population ≥ 400 mm FL than in 2003 (0.138 or 2,289 northern pike in 1997 (Roach 1998a) compared to 0.065 or 1,656 fish in 2003). The higher capture probabilities were achieved despite more variable and generally higher water levels in 1997. Based upon the success of the 1997 project, where the estimate of abundance (16,546) was achieved with high precision (RP = 17%), it was believed that to conserve resources, future experiments to estimate abundance and composition of northern pike in the Minto Lakes study area could be completed with two two-person crews rather than four two-person crews. In 2000, an attempt was made to conduct this experiment with a four-person crew but due to abnormally high water and heavy rains, which in turn flooded the study area and made gear deployment difficult in several places, the objectives of this experiment were not achieved (Scanlon 2001). In preparation for the 2003 experiment on northern pike in the Minto Lakes area, it was decided that the severe weather and consequently poor sampling conditions in 2000 was an anomaly, and that again an attempt would be made to conduct the experiment with two crews of two people each. In spite of favorable sampling conditions and high catch rates in 2003, desired precision was not achieved. Increasing the number of sampling crews can lead to larger sample sizes and better precision on abundance and composition estimates without increased fish mortality or compromises to the sampling design.

Another modification in the sampling protocol from 1997 was that sampling in 2003 was conducted in the daylight hours (0900 to 1700 hours) rather that at night (2300 to 0700 hours). While this was not expected to affect catch rates for hoop traps (which are fished 24 hours/day and are checked twice a day), gill net catches can be higher due to the pattern of movement of northern pike in the summer. Northern pike, which are primarily ambush predators, tend to feed largely during the low-light hours (Craig 1996) and may be less susceptible to gillnets at night than during the day when they may be traveling more. In addition, by conducting sampling during the day, northern pike captured in hoop traps spend less time in the traps during the heat of the day, and are less likely to succumb to stress. For these reasons, it is recommended that sampling and gear deployment in future projects on northern pike in Minto Lakes should be conducted during the day as well.

Due to the difficulty in aging older northern pike observed in this and other studies (Craig 1996), which for example can lead to biased population parameters (Pearse and Hansen 1993), it is recommended that in the future northern pike scales from Minto Lakes be considered valid ageing structures until age-5, after which scale ages be grouped into a age-6+ category. Craig (1996) reported that growth of scales of slow-growing or old northern pike may be reduced to the point that checks associated with annuli either do not form or cannot be resolved, resulting in the underestimation of ages, and that this method of ageing becomes invalid at 8-10 years. Because Minto Lakes is near the upper latitudinal limit for northern pike populations in North America and these fish grow more slowly the age at which scales becomes invalid is likely less than the range presented by Craig (1996). The use of age-6+ category is preferred because it is conservatively below the range presented by Craig (1996) and still identifies age-5 northern pike, which has been determined as the age at which northern pike recruit to the spawning population for Interior Alaska stocks (Pearse and Hansen 1993).

Given the potential for under ageing older northern pike, the statistically significant negative bias in incremental age determination was not unexpected; particularly when 10 of the 12 northern pike used in this analysis had predicted ages of 10+. In fact, only one fish had an expected age of six or less and that fish's incremental age was determined without error. The average percent error in aging a scale more than once (APE = 4.8%, with 68 of 100 scales aged identically in both readings and no apparent trend in under- or over-aging scales), indicate that the precision of the reader is good. However, the APE results need to be interpreted in light of the uncertainties in ageing in that reproducibility can not be viewed as accuracy.

As the largest sport fishery for northern pike in the AYK region, it is recommended that the periodic (3-5 year intervals) stock assessment experiments be continued to monitor the status of this population. Since a portion of the subsistence harvest occurs during the winter when the potential for over harvest is high, the subsistence harvest should be monitored closely with attention given to any increase in current levels of activity. Currently, the permit and reporting processes for the subsistence fishery for northern pike in the Chatanika-Tolovana-Goldstream area allows management biologists to closely monitor trends in effort and harvest. Accurate harvest and effort information for both the sport and subsistence fishery combined with periodic stock assessments are essential to the future of this important resource.

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APPENDIX A

DATA FILE LISTING

Appendix A1.–Data files used to estimate parameters of the Minto Lakes northern pike populations, 2003.

Data file[a]	Description
2003MintoNPdata.xls	Population and recapture data for Minto Lakes northern pike captured from 3 July through 28 July, 2003

[a] Data files were archived at and are available from the Alaska Department of Fish and Game, Sport Fish Division, 1300 College Road, Fairbanks, Alaska 99701.

APPENDIX B

PRESENT AND HISTORICAL DATA SUMMARIES

Appendix B1.-Floy tag numbers used for Minto Flats northern pike mark-recapture experiments by year and color, 1987-2003.

	Tag Color			
Year	Green	White	Blue	Gray
1987		27,000-27,999		
		32,500-32,999		
		45,000-45,408		
		58,000-58,220		
1988	89,000-89,045	45,500-45,547		
		49,000-49,822		
		56,000-57,999		
		58,221-58,999		
1989	5,000-5,432			
	7,000-7,344			
1990			60,000-62,764	
			75,000-75,238	
1991			77,000-78,492	
			79,000-79,991	
1994				15,000-17,059
				17,450-17,784
1995				9,719-9,735
				53,700-53,749
1996			41,000-41,989	
2000				45,275-45,572
2003				5,119-5,573
				46,000-46,299

Appendix B2.–Sample sizes, estimated abundances, and standard errors by length category for northern pike in the Minto Lakes study area, 1996, 1997, and 2000.

Length class	1996			1997		
(mm FL)	n	$\hat{N}$	SE	n	$\hat{N}$	SE
400-424	5	133	43	1	7	1
425-449	5	133	43	2	14	2
450-474	12	318	104	28	202	21
475-499	36	955	312	58	419	44
500-524	61	1,618	529	175	1,265	134
525-549	144	3,820	1,249	413	2,985	316
550-574	211	5,598	1,831	723	5,226	554
575-599	138	3,661	1,197	439	3,173	336
600-624	73	1,937	633	207	1,496	159
625-649	35	929	304	74	535	57
650-674	31	822	269	31	224	24
675-699	36	955	312	26	188	20
700-724	22	584	191	19	137	15
725-749	17	451	147	20	145	15
750-774	13	345	113	9	65	7
775-799	7	186	61	13	94	10
800-824	9	239	78	12	87	9
825-849	14	371	121	6	43	5
850-874	15	398	130	13	94	10
875-899	5	133	43	10	72	8
900-924	5	133	43	5	36	4
925-949	-	-	-	-	-	-
950-974	2	53	17	1	7	1
975-999	2	53	17	-	-	-
>999	1	27	9	4	29	3
Totals	899	23,850		2,289	16,546	

-continued-

Appendix B2.–Page 2 of 2.

Length class (mm FL)	2000		
	n	$\hat{N}$	SE
400-424			
425-449			
450-474			
475-499			
500-524			
525-549			
550-574			
575-599			
600-624	141	1,222	277
625-649	114	988	227
650-674	85	737	173
675-699	78	676	160
700-724	63	546	132
725-749	46	399	101
750-774	47	407	102
775-799	13	113	37
800-824	10	87	31
825-849	5	43	20
850-874	6	52	22
875-899	2	17	12
900-924	2	17	12
925-949	1	9	8
950-974	0	0	0
975-999	0	0	0
>999	2	18	16
Totals	615	5,331	

Appendix B3.-Sample sizes, estimated abundances, and standard errors by length category for northern pike in the Minto Lakes study area, 2003.

Length Class (mm FL)	n	$\hat{N}$	SE
400-424	32	489	122
425-449	73	1115	236
450-474	149	2275	444
475-499	161	2459	477
500-524	203	3100	592
525-549	203	3100	592
550-574	192	2932	562
575-599	123	1878	373
600-624	107	1634	330
625-649	103	1573	319
650-674	100	1527	310
675-699	71	1084	231
700-724	43	657	153
725-749	17	260	77
750-774	12	183	61
775-799	19	290	83
800-824	8	122	48
825-849	7	107	44
850-874	10	153	55
875-899	7	107	44
900-924	6	92	40
925-949	6	92	40
950-974	0	0	0
975-999	0	0	0
>1,000	0	0	0
Totals	1,652	25,227	

Appendix B4.-Sample sizes, estimated abundances, and standard errors by age for northern pike in the Minto Lakes study area, 2003.

Age	n	$\hat{N}$	SE
1	7	137	57
2	265	5,202	975
3	522	10,248	1,871
4	211	4,142	787
5	64	1,256	271
6	40	785	185
7	43	844	196
8	62	1,217	264
9	28	550	141
10	24	471	126
11	10	196	70
12	3	59	35
13	6	118	52
Totals	1,285	25,227	

APPENDIX C

TESTS OF ASSUMPTIONS

Appendix C1.-Methodologies for alleviating bias due to size selectivity

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

[a] The first Kolmogorov-Smirnov (K-S) 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 event 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. Estimate length and age distributions from second event and adjust these estimates for differential capture probabilities.

Appendix C2.-Tests of consistency for the Petersen estimator (from Seber 1982, page 438).

TESTS OF CONSISTENCY FOR PETERSEN ESTIMATOR

Of the following conditions, at least one must be fulfilled to meet assumptions of a Petersen estimator:

1. Marked fish mix completely with unmarked fish between events;
2. Every fish has an equal probability of being captured and marked during event 1; or,
3. Every fish has an equal probability of being captured and examined during event 2.

To evaluate these three assumptions, the chi-square statistic will be used to examine the following contingency tables as recommended by Seber (1982). At least one null hypothesis needs to be accepted for assumptions of the Petersen model (Bailey 1951, 1952; Chapman 1951) to be valid. If all three tests are rejected, a geographically stratified estimator (Darroch 1961) should be used to estimate abundance.

I.-Test for complete mixing[a]

Section Where Marked	Section Where Recaptured				Not Recaptured
	1	**2**	**…**	**t**	(n_1-m_2)
1					
2					
…					
s					

II.-Test for equal probability of capture during the first event[b]

	Section Where Examined			
	1	**2**	**…**	**t**
Marked (m_2)				
Unmarked (n_2-m_2)				

III.-Test for equal probability of capture during the second event[c]

	Section Where Marked			
	1	**2**	**…**	**s**
Recaptured (m_2)				
Not Recaptured (n_1-m_2)				

[a] This tests the hypothesis that movement probabilities (θ) from section *i* (*i* = 1, 2, ...s) to section *j* (*j* = 1, 2, ...t) are the same among sections: H_0: $\theta_{ij} = \theta_j$.

[b] This tests the hypothesis of homogeneity on the columns of the 2-by-t contingency table with respect to the marked to unmarked ratio among river sections: H_0: $\Sigma_i a_i \theta_{ij} = kU_j$, where k = total marks released/total unmarked in the population, U_j = total unmarked fish in stratum *j* at the time of sampling, and a_i = number of marked fish released in stratum *i*.

[c] This tests the hypothesis of homogeneity on the columns of this 2-by-s contingency table with respect to recapture probabilities among the river sections: H_0: $\Sigma_j \theta_{ij} p_j = d$, where p_j is the probability of capturing a fish in section *j* during the second event, and d is a constant.

Appendix C3.–Equations for calculating estimates of abundance and its variance using the Chapman-modified Petersen estimator.

The abundance estimate for northern pike in the Minto Lakes study area was calculated using Chapman's modification of the Petersen two-sample model (Seber 1982) as follows:

$$\hat{N} = \frac{(n_2 + 1)(n_1 + 1)}{m_2 + 1} - 1 \qquad \text{(C1)}$$

where:

n_1 = the number of northern pike marked and released during the first event;
n_2 = the number of northern pike examined for marks during the second event; and,
m_2 = the number of northern pike recaptured in the second event.

Variance of this estimator was calculated as:

$$V\hat{a}r\left[\hat{N}\right] = \frac{(n_1 + 1)(n_2 + 1)(n_1 - m_2)(n_2 - m_2)}{(m_2 + 1)^2 (m_2 + 2)} \qquad \text{(C2)}$$

Appendix C4.–Equations for estimating length and age compositions and their variances for the population.

No size selectivity was identified for northern pike ≥ 400 mm Fl sampled in the Minto Lakes study area (Case I; Appendix C1) Therefore, population compositions of lengths and ages were estimated using measurements from both sampling events. First the proportions from the sample were calculated:

$$\hat{p}_k = \frac{n_k}{n} \quad (1)$$

where:

$\hat{p}_k =$ the proportion of northern pike that were within age or length class k;

n_k = the number of northern pike sampled that were within age or length class k, and

n = the total number of northern pike sampled.

The variance of this proportion was estimated as (from Cochran 1977):

$$\hat{V}\left[\hat{p}_k\right] = \frac{\hat{p}_k\left(1-\hat{p}_k\right)}{n-1}. \quad (2)$$

The estimated abundance of age or length k fish in the population was then:

$$\hat{N}_k = \sum_{k=1}^{s} \hat{p}_k \hat{N}, \quad (3)$$

where:

$\hat{N}_k$ = the estimated abundance of age or length class k; and,

s = the number of age or length classes.

The variance for $\hat{N}_k$ in this case was estimated using the formulation for the exact variance of the product of two independent random variables (Goodman 1960):

$$\hat{V}\left[\hat{N}_k\right] \approx \sum_{k=1}^{s}\left(\hat{V}\left[\hat{p}_k\right]\hat{N}^2 + \hat{V}\left[\hat{N}\right]\hat{p}_k^2 - \hat{V}\left[\hat{p}_k\right]\hat{V}\left[\hat{N}\right]\right). \quad (4)$$

For each identified age class, the mean lengths (mm FL) of fish were estimated as the arithmetic mean length of all fish assigned to the same age:

$$\hat{\bar{L}}_k = \frac{\sum_{j=1}^{n_k} L_{jk}}{n_k} \quad (5)$$

-continued-

where:

L_{jk} = FL (mm) of the j^{th} fish sampled that were age *k*; and,

n_k = the number sampled for length that were age *k*.

The variances of the means were estimated as:

$$\hat{V}\left[\hat{\bar{L}}_k\right] = \frac{\sum_{j=1}^{n_k}\left(L_{jk} - \hat{\bar{L}}_k\right)^2}{n_k\left(n_k - 1\right)}. \qquad (6)$$