Fishery Data Series No. 10-69

Abundance and Composition of Northern Pike in Volkmar Lake, 2005, and George Lake, 2006

by

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and

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November 2010

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)

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. 10-69

ABUNDANCE AND COMPOSITION OF NORTHERN PIKE IN VOLKMAR LAKE, 2005, AND GEORGE LAKE, 2006

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ABSTRACT

Abundance of northern pike *Esox lucius* ≥450 mm FL in Volkmar Lake during 2005 and in George Lake during 2006 was estimated using two-event mark recapture experiments. The primary purpose of the studies was to compare population sizes to abundance-based management objectives for evaluating potential regulatory changes during the 2007 Alaska Board of Fisheries meeting. Relative to Volkmar Lake, a minimum population size of 2,000 northern pike ≥450 was the threshold above which regulatory proposals that might increase harvest would be considered for support by the Alaska Department of Fish and Game. Relative to George Lake, 7,300 fish ≥ 450 mm FL was the minimum threshold below which regulatory proposals that restrict harvest would be considered for support. At both lakes, northern pike were captured by fishing a beach seine around the lake perimeter each day over a period of 8 or 9 days immediately following ice-out. The estimated abundance of fish ≥450 mm FL in Volkmar Lake was 1,814 (SE = 449) and in George Lake was 16,204 (SE = 3,293). The proportion of the population comprised of fish ≥720 mm FL (30 in) was relatively large in Volkmar Lake (0.36, SE < 0.02) compared to George Lake (0.07, SE = <0.01). Based on the estimated population sizes, 2010 Board of Fisheries proposals to relax regulations in Volkmar Lake or to restrict regulations in George Lake were not supported by the department.

Key words: northern pike, *Esox lucius*, Volkmar Lake, George Lake, abundance, mark-recapture, composition

INTRODUCTION

George Lake (1,823 ha) and Volkmar Lake (373 ha) constitute the second and third largest northern pike *Esox lucius* fisheries in the in the Tanana River basin, respectively, in terms of angler effort, ranked behind Minto Flats (Figures 1, 2 and 3). In George and Volkmar lakes fishing effort is almost exclusively directed at northern pike. Both lakes are popular, relatively close to Delta Junction and Fort Greely, and have good catch rates of northern pike. Because both lakes are situated north of the Tanana River, most of the fishing effort occurs though the ice during spring when temperatures are more moderate and the Tanana River can be safely crossed. During summer Volkmar Lake can only be accessed by float-equipped aircraft, and George Lake can be accessed by aircraft on floats or by boats designed to operate in shallow water by navigating the Tanana River and the lake's outlet, George Creek. However, during low water years, navigation of George Creek is restricted to air boats.

The current fishing regulations for northern pike in both George and Volkmar lakes are predicated on a series of stock assessments conducted during the late 1980s and early 1990s, which attempted to better understand their population dynamics and identify levels of sustainable yield. Although no formal abundance-based management objectives resulted from these efforts, these previous abundance estimates have provided managers with gross measures of exploitation based on annual harvests as reported by the Alaska Department of Fish and Game (ADF&G) statewide annual mail survey, and when combined with use patterns, angler reports and angler preferences, have provided the basis to formulate regulatory measures. For example, in 1988 the bag limit for northern pike in the Tanana River drainage was reduced from 10 to five fish because prior stock assessments demonstrated that exploitation rates were potentially excessive across the drainage, including George Lake where estimated exploitation rates exceeded 20% in 1987 (Figure 2). In Volkmar Lake, the bag limit was reduced from 5 fish to 1 fish due to concerns about overexploitation in 1995 and angler concerns about sustainability of the fishery (Figure 3). Since the most recent reduction in bag limits, levels of fishing effort, catch and harvest have remained relatively stable with annual variations attributed to such factors as favorable fishing weather (i.e., during March and April) and adequate ice-conditions on the Tanana River that provides access (Figures 2 and 3).

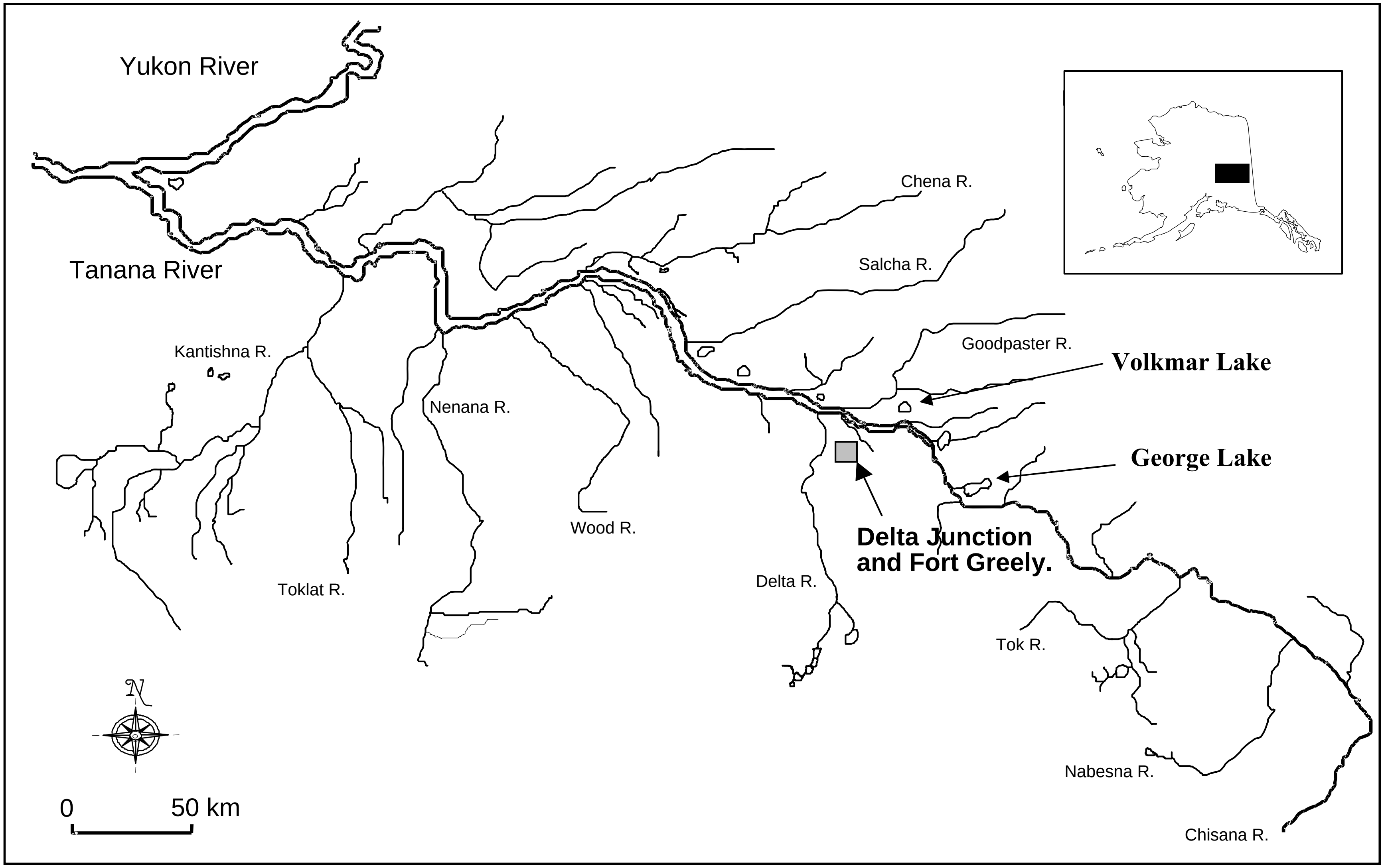
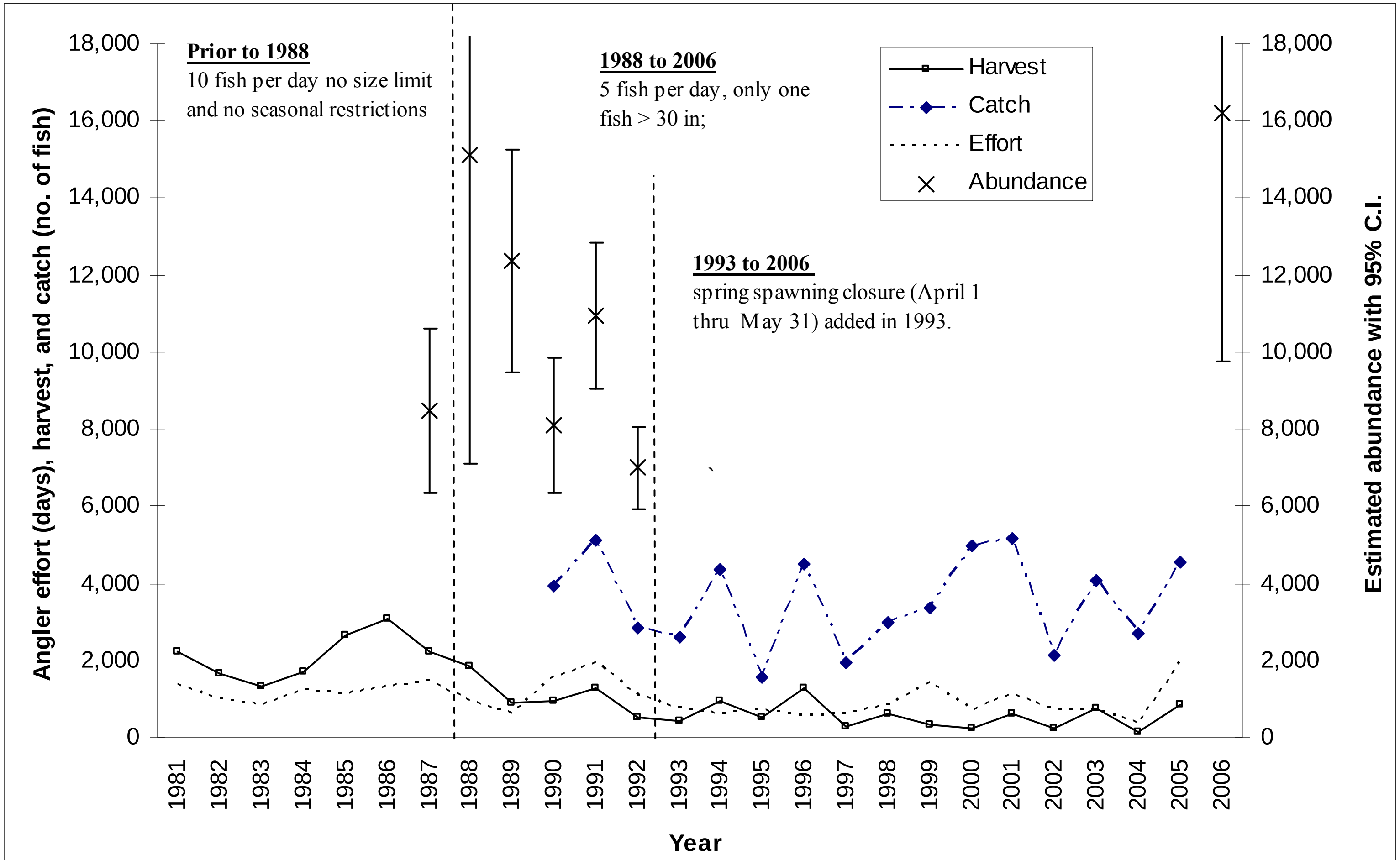


Figure 1.–Locations of Volkmar and George lakes.



Data from Parker (*In prep*) and Pearse and Burkholder (1993).

Figure 2.–Historic estimates of angler effort, harvest, and catch, and estimates of abundance for mature-sized (≥450 mm FL) northern pike for George Lake. Vertical dashed lines demarcate relevant regulatory changes. Estimates of effort, harvest and catch are presented in Parker (*In prep*) and estimates of abundance prior to 2006 are presented in Burkholder (1993).

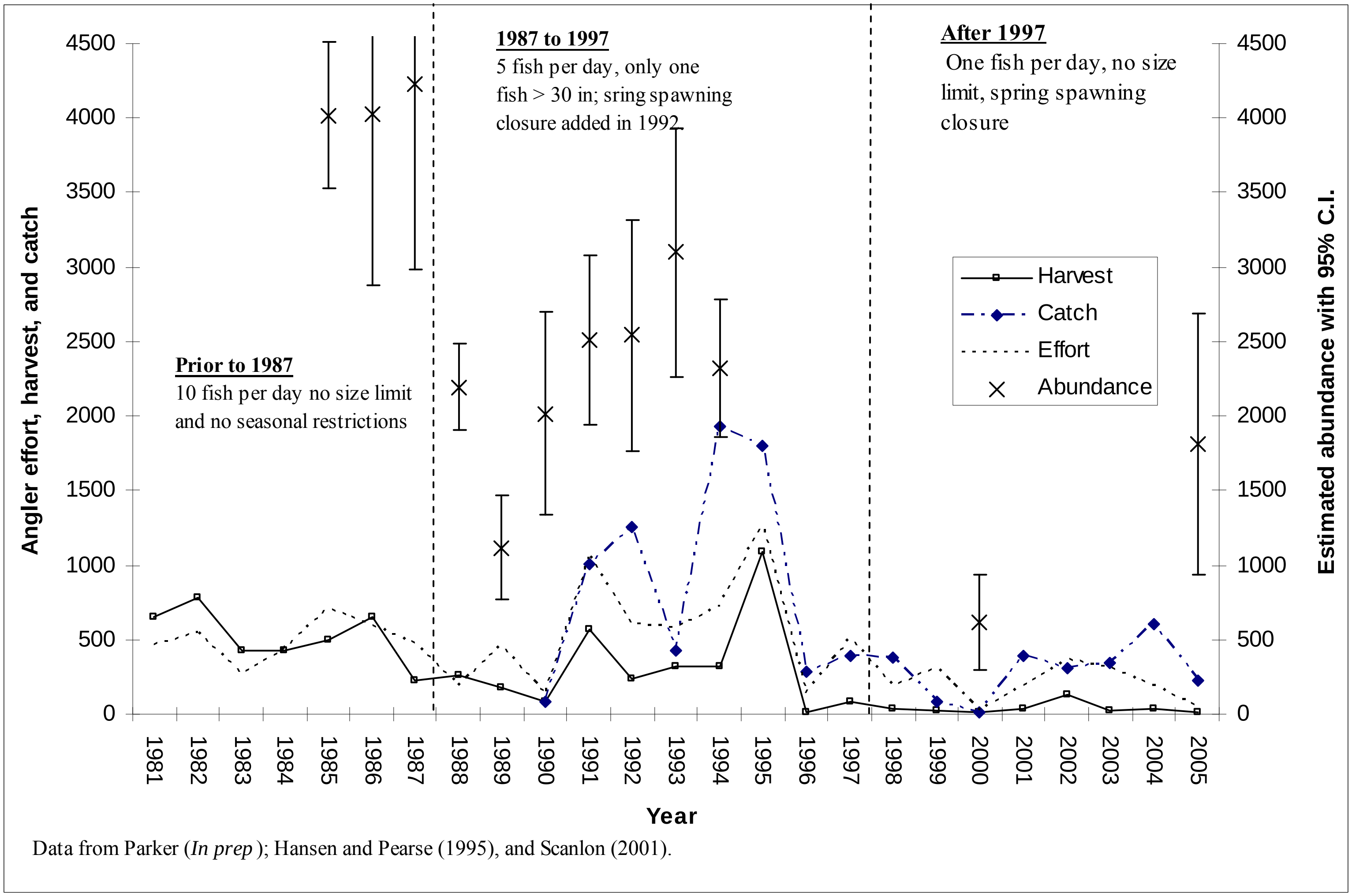


Figure 3.–Historic estimates of angler effort, harvest and catch, and estimates of abundance for mature-sized (≥450 mm FL) northern pike for Volkmar Lake. Vertical dashed lines demarcate relevant regulatory changes. Estimates of effort, harvest and catch are presented in Parker (*In prep*) and estimates of abundance prior to 2005 are presented in Hansen and Pearse (1995) and Scanlon (2001).

In this study, a need for stock assessments of both George and Volkmar lakes was identified in anticipation of regulatory proposals being submitted to the Alaska Board of Fisheries (BOF) for the meeting in January of 2007. In 2000 the most recent stock assessment of Volkmer Lake corroborated reports from anglers that the population size of sexually mature fish was small (615 ≥ 450 fish; Scanlon 2001). However, during recent winters anglers have reported that catch rates had improved, especially for larger-sized fish, suggesting that the population may have rebounded since 2000 and that a liberalization of the bag limit may be permissible. Relative to George Lake, the most recent assessment was conducted in 1992. In 2002 to 2005 increasing harvest created concerns among anglers that harvests were too high and not sustainable. During the late 1980s and early 1990s George Lake had a reputation of supporting a large population of small fish (e.g., ≤ 450 mm TL). However, more recently anglers and the local Fish and Game Advisory Committee have expressed their satisfaction with the improved catch rates, particularly of larger-sized fish (e.g., >750 mm TL).

Therefore, the goal of these studies was to conduct assessments of the northern pike population in Volkmar Lake (2005) and George Lake (2006) in order to address regulatory proposals and to estimate the population's abundances and length compositions that could be used to formulate future management objectives.

Because no formal abundance- or exploitation-based management objectives existed prior to the 2007 BOF meeting, interim management objectives were created to serve as criteria for consideration of regulatory proposals. For Volkmar Lake, the interim management objective established a minimum population size of 2,000 northern pike ≥ 450 mm FL as the threshold above which any regulatory changes that might increase harvest would be supported by ADF&G. This threshold was selected because it related directly to the desired spawning population size recommended by Hansen and Pearse (1995) based on a stock-recruitment analysis that identified a sustainable harvest of 300 fish, well below recent trends.

Relative to George Lake, an interim management objective of 7,300 fish ≥ 450 mm FL (18 in TL) was selected as the minimum threshold below which any regulatory changes that restrict harvest may be supported by the department. This relatively conservative threshold was based on the most recent 5-year reporting period (2000–2004) for fish ≥ 450 mm FL and was calculated by expanding the highest observed fishing mortality (a harvest of 584 fish plus a 10% hooking mortality applied to the catch of 5,067 fish) by a sustainable exploitation rate of 15%.

OBJECTIVES

VOLKMAR LAKE

The research objectives for Volkmar Lake in 2005 were to:

1. test the null hypothesis that the abundance of northern pike ≥ 450 mm FL in Volkmar Lake was ≤ 2,000 with 50% power of rejecting the null hypothesis if the true abundance was ≥ 2,518 using $\alpha = 0.05$; and,
2. estimate the age and length composition of the northern pike population ≥ 450 mm FL in Volkmar Lake such that the estimates of proportions were within 5 percentage points of the actual value 95% of the time.

Additional project tasks were to:

1. estimate the abundance of northern pike ≥ 300 mm FL; and,
2. estimate the age and length composition of the northern pike population ≥ 300 mm FL in Volkmar Lake.

Objective 1 related directly to the sustainable population size and the desired level of certainty needed to evaluate proposals to liberalize fishing regulations. Objective 2 was to provide an estimate of abundance of age-5 fish (recruitment) and fish older than age-5. The 450-mm lower length limit was expected to adequately capture almost the entire cohort of age-5 fish because the average length of an age-5 fish from previous studies (1985 to 1991) was 517 mm FL (n = 836) and age-4 fish were 432 mm FL (n = 849). Task 1 related to the minimum size limit attained in previous studies and when combined with Task 2 was to provide insight on the magnitude of recruitment in 2006 and 2007.

GEORGE LAKE

The research objectives for George Lake in 2006 were to:

1. test the null hypothesis that the abundance of northern pike ≥ 450 mm FL in George Lake was ≥ 7,300 with 50% power of rejecting the null hypothesis if the true abundance was ≤ 5,863 using $\alpha = 0.025$ (one-tailed test);
2. estimate the abundance of northern pike ≥ 450 mm FL in George Lake such that the estimate was within 25% of the actual value 95% of the time; and,
3. estimate the age and length composition of the northern pike population ≥ 450 mm FL in George Lake such that the estimates of proportions were within 5 percentage points of the actual value 95% of the time.

Additional project tasks were to:

1. estimate the abundance of northern pike ≥ 300 mm FL; and,
2. estimate the age and length composition of the northern pike population ≥ 300 mm FL in George Lake.

Objective 1 related directly to the interim management objective and the desired level of certainty needed to evaluate proposals to restrict fishing if warranted. Objective 2 was, in part, a direct by-product of achieving Objective 1, however precision criteria for estimating abundance regardless of the outcome of the Objective 1 hypothesis test was included to ensure adequate precision for future trend analyses. Objective 3 was to provide an estimate of abundance of age-5 fish (the age at which northern pike recruit to the sampling gear and spawning population; (Pearse 1991) and fish older than age-5 that could be used in the future to directly model a stock-recruitment relationship. Based on a length-frequency plot by age of northern pike sampled from George Lake during 1987 to 1991 (n = 1,724 fish) presented by Pearse (1991), the 450-mm lower length limit appeared to capture most (i.e., approximately 80%) of age-5 fish and 35% of age-4 fish. Objective 3 would also provide a range of statistics, such as an abundance of fish for various length increments ≥ 450 mm TL that could be used to derive a range of possible management objectives. Task 1 related to the minimum size limit attained in previous studies and when combined with Task 2 was to provide insight on the magnitude of recruitment in 2008 and 2009. Objective criteria were not set for Tasks 1 and 2 because these estimates were ancillary to the primary study goal. Because northern pike <450 mm FL are typically not fully-recruited to the seine gear (Pearse and Burkholder 1993), precision estimates in Tasks 1 and 2 would likely be less than precision for estimates in Objectives 2 and 3. However, based on estimates obtained from 1987–1992 (Pearse and Burkholder 1993), it was anticipated that precision of these estimates would be adequate for making inferences regarding potential recruitment in 2008 and 2009.

METHODS

DESCRIPTION OF STUDY AREAS

Volkmar Lake (64°07'N, 145°11'W) is a 373 ha lake within the Tanana River drainage located approximately 25 km northeast of Delta Junction (Figures 1 and 4). Volkmar Lake is at an elevation of 326 m, has a maximum depth of 12.8 m, and a shoreline circumference of 8.2 km. The lake has two small ephemeral inlets and an ill-defined outlet that drains westerly through wetlands towards the Goodpaster River. Nearshore waters are shallow, with beds of aquatic vegetation providing spawning and rearing substrate for northern pike. Volkmar Lake is typically ice-free from late May to early October and spawning of northern pike generally coincides with the beginning of the ice-free period and continues for up to two weeks into late May. Other fish species present in the lake include humpback whitefish *Coregonus pidschian*, least cisco *C. sardinella*, and slimy sculpin *Cottus cognatus*.

George Lake (63°47' N, 145°31' W) is 1,823 ha and lies within the Tanana River drainage located approximately 8 km north of the Tanana River and 45 km southeast of Delta Junction (Figures 1 and 5). George Lake sits at an elevation of 389 m and has a maximum depth of 11 m. The lake has one primary inlet and six smaller inlets and a navigable outlet that flows into the Tanana River (Pearse and Burkholder 1993). Nearshore waters are generally shallow, with beds of aquatic vegetation providing spawning and rearing substrate for northern pike. George Lake is typically ice-free from late May to mid-October and spawning of northern pike generally coincides with the beginning of the ice-free period and continues for up to two weeks into early June. Other fish species present in the lake include burbot *Lota lota*, Arctic grayling *Thymallus arcticus*, humpback whitefish, least cisco, round whitefish *Prosopium cylindraceum*, longnose sucker *Catostomus catostomus*, and slimy sculpin.

EXPERIMENTAL AND SAMPLING DESIGNS

Similar to the most recent studies at Volkmar Lake during 1992–1994 and in 2000 and at George Lake during 1992, these studies were designed to estimate abundance and length and age composition of northern pike in each of George and Volkmar lakes using multiple-event mark-recapture techniques for a closed population (Seber 1982) designed to satisfy the following assumptions:

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 during each sampling event, or marked and unmarked northern pike mixed completely between events;
3. marking of northern pike did not affect the probability of capture in the later sampling events;
4. marked northern pike were identifiable during the all subsequent sampling events; and,
5. all marked northern pike were reported when recovered in all subsequent sampling events.

Failure to satisfy these assumptions may result in a biased estimate; therefore, the experiments were designed to allow the validity of these assumptions to be ensured or tested. Sufficient data were collected to perform diagnostic tests to identify heterogeneous capture probabilities (violations of Assumption 2) so that prescribed model selection procedures could be followed in the event of such violations. If multi-event models were used to estimate abundance, statistical software used for model selection allowed an assessment of Assumption 3 by testing if a model that includes behavioral response fitted the data significantly better than a model without behavioral response. Where 2-event models were used to estimate abundance, diagnostic methods are not available so field procedures for handling and carefully inspecting fish as well as elapsed time between sampling events were used to address Assumption 3. Diagnostic tests were not available to evaluate assumptions 1, 4, and 5; instead, the experiments were designed to ensure that these assumptions would be met thereby avoiding potential biases, which is detailed later in this report in the section titled Evaluation of Assumptions. In addition, the designs ensured that planned sample sizes were adequate to meet objective precision criteria for each experiment and to perform reliable diagnostic testing.

VOLKMAR LAKE SAMPLING METHODS

Eight daily sampling events were conducted during May 12–19, immediately following breakup. Each day, the entire lake perimeter was sampled. In 2005, the study area was divided into 14 asymmetric sections with each section fished once daily (Figure 4) in an attempt to more proportionately distribute fishing effort and increase sample sizes. The distribution and length of the sampling sections were selected based on the historic distribution of catches (1992–1994 and 2000) while trying to avoid creating sections that are too large to sample effectively. The size of the sections ranged from approximately 300 m (Sections 10–14) to a maximum of 900 m (Sections 8 and 9). The number of sections was dictated by the maximum number of seine hauls that one crew can reasonably conduct during one day.

Each sampling day one seine haul was conducted in each section, and the lake sections were seined sequentially in a clockwise direction. To guard against any potential diel patterns in fish movement related to environmental factors (e.g., water temperature, time of day, or weather) that may affect the capture probabilities by section, sampling began each day in a different section. The first section on day one was chosen randomly and the starting section was moved forward three units each subsequent sampling day.

A five-person crew used a beach seine (100 m x 10 m with 25 mm square mesh and with an attached bag) to capture northern pike. Seines were normally set in water less than 3 m deep usually within 100 m of the shore. The seines were drawn to the shore around the northern pike, which were transferred to holding containers for sampling. All fish were released at their capture location.

During the first and subsequent sampling events, each unmarked captured northern pike ≥ 250 mm FL was marked with an individually numbered Floy™ [1] FD-94 internal anchor tag (primary mark) and a partial left-pectoral fin clip was given to evaluate tag loss. Although a task was to estimate abundance of northern pike ≥ 300 mm FL, tagging all fish ≥ 250 mm FL allowed a better assessment of gear selectivity for fish near 300 mm FL. During the second and subsequent sampling event(s), each fish was inspected for a tag or tag scar and a partial left-pectoral fin clip

[1] Product names used in this report are included for scientific completeness, but do not constitute product endorsement.

to determine if it had lost its primary mark. If a fish lost its primary mark it was recorded as a "tag loss", fitted with a new tag and released. All previously unmarked fish also received a Floy tag and were released. Capture locations (GPS way point and section number) of all fish marked and recapture locations of fish bearing marks were recorded.

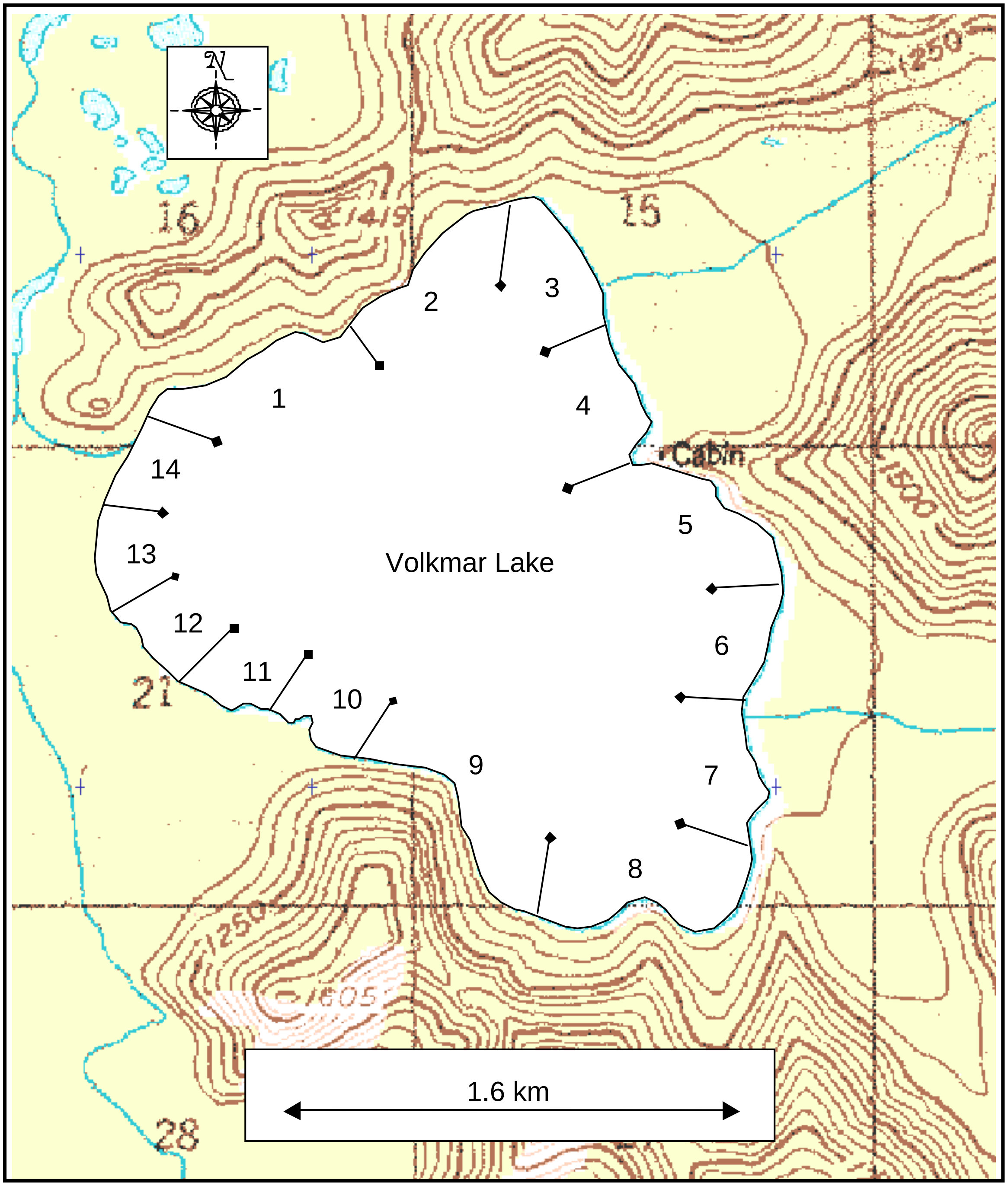


Figure 4.–Volkmar Lake with demarcations of sample sections.

George Lake Sampling Methods

Nine sampling events were conducted during May 31–June 8, immediately following breakup. Each day, the entire lake perimeter was sampled. In 2006, the study area was divided into 26 asymmetric sections with each section fished once daily (Figure 5) in an attempt to more proportionately distribute fishing effort and increase sample sizes. The distribution and length of the sampling sections were selected in attempt to distribute effort based on the observed distribution of catches from 1986-1992 while trying to avoid creating sections that are too large to sample effectively. The size of the sections ranged from approximately 300 m (Sections 10–14) to a maximum of 2,000 m (Sections 8 and 9). The number of sections was dictated by the maximum number of seine hauls that two independent crews could reasonably conduct during one day.

Each sampling day, the two 5-person crews started in adjacent sections and seined sequentially around the lake in opposite directions until all sections had been sampled. To guard against any potential diel patterns in fish movement related to environmental factors (e.g., water temperature, time of day, or weather) that may affect the capture probabilities by section, sampling began each day in a different pair of sections. The first pair of sections on day one was chosen randomly and the starting sections were moved forward five units each subsequent sampling day. To minimize disruption to spawning areas and guard against the possibility of not subjecting a segment of the population within a section to capture, efforts were made to fish throughout the section over the nine sampling days, and within a three-day period, repeated seine hauls were avoided.

Procedures for deploying the beach seine, sampling individual pike and for recording data, and the beach seine used, were identical to those described for the 2005 Volkmar Lake experiment, above.

Evaluation of Assumptions

Assumption 1: In Volkmar Lake, Assumption 1 was not violated because the system is closed. A small outlet exists but is too small to serve as a migration corridor for non-juvenile fish. George Lake is presumably a closed system. Although an outlet stream exists, no fish have been observed nor captured in George Creek in previous experiments (Pearse and Burkholder 1993). In addition, the short duration of these experiments helped guard against significant immigration or emigration and also rendered growth recruitment insignificant. Inlets exist, but are considered too small to serve as rearing or spawning areas for fish >250 mm FL. Natural mortality during these experiments was assumed insignificant and both lakes are closed to northern pike fishing until June 1.

Assumption 2: Previous and similarly designed studies have demonstrated that capture probabilities will vary by sampling day or event (Hansen and Pearse 1995; Pearse and Burkholder 1993; Scanlon 2001). Based on a 1991 radiotelemetry study of northern pike movements in Volkmar Lake (Pearse and Clark 1992), partial mixing among sampling sections over two consecutive sampling days or events was expected to occur, but complete mixing was unlikely. The establishment of the 14 asymmetric sampling sections in Volkmar Lake and 26 asymmetric sampling sections in George Lake was intended to help minimize daily heterogeneity in capture probabilities among sections each event because fishing effort would be directed more proportionate to fish densities than in previous studies. Systematically rotating the daily starting section was expected to help to minimize spatial heterogeneity in capture probabilities that could result from undetectable diel movement patterns.

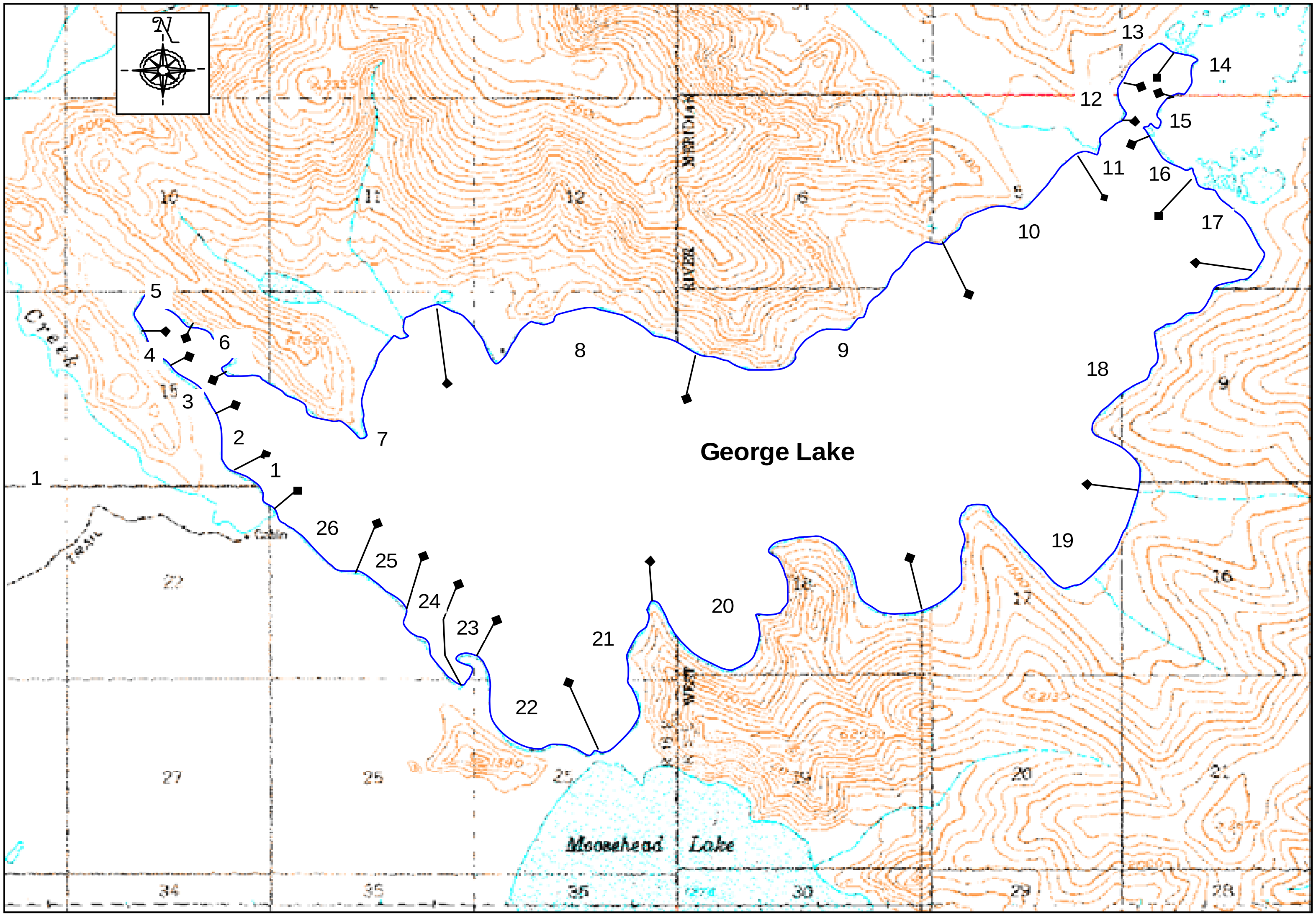


Figure 5.–George Lake with sampling sections demarcated.

Tests for size-selective sampling were based on the Kolmogorov-Smirnov (K-S) test (Conover 1980). Two series of tests were conducted.

The first series of tests evaluated size selective sampling for events *1* through *T-1* from the perspective that they were "marking" events. For each event *t*, we compared the cumulative length frequency distributions of: 1) those fish that were handled during event *t* and released alive and marked into the lake; and, 2) those fish from (1) that were observed at least once as recaptures during events *t+1* through *T*. Rejection of the null hypothesis (no difference in distributions) indicates size bias sampling during event *t*.

The second series of tests evaluated size selective sampling for events *t+1* through *T* from the perspective that they were "recapture" events. For each event *t*, we compared the cumulative length frequency distributions of 1) those fish that were inspected for marks during event *t*, and 2) those fish from (1) that are recaptures of fish marked during events *1* through *t-1*. Rejection of the null hypothesis (no difference in distributions) indicates size bias in sampling during event *t*.

If size selective sampling was detected, and stratification is necessary to reduce bias, data were to be stratified by size after inspecting the cumulative length frequency distributions to identify near optimal stratification breaks, and diagnostic tests for size selectivity were repeated for each size strata. Once a stratification scheme was identified that was sufficient to minimize potential for bias due to size selectivity within strata, further diagnostic testing and model selection for estimating abundance was conducted independently for each size stratum.

Contingency table analyses were used to expose problems with varying probability of capture between sections. Three types of tests were adapted from tests described by Seber (1982) to evaluate equal probability of capture between temporally or geographically distinct sample nodes and mixing between sampling events.

The first type of test evaluated equal probability of capture from the perspective that an event is a "marking" event. Contingency tables were constructed and tested for all but the final sampling event. For each event *t* (*t* = *1* to *T-1* where *T* is the number of sampling events), rows were comprised of sections and the column entries within each row summed to all individual fish inspected for marks in that section during events *t+1* thru *T*; all second and later observations of individual fish were ignored regardless of the section these later observations are made in. Only those fish that were handled during event *t* and released alive and marked into the lake were be considered "marked" fish, both those marked initially during event *t* and those that were marked previously and recaptured during event *t*. The two entries (columns) for each row are 1) those fish that are recaptures of "marked" fish; and, 2) those fish that were not "marked". This contingency table analysis tests the null hypothesis that probability that an inspected fish was "marked" during event *t* is independent of the section where the fish was inspected. Rejection of the null hypothesis was considered evidence that equal probability of capture did not occur across sections during event *t*. Adjacent sections (rows) were pooled where sample sizes were small and there was no apparent evidence of heterogeneity between sections considered for pooling.

The second type of test evaluated equal probability of capture from the perspective that an event is a "recapture" event. Contingency tables were constructed and tested for all but the first sampling event. For each event *t* (*t* = *2* to *T*), rows were comprised of sections and column entries within each row summed to all individual fish sampled and marked for the first time in that section during events *1* through *t-1*; all second and later observations of individual fish were ignored regardless of the section these later observations are made in, and all fish known to have died or been removed from the lake prior to event *t* were be excluded. The two entries (columns) for each row are 1) those fish that are "recaptured" during event *t*; and, 2) those fish that are not "recaptured during event *t*. This contingency table analysis tests the null hypothesis that the probability that any previously marked fish is "recaptured" during event *t* is independent of the section where the fish was originally marked. Rejection of the null hypothesis was considered evidence that equal probability of capture did not occur across sections during event *t*. Adjacent sections (rows) were pooled where sample sizes were small and there was no apparent evidence of heterogeneity between sections considered for pooling.

If unequal probability of capture between sections was not detected for any sampling events, or was only detected for either the first or last sampling event, we could conclude that geographic heterogeneity in probability of capture is not a potential source of bias in estimating abundance and program CAPTURE (Rexstad and Burnham 1992) could be used to identify the most appropriate closed-population multi-event model for estimating abundance.

When geographic capture heterogeneity was detected at levels sufficient to bias abundance estimation, the multi-event closed-population model approach was abandoned and the data were reconstructed to be analyzed as a two-event closed population experiment to estimate abundance. The first several days of sampling data (roughly half) were grouped and treated as the first (marking) sampling event and the remaining days of sampling data were grouped and treated as the second (recapture) sampling event. Replicate observations of individual fish within each of these two groupings were ignored. Only fish that were sampled and tagged during the first grouping were considered "marked", and any of the "marked" fish observed in the second grouping were considered "recaptures".

Diagnostic testing using the K-S test for size bias was conducted as described above for a two-sample experiment and size stratification of these data were performed if necessary to minimize bias in abundance estimation.

Diagnostic testing using contingency table analysis for geographic capture heterogeneity was conducted as described above for a two-sample experiment. If geographic capture heterogeneity was detected in both the first and second sampling event, the partially stratified model described by Darroch (1961) was necessary to estimate abundance. If geographic capture heterogeneity was not detected in either the first and second sampling event, or both, Chapman's modification to Petersen estimator (Seber 1982) was appropriate for estimating abundance.

Assumption 3: No handling and marking induced behavioral effects were anticipated because a beach seine was used and water temperatures were relatively cool. In the rare event a fish appeared injured or overly stressed it was tagged <u>and</u> noted as such so that they could be removed from experiment. This is because an overly stressed fish may have sulked or failed to move from its release site and therefore been more vulnerable to capture by the beach seine the following day.

Assumption 4: This assumption was addressed by double-marking each northern pike captured during each event. Tag loss was noted whenever a fish was recovered during the second and later events with a secondary mark (left pectoral fin clip) but without a Floy™ tag. In addition, tag placement was standardized, which enabled the fish handlers to verify tag loss by locating recent tag wounds. Because of the short duration of the experiment, no tag loss was anticipated.

Assumption 5: All fish were thoroughly examined for tags or recent fin clips. All markings (tag number, tag color, fin clip, and tag wound) for each fish were recorded.

ESTIMATING ABUNDANCE AND SIZE COMPOSITION

While these projects were designed to use a multi-event closed population model to estimate abundance, this type of model was not used due to violations of assumptions of uniform capture probability.

A two-event closed population model was used to estimate abundance. When necessary assumptions of uniform capture probability were not violated, abundance was estimated in each size stratum using the Chapman modification to the Petersen estimator (Chapman 1951):

$$\hat{N}_s = \frac{(C_s + 1)(M_s + 1)}{R_s + 1} - 1; \tag{1}$$

where:

$\hat{N}_s$ = estimated abundance of pike in size stratum *s*;

M_s = the number of pike marked and released during Event 1 in size stratum *s*;

R_s = the number of pike in size stratum *s* observed during Event 2 that had been marked during the first event; and,

C_s = the number of pike inspected for marks during Event 2 in size stratum *s*;

Variance of this estimator was calculated using (Seber 1982):

$$V\left[\hat{N}_s\right] = \frac{(M_s + 1)(C_s + 1)(M_s - R_s)(C_s - R_s)}{(R_s + 1)^2 (R_s + 2)}. \tag{2}$$

When geographic capture heterogeneity was detected in both Event 1 and Event 2, the partially stratified model described by Darroch (1961) was necessary to estimate abundance.

Within size strata, length (25-mm FL categories) and age proportions and variances of proportions for northern pike ≥ 300 mm FL and ≥ 450 mm FL were estimated using:

$$\hat{p}_{sk} = \frac{n_{sk}}{n_s} \tag{3}$$

where:

n_s = the number samples of pike sampled from size stratum *s* (*s* = 1 to *S*);

n_{sk} = the number of pike sampled from size stratum *s* that are in length or age category *k*; and,

$\hat{p}_{sk}$ = the estimated proportion of length or age category *k* pike in size stratum *s*.

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

$$\hat{V}\left[\hat{p}_{sk}\right] = \frac{\hat{p}_{sk}(1 - \hat{p}_{sk})}{n_s - 1}. \tag{4}$$

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

$$\hat{N}_k = \sum_{s=1}^{S} \hat{p}_{sk} \hat{N}_s \; . \tag{5}$$

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

$$\hat{V}\left[\hat{N}_k\right] = \sum_{s=1}^{S} \left(\hat{V}\left[\hat{p}_{sk}\right]\hat{N}_s^2 + \hat{V}\left[\hat{N}_s\right]\hat{p}_{sk}^2 - \hat{V}\left[\hat{p}_{sk}\right]\hat{V}\left[\hat{N}_s\right] \right). \tag{6}$$

The estimated proportion of the population of length or age k was then:

$$\hat{p}_k = \hat{N}_k \big/ \hat{N} \tag{7}$$

where:

$$\hat{N} = \sum_{s=1}^{S} \hat{N}_s \; . \tag{8}$$

Variance of the estimated proportion was approximated with the delta method (Seber 1982):

$$\hat{V}\left[\hat{p}_k\right] \approx \sum_{s=1}^{S} \left\{ \left(\frac{\hat{N}_s}{\hat{N}} \right)^2 \hat{V}\left[\hat{p}_{sk}\right] \right\} + \frac{\sum_{s=1}^{S} \left\{ \hat{V}\left[\hat{N}_s\right] \left(\hat{p}_{sk} - \hat{p}_k\right)^2 \right\}}{\hat{N}^2} \, . \tag{9}$$

RESULTS

VOLKMAR LAKE 2005

A total of 812 unique northern pike were sampled over 8 days. Of these 812 fish, 88 were subsequently recaptured and 9 of these 88 were recaptured twice. There was no observed tag loss or immediate mortalities during the experiment. One northern pike with a Floy tag from a previous study was encountered during sampling.

Significant evidence of size bias sampling was detected during several sampling events when evaluating the entire data set, with lengths of northern pike ranging from 247 to 983 mm FL. Therefore, the data were stratified into size strata based on experimental objectives, fish 300-449 mm FL and fish ≥ 450 mm FL. When diagnostic tests for size bias were repeated within strata, no significant evidence of size bias was detected for fish 300-449 mm FL (Table 1). However, evidence of size bias sampling was detected for fish ≥ 450 mm FL (Table 1) and these data were further stratified into pike 450-599 mm FL and pike ≥ 600 mm FL. No significant evidence of size bias was detected within each of these strata (Table 1).

Table 1.–Results of series of K-S tests by sampling event (day) per length stratum used to identify and correct for size selective sampling of northern pike in Volkmar Lake, 2005.

		K-S Test Series #1				K-S Test Series #2			
Length Stratum (mm FL)	Event (t)	Marks Released (n_1)	# Recaps From Event t	KS test Statistic (D)	*p*-value	Captures Inspected (n_2)	Recaps in Captures	KS test Statistic (D)	*p*-value
300–449									
	5/12	10	2	0.300	0.999				
	5/13	12	0			12	0		
	5/14	37	2	0.460	0.696	37	0		
	5/15	70	6	0.457	0.176	70	1	0.686	0.747
	5/16	30	4	0.300	0.834	30	2	0.333	0.968
	5/17	48	2	0.354	0.934	48	3	0.646	0.118
	5/18	34	3	0.672	0.160	34	4	0.206	0.992
	5/19					55	9	0.303	0.379
≥ 450									
	5/12	35	8	0.207	0.878				
	5/13	63	19	0.297	0.114	63	3	0.651	0.168
	5/14	71	16	0.460	**0.005**[a]	71	1	0.803	0.551
	5/15	95	19	0.158	0.791	95	9	0.284	0.486
	5/16	36	2	0.889	**0.043**[a]	36	7	0.266	0.710
	5/17	110	8	0.336	0.342	110	23	0.210	0.287
	5/18	37	4	0.284	0.859	37	10	0.387	0.142
	5/19					104	23	0.253	0.119
450–599									
	5/12	19	4	0.276	0.898				
	5/13	11	0			11	1	0.546	0.999
	5/14	35	3	0.295	0.923	35	1	0.600	0.833
	5/15	38	5	0.421	0.315	38	1	0.711	0.615
	5/16	12	0			12	4	0.250	0.991
	5/17	21	1	0.667	0.727	21	2	0.476	0.680
	5/18	10	1	0.700	0.727	10	1	0.600	0.909
	5/19					33	4	0.364	0.618
≥ 600									
	5/12	16	4	0.500	0.348				
	5/13	52	19	0.180	0.642	52	2	0.789	0.177
	5/14	36	13	0.374	0.103	36	0		
	5/15	57	14	0.181	0.759	57	8	0.147	0.986
	5/16	24	2	0.833	0.092	24	3	0.583	0.253
	5/17	89	7	0.369	0.313	89	21	0.149	0.763
	5/18	37	3	0.370	0.754	37	9	0.296	0.559
	5/19					71	19	0.237	0.295

[a] Significant test result.

Probability of capture for fish in the 300-449 mm FL stratum varied significantly between sampling sections (Tables 2 and 3). As a result, data were pooled across sampling days and analyzed as a two-sample closed population experiment. Fish sampled during the first four days of the experiment (May 12–15) were considered Event 1 and fish sampled during the last four days (May 16–19) were considered Event 2. Within Events 1 and 2, second and later observations of individual fish were ignored. When evaluating geographic capture heterogeneity for the two sample model, capture probabilities did vary between sections during both Event 1 (χ^2=16.670, df=3; P=0.001; Table 2) and Event 2 (χ^2=5.737, df=1; P=0.017; Table 3), so the partially stratified model of Darroch (1961) was appropriate for estimating abundance. The only partial stratification scheme that yielded an admissible estimate of abundance was two strata partition for Event 1 (sections 2 + 3 and sections 1 + 4-14) and three strata for Event 2 (section 2, sections 3 and sections 1 + 4-14).

The estimated abundance of northern pike 300-449 mm FL in Volkmar Lake was 7,758 (SE = 7,106).

In the 450-599 mm FL stratum, probability of capture for fish varied significantly between sampling sections (Appendix A3). Data were pooled across sampling days and analyzed as a two-sample experiment for a closed population; fish sampled during the first four days of the experiment were considered Event 1, and fish sampled during the last four days were considered Event 2. Within Events 1 and 2, second and later observations of individual fish were ignored. When evaluating geographic capture heterogeneity for the two sample model, capture probabilities varied between sections during Event 1 (χ^2=6.691; df=1; P=0.010; Table 2). However no evidence of significant variation between sections was found during Event 2 (χ^2=2.060; df=1; P=0.151; Table 3), indicating a Chapman model was appropriate for estimating abundance.

The estimated abundance of northern pike 450-599 mm FL in Volkmar Lake was 742 (SE = 198).

Probability of capture for fish in the ≥ 600-mm FL stratum varied significantly between sampling sections (Appendix A3). As a result, data were pooled across sampling days and analyzed as a two-sample closed-population experiment. Fish sampled during the first four days of the experiment (May 12–15) were considered Event 1 and fish sampled during the last four days (May 16–19) were considered Event 2. Within Events 1 and 2, second and later observations of individual fish were ignored. When evaluating geographic capture heterogeneity for the two sample model, we concluded that capture probabilities varied between sections during both Event 1 (χ^2=6.079; df=1; P=0.014; Table 2) and Event 2 (χ^2=7.734; df=1; P=0.005; Table 3), so the partially stratified model of Darroch (1961) was appropriate for estimating abundance. The only partial stratification scheme that yielded an admissible estimate of abundance was a partition into three strata for Event 1 (sections 1, 13-14, sections 2-7 and sections 8-12) and two strata for Event 2 (sections 1-12 and sections 13-14).

The estimated abundance of northern pike 600 mm FL and larger in Volkmar Lake was 1,072 (SE = 404). After summing the two larger strata, the estimated abundance of northern pike 450 mm FL and larger was 1,814 (SE = 449).

Estimates of size and age composition for northern pike ≥ 300 mm FL were not presented due to very poor precision of the abundance estimate (CV = 94%). For fish ≥ 450 mm FL, their distribution was relatively uniform across all 25-mm FL length categories except for those fish ≥ 850 mm FL (Figure 6; Appendices B1 and B2). A minimum abundance of 221 age-5 fish was determined from those fish ≥ 450 mm FL. The mean size of age-5 fish has ranged between 511 and 543 mm FL from 1985 to 1994 and the mean size age of age-4 fish has ranged between 405 and 443 mm FL (Hansen and Pearse 1995), demonstrating that that the minimum abundance of age-5 fish represents at least 50% of the true population of age-5 fish.

Table 2.–Results of contingency table analysis to identify geographic capture heterogeneity by size stratum during the first event (May 12 to 15) in Volkmar Lake, 2005.

Length Strata (mm FL)	Sections	Recaptured (m_2)	Unmarked ($n_2 - m_2$)	Capture Probability (m_2/n_2)	χ^2	df	*p*-value
300–449							
	1	2	35	0.054	16.670	3	0.001
	2	1	9	0.100			
	3	6	24	0.200			
	4–14	0	81	0.000			
450–599							
	3-6	6	16	0.273	6.691	1	0.010
	1–2,7–14	3	49	0.058			
≥600							
	13–14	30	85	0.261	6.079	1	0.014
	1–12	10	74	0.119			

Table 3.–Results of contingency table analysis to identify geographic capture heterogeneity by size stratum during the second event (May 16 to 19) in Volkmar Lake, 2005.

Length Strata (mm FL)	Sections	Recaptured (m_2)	Unmarked ($n_1 - m_2$)	Capture Probability (m_2/n_1)	χ^2	df	*p*-value
300 - 449							
	2–3	8	57	0.123	5.737	1	0.017
	1,4–14	1	63	0.016			
450–599	1–6	7	47	0.130	2.060	1	0.151
	7–14	2	42	0.045			
≥600							
	1,8–14	37	80	0.316	7.734	1	0.005
	2–7	3	33	0.083			

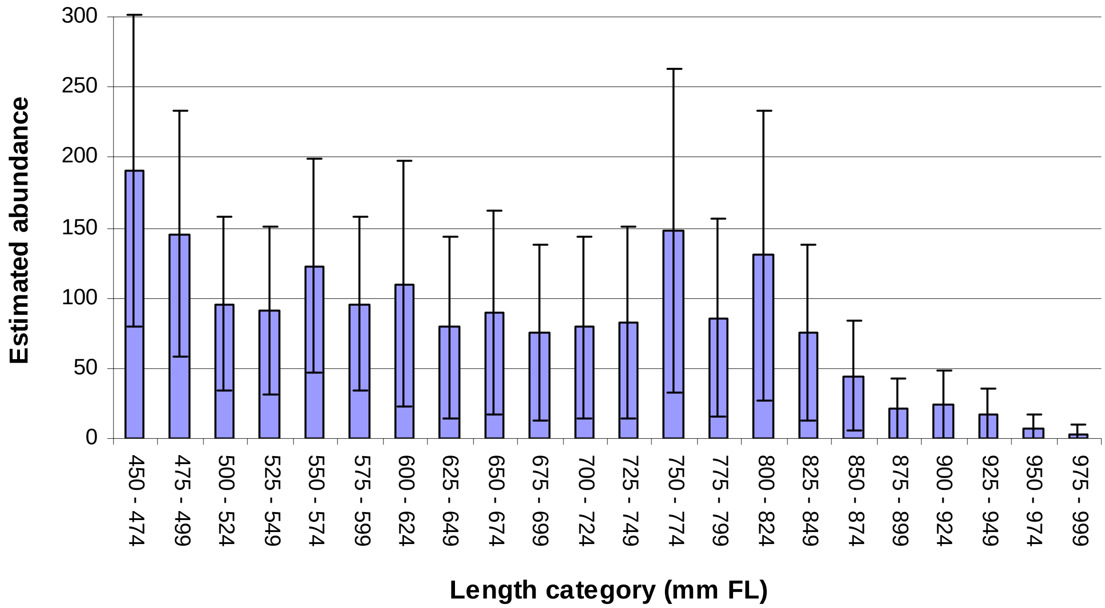


Figure 6.–Estimated length composition with 95% confidence intervals of northern pike by 25-mm length categories in Volkmar Lake, 2005.

GEORGE LAKE 2006

A total of 2,207 unique northern pike were sampled over 9 days. Of these fish, 129 were subsequently recaptured and 3 of these 129 were recaptured twice. There was no observed tag loss or immediate mortalities during the experiment.

Significant evidence of size bias sampling during several sampling events was detected when evaluating the entire data set, with pike lengths ranging from 224 to 978 mm FL. The data were then stratified into size strata based on experimental objectives, northern pike 300-449 mm FL and those ≥ 450 mm FL. When diagnostic tests for size bias were repeated within strata, no significant evidence of size bias was detected for fish 300-449 mm FL (Table 4). Similarly, no significant evidence of size bias sampling was detected for fish ≥ 450 mm FL (Table 4).

Probability of capture for fish in the 300-449 mm stratum varied significantly between sampling sections (Appendices A4 and A5). As a result, data were pooled across sampling days and analyzed as a two-sample closed-population experiment. Fish sampled during the first five days of the experiment (May 31–June 4) were considered Event 1 and fish sampled during the last three days (June 6–8) were considered Event 2. Data collected during June 5 were deleted; only 36 fish were captured on this day. Within Events 1 and 2, second and later observations of individual fish were ignored. When evaluating geographic capture heterogeneity for the two sample model, we concluded that capture probabilities varied between sections during Event 2 (χ^2=8.312; df=1; P=0.004; Table 5). However, no significant evidence of geographic capture heterogeneity was detected during Event 1 (χ^2=2.803; df=1; P=0.094, Table 6), so Chapman's (1951) model was appropriate for estimating abundance. The estimated abundance of northern pike 300-449 mm FL in George Lake was 4,268 (SE = 801).

Table 4.–Results of series of K-S tests by sampling event (day) per length stratum used to identify and correct for size selective sampling of northern pike in George Lake, 2006.

		K-S Test Series #1				K-S Test Series #2			
Length Stratum (mm FL)	Event (t)	Marks Released (n_1)	# Recaps From Event t	KS Test Statistic (D)	*p*-value	Captures Inspected (n_2)	Recaps in Captures	KS Test Statistic (D)	*p*-value
300–449									
	5/31	129	12	0.147	0.966				
	6/1	114	16	0.183	0.686	114	1	0.553	0.925
	6/2	104	16	0.236	0.362	104	10	0.289	0.397
	6/3	91	6	0.341	0.510	91	8	0.306	0.464
	6/4	66	3	0.606	0.233	66	7	0.238	0.776
	6/5	36	0			36	5	0.411	0.348
	6/6	65	4	0.381	0.634	65	8	0.227	0.764
	6/7	93	1	0.903	0.396	93	13	0.342	0.108
	6/8					51	6	0.343	0.443
≥ 450									
	5/31		352	32	0.080				
	6/1		239	16	0.157	239	6	0.234	0.903
	6/2		261	14	0.157	261	15	0.199	0.603
	6/3		316	4	0.367	316	26	0.147	0.645
	6/4		112	3	0.307	112	1	0.545	0.932
	6/5		31	1	0.710	31	2	0.258	0.999
	6/6		96	3	0.417	96	8	0.240	0.772
	6/7		153	1	0.778	153	13	0.359	0.075

Table 5.–Results of contingency table analysis to identify geographic capture heterogeneity by size stratum during the second event (May 16 to 19) in George Lake, 2006.

Length Strata (mm FL)	Sections	Marked (m_2)	Unmarked ($n_1 - m_2$)	Capture Probability (m_2/n_1)	χ^2	df	*p*-value
300–449							
	1-5,18-26	7	285	0.025	8.312	1	0.004
	6-17	15	171	0.088			
≥450							
	1-11,23-26	8	900	0.009	17.434	3	0.001
	12-15	10	224	0.043			
	16-21	0	52	0.000			
	22	2	36	0.053			

Probability of capture for fish in the ≥ 450 mm FL stratum varied significantly between sampling sections (Appendix A6 and A7). Data were pooled across sampling days and analyzed as a two-sample closed population experiment and fish sampled during the first five days of the experiment were considered Event 1 and fish sampled during the last three days were considered Event 2. Within Events 1 and 2, second and later observations of individual fish were ignored. When evaluating geographic capture heterogeneity for the two sample model, we concluded that capture probabilities varied between sections during Event 2 (χ^2=17.434; df=3; P=0.001; Table 5). However we found no evidence of significant variation between sections during Event 1 (χ^2=2.710; df=1; P=0.100; Table 6), so a Chapman (1951) model was appropriate for estimating abundance.

Table 6.–Results of contingency table analysis to identify geographic capture heterogeneity by size stratum during the first event (May 31 to June 4) in George Lake, 2006.

Length Strata (mm FL)	Sections	Recaptured (m_2)	Unmarked ($n_2 - m_2$)	Capture Probability (m_2/n_2)	χ^2	df	*p*-value
300–449							
	1-13,21-26	19	126	0.151	2.803	1	0.094
	14-20	3	56	0.054			
≥450							
	1-6,16-26	8	156	0.049	2.710	1	0.100
	7-15	12	109	0.099			

The estimated abundance of northern pike ≥ 450 mm FL in Volkmar Lake was 16,204 (SE = 3,293). For fish ≥ 450 mm FL, the estimated abundance of fish ≥ 720 mm FL (i.e., 30 in) was 1,423 (SE = 311) or 8.8% (SE=0.7%) of the population. The length category 500-524 mm comprised the most abundant category of the estimated population (Figure 7; Appendix B3) and age-5 fish the most abundant age class (Appendix B4).

For fish ≥ 300-449 mm FL, the length category 425-449 mm comprised the most abundant 25-mm length category of the estimated population (Appendix B5) and age-3 fish the most abundant age class (Appendix B6).

DISCUSSION

The information collected in this study provided for a clear interpretation of the interim management objectives. In Volkmar Lake the estimated population size of northern pike ≥ 450 mm FL did not exceed the defined minimum abundance threshold of 2,000 fish and consequently regulation changes to liberalize harvest were not supported by the department. In George Lake the estimated population far exceeded the objective of 7,300 fish demonstrating that current exploitation rates were sustainable and regulatory changes that restrict harvest were not supported by the department.

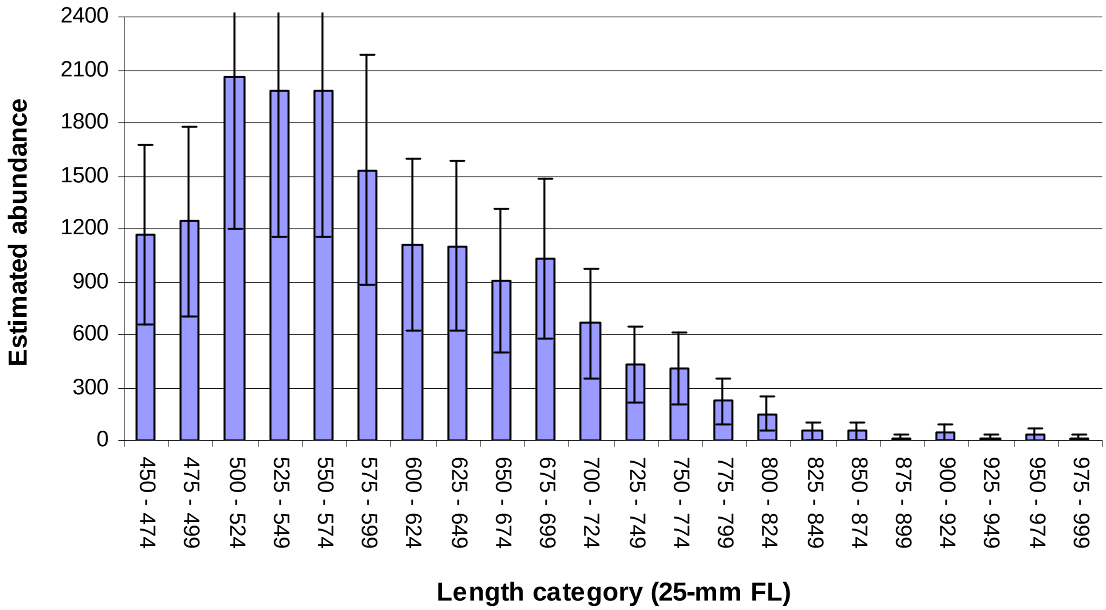


Figure 7.–Estimated length composition with 95% confidence intervals of northern pike by 25-mm length categories in George Lake, 2006.

Although the management criteria were easily interpreted, the precision attained for northern pike ≥ 450 mm FL in Volkmar Lake (± 49%, $\alpha = 0.05$) and George Lake (± 40%) did not meet levels typically desired for research objectives (i.e., ± 25%) and was at the upper range of what has been historically achieved (Figure 8). The less than desired level of precision was in part attributed to a change in the planned study design from a multi-event mark-recapture experiment analyzed using the program CAPTURE (Rexstad and Burnaham 1992) to a two-event mark-recapture experiment. imilar to the design of previous studies conducted for Volkmar Lake (1992–1994, 2000) and George Lake (1992), the multi-event design treated each day as a sampling event, however, diagnostics identified potentially severe geographic heterogeneity in capture probabilities within an event, which violated the assumptions of the multi-event experiment.

To account for this geographic heterogeneity and eliminate any associated biases, data were reorganized into a two-event model, which permitted the use of Darroch's (1961) model to cope with geographic heterogeneity within identified size strata. This reorganization resulted in a net loss of information from recaptured fish by eliminating multiple recaptures, and by eliminating repeated observations within the first or second events of the two-event model. Essentially, this loss of information from several fish seen multiple times yielded a concomitant loss of precision (although point estimates between models were similar). In Volkmar Lake, Darroch's (1961) model was required for two of the three size strata identified. In George Lake geographic heterogeneity was not detected, and we hypothesize that the cold weather event (< 0°C at night) on about day six resulted in the redistribution of fish (i.e., mixing) that would not have occurred if weather and water temperatures remained mild or unchanged. The cold weather drove fish away from near-shore areas, as evidenced by the extremely low catch rate on day 6, and fish had redistributed themselves along the shorelines as temperatures rose again.

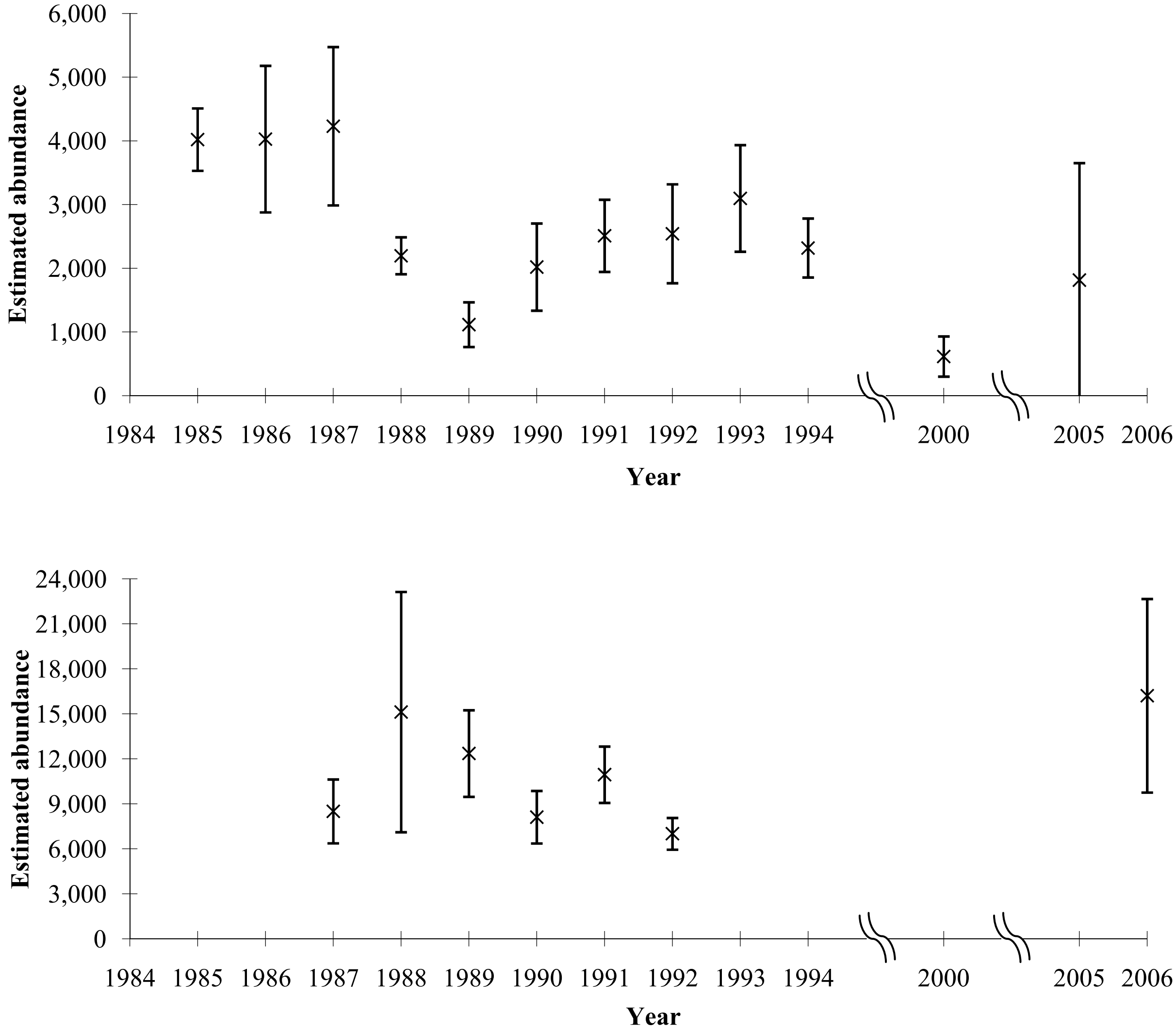


Figure 8.–Chronology of estimated abundances of northern pike with 95% confidence intervals and associated levels of relative precision for George and Volkmar lakes.

The results of this study emphasize the need to re-evaluate future study designs. The design of mark-recapture experiments in both Volkmar and George lakes have evolved from conducting a two-event mark recapture experiment during 1986 through 1991 with a hiatus ranging from 10 to 3 days to a multi-event model (i.e., use of program Capture) comprised of 8 to 10 events (days). The rationale for the use of a multi-event model was that the experiment could be done quickly (cost savings) immediately after ice-out (during and immediately after spawning) when beach seining is very effective and sample sizes more easily attained. Concerns over attaining a simple random sample each in event or sampling day or achieving mixing were addressed by a telemetry study in Volkmar Lake (Pearse and Clark 1992). Fourteen fish were radio-tagged immediately after ice-out and convincingly demonstrated that during spawning and immediately thereafter these northern pike were relatively mobile after ice-out with 50% of fish moving at least 642 m per day suggesting that the assumptions of the multi-event (day) experiment could be adequately satisfied by a combination of their movements (mixing) and a dividing the lake's perimeter into 13 "pie" sections" to help distribute daily fishing effort (beach seining) more appropriately. The underlying fallacy of this study design, particularly in a much larger lake such as George Lake where sampling sections approached 2 km in width, is that it relied too heavily on the sole use of the beach seine to capture fish in some reasonable approximation to fish densities.

Beach seining is problematic because of its relative effectiveness in fishing different shoreline gradients, where the gradients (habitat) are highly correlated with densities of northern pike. Capture probabilities are inherently far greater in shallow-sloped, vegetated areas where pike tend to be more dense during spawning or for feeding and far less effective in areas with a steeper gradient where northern pike are still present but at lower densities. Moreover, during the course of a 24-hr period, some significant proportion of the northern pike population may be isolated from the beach seine. Pearse and Clark demonstrated that during May mature-sized pike frequented offshore areas (≥ 100 m) during approximately 50% of all relocations for periods ranging from, for example, 8 to 48 h. Attempts by Pearse and Clark (1992) to create a more efficient mark-recapture experiment were commendable, but in our judgment, it is simply too unrealistic to assume that a simple random sample each event (day) can be attained using a beach seine despite tendencies of the northern pike population to be relatively mobile during spawning, and therefore changes to the study design are recommended predicated on cost.

The preferred solution would be a two-event experiment where fish are marked immediately after ice out over a 6-8 day period using a beach seine, a longer hiatus (e.g., two weeks) is incorporated to promote mixing (complete or partial) to eliminate spatial heterogeneity, and use a combination of gear types (beach seine, gill nets, and hook and line) that could sample all lake habitats during the second event. The primary disadvantages of this approach is that, first it would required much greater effort during the second event because catch rates would likely be much lower, however, this would be partially offset by taking advantage the higher catch rates during spring - this strategy was employed in George Lake in 1986 where n1= 2,132 and n2 = 661 (Clark et al. 1988). Secondly, this approach could result in a substantial reduction in recaptured fish and a commensurate reduction in power to detect bias when conducting diagnostics.

A compromise solution may be to incorporate a shorter hiatus (e.g., 3–4 days), as was employed in Volkmar Lake during 1990–1992. Based on observations by Pearse and Clark (1992) movements over a 3- or 4-day window during spawning would be considerable and combined with efforts to distribute fishing effort proportional to fish densities would likely satisfy assumption 2. More importantly, this approach, as compared to the multi-event design, would increase the number of recaptures by event and our ability to detect and correct for size or spatial differences in capture probabilities. Regardless of the solution, a two-event strategy should be pursued and efforts to collect detailed information on capture locations by dividing the lake into numerous sampling sections is recommended to facilitate diagnostic testing and use of Darroch's (1961) model if needed. Prior to 1992, George and Volkmar lakes were divided into only 2 or 3 sampling sections, which based on the results of our study, may have simply masked geographic differences in capture probabilities.

The stock-assessment in Volkmar Lake provided an additional datum for the observed relationship between the number of spawning northern pike (≥ 500 mm FL) and the resultant number of recruits in Volkmar Lake (age-5 fish) that was first examined in 1992 (Figure 9).

Because of the extremely poor precision of the 300 to 449 mm FL, which includes some age-5 fish, a range of 211 to 422 fish based on the ≥ 450-mm stratum is presented. Excluding this most recent observation, Hansen and Pearse (1995) concluded that there is a strong negative correlation between the number of spawners and recruits when the spawning abundance exceeds approximately 2,000 fish, and that the population could sustain annual harvests of approximately 250 to 300 fish. The purpose of presenting this updated relationship is not to perform a rigorous stock-recruitment analysis, but to demonstrate that the conclusions of Hansen and Pearse (1995) are still in large part valid, and to provide support for conducting stock-assessments of northern pike populations, such as Volkmar Lake, on a five-year rotation to possibly provide for a better understanding of their population dynamics and development of management objectives.

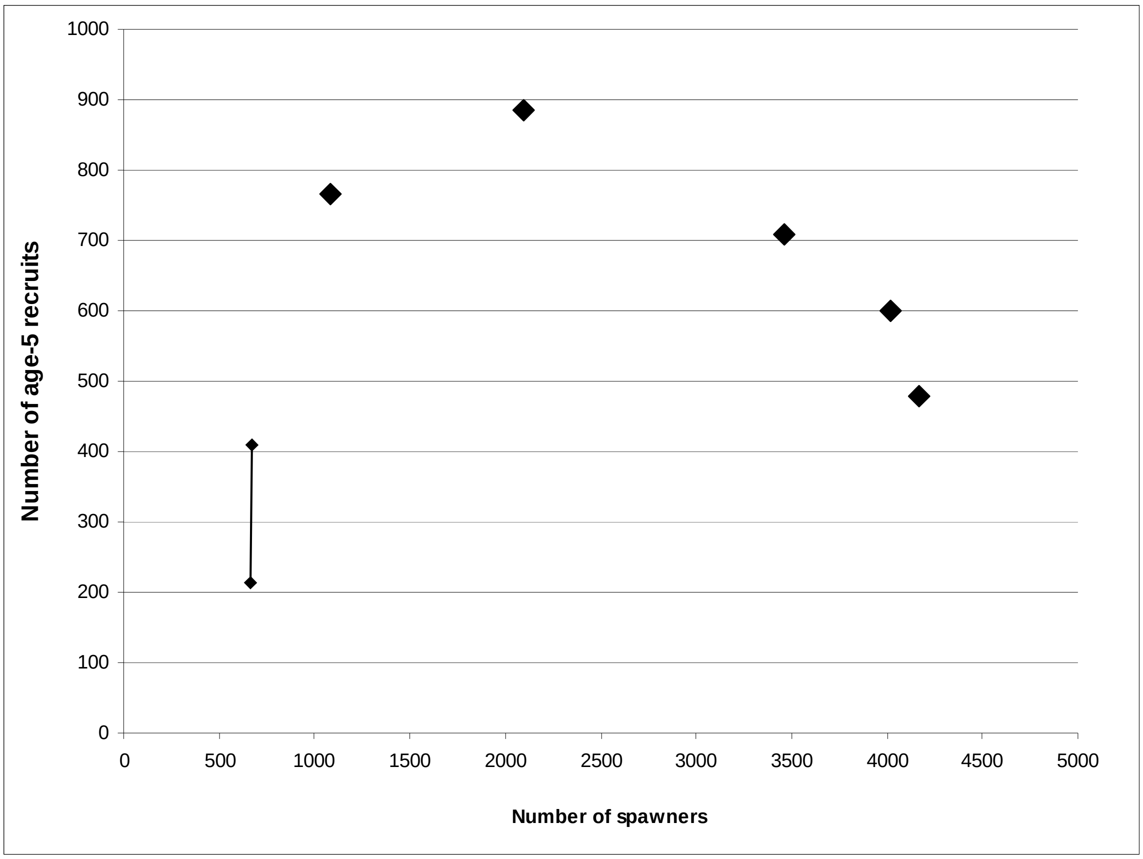


Figure 9.–Relationship between the number of spawning northern pike 1985-1989 and 2000 and the resultant number of age-5 recruits (1990–1994 and 2005) in Volkmar Lake. Recruits from spawners during 2000 depicted as a range from 211 to 422 fish.

For both Volkmar and George lakes interim management objectives were developed to provide abundance-based criteria to address regulatory proposals. In the development of a proposed new management plan for northern pike in Volkmar and George lakes it is recommended that several factors be considered. If periodic assessments are recommended, that they be conducted on a five-year rotation to assist in developing a potentially more robust spawner-recruit relationship. Abundance-based management objectives or decision criteria should take into account reasonable expectations of relative precision (e.g., ±40% using $\alpha = 0.05$) based on previous studies. Criteria should be developed only on fish that are fully recruited to the gear (i.e., ≥ 450 mm FL). Because of the ever-present potential for the creation of a northern pike fishery based on anglers preferences to catch large fish (e.g., a "trophy fishery"), associated metrics (e.g., abundance of 30-in fish) should be developed that are always estimated when conducting stock assessments regardless of the current management strategy. Lastly, management objectives should take into account the observed natural variation in the population to provide for stability in fishing regulations.

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APPENDIX A

Appendix A1.–Results of contingency table analyses for detecting geographic capture heterogeneity among sampling sections by events (t) for fish 300-449 mm FL in Volkmar Lake, 2005.

Test 1: "Marking Events" for Events 1 to (T-1)							Test 2: "Recapture Event" for t+1 Through T						
Event (t)	Sections	Recap (m_2)	Unmarked ($n_2 - m_2$)	χ^2	df	*p*-value	Event (t)	Sections	Recaps (m_2)	Not recaptured ($n_1 - m_2$)	χ^2	df	*p*-value
12-May	2–3	2	93	3.691	1	0.055							
	1,4–14	0	174										
13-May		0	257				13-May		0	10			
14-May	1–2	2	75	3.800	1	0.051	14-May		0	24			
	3–14	0	145										
15-May	1–2,4–14	2	125	8.753	1	0.003	15-May	1,3–14	0	52	7.557	1	0.006
	3	4	27					2	1	6			
16-May	1–5,9–14	1	101	6.418	1	0.011	16-May	1–2,4–14	0	94	5.617	1	0.018
	6–8	3	27					3	2	32			
17-May	1	1	21	14.628	3	0.002	17-May	1,3–14	1	121	3.914	1	0.048
	2–5	0	36					2	2	30			
	6	1	2										
	7–14	0	25										
18-May	1,7–14	0	28	12.986	3	0.005	18-May	1–3,7–14	2	166	3.354	1	0.067
	3	2	10					4–6	2	31			
	4	0	13										
	6	1	1										
							19-May	1	2	42	33.136	7	0.000
								2	0	39			
								3	4	45			
								4–5	0	17			
								6	2	21			
								7–12	0	53			
								13	1	0			
								14	0	5			

Appendix A2.–Results of contingency table analyses for detecting geographic capture heterogeneity among sampling sections by events (t) for fish 450-599 mm FL in Volkmar Lake, 2005.

Test 1: "Marking Events" for Events 1 to (T-1)							Test 2: "Recapture Event" for t+1 through T						
Event (t)	Sections	Recap (m2)	Unmarked (n2 – m2)	χ2	df	*p*-value	Event (t)	Sections	Recaps (m2)	Not Recaptured (n1 – m2)	χ2	df	*p*-value
12-May	1–7,12	0	98	11.769	3	0.008							
	8	3	23										
	9–12	0	10										
	13	1	13										
13-May		0	138				13-May	1–12,14	0	15	3.958	1	0.047
								13	1	3			
14-May	1–3,5–14	2	99	5.625	1	0.018	14-May	1–2,4–14	0	19	2.189	1	0.139
	4	1	4					3	1	8			
15-May	1–2,13–14	0	26	16.793	5	0.005	15-May	1–3,5–14	0	61	62.000	1	0.000
	3	3	13					4	1	0			
	4–5	0	3										
	6	1	2										
	7–11	0	24										
	12	1	1										
16-May	6–8	0	54				16-May	1–2,4–14	2	72	1.468	1	0.226
								3	2	22			
17-May	1	1	7	4.354	1	0.037	17-May	1–3	2	52	2.337	1	0.126
	2–14	0	34					4–14	0	62			
18-May	1–13	0	31	15.984	1	0.000	18-May	1–2,4–14	0	97	3.492	1	0.062
	14	1	1					3	1	27			
							19-May	1	2	25	11.195	5	0.048
								2–5	0	40			
								6	1	3			
								7	0	7			
								8	1	21			
								9–14	0	34			

Appendix A3.–Results of contingency table analyses for detecting geographic capture heterogeneity among sampling sections by events (t) for fish ≥ 600 mm FL in Volkmar Lake, 2005.

Test 1: “Marking Events” for Events 1 to (T-1)							Test 2: “Recapture Event” for t+1 Through T						
Event (t)	Sections	Recap (m2)	Unmarked (n2 – m2)	χ2	df	*p*-value	Event (t)	Sections	Recaps (m2)	Not Recaptured (n1 – m2)	χ2	df	*p*-value
12-May	8–12	3	34	14.725	1	0.000							
	1–7,13–14	1	262										
13-May	1–3,12–14	19	209	3.410	1	0.065	13-May	1–2,4–14	1	13	2.939	1	0.086
	4–11	0	38					3	1	1			
14-May	1,12–14	13	169	4.603	1	0.032	14-May		0	66			
	2–11	0	61										
15-May	13	10	81	4.008	1	0.045	15-May	1,8–14	8	72	2.494	1	0.114
	1–12,14	4	104					2-7	0	23			
16-May	12–13	2	106	1.292	1	0.256	16-May	1,14	3	86	2.200	1	0.138
	1–11,14	0	69					2–13	0	64			
17-May	1–2,14	6	38	4.478	1	0.034	17-May	1,14	17	76	7.261	1	0.007
	4–11	1	48					2–13	4	77			
18-May	3	1	7	1.525	1	0.217	18-May	1–13	6	210	4.974	1	0.026
	1–2,4–14	2	61					14	3	23			
							19-May	1–3,5–14	17	236	4.802	1	0.028
								4	2	5			

Appendix A4.–Results of contingency table analyses (test 1) for detecting geographic capture heterogeneity among sampling sections by events (t) for fish 300-449 mm FL in George Lake, 2005. Sampling in second event is pooled over all days subsequent to mark date.

Event (t)	Sections	Recap (m2)	Unmarked (n2 – m2)	χ2	df	*p*-value
31-May	1,25–26	0	114	2.757	1	0.097
	2–24	12	494			
1-Jun	1–12,20–26	16	382	4.483	1	0.034
	13–19	0	108			
2-Jun	1–12,14–26	12	361	7.875	1	0.005
	13	4	25			
3-Jun	1	1	22	15.666	7	0.028
	2–11	0	101			
	12	3	51			
	13–14	0	29			
	15	1	10			
	16–24	0	62			
	25	1	8			
	26	0	22			
4-Jun	1–11,15–26	0	179	8.237	1	0.004
	12–14	3	63			
5-Jun		0	199			
6-Jun	1	1	1	22.854	3	0.000
	2–11	0	42			
	12	3	29			
	13–26	0	58			
7-Jun	1–11,13–26	0	40	3.709	1	0.054
	12	1	10			
8-Jun						

Appendix A5.–Results of contingency table analyses (test 1) for detecting geographic capture heterogeneity among sampling sections by events (t) for fish 300-449 mm FL in George Lake, 2005. Sampling in first event is pooled over all days prior to mark date.

Event (t)	Sections	Recap (m_2)	Unmarked ($n_2 - m_2$)	χ^2	df	*p*-value
31-May						
1-Jun	1	1	17	6.215	1	0.013
	2–26	0	111			
2-Jun	1–10,24–26	5	146	12.774	3	0.005
	11	1	3			
	12-19	0	56			
	20–23	4	28			
3-Jun	1–12,26	2	230	30.749	3	0.000
	13–14	5	36			
	15–24	0	70			
	25	1	3			
4-Jun	1	3	36	13.913	3	0.003
	2–22	3	313			
	23	1	13			
	24–26	0	69			
5-Jun	1–7,24–26	0	302	14.760	3	0.002
	8	1	13			
	9–22	3	171			
	23	1	13			
6-Jun	1–14,26	6	424	8.596	3	0.035
	15	1	12			
	16–24	0	85			
	25	1	11			
7-Jun	1–10,24–26	3	371	18.095	5	0.003
	11–13	8	120			
	14–16	0	34			
	17	1	12			
	18–22	0	39			
	23	1	16			
8-Jun	1–5,13–26	0	533	19.550	1	0.000
	6–12	6	159			

Appendix A6.–Results of contingency table analyses (test 1) for detecting geographic capture heterogeneity among sampling sections by events (t) for fish ≥450 mm FL in George Lake, 2005. Sampling in first event is pooled over all days prior to mark date.

Event (t)	Sections	Recap (m_2)	Unmarked ($n_2 - m_2$)	χ^2	df	*p*-value
31-May	1–12,26	9	501	20.465	4	0.000
	13–14	4	123			
	15–23	3	275			
	24	14	300			
	25	2	8			
1-Jun	1-9,25–26	2	315	22.291	5	0.000
	10	1	3			
	11	0	33			
	12	3	63			
	13–22	1	179			
	23–24	9	390			
2-Jun	1–6,26	1	160	22.210	5	0.000
	7	1	9			
	8–14	0	198			
	15	1	5			
	16–22	0	65			
	23–25	11	287			
3-Jun	1–20,24–26	0	345	17.861	1	0.000
	21–23	4	74			
4-Jun	1–6,14–26	0	188	4.630	1	0.031
	7–13	3	120			
5-Jun	1–10,12–26	0	247	7.747	1	0.005
	11	1	31			
6-Jun	1–10,13–26	0	143	10.904	1	0.001
	11–12	3	37			
7-Jun	1–22,24–26	0	24	4.138	1	0.042
	23	1	5			
8-Jun						

Appendix A7.–Results of contingency table analyses (test 2) for detecting geographic capture heterogeneity among sampling sections by events (t) for fish ≥ 450 mm FL in George Lake, 2005. Sampling in second event is pooled over all days subsequent to mark date.

Event (t)	Sections	Recap (m_2)	Unmarked ($n_2 - m_2$)	χ^2	df	*p*-value
1-Jun	1–14,25–26	1	139	31.379	3	0.000
	15	2	5			
	16–22	0	23			
	23-24	3	179			
2-Jun	1,22–26	8	260	12.611	3	0.006
	2	4	58			
	3–20	1	240			
	21	2	19			
3-Jun	1–21,26	3	473	41.009	2	0.000
	22–24	21	351			
	25	2	3			
4-Jun	1–23,25–26	0	793	2.116	1	0.146
	24	1	374			
5-Jun	1–12,15–26	0	1,164	38.342	2	0.000
	13	1	96			
	14	1	18			
6-Jun	1–11,23–26	2	973	14.530	3	0.002
	12–14	4	210			
	15–20	0	54			
	21–22	2	67			
7-Jun	1-11,16-26	6	1,105	8.457	1	0.004
	12-15	7	290			
8-Jun	1-11,14-26	1	1,307	5.635	1	0.018

APPENDIX B

Appendix B1.–Number of fish sampled (n), estimated proportion ($\hat{p}_k$), and estimated abundance ($\hat{N}_k$) by length category for the population of northern pike (≥450 mm FL) in Volkmar Lake during May 12–19, 2005.

Length (mm FL)	n	$\hat{p}_k$	$\hat{SE}[\hat{p}_k]$	$\hat{N}_k$	$\hat{SE}[\hat{N}_k]$
450–474	42	0.105	0.022	191	57
475–499	32	0.080	0.018	146	45
500–524	21	0.053	0.014	96	32
525–549	20	0.050	0.013	91	30
550–574	27	0.068	0.016	123	39
575–599	21	0.053	0.014	96	32
600–624	32	0.061	0.014	110	45
625–649	23	0.044	0.011	79	33
650–674	26	0.049	0.012	89	37
675–699	22	0.042	0.011	76	32
700–724	23	0.044	0.011	79	33
725–749	24	0.045	0.011	82	34
750–774	43	0.081	0.017	148	59
775–799	25	0.047	0.012	86	36
800–824	38	0.072	0.016	131	52
825–849	22	0.042	0.011	76	32
850–874	13	0.025	0.008	45	20
875–899	6	0.011	0.005	21	11
900–924	7	0.013	0.005	24	12
925–949	5	0.009	0.004	17	10
950–974	2	0.004	0.003	7	5
975–999	1	0.002	0.002	3	3

Appendix B2.–Number of fish sampled (n), estimated proportion ($\hat{p}_k$), and estimated abundance ($\hat{N}_k$) by age for the population of northern pike (≥450 mm FL) in Volkmar Lake during May 12–19, 2005.

Age (Years)	n	$\hat{p}_k$	$\hat{SE}[\hat{p}_k]$	$\hat{N}_k$	$\hat{SE}[\hat{N}_k]$
1	0	0.000	0.000	0	0.000
2	0	0.000	0.000	0	0.000
3	0	0.000	0.000	0	0.000
4	15	0.069	0.020	125	0.020
5	27	0.122	0.026	221	0.026
6	31	0.136	0.026	247	0.026
7	25	0.103	0.022	186	0.022
8	48	0.189	0.037	343	0.037
9	42	0.162	0.036	295	0.036
10	27	0.104	0.026	189	0.026
11	16	0.061	0.018	111	0.018
12	8	0.031	0.011	56	0.011
13	5	0.019	0.009	34	0.009
14	1	0.004	0.004	7	0.004
15	0	0.000	0.000	0	0.000

Appendix B3.–Number of fish sampled (n), estimated proportion ($\hat{p}_k$), and estimated abundance ($\hat{N}_k$) by length category for the population of northern pike (≥450 mm FL) in George Lake during May 31 to June 8, 2006.

Length (mm FL)	n	$\hat{p}_k$	$\hat{SE}[\hat{p}_k]$	$\hat{N}_k$	$\hat{SE}[\hat{N}_k]$
450–474	109	0.072	0.007	1,167	259
475–499	116	0.077	0.007	1,242	275
500–524	193	0.127	0.009	2,066	441
525–549	185	0.122	0.008	1,980	424
550–574	185	0.122	0.008	1,980	424
575–599	143	0.094	0.008	1,531	333
600–624	104	0.069	0.007	1,113	249
625–649	103	0.068	0.006	1,102	246
650–674	85	0.056	0.006	910	207
675–699	96	0.063	0.006	1,027	231
700–724	62	0.041	0.005	664	157
725–749	40	0.026	0.004	428	109
750–774	38	0.025	0.004	407	104
775–799	21	0.014	0.003	225	66
800–824	14	0.009	0.002	150	50
825–849	5	0.003	0.001	54	26
850–874	5	0.003	0.001	54	26
875–899	1	0.001	0.001	11	11
900–924	4	0.003	0.001	43	23
925–949	1	0.001	0.001	11	11
950–974	3	0.002	0.001	32	19
975–999	1	0.001	0.001	11	11

Appendix B4.–Number of fish sampled (n), estimated proportion ($\hat{p}_k$), and estimated abundance ($\hat{N}_k$) by age for the population of northern pike (≥450 mm FL) in George Lake during May 12–19, 2005.

Age (Years)	n	$\hat{p}_k$	$\hat{SE}[\hat{p}_k]$	$\hat{N}_k$	$\hat{SE}[\hat{N}_k]$
1	0	0.000	0.000	0	0
2	0	0.000	0.000	0	0
3	61	0.076	0.007	1,237	274
4	102	0.128	0.009	2,069	442
5	210	0.263	0.011	4,259	884
6	108	0.135	0.009	2,190	466
7	100	0.125	0.009	2,028	434
8	101	0.126	0.009	2,048	438
9	60	0.075	0.007	1,217	270
10	36	0.045	0.005	730	171
11	16	0.020	0.004	324	87
12	4	0.005	0.002	81	33
13	1	0.001	0.001	20	15
14	0	0.000	0.000	0	0
15	0	0.000	0.000	0	0

Appendix B5.–Number of fish sampled (n), estimated proportion ($\hat{p}_k$), and estimated abundance ($\hat{N}_k$) by length category for the population of northern pike (≥300 - mm FL) in George Lake during May 31–June 8, 2006.

Length (mm FL)	n	$\hat{p}_k$	$\hat{S}E[\hat{p}_k]$	$\hat{N}_k$	$\hat{S}E[\hat{N}_k]$
300–324	120	0.174	0.014	741	152
325–349	87	0.126	0.013	537	114
350–374	109	0.158	0.014	673	139
375–399	104	0.151	0.014	642	133
400–424	134	0.194	0.015	828	168
425–449	137	0.198	0.015	846	171

Appendix B6.–Number of fish sampled (n), estimated proportion ($\hat{p}_k$), and estimated abundance ($\hat{N}_k$) by age for the population of northern pike (300 - 449 mm FL) in George Lake during May 31–June 8, 2006.

Age (Years)	n	$\hat{p}_k$	$\hat{S}E[\hat{p}_k]$	$\hat{N}_k$	$\hat{S}E[\hat{N}_k]$
1	0	0.000	0.000	0	0
2	107	0.311	0.025	1,328	270
3	179	0.520	0.027	2,221	432
4	46	0.134	0.018	571	132
5	9	0.026	0.009	112	42
6	3	0.009	0.005	37	22
7	0	0.000	0.000	0	0

APPENDIX C

Appendix C1.–Data files[a] for all northern pike sampled in the Volkmar and George lakes, 2005 and 2006.

Data file	Description
George lake creel data.xls	George Lake_2006_Tables.xls
Volkmar Lake_2005_Tables..xls	Volkmar pike spawner recruit.xls
Volkmar Pike_2005_MR data.xls	George Lake_2006_MR data.xls
George and Volkmar Lakes.xls	Volkmar, George catch, effort, harvest-figure.xls

[a] Data files are 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.