Fishery Data Series No. 15-39

Estimated Abundance of Northern Pike in Harding Lake, 2012

by

Klaus Wuttig

November 2015

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

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ABSTRACT

The abundance of northern pike ≥450 mm FL was estimated in Harding Lake during 2012 using a 2-sample mark–recapture experiment for a closed population. The first event occurred during May 29–June 7 and a combination of gillnets, fyke nets, hoop traps, and hook-and-line was used to capture fish. The second event occurred during August 7–14 and hook-and-line gear was used exclusively. Abundance was estimated at 567 (SE = 47) northern pike ≥450 mm FL. The length composition was divided into 25 mm length categories, and the 550-574 category represented the largest segment (16%) of the estimated population. Harding Lake has been closed to fishing for northern pike since the summer of 2000, and the estimated abundance of northern pike during 2012 was well below the minimum level of 1,000 fish ≥450 mm FL needed to open the fishery to catch-and-release. The low population size is attributed to the chronic loss of shallow littoral areas with emergent vegetation and the associated poor recruitment, which was first evident during the most recent stock assessment in 1999. The last stock assessment during which good recruitment of age-3 and -4 fish was observed occurred in 1996 and corresponded to cohorts from 1992 and 1993 when the water levels ranged between 717.5-717.8 ft above sea level. Therefore, this range should be used as a target for reestablishing water levels and historic pike production using the water diversion structure on Rogge Creek. Water level in 2012 was measured at 714.0 ft above sea level.

Key words: Northern pike, Esox lucius, Harding Lake, abundance, mark-recapture, spawning habitat, rearing habitat, recruitment, lake level, Rogge Creek.

INTRODUCTION

The purpose of this project in 2012 was to conduct an assessment of the indigenous northern pike *Esox lucius* population in Harding Lake (Figure 1). Historically, this lake provided the only major roadside sport fishery for northern pike within the Tanana Drainage. Estimates of fishing effort for all species exceeded 5,000 angler-days during the 1990s, and a majority of this effort was directed at northern pike. In 2000, the northern pike fishery was closed due to declining abundance that was attributed to falling water levels and significant losses of vegetated littoral areas needed for spawning and rearing (Doxey 2003). Current fisheries exist for introduced lake trout *Salvelinus namaycush* and Arctic char *Salvelinus alpinus*. The lake trout are now naturally reproducing and the Arctic char fishery is sustained by periodic stockings. Other indigenous fish species include burbot *Lota lota*, least cisco *Coregonus sardinella*, and slimy sculpins *Cottus cognatus*.

The northern pike population in Harding Lake was regularly assessed during the 1990s and the estimates have declined from a high of 2,479 (SE = 307) fish ≥450 mm FL in 1993 to 531 (SE = 54) fish ≥450mm FL in 1999, the last year it was assessed. Efforts to raise water levels in Harding Lake were initiated in 2007 by diverting water from Rogge Creek into Harding Lake in hopes of reestablishing the vegetated littoral areas.

A management plan for northern pike in Harding Lake was developed in 2003 that specifies recommended management actions based on changes in abundance. The first action would be to propose opening the lake to catch-and-release if the abundance exceeds 1,000 fish ≥450 mm FL, and the second would be to propose opening it to harvest (e.g., one-fish bag limit) if abundance exceeds 2,500 fish (Doxey 2003). In 2012, a stock assessment was conducted to evaluate the population after an extended period (12 years) of closure of fishing for northern pike. A more complete history of stock assessments and management of northern pike in Harding Lake is detailed by Brase (2008), Doxey (2003), and Scanlon and Roach (2000).

DESCRIPTION OF STUDY AREA

Harding Lake is the largest road-accessible lake in the Tanana River drainage (Figures 1 and 2) with a surface area of 1,000 ha, a maximum depth of 43 m, and a shoreline circumference of

12.4 km. With its proximity to Fairbanks and surrounding communities, Harding Lake provides many recreational opportunities such as water skiing, fishing, and camping. It is relatively developed with approximately 70% of its shoreline bordered by private property including permanent homes and recreational cabins, many of which have floating docks and watercraft. There is a large State campground with a boat launching area, and several other small public access rights-of-way and private boat launches.

Harding Lake is oligotrophic (LaPerriere 1975) and it is believed that the production of northern pike in Harding Lake is strongly influenced by water levels and the availability of emergent vegetation in waters depths of up to 1.0 m, particularly along its northern and northeastern shores. Currently, nearly all of the littoral zone (0-3 m) is unproductive and free of aquatic vegetation and primarily consists of bare sand, mixed sand and gravel, or gravel (Roach and McIntyre (1999). Doxey (1991) hypothesized that macrophytes are not able to colonize large areas of the littoral zone within the lake because of wave action, freeze-down, and ice-scouring. Historically, most of the aquatic vegetation (up to 220 ha) was along the northern shore but that area has since been dewatered and is being colonized by riparian vegetation (Figure 2). There are a few sporadic deep beds of *Potamageton* sp. and *Chara* sp. located at about the depth contour of 3 to 5 m.

The drainage basin of Harding Lake is relatively small (~23 km^2, excluding Rogge Creek), there is no surface outlet, and its water level is controlled by annual precipitation. The lake is fed by hillside runoff, a few springs, and two inlets. To the southwest, a small, ephemeral inlet drains the adjacent Little Harding Lake basin. The largest inlet, Rogge Creek, drains a similar-sized basin to the east of ~26 km^2. The channel of Rogge Creek flows across a divide that has historically flowed into either Harding Lake or the Salcha River depending on which channel was active (Figure 1). When water flowed down the channel toward the Salcha River, lake levels tended to decline or remain stable, and when Rogge Creek flowed into the lake, the level remained stable or rose. Lake levels have ranged between 714.5 ft in 2005 and 719.5 ft in 1968 (USDA 2006). This phenomenon and its implications are described by Nakao (1980), Kane (et al. 1979), Doxey (1991), and USDA (2006).

During the late 1980s and early 1990s, when production of northern pike supported a directed fishery, the lake levels were ~717.5 ft. By 2007, the lake level was at ~714.5 feet. In 2007, a diversion structure was constructed on Rogge Creek to permanently divert a fraction of its flow into Harding Lake with a plan to restore approximately 135 acres of emergent aquatic vegetation, which equates to a lake level of 717 ft. Low annual precipitation has since kept the lake from rising and reclaiming any of the primary spawning and rearing habitat along its northern shore.

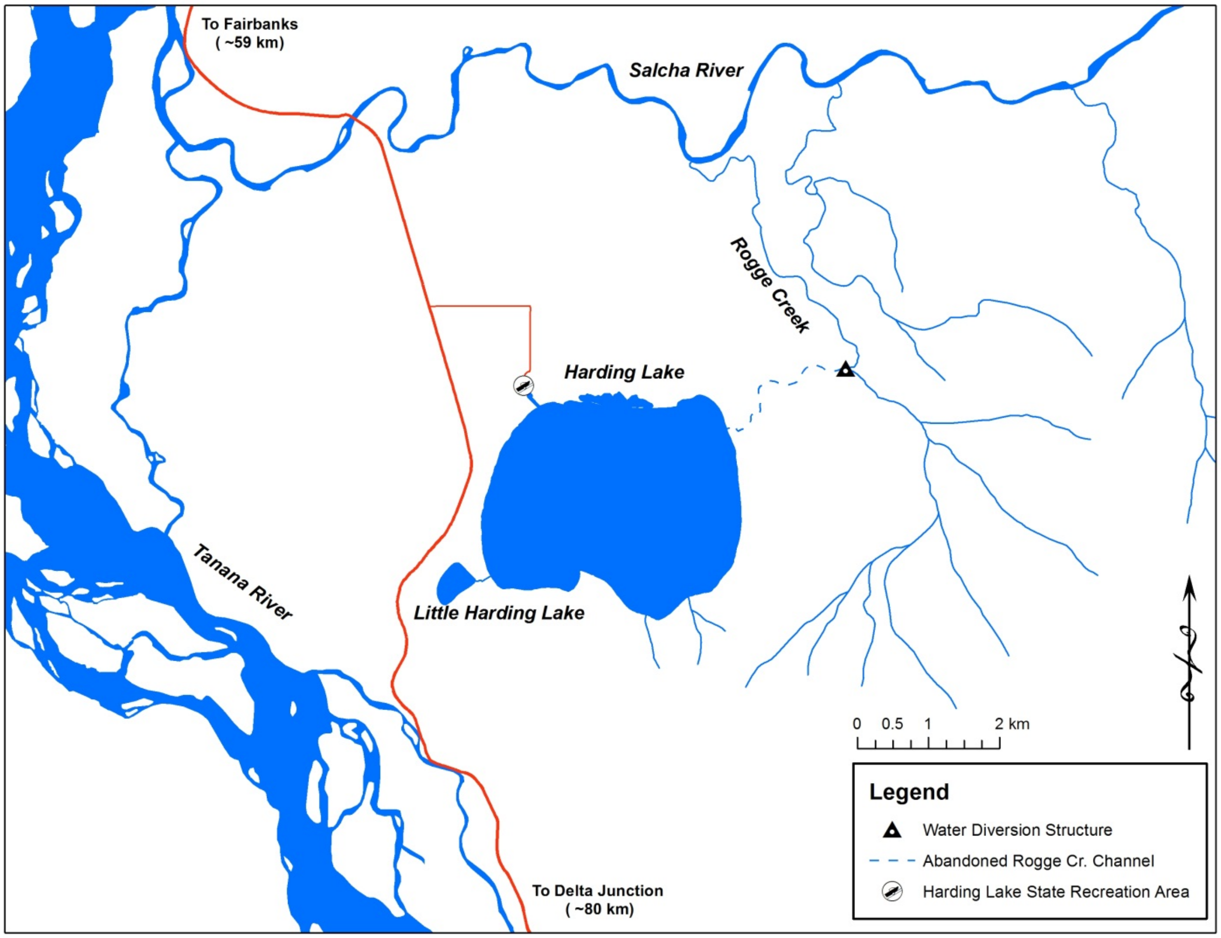


Figure 1.–Location of Harding Lake and location of the water diversion structure on Harding Lake.

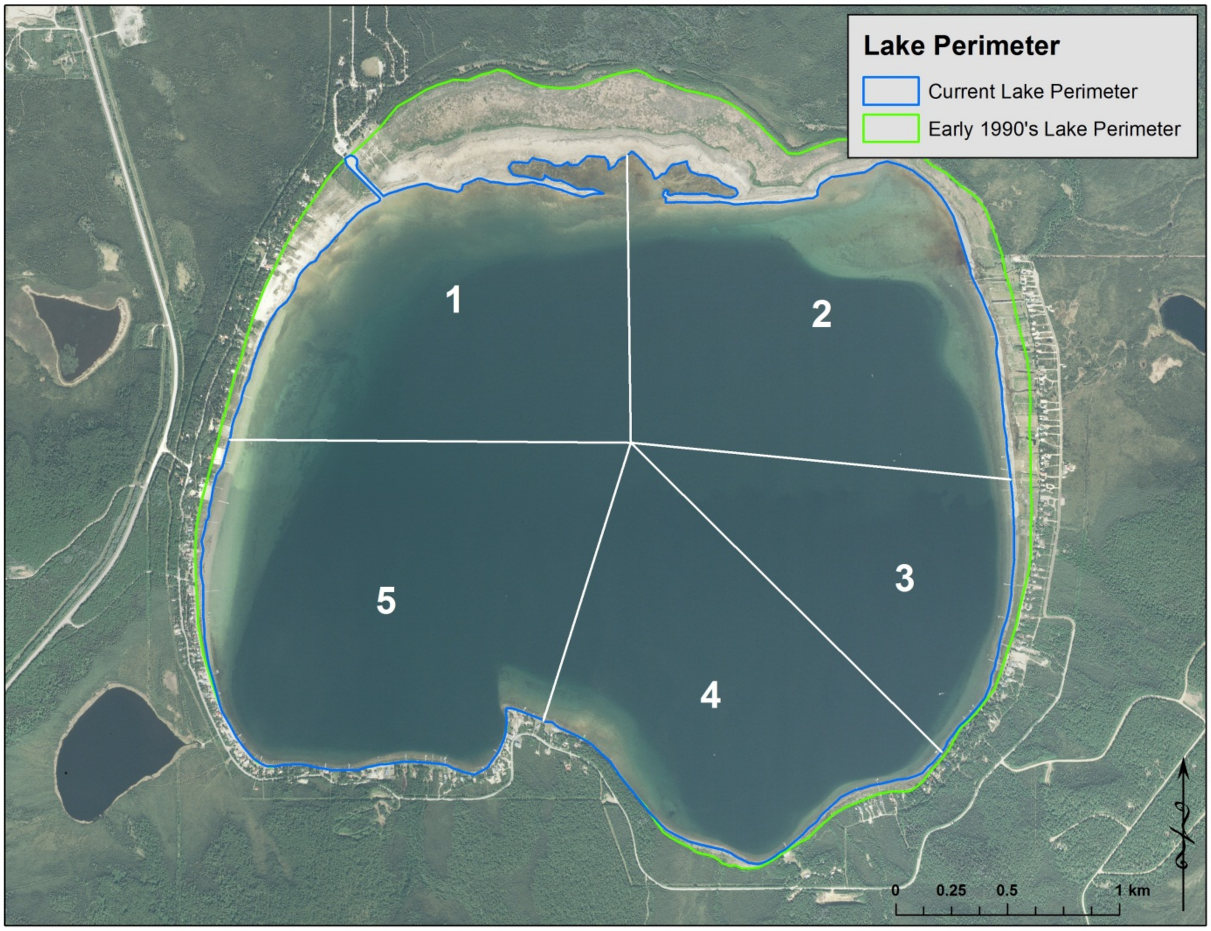


Figure 2.–An aerial view of Harding Lake depicting the study sections 1–5 and the approximate shoreline water levels during the early 1990s and during this experiment in 2012. The area between the lines indicates historic littoral areas with aquatic vegetation. The current boundary between the littoral and pelagic zone (~3 m contour) is shown by the contrasting light and dark areas of Harding Lake.

OBJECTIVES

The research objectives for Harding Lake in 2012 were to

1) estimate the abundance of the northern pike population ≥450 mm FL in Harding Lake during summer 2012 such that the estimate is within 25 percentage points of the actual value 90% of the time;

2) test the null hypothesis that the abundance of northern pike ≥450 mm in Harding Lake is ≤1,000 with 50% power of rejecting the null hypothesis if the true abundance is ≥1,210 using alpha = 0.05; and

3) estimate the length composition of the northern pike population ≥450 mm FL in Harding Lake such that the estimates of proportions are within 5 percentage points of the actual value 95% of the time.

METHODS

EXPERIMENTAL DESIGN AND FISH CAPTURE

The abundance of northern pike ≥450 mm FL inhabiting Harding Lake was estimated using two-event Petersen mark–recapture techniques for a closed population (Seber 1982) designed to satisfy the following assumptions:

1. the population was closed (northern pike did 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 fish mixed completely between events;

3. marking of northern pike 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 recovered in the second event.

The estimator used was a modification of the general form of the Petersen estimator:

$$\hat{N} = \frac{n_1 n_2}{m_2}, \tag{1}$$

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 sampling design and data collected allowed the validity of the 5 assumptions to be ensured or tested. 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 (Appendices A1–A4).

The study design was modified in 2012 compared to prior studies conducted in the 1990s. Previously, two 4-day sampling events occurred after ice-out (i.e., mid-to-late May) when catch rates are generally highest, and the hiatus between events lasted 3–4 days. In 2012, the first event occurred during May 29–June 7 when catch rates are still reliably high. Catch rates in the second event (August 7–13) were expected to be lower but a long hiatus was desired to maximize mixing because attaining a random sample during a single event is difficult even under the best sampling strategy. Catch rates in August were expected to be lower but were to be offset by the expected higher catch rates in June.

During the June event, the study area was initially divided into five sections to help apportion the crews and gear such that the lake was systematically fished around the lake's perimeter. After two days of sampling more effort was shifted to the areas where densities were highest to improve sample sizes. Up to 4 two-person crews sampled on a given day using a combination of gear: fyke nets (1-m x 1-m frames, 2.24-cm bar mesh, and a 15-m center lead), gillnets (~30 x 1.3 m with 2.54-cm bar mesh), and hook-and-line (Table 1).

Table 1.–Sampling schedule for the northern pike mark–recapture experiment at Harding Lake, 2012.

Event	Date	Number of 2-person crews	Gear used
1st			
	5/29	3	Gillnets, hoop traps, fyke nets, hook-and-line
	5/30	4	Gillnets, hoop traps, fyke nets, hook-and-line
	5/31	4	Gillnets, hoop traps, fyke nets, hook-and-line
	6/1	4	Gillnets, hoop traps, fyke nets, hook-and-line
	6/5	1	Hook-and-line
	6/6	2	Hook-and-line, gillnets
	6/7	1	Hook-and-line
2nd			
	8/7	1	Hook-and-line
	8/8	2	Hook-and-line
	8/9	2	Hook-and-line
	8/10	2	Hook-and-line
	8/13	2	Hook-and-line
	8/14	1	Hook-and-line

In general, one crew fished the fyke nets (n = 6) and hoop traps (n = 10), and the other crews fished gillnets. Fyke traps were set such that fish swimming parallel to shore would be directed into the trap by a wing or center lead extended toward the shoreline. After being set, these were checked in the morning and at the end of the workday, and some were periodically moved to a new location to improve catches. Hook-and-line gear was used opportunistically throughout the workday between checking fyke nets and hoop traps. Each of the remaining crew(s) fished 2–3 gillnets, allowing them to fish for 20–30 min, and angled between sets. Over the course of the first event, gillnets and hoop nets were abandoned because they were relatively ineffective compared to hook-and-line. Terminal tackle consisted of spoons, rubber-bodied jigs, crank baits such as Rapala lures, and soft plastic worms (Lunker City Slug-Go lures). Periodically the lure was tipped with herring to entice a reluctant fish to strike.

During the second event the lake was divided into eastern and western halves and 1 or 2 two-person crews systematically fished along the shoreline in their assigned half. Hook-and-line gear was used exclusively. All waters were fished, but crews focused on areas where fish densities were highest, which included nearshore areas with emergent vegetation and adequate water depths (i.e., ≥0.3 m), boat docks, and the few deep water weed beds along the littoral and deep-water interface.

During the first event, each northern pike ≥400 mm FL was marked with an individually numbered Floy FD-94 internal anchor tag and a partial left-pectoral fin clip was given to evaluate tag loss. Fish captured in the first event that exhibited signs of injury or excessive stress were not marked and were censored from the experiment. To eliminate duplicate sampling in the second event, all fish were given a right-pectoral fin clip. All fish in both events were carefully inspected for attendant Floy tags and fin clips, and capture/release locations were recorded using a GPS.

The experimental design as described helped to ensure that the assumptions of the mark–recapture experiment were not violated. Harding Lake is a closed system with the exception of small inlets considered too small to serve as a migration corridor for non-juvenile fish. This study was of short duration; therefore, growth recruitment for fish ≥450 mm was insignificant and within the range of measurement error (i.e., ±10 mm). Natural mortality during the 60-day hiatus was assumed to be insignificant and the lake was closed to harvest. The relatively long hiatus between events was planned to promote sufficient mixing of marked and unmarked fish and allowed marked fish to fully recover from the effects of handling between events.

DATA ANALYSIS

Abundance Estimate

Violations of Assumption 2 relative to size effects were tested using two Kolmogorov–Smirnov two-sample tests (K–S). There were four possible outcomes of these two tests relative to evaluating size-selective sampling (either one of the two samples, both, or neither of the samples were biased) and two possible actions for abundance estimation (length stratify or not). The tests and possible actions for data analysis are outlined in Appendix A1. If stratification by size was required, capture probabilities by location were examined for each length stratum.

The tests for consistency of the Petersen estimator (Seber 1982; Appendix A2) were used to determine if, for each identified length stratum, stratification by location was required due to spatiotemporal effects and to determine the appropriate abundance estimator: the pooled

Chapman-modified Petersen estimator, the completely stratified Chapman-modified Petersen estimator, or a partially stratified estimator (Darroch 1961). Testing was performed at the scale of a section (Figure 2).

Length Composition

Length composition of the population was estimated using the procedures outlined in Appendix A3. Length composition was estimated in 25-mm length categories.

RESULTS

Fish capture and movements

During both events combined, a total of 405 northern pike were sampled, most of which were captured in sections 3, 4, and 5 (Figure 3). Of these, 24 were captured by fyke nets, 21 by hoop traps, 51 by gillnets, and 309 by hook-and-line. Of the 61 recaptured fish, 25 had moved into a different section between events (Figure 4). The straight-line distance between events was determined for 55 fish and averaged 906 m (SD = 1,067; Figures 4 and 5). Measurement error of distance travel was assumed to be <50 m.

Diagnostic test results and abundance Estimate

A total of 395 northern pike ≥450 mm FL were sampled during both events and included in the experiment (n_1 = 258, n_2 = 137, m_2 = 61; Table 2). No tag loss was observed.

K–S test results indicated length stratification was not required (i.e., Case I from Appendix A1) for northern pike ≥450 mm FL:

a) test M vs. R, D = 0.16, P-value=0.08; and

b) test C vs. R, D = 0.57, P-value=0.99.

Consistency tests using the five sections indicated that geographic stratification for fish ≥450 mm FL was not needed:

a) mixing was not complete (χ^2 = 49.5, P-value < 0.01);

b) probability of capture by section in the first event were significantly different (χ^2 = 20.2, P-value < 0.01); and

c) probability of capture by section in the second event were not significantly different (χ^2 = 5.89, P-value = 0.21).

These test results indicated that a pooled Chapman-modified Petersen model (Chapman 1951) was the appropriate estimator. The abundance of northern pike ≥450 mm FL was estimated at 567 (SE = 47).

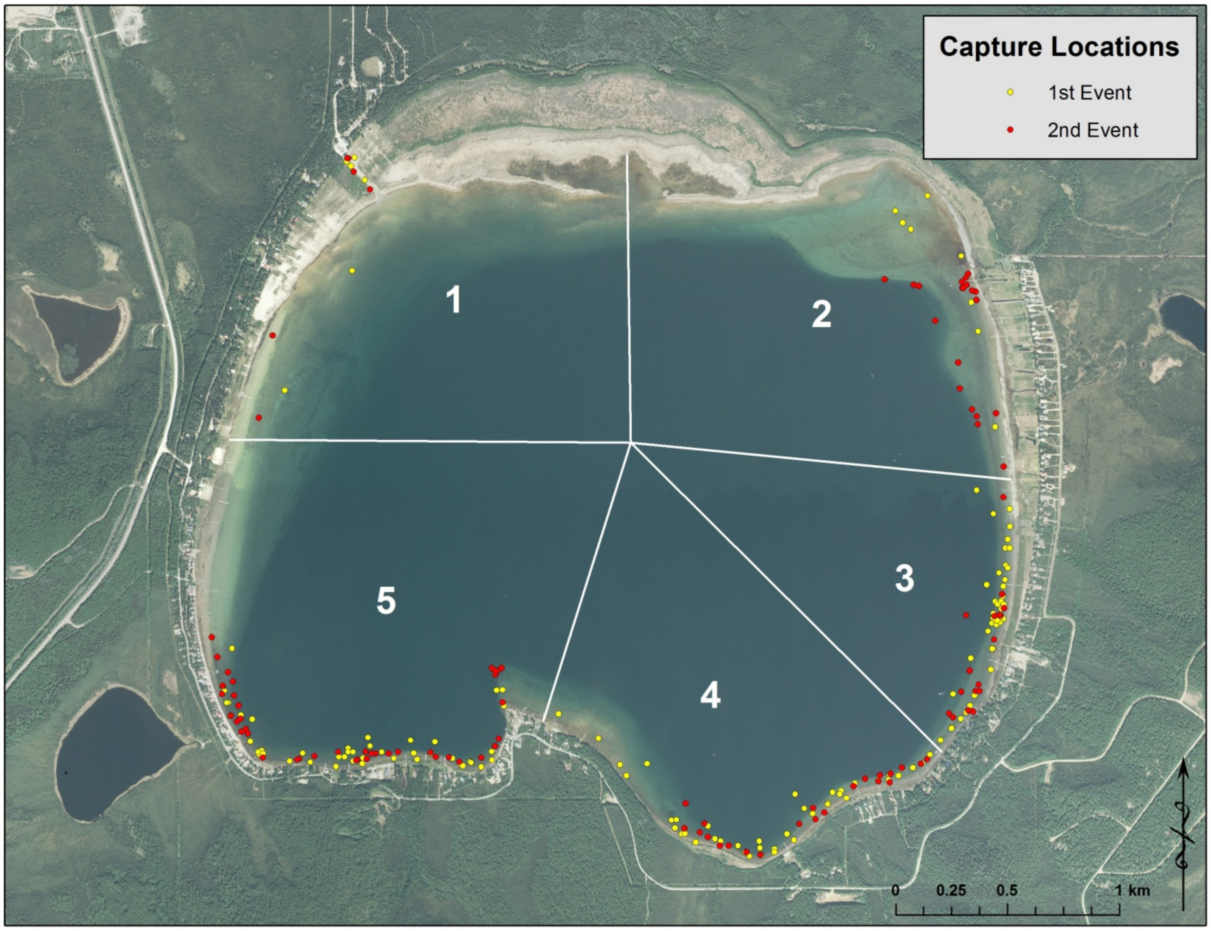


Figure 3.–Capture locations of northern pike by sampling event during the mark–recapture experiment in Harding Lake, 2012.

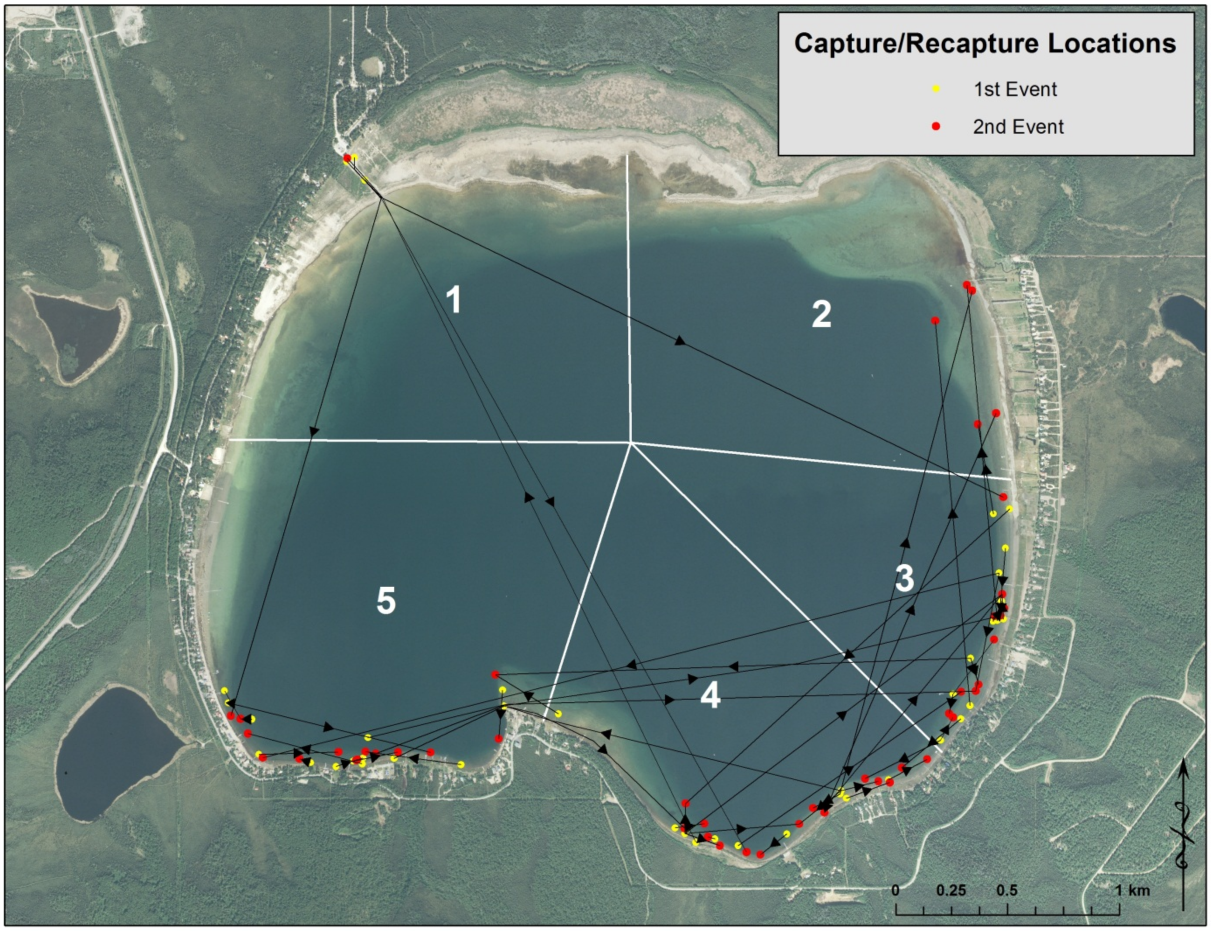


Figure 4.–Difference in capture location for recaptured northern pike between the first and second events during the mark–recapture experiment in Harding Lake, 2012.

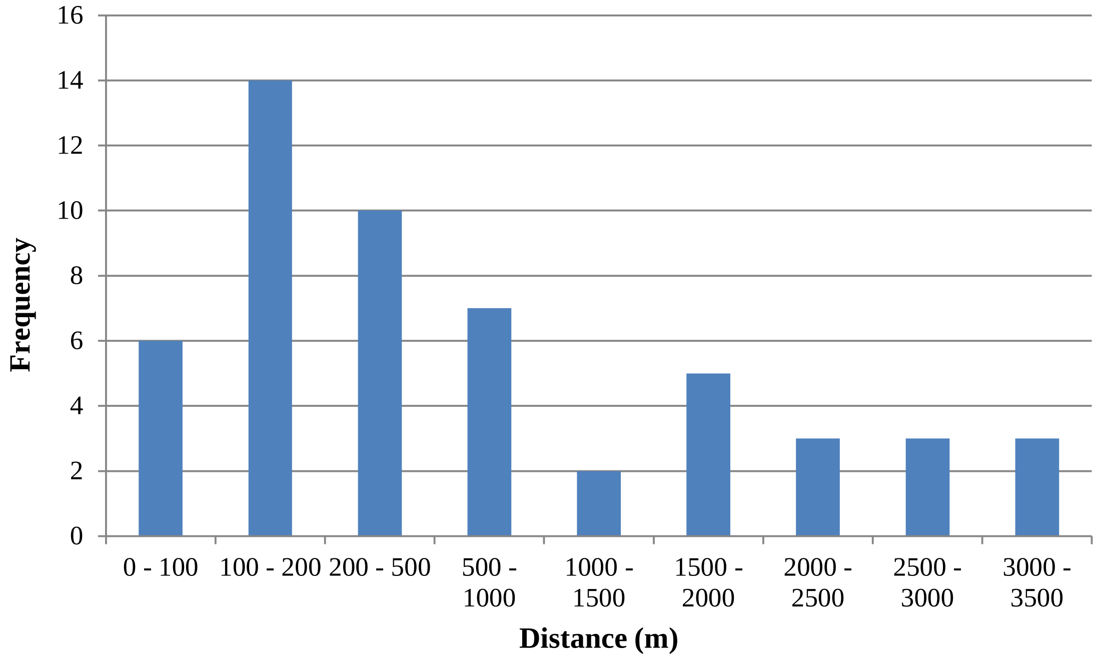


Figure 5.–Minimum distance traveled of recaptured northern pike between the first and second events during the mark–recapture experiment in Harding Lake, 2012

Table 2.–Number of northern pike ≥450 mm FL marked (n_1), examined (n_2), and recaptured (m_2) by section in Harding Lake, 2012.

		Section Recaptured							
		1	2	3	4	5	m_2	n_1	m_2/n_1[b]
Section Marked	1	0	0	1	0	2	3	19	0.16
	2	0	0	0	1	0	1	17	0.06
	3	0	3	10	4	2	19	65	0.29
	4	1	2	3	13	1	20	71	0.28
	5	0	1	3	1	13	18	86	0.21
	m_2	1	6	17	19	18	61	197	0.31
	n_2	7	24	24	29	53	167		
	(m_2/n_2)[a]	0.14	0.25	0.71	0.66	0.34	0.44		

[a] Probability of capture during first event.

[b] Probability of capture during second event.

Length Composition

For all 405 fish sampled, the most frequent 25 mm length categories ranged between 525 and 625 mm FL (Appendix B1). Similarly, for the estimated population of fish ≥450 mm FL, the most frequent length categories ranged between 525 and 625 mm FL (Appendix B1).

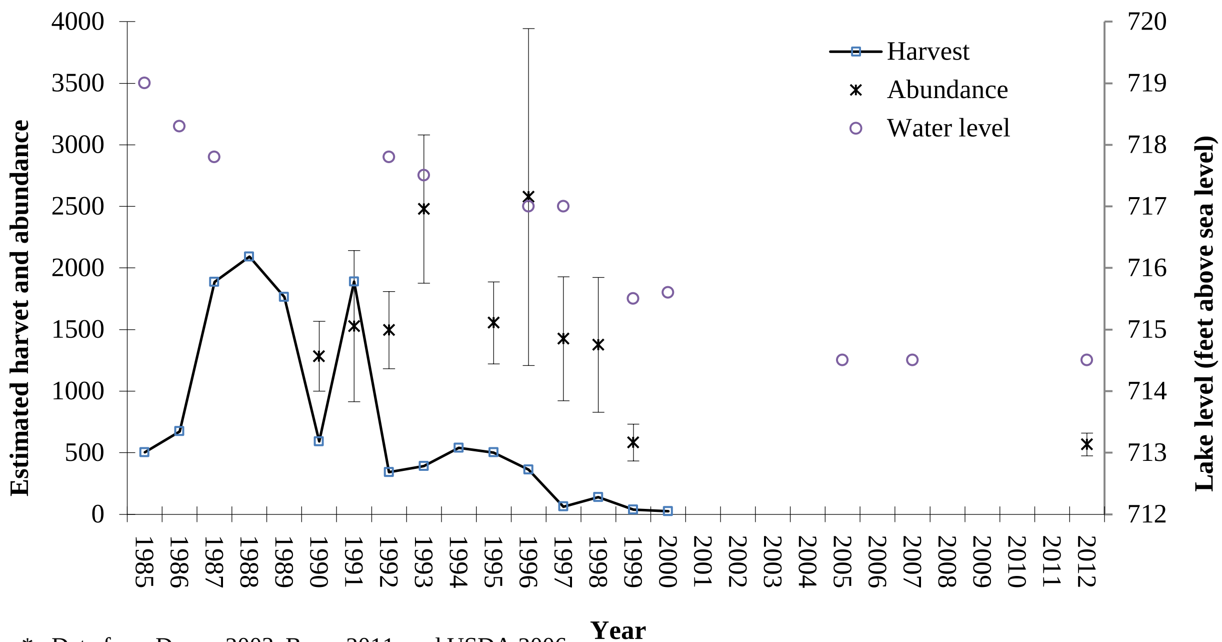
DISCUSSION

Based on the results of this and prior studies (Roach and McIntyre 1999, USDA 2006), it is clearly evident that the persistent low water levels in Harding Lake since the late 1990s have decreased the carrying capacity of northern pike through the loss of emergent aquatic vegetation. The role of aquatic vegetation in the life cycle of northern pike is well documented. It is widely agreed that adequate vegetation is essential for establishing a robust pike population because it provides spawning substrate, production of invertebrate prey, cover for predator avoidance up to advanced sizes (e.g., 280 mm FL), and ambush habitat for adults (Bry 1996). Casselman (1996) contends that nursery habitat for fry and juvenile northern pike and macrophtye cover for adults are the most critical or limiting factors, as opposed to spawning habitat.

After a 13-year period of continual low water in Harding lake there was, unsurprisingly, no increase in the abundance of northern pike ≥450 mm FL compared to 1999 (Figure 6). The low abundance is attributed to habitat loss and chronically poor recruitment. Evidence of very poor recruitment was first noted by Scanlon and Roach (2000) because of a sharp decline in the numbers of subadult fish (300–449 mm FL) sampled during annual stock assessments. For example, during 1995 when abundance was relatively high, fish 300–449 mm FL accounted for 21% of all fish sampled. By 1999 this proportion had dropped to 8.9%, and in 2012 it was 2.4% (Figure 7). Evidence of poor annual recruitment was also in observed in 2012 because there was a greater proportion of fish ≥675 mm FL than in previous years and evidence that these could be much older than expected. During 2012, two fish (670 and 690 mm FL in 2012) were captured from previous experiments. These fish were at least age-4 when initially tagged in 1997 and 1998 for a minimum age of 18 or 19 years. These minimum ages correspond to brood years (1993 or 1994) when water levels were still adequate to support good recruitment and a directed fishery. Although this evidence is limited, the potential dependency of the current population on water levels from the early to mid-1990s should be considered in reestablishing lost habitat.

The target for raising Harding Lake by redirecting flows from Rogge Creek is 717 ft (USDA 2006), and the ability of this level to restore pike habitat to an amount that can sustain a sport fishery, even a catch-and-release fishery, is suspect. Relative to reestablishing pike habitat, 717 ft level was selected and defended because it related to the *minimum* of a range of depths (8–16 in) needed for spawning identified by Casselman and Lewis (1996), and it corresponded to the last period when the abundance of fish was satisfactory (i.e., 1996 and 1997). The potential fallacy of the 717 ft selection is that it focused on spawning habitat (not rearing), that a minimum value (i.e., only 8 inches of water) of a range was used, and that it used lake levels from 1996 and 1997 (i.e., 717 ft), when the lake had adequate abundance but was already experiencing poor recruitment. Fish 300–449 mm FL are generally age-3 or -4, and if a water level of 717 ft supported good recruitment, then arguably these fish should have been far more abundant in 1999. The last stock assessments during which good recruitment of age-3 and 4 fish was observed occurred in 1996, which corresponds to cohorts from 1992 and 1993 when the water levels ranged between 717.5 and 717.8 ft. Casselman and Lewis (1996) and Minns et al. (1996) provided convincing arguments that fry and juvenile-adult habitats, which are deeper than those needed for just egg deposition, are more critical or limiting than spawning habitats. Therefore, it is recommended that the water level from 1992 and 1993, which provided good recruitment, be used as a minimum benchmark. A higher lake level will better guarantee enhanced northern pike production, and the increased productivity associated with the added littoral vegetation will benefit all fish species.

Currently, the available cover in Harding Lake is very marginal to nonexistent and has affected the distribution of fish in Harding Lake. For example, during 1993, 64% of the northern pike sampled were captured between the boat launch and Rogge Creek using primarily gillnets, whereas in 2012, less than 1% was captured in that area using all gear types (Figure 3). Most (i.e., ≥90%) of the existing shoreline emergent vegetation is too shallow (around ankle depth) to hold fish recruited to the gear. Instead northern pike were often found simply holding offshore in open water (i.e., no vegetation) using shallow depressions in the sandy bottom for cover, or were associated with artificial structures such as boat docks or refuse on the lake's bottom (e.g., lying next to discarded beverage cans). During sampling, northern pike were quick to use the fyke nets and hoop traps as cover; in almost every instance where gear was set, even far from the shoreline, 1-3 fish could be observed lying next to the trap when the trap was checked. During August, more fish had moved offshore to the beds of *Potamageton* sp. and *Chara* sp. vegetation near the 5 m contour, but these beds are very small, few in number, and isolated.



* Data from Doxey 2003, Brase 2011, and USDA 2006

Figure 6.–Estimated abundance of northern pike ≥450 mm FL (95% CI), estimated harvest, and water elevation of Harding Lake.

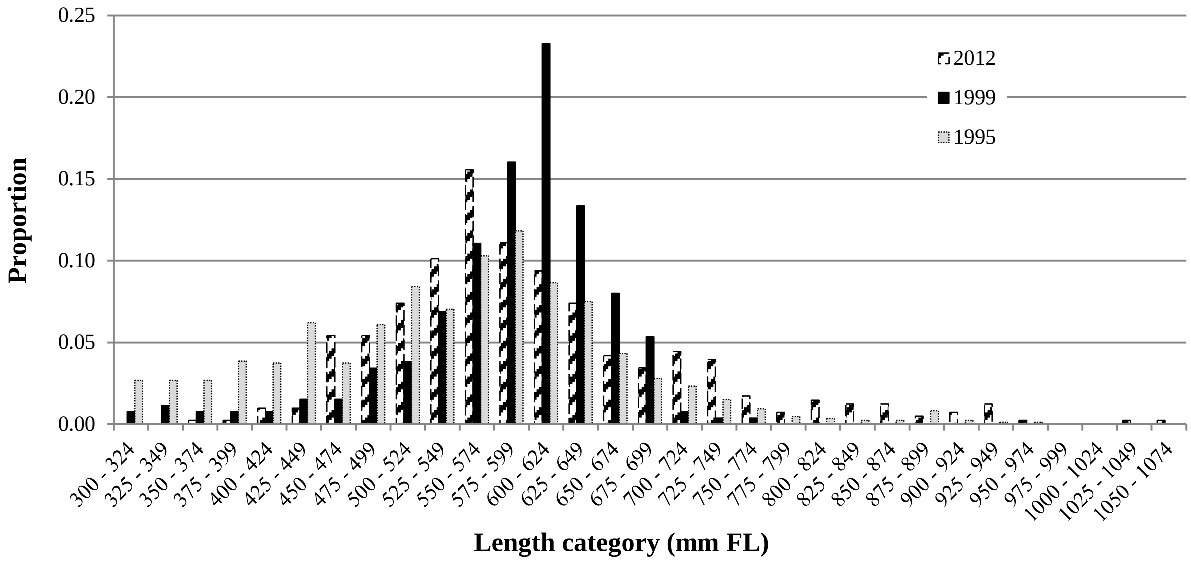


Figure 7.–Length distribution of all northern pike sampled during mark–recapture experiments in Harding Lake during 1995, 1999, and 2012.

If future stock assessments are required and low lake levels persist, the basic sampling design and capture methods in this study should be replicated, particularly the use of hook-and-line, the long hiatus, and recording of capture/release locations. During both events combined, 70% of the population ≥450 mm FL was captured, which resulted in rigorous diagnostic testing and good precision (95% CI of ±16%). Hook-and-line was effective gear because with so little cover fish were easily spotted, and areas with cover, such as the boat dock and vegetated shorelines, could be easily fished without being intrusive to property owners (e.g., having to set nets or traps in between private boat docks). Concerns of capturing smaller fish (i.e., 400-500 mm FL) were alleviated because they were recruited to the smaller-sized lures and traps (Figure 8). The long hiatus and associated mixing allowed the crews to focus their attention on high-density areas and improve sample sizes versus spending an inordinate amount of time fishing a barren lake bottom with gill nets. The recording of individual capture locations was advantageous because it permitted a detailed examination of fish movements, allowed multiple options for geographic stratification, and provided a good visual depiction of fish distributions during low water conditions.

Gillnets were the least efficient gear, when set either in open water or perpendicular to shore, with crews typically catching only 1–3 fish per day. These should be used in future studies but may need to be abandoned if catch rates are similarly low. Where adequate shoreline depth and aquatic vegetation occurred, fyke nets and hoop traps were relatively effective but tended to catch smaller sized fish (Figure 8). However, because of the unavailability of suitable sites and the time required to attend to the hoop traps and fykes, only a limited number (i.e., n = 10) can be fished. In 2012, more than half of the fykes and hoop traps had to be set in open water approximately 50-100 ft from shore with the leads, for example, only reaching half the distance to the shore in order to submerge the trap throats.

Finally, it is recommended that a different approach be used to identify annual sustainable harvest levels. Doxey (2003) outlines several management actions for reestablishing the fishery in Harding Lake based on modeling efforts by Roach and McIntyre (1999) to predict sustained yields. For example, the plan allows a harvest of 400 fish annually to occur if the abundance of fish ≥450 mm FL exceeds 1,700. However, with the benefit of hindsight, these estimates of yield were developed based on stock assessments from 1990–1998, a period during which the carrying capacity was appreciably declining due to habitat loss, and violated the model assumptions of a constant carrying capacity. A simple and more conservative approach that may be considered is applying a fixed percentage (e.g., 10%) to the most recent abundance estimate.

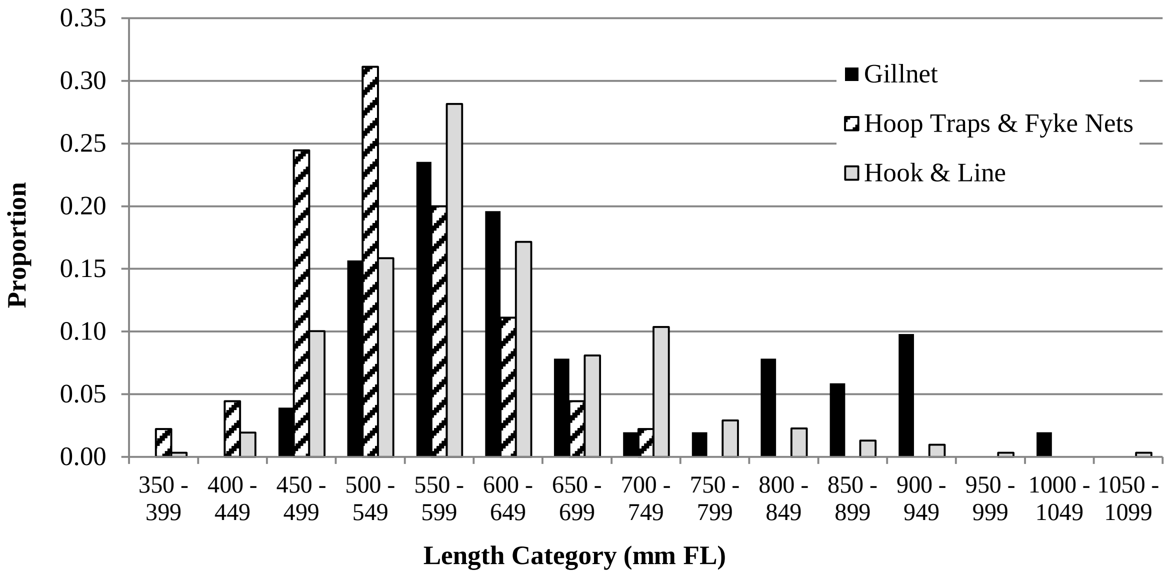


Figure 8.–Length composition of northern pike captured by gear type during the mark–recapture experiment at Harding Lake, 2012.

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REFERENCES CITED

Bailey, N. T. J. 1951. On estimating the size of mobile populations from capture-recapture data. Biometrika 38:293-306.

Bailey, N. T. J. 1952. Improvements in the interpretation of recapture data. Journal of Animal Ecology 21:120-127.

Brase, A. L. J. 2008. Fishery management report for recreational fisheries in the Lower Tanana River management area, 2006. Alaska Department of Fish and Game, Fishery Management Report No. 08-27, Anchorage.

Bry, C. 1996. Role of vegetation in the life cycle of pike. Pages 45-67 [*In*] J. F. Craig, editor. Pike: biology and exploitation. Chapman & Hall, London.

Casselman, J. M., and Lewis, C. A. 1996. Habitat requirements of Northern Pike (Esox lucius). Canadian Journal of Fisheries and Aquatic Sciences 53(Suppl.1):161-174 (1996).

Chapman, D. G. 1951. Some properties of the hypergeometric distribution with applications to zoological censuses. University of California Publications in Statistics 1:131-160.

Cochran, W. G. 1977. Sampling techniques. 3rd edition. John Wiley. New York.

Conover, W. J. 1980. Practical nonparametric statistics. 2nd edition. John Wiley & Sons, New York.

Darroch, J. N. 1961. The two sample capture-recapture census when tagging and sampling are stratified. Biometrika 48:241-260.

Doxey, M. 1991. A history of Fisheries Assessments and Stocking Programs in Harding Lake, Alaska, 1939-1989. Alaska Department of Fish and Game, Fishery Data Series No. 91-2, Anchorage.

Doxey, M. 2003. Fishery Management Plan and Restoration Plan for the Harding Lake Northern Pike Sport Fishery, 2000–2004. Alaska Department of Fish and Game, Fishery Management Plan No. 03-01, Fairbanks.

Kane, D., P. Fox, J. Fox, and R. Carlson. 1979. Effect of diverting additional drainage area runoff into Harding Lake. Institute of Water Resources. University of Alaska, Fairbanks.

LaPerriere, J. D. 1975. Evaluation of the trophic types of several Alaskan lakes by assessment of the benthic fauna. Institute of Water Resources, University of Alaska, Report IWR-63.

Minns, C. K., R. G. Randall, J.E. Moore, and V. W. Cairns. 1996. A model simulating the impact of habitat supply limits on northern pike, Esox Lucius, in Hamilton Harbour, Lake Ontario. Canadian Journal of Fisheries and Aquatic Sciences 53(Suppl.1):20-34 (1996).

Nakao, K. 1980. Climatic changes in the Interior Alaska. Report of the Alaskan Paleolimnology Research Project, 1977/78/79. Laboratory of Hydrology, Hokkaido University.

Roach, S. M., and J. McIntyre. 1999. Abundance, composition, sustainable yield, and risk analysis of the northern pike population in Harding Lake, 1998. Alaska Department of Fish and Game, Fishery Data Series No. 99-31, Anchorage.

Scanlon, B. P., and Roach, S. M. 2000. Abundance and composition of the northern pike population in Harding Lake, 1999. Alaska Department of Fish and Game, Fishery Data Series No. 00-3, Anchorage.

Seber, G. A. F. 1982. The estimation of animal abundance and related parameters. 2nd edition. Charles Griffin and Company, Limited, London.

USDA. 2006. Environment Assessment: Harding Lake Aquatic Habitat Enhancement project. Natural Resources Conservation Service, United States Department of Agriculture. 8837. FR Doc. 06–1573.

APPENDIX A

Appendix A1.–Detection of size- and/or sex-selective sampling during a 2-sample mark–recapture experiment and its effects on estimation of population size and population composition.

Size-selective sampling: The Kolmogorov–Smirnov 2-sample test (Conover 1980) is used to detect significant evidence that size selective sampling occurred during the first and/or second sampling events. The second sampling event is evaluated by comparing the length frequency distribution of all fish marked during the first event (M) with that of marked fish recaptured during the second event (R) by using the null test hypothesis of no difference. The first sampling event is evaluated by comparing the length frequency distribution of all fish inspected for marks during the second event (C) with that of R. A third test that compares M and C is then conducted and used to evaluate the results of the first two tests when sample sizes are small. Guidelines for small sample sizes are <30 for R and <100 for M or C.

Sex-selective sampling: Contingency table analysis (Chi^2-test) is generally used to detect significant evidence that sex selective sampling occurred during the first and/or second sampling events. The counts of observed males to females are compared between M&R, C&R, and M&C using the null hypothesis that the probability that a sampled fish is male or female is independent of sample. If the proportions by gender are estimated for a sample (usually C), rather an observed for all fish in the sample, contingency table analysis is not appropriate and the proportions of females (or males) are then compared between samples using a two sample test (e.g. Student's *t*-test).

M vs. R	**C vs. R**	**M vs. C**
Case I:		
Fail to reject H_o	Fail to reject H_o	Fail to reject H_o
There is no size/sex selectivity detected during either sampling event.		
Case II:		
Reject H_o	Fail to reject H_o	Reject H_o
There is no size/sex selectivity detected during the first event but there is during the second event sampling.		
Case III:		
Fail to reject H_o	Reject H_o	Reject H_o
There is no size/sex selectivity detected during the second event but there is during the first event sampling.		
Case IV:		
Reject H_o	Reject H_o	Either result possible
There is size/sex selectivity detected during both the first and second sampling events.		
Evaluation Required:		
Fail to reject H_o	Fail to reject H_o	Reject H_o

Sample sizes and powers of tests must be considered:

A. If sample sizes for M vs. R and C vs. R tests are not small and sample sizes for M vs. C test are very large, the M vs. C test is likely detecting small differences which have little potential to result in bias during estimation. *Case I* is appropriate.

B. If a) sample sizes for M vs. R are small, b) the M vs. R p-value is not large (~0.20 or less), and c) the C vs. R sample sizes are not small and/or the C vs. R p-value is fairly large (~0.30 or more), the rejection of the null in the M vs. C test was likely the result of size/sex selectivity during the second event which the M vs. R test was not powerful enough to detect. *Case I* may be considered but *Case II* is the recommended, conservative interpretation.

C. If a) sample sizes for C vs. R are small, b) the C vs. R p-value is not large (~0.20 or less), and c) the M vs. R sample sizes are not small and/or the M vs. R p-value is fairly large (~0.30 or more), the rejection of the null in the M vs. C test was likely the result of size/sex selectivity during the first event which the C vs. R test was not powerful enough to detect. *Case I* may be considered but *Case III* is the recommended, conservative interpretation.

D. If a) sample sizes for C vs. R and M vs. R are both small, and b) both the C vs. R and M vs. R p-values are not large (~0.20 or less), the rejection of the null in the M vs. C test may be the result of size/sex selectivity during both events which the C vs. R and M vs. R tests were not powerful enough to detect. *Cases I, II, or III* may be considered but *Case IV* is the recommended, conservative interpretation.

-continued-

Case I. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated after pooling length, sex, and age data from both sampling events.

Case II. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated using length, sex, and age data from the first sampling event without stratification. If composition is estimated from second event data or after pooling both sampling events, data must first be stratified to eliminate variability in capture probability (detected by the M vs. R test) within strata. Composition parameters are estimated within strata, and abundance for each stratum needs to be estimated using a Petersen-type formula. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance according to the formulae below.

Case III. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated using length, sex, and age data from the second sampling event without stratification. If composition is estimated from first event data or after pooling both sampling events, data must first be stratified to eliminate variability in capture probability (detected by the C vs. R test) within strata. Composition parameters are estimated within strata, and abundance for each stratum needs to be estimated using a Petersen-type type formula. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance according to the formulae below.

Case IV. Data must be stratified to eliminate variability in capture probability within strata for at least one or both sampling events. Abundance is calculated using a Petersen-type model for each stratum, and estimates are summed across strata to estimate overall abundance. Composition parameters may be estimated within the strata as determined above, but only using data from sampling events where stratification has eliminated variability in capture probabilities within strata. If data from both sampling events are to be used, further stratification may be necessary to meet the condition of capture homogeneity within strata for both events. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance.

If stratification by sex or length is necessary prior to estimating composition parameters, then an overall composition parameter (p_k) is estimated by combining within-stratum composition estimates using:

$$\hat{p}_k = \sum_{i=1}^{j} \frac{\hat{N}_i}{\hat{N}_\Sigma} \hat{p}_{ik} \text{ ; and,} \tag{A1-1}$$

$$\hat{V}[\hat{p}_k] \approx \frac{1}{\hat{N}_\Sigma^2} \sum_{i=1}^{j} \left(\hat{N}_i^2 \hat{V}[\hat{p}_{ik}] + \left(\hat{p}_{ik} - \hat{p}_k\right)^2 \hat{V}[\hat{N}_i] \right). \tag{A1-2}$$

where: j = the number of sex/size strata;

$\hat{p}_{ik}$ = the estimated proportion of fish that were age or size k among fish in stratum i;

$\hat{N}_i$ = the estimated abundance in stratum i; and,

$\hat{N}_\Sigma$ = sum of the $\hat{N}_i$ across strata.

Appendix A2.–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	Section Where Recaptured				Not Recaptured
Where Marked	A	B	…	F	(n_1-m_2)
A					
B					
...					
F					

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

	Section Where Examined			
	A	B	…	F
Marked (m_2)				
Unmarked (n_2-m_2)				

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

	Section Where Marked			
	A	B	…	F
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 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 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 A3.–Equations for calculating estimates of abundance and its variance using the Chapman-modified Petersen estimator.

The abundance of northern pike was estimated as:

$$\hat{N} = \frac{(n_2 + 1)(n_1 + 1)}{(m_2 + 1)} - 1, \qquad \text{(A3-1)}$$

where:

n_1 = the number of northern pike released alive 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 marked in the first event that were recaptured during the second event.

The variance was estimated as (Seber 1982):

$$\hat{V}[\hat{N}] = \frac{(n_1 + 1)(n_2 + 1)(n_1 - m_2)(n_2 - m_2)}{(m_2 + 1)^2 (m_2 + 2)}. \qquad \text{(A3-2)}$$

Appendix A4.–Equations for estimating length composition and variances for the population.

From Appendix B1, Case III was determined through inference testing and occurs when there is size-selectivity during the first event, but not for the second event. Proportions from the second event in 25-mm FL categories were calculated by:

$$\hat{p}_{jk} = \frac{n_{jk}}{n_j} \tag{A4-1}$$

where:

n_j = the number sampled from size stratum *j* in the mark-recapture experiment;

n_{jk} =the number sampled from size stratum *j* that were in length category *k*; and

$\hat{p}_{jk}$ = the estimated proportion of length category *k* in size stratum *j*.

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

$$\hat{V}\left[\hat{p}_{jk}\right] = \frac{\hat{p}_{jk}\left(1 - \hat{p}_{jk}\right)}{n_j - 1}. \tag{A4-2}$$

APPENDIX B

Appendix B1.–Length composition of all northern pike captured during the mark–recapture experiment and estimated length composition of fish ≥450 mm FL in Harding Lake, 2012**.**

Length category (mm FL)	All fish		≥450 mm		
	n	*p*	*n*	p_k	$SE(p_k)$
325 - 349	0	0.00			
350 - 374	1	0.00			
375 - 399	1	0.00			
400 - 424	4	0.01			
425 - 449	4	0.01			
450 - 474	22	0.05	22	0.06	0.012
475 - 499	22	0.05	22	0.06	0.012
500 - 524	30	0.07	30	0.08	0.013
525 - 549	41	0.10	41	0.10	0.015
550 - 574	63	0.16	63	0.16	0.018
575 - 599	45	0.11	45	0.11	0.016
600 - 624	38	0.09	38	0.10	0.015
625 - 649	30	0.07	30	0.08	0.013
650 - 674	17	0.04	17	0.04	0.010
675 - 699	14	0.03	14	0.04	0.009
700 - 724	18	0.04	18	0.05	0.011
725 - 749	16	0.04	16	0.04	0.010
750 - 774	7	0.02	7	0.02	0.007
775 - 799	3	0.01	3	0.01	0.004
800 - 824	6	0.01	6	0.02	0.006
825 - 849	5	0.01	5	0.01	0.006
850 - 874	5	0.01	5	0.01	0.006
875 - 899	2	0.00	2	0.01	0.004
900 - 924	3	0.01	3	0.01	0.004
925 - 949	5	0.01	5	0.01	0.006
950 - 974	1	0.00	1	0.00	0.003
975 - 999	0	0.00	0	0.00	0.000
1000 - 1024	0	0.00	0	0.00	0.000
1025 - 1049	1	0.00	1	0.00	0.003
1050 - 1074	1	0.00	1	0.00	0.003
1075 - 1099	0	0.00	0	0.00	0.000

APPENDIX C

Appendix C1.–Data files for northern pike from Harding Lake during 2012.

Data file[a]	Description
Harding lake northern pike data_2012.xls	File includes data from all northern pike sampled and analysis for the mark–recapture experiment for Harding Lake during 2012.

[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.