Fishery Data Series No. 05-43

An Investigation of Hooking Mortality of Lake Trout Angled Through Ice

by

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and

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August 2005

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

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Measures (fisheries)

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

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log_2, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

FISHERY DATA REPORT NO. 05-43

AN INVESTIGATION OF HOOKING MORTALITY OF LAKE TROUT ANGLED THROUGH ICE

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ABSTRACT

Long-term post-release mortality of lake trout *Salvelinus namaycush* angled and released through ice in Sevenmile Lake was examined in 2002. A control group was established to provide a relative measure of natural mortality and consisted of fish captured from the spawning grounds during September 2001 using a non-lethal gear (beach seine), marked, and released. The treatment groups consisted of 45 lake trout that were angled through the ice with lures, marked, and released between November 2001 and March-April 2002. In July of 2003, gillnets were fished throughout the lake to recover marked fish from the treatment and control groups. The recapture rates of seine-caught and lure-caught lake trout ≥ 375 mm FL were compared by constructing 2x2 contingency tables and using chi-square tests of independence.

The recovery rate for fall lure-caught fish (0.54) was significantly greater than that for the seine-caught fish (0.28), which was unexpected. However, the recovery rate for the spring lure-caught fish (0.33) was not significantly different than that of the control. Our ability to isolate the most plausible explanation for these observations was compromised by small sample sizes, particularly for lure-caught fish. Possible explanations include: 1) by chance the proportion of fall lure-caught fish in the final event was not representative of the proportion of fall lure-caught fish in the population, an artifact of small sample sizes; 2) the magnitude and seasonal distribution of natural mortality; in particular, that a spike in mortality associated with spawning rendered the seine-caught fish a poor control; 3) lake trout captured in a seine, particularly during spawning, and held overnight have a greater post-release mortality than lure-caught fish; 4) a combination of factors; and, 5) another source of bias. Recovery rates of lake trout were shown not to be affected by gender, and for lure-caught fish, not affected by incidence of bleeding, or length of time spent out of the water while handling.

In order to successfully complete a similar experiment to measure hooking mortality rates of lake trout, it is likely that the resource commitment in personnel and field supplies would need to be greater than for this experiment due to the low catch rates of lake trout when angled through ice. In addition to the reasons stated, seining induced mortality and the prevalence of post-spawning mortality of lake trout need to be further researched, because mark-recapture experiments often involve capturing spawning lake trout during the marking event.

Key words: bait, bias, bleeding, catch-and-release, handling, hooking, lake trout, length composition, lures, mortality, *Salvelinus namaycush*, Sevenmile Lake.

INTRODUCTION

Lake trout *Salvelinus namaycush* support important recreational fisheries in Alaska roadside and remote lake systems. Sport fishing for lake trout in Alaska is popular throughout the year, with some of the best fishing occurring through the ice. From 1985 to 2000, the average of the estimated yearly sport catch of lake trout in Alaska was 37,703 fish, and the average of the harvest estimates was 12,542 (Mills et al. 1986 – 1994; Howe et. al 1995, 1996, 2001a-d). From 1985 to 2000, the greatest catch of lake trout in Alaska was in 1993 (estimated at 53,578 fish) and the greatest harvest (estimated at 21,463) was in 1986 (Table 1). In most lakes in Region III (Arctic-Yukon-Kuskokwim region and the Upper Copper and Upper Susitna River drainages), sport fishing harvest regulations for lake trout are composed of a minimum-size limit, and a bag and possession limit of one or two fish per day (Table 2). Minimum length restrictions usually reflect the size at which at least 50% of the population is sexually mature, and are usually enacted to protect a component of the spawning population while maintaining the opportunity for harvest of large fish.

Lake trout are characterized as having slow growth rates, low fecundity, alternate-year spawning regimes, strict habitat requirements (cold, deep, oligotrophic lakes with a sufficient prey base and few competitors), and as being extremely susceptible to changes in habitat (Martin and Olver 1980). These characteristics makes these fish sensitive to over-exploitation, and as angling-for-sport becomes more popular and harvests levels decline, the mortality associated with catch-and-release fishing must be considered in managing lake trout fisheries in Alaska.

Table 1.-Estimated number of angler days, lake trout harvested, lake trout caught, lake trout caught per angler day, and lake trout harvested per catch in Alaska, 1985-2000.

		Number of Lake Trout			
Year	Angler Days	Harvested	Caught	Caught/Angler Day	Harvested/Caught
1985	1,336,717	18,473			
1986	1,449,474	21,463			
1987	1,486,310	15,209			
1988	1,626,244	17,193			
1989	1,555,327	17,070			
1990	1,589,087	12,602	42,443	0.04	0.20
1991	1,607,317	13,772	35,670	0.03	0.41
1992	1,651,296	12,525	43,295	0.05	0.26
1993	1,669,388	13,094	53,578	0.04	0.27
1994	1,695,551	11,374	45,107	0.03	0.26
1995	1,738,924	8,412	28,262	0.02	0.25
1996	1,262,580	9,772	34,781	0.07	0.21
1997	1,263,675	7,486	30,701	0.07	0.20
1998	1,153,277	5,985	22,807	0.06	0.20
1999	1,574,744	9,948	45,910	0.07	0.19
2000	1,649,833	6,292	32,176	0.06	0.21
			Average		
	1,519,359	12,542	37,703	0.05	0.24

Table 2.-Locations and sport fishing regulations for lake trout in Region III during 2002.

Location	Daily Bag and Possession Limit	Special Harvest Regulations
Summit Lake	2	must be 24" or larger
Paxson Lake	2	must be 24" or larger
Fielding Lake	1	must be 26" or larger
Harding Lake	1	must be 26" or larger
Crosswind Lake	1	must be 24" or larger
Tyone Lake	1	must be 24" or larger
Lake Louise	1	must be 24" or larger
Trans Alaska Pipeline Corridor	0	catch and release all year
North Slope Drainages	4	no size limit
Sevenmile Lake	2	no size limit
Other Lakes	2	no size limit

Hooking mortality has received considerable attention because of its potential effects on fish populations. Numerous studies have tried to estimate hooking mortality of lake trout, however in most of these studies mortality was evaluated by holding the fish in net pens or tanks for a period of 24 to 72 hrs (Falk et al. 1974; Loftus et al. 1988; Dextrase and Ball 1991; Persons and Hirsch 1994), only short-term mortality was assessed (up to 12 days), and only 2 were conducted during winter conditions. Persons and Hirsch (1994) examined hooking mortality of lake trout angled through the ice and reported that lake trout caught with dead bait and then released had a mortality rate of 32% (20 of 63 fish) after 12 days, whereas lake trout caught on artificial lures (jigs) and then released had a mortality of 9% (3 of 33 fish). 70% (44 of 63 fish) of the lake trout caught by dead bait were hooked in the gills or gut, compared to 9% (3 of 33 fish) of the lake trout caught by jigging. In a mortality study using minnows as bait on still lines through the ice, Dextrase and Ball (1991) reported a hooking mortality of 10% (5 of 50), and all lake trout that died after release were hooked deep in critical areas (gills, deep mouth, and stomach) and bled. However in both of these and other studies, holding pen effects and more subtle long-term mortality factors such as decreased fitness or stress were not accounted for in mortality rates. In this study, we wanted to improve on these experimental designs by limiting the potential for holding pen effects and by assessing long-term survival of lake trout that have been caught and released through the ice.

OBJECTIVES

The goal of this study was to determine if lake trout angled and released through the ice in Sevenmile Lake had a significantly higher probability of mortality due to capture and handling compared to fish not caught by hook-and-line gear. In addition, we wanted to see if the mortality rate of fish caught using bait was significantly greater than that for fish caught with lures. The research objectives for this experiment were to test for differences in the relative rate of long-term survival (i.e., from November to mid-July) for lake trout angled and released through the ice using:

1) lures compared to lake trout captured and released using a beach seine;
2) bait compared to lake trout captured and released using a beach seine;
3) lures compared to bait; and,
4) a combination of lures and bait compared to lake trout captured and released using a beach seine.

We designed the experiment to detect true differences in survival rates of 30%, 80% of the time at an alpha level of 0.20. The relatively high probability of type one error (a 1-in-5 chance of rejecting the null by chance alone), while not optimal, was considered the best that could be achieved given resource limitations and expected catch rates.

METHODS

DESCRIPTION OF STUDY AREA

Sevenmile Lake is located 7 miles west of Paxson and can be accessed by road from the Denali Highway (Figure 1). Estimated surface area of this lake is 33 ha and the maximum-recorded depth is 12.5 m (Figure 2). Sevenmile Lake was selected for this study because spawning lake trout are easily captured there, the density of lake trout is relatively high, and the size distribution of the population was likely representative of the size range of lake trout that are below the minimum length restrictions in many lakes in Region III and, therefore, likely to be released. These factors provided us an opportunity to capture sufficient numbers of fish to meet our required sample sizes, and thereby meet our project objectives.

Numerous stock assessments of lake trout have been conducted in Sevenmile Lake. Abundance of lake trout ≥ 375 mm FL in Sevenmile Lake has been estimated 10 times from 1988-2000 using a variety of methods, and estimates ranged from 459 to 1,139 fish ≥ 375 mm FL (Burr 1988, 1989, 1991, 1992, 1994; Taube et al. 1998; Parker and Wuttig 2000; Figure 3). The most recent study yielded an estimate of abundance of 1,109 fish ≥ 375 mm FL (SE = 170), and of density of 33.6 fish/ha ≥ 375 mm FL (Parker and Wuttig 2000). For comparison, the most recent estimate of abundance of lake trout in nearby Paxson Lake was 3,817 fish (≥ 362 mm FL) in 1995, and of density was 2.42 fish/ha ≥ 362 mm FL (Szarzi and Bernard 1997). Parker and Wuttig (2000) reported that the mean length of lake trout examined in Sevenmile Lake during the first sampling event in 1999 was 391 mm (16 in) FL with measurements ranging from 254 to 497 mm (10 - 20 in) FL.

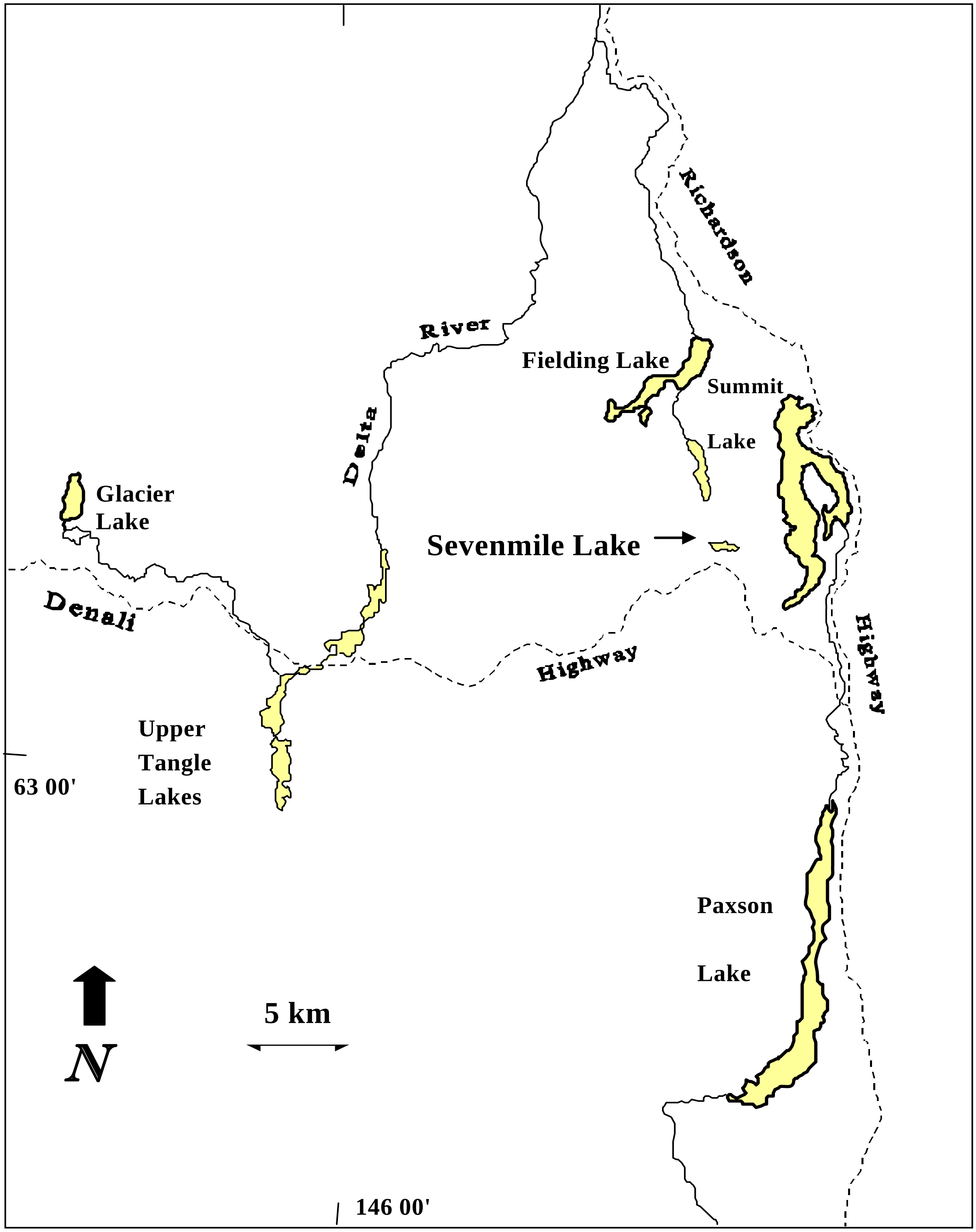

Figure 1.-Location of Sevenmile Lake.

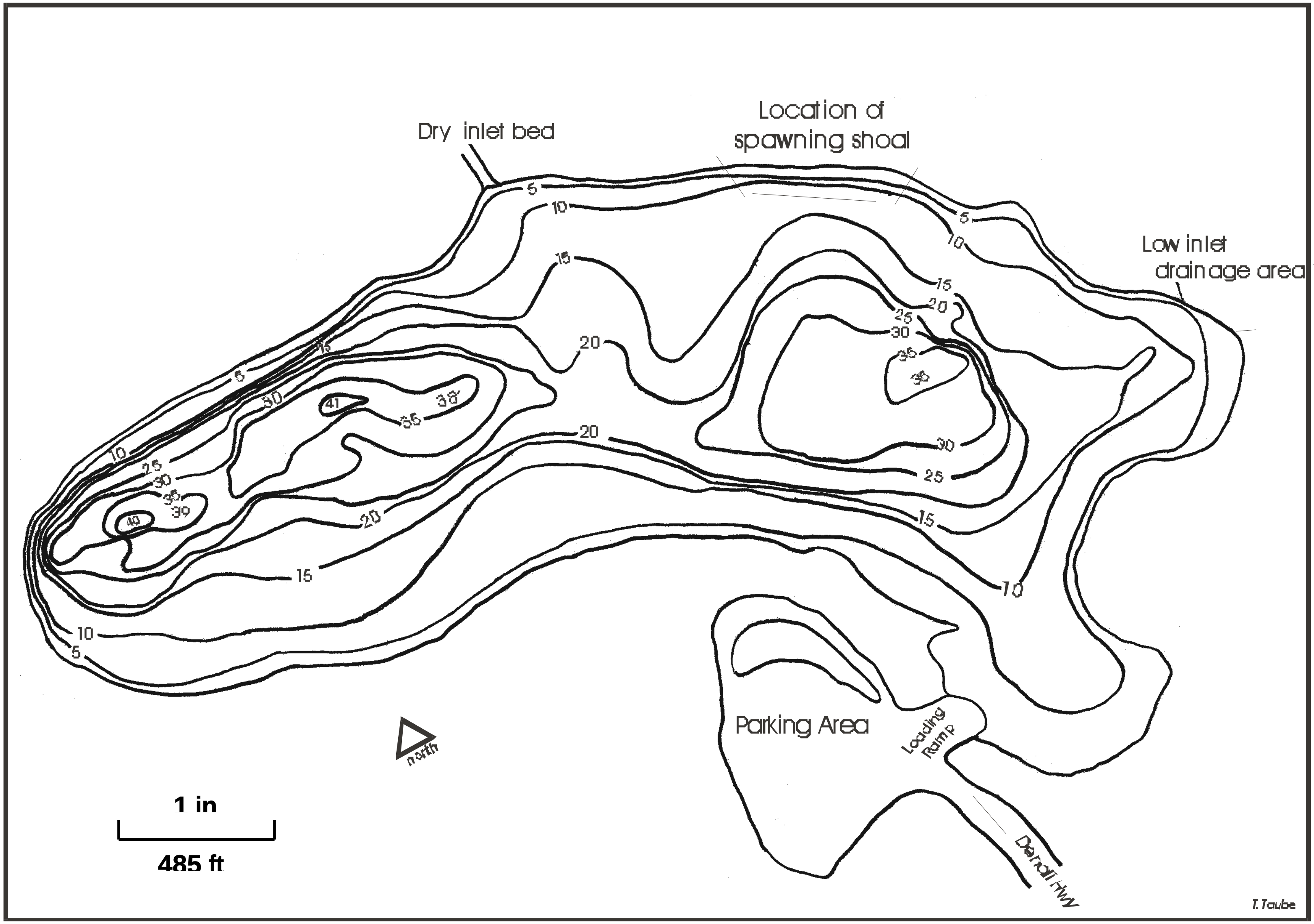

Figure 2.-Bathymetric map of Sevenmile Lake.

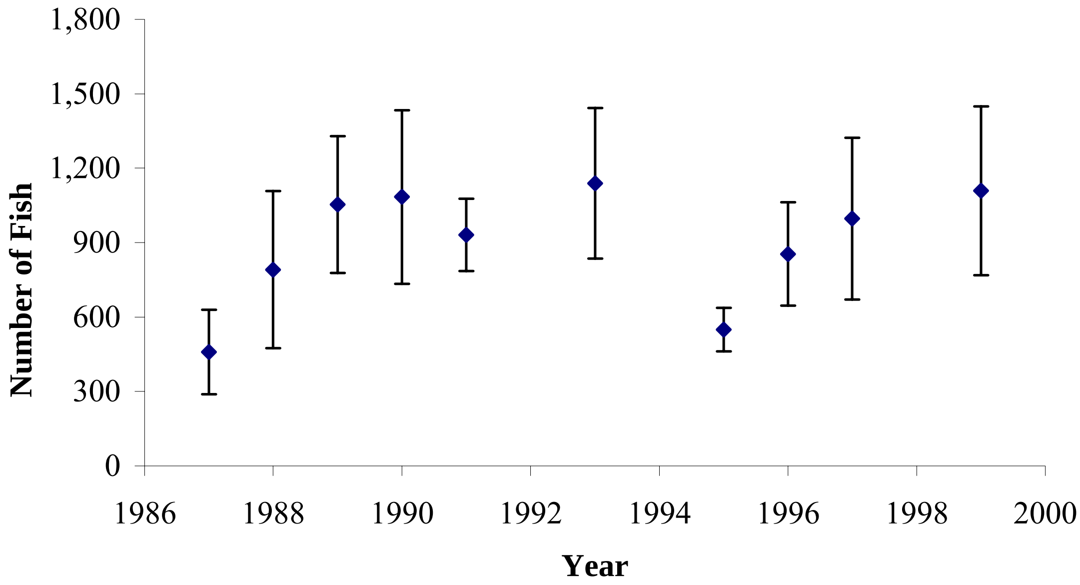

Figure 3.-Estimates of abundance for lake trout ≥ 375 mm FL (± 2 SE) in Sevenmile Lake from 1987-1999 (Parker and Wuttig 2000).

STUDY DESIGN

This study used mark-recapture techniques to determine if the long-term survival of lake trout angled and released through the ice was significantly lower than "natural" survival. A control treatment group was established to provide a relative measure of natural mortality. The control group consisted of fish captured from the spawning grounds during September 2001 using a beach seine that were marked and then released. The other treatment groups consisted of lake trout that were angled through the ice with two types of hook-and-line gear (lures and bait), marked, and released back into the lake during winter of 2001-2002. During the recovery event in July of 2002, gillnets were fished throughout the lake to recover marked fish from all treatment groups. Objectives for this project were to test four null hypotheses:

H_o: $S_{Seine} \le S_{Lure}$ vs. H_a: $S_{Seine} > S_{Lure}$;

H_o: $S_{Seine} \le S_{Bait}$ vs. H_a: $S_{Seine} > S_{Lure}$;

H_o: $S_{Lure} \le S_{Bait}$ vs. H_a: $S_{Seine} > S_{Lure}$; and,

H_o: $S_{Seine} \le S_{Lure\&Bait}$ vs. H_a: $S_{Seine} > S_{Lure}$.

where:

S_{seine} = the survival of lake trout (control group) seined from the spawning grounds to the July recovery event;

S_{lure} = the survival of lake trout caught using lures in late fall (November) to the July recovery event;

S_{Bait} = the survival of lake trout caught using bait in late fall (November) to the July recovery event; and,

$S_{Lure\ \&\ Bait}$ = the survival of lake trout caught using both lures and bait in late fall (November) to the July recovery event.

Differences in survival were examined by comparing recovery rates among treatment groups, i, with the recovery rates, r_i, estimated as $\hat{r}_i = \frac{m_{2,i}}{n_{1,i}}$, where $n_{1,i}$ is the number of lake trout ≥ 375 mm FL marked in each treatment group and $m_{2,i}$ is the number of fish marked as part of treatment group, i, that were caught during the recovery event. Differences in recovery rates were tested for by comparing the ratio of the number of marked lake trout that were recovered to the number not recovered, $\frac{m_{2,i}}{n_{1,i} - m_{2,i}}$, among treatment groups. To do so, we constructed 2x2 contingency tables and performed chi-square tests for independence (Fleiss 1981).

In order to meet the project objectives, several assumptions necessary for reliable comparison of survival from winter to summer for this experiment needed to be satisfied. These assumptions were that:

1) all lake trout captured using a beach seine survived until fish were caught with hook and line;
2) all lake trout used in the experiment and subsequently recovered were identified to a treatment group;
3) all lake trout had the same probability of capture at the time of hook-and-line fishing; and,
4) each lake trout that remained part of the experiment had the same probability of capture during the final sampling event.

To help satisfy Assumption 1, the seine-captured fish were captured as close to freeze-up as possible and angling commenced as soon as ice conditions permitted. Moreover, only seined fish that were judged to be in excellent condition were marked as part of the experiment. Seine-captured fish subsequently caught by hook and line were re-assigned to the appropriate hook-and-line treatment group thus satisfying Assumption 2. Assumption 3 was presumed to be valid because anglers were distributed throughout the lake to fish through the ice and the gear used was not size selective for the sizes under consideration. Assumption 4 was likely met because the July sampling effort was conducted throughout the lake at various depths and locations and by the time the final July event occurred, it was likely that marked and unmarked fish had mixed throughout the lake.

To estimate sample sizes needed to meet the precision criteria, an abundance of 1,200 lake trout ≥ 375 mm FL was assumed. Procedures for calculating sample sizes required to detect a given "true" difference between 2 proportions described by Sokal and Rohlf (1969) were used to estimate the following:

1) 173 unique lake trout ≥ 375 mm FL in the seining event;
2) 134 unique lake trout ≥ 375 mm FL with lures in the hook-and-line event;
3) 134 unique lake trout ≥ 375 mm FL with bait in the hook-and-line event; and,
4) 360 unique lake trout ≥ 375 mm FL in the recovery event.

SAMPLING METHODS

The seining event was conducted during the night of 10 September, 2001. Mature lake trout were captured using a beach seine (400 x 8 ft) deployed around spawning fish while they were aggregated over the spawning shoal (Figure 2). There were 4 seine hauls required and after each seine haul was completed the captured lake trout were transferred to a large holding pen. During the daylight hours of 11 September, the lake trout were sampled and the data were recorded on an ADF&G Tagging-Length Form, Version 1.0. Fish were measured for fork length to the nearest millimeter, tagged with a uniquely numbered Floy-FD-94 internal anchor tag (if one was not already present), given a hole punch in the left pectoral fin, and the sex was determined by presence of extruded sex products. Only those lake trout ≥ 375 mm FL that were determined to be in excellent condition (all but 2) were tagged and released.

The "fall" hook-and-line event commenced on 7 November, 2001, as soon as the ice was thick enough to safely travel upon. In this event, dead bait and lures were used as terminal gear. Fishing normally occurred during daylight (1000-1700 hours), and the number of anglers on the lake at one time ranged from 4 to 16. Lines rigged with whitefish or herring were allowed to fish without jigging and the angler set the hook when they observed that the bait was taken. Lures with barbed hooks (spoons, airplane jigs, bucktail jigs, and baitfish imitations) were angled by jigging, and the hook was set when a fish struck. All fish, including injured and dead fish, were sampled immediately. Fish were measured to the nearest 1 mm FL, tagged with a uniquely numbered Floy-FD-94 internal anchor tag, and marked secondarily with a hole punch through the right ventral fin. In addition, location of hook placement (lip, mouth, gills, stomach, or other specified), incidence of bleeding, time out of the water, and presence of tag or fin punch were recorded. All data were recorded in field notebooks. Data were later entered into Excel spreadsheets for analysis and archival (Appendix A). Attempts were made to handle fish similar to how the angling public may handle lake trout when ice fishing. Specifically, we used popular lake trout lures and gear, fish were not released while still in the water, and fish were exposed to air and wind and laid on snow for 15-120 seconds (sampling procedures typically added 10 – 30 seconds to total amount of time a fish was out of water). All fish were released immediately after sampling. Because only 24 lake trout ≥ 375 mm FL of the desired sample size of 134 were caught by lure, and only 9 lake trout ≥ 375 mm FL were caught using bait, an additional "spring" sampling event was conducted from 21 March through 4 April 2002. Due to the low catch rates of both treatment groups in the fall angling sample, it was decided to eliminate bait-caught fish from the experiment and concentrate all resources and effort into reaching the desired sample size for the lure-caught treatment group.

The recovery event took place from 8 July through 18 July 2002. There were 2 crews of 2 people who fished gill nets (0.75- to 1.25- in stretch mesh) throughout the lake to capture lake trout and opportunistically fished with hook-and-line gear between net sets. Only 2 lake trout ≥ 375 mm FL were caught by angling. Each crew fished 3 nets, rotating between them at 15- to 30-minute intervals depending on catch rates. Fishing was generally conducted at night between the hours of 2100 and 0500. All captured lake trout were measured for length and examined for marks. Both the left and right sides of the dorsal fin were examined closely for signs of tag loss (wounds); and, all fins were examined closely for recent punches. Before being released, the upper caudal fin was slightly clipped to prevent double counting of fish.

METHODS MODIFICATIONS

Only if Assumption 1 (i.e., all lake trout captured using a beach seine survive until fish were caught with hook and line) was not violated relative to the spring lure-fishing event, could results from that event be analyzed without modification. If lake trout caught with lures during the spring event experienced significantly less mortality than those caught by the seine and lure in the fall, then the recovery rate for lure-caught fish in the spring would be biased high relative to those caught in the fall and would need to be adjusted. The survival rate for lake trout ≥ 375 mm FL in Sevenmile Lake was estimated from mark-recapture data collected while sampling the spawning grounds in 1993, 1995, and 1997 (Parker and Wuttig 2000). An annual mortality rate of 0.22 with a 95% confidence interval of (0.10, 0.34) was determined using Program JOLLY (Jolly 1965; Jolly 1982; and Brownie et al. 1986). However, this estimate may be biased low due to delayed mortality from handling during these experiments, which involved holding pre-spawning lake trout for up to 6 days in holding pens. During these sampling events, spawning lake trout were held in holding pens for up to 4 days, and each year some of these fish were subject to gamete removal. This degree of handling has been observed to kill lake trout (T. Viavant, Sport Fish Biologist, ADF&G, Fairbanks; personal communication); therefore, an alternate value for natural mortality was calculated using a model developed by Shuter et al. (1998). This model is based on growth rate, water temperature, and maximum length information from 175 lake trout lakes in North America. Estimates of mortality generated from this model explained 72% of the variation in direct, independent estimates of lake trout mortality from six unexploited Ontario lakes and two Ontario lakes with known exploitation rates. The model equation describes the relationship between lake trout natural mortality, M, and the von Bertalanffy growth parameters K and L_∞ given an average yearly water temperature of ~6° C, which is comparable to average yearly temperature of Sevenmile Lake:

$$M = 2.064 \times \omega^{0.655} \times L_\infty^{-0.933} \qquad (1)$$

where:

L_∞ = asymptotic length (cm) of lake trout, and

ω = the early rate of length growth (cm/year) and is approximated by $K \times L_\infty$

where:

K = von Bertalanffy growth parameter (year^{-1}).

The mean length of the ten largest lake trout sampled by Burr (1997) in Sevenmile Lake was 51.9 cm and the von Bertalanffy growth parameter was determined to be 0.41 (Burr 1993; Burr 1997). Using these parameter values, the annual natural mortality rate for adult lake trout in Sevenmile Lake was estimated at 0.38. A measure of the uncertainty associated with model predictions was not provided in Shuter et al., 1998; however, a 95% confidence interval of (0.26, 0.50) was estimated using data provided in Table 2 of their manuscript. The confidence interval of this mortality estimate overlaps considerably with that based on mark-recapture data from Sevenmile Lake (Parker and Wuttig 2000). The potential for a relatively high annual mortality at Sevenmile Lake indicated that Assumption 1 was not likely valid relative to lake trout captured with lures in the spring and that differential rates of mortality between control and treatment groups needed to be accounted for when analyzing data collected during this event.

RESULTS

CATCH STATISTICS

We captured, sampled, and released 184 unique lake trout ≥ 375 mm FL during the seining event in September 2001. Of these, 12 were subsequently captured with hook-and-line sampling. These 12 fish were removed from the seine control group and added to the hook-and-line groups, reducing the number of fish in the control group to 172 lake trout (Table 3). In November 2001, 24 lake trout ≥ 375 mm FL were captured with lures and 9 were captured with bait. Air temperatures during sampling ranged from -32° C to -6° C. In March and April 2002, 21 unique lake trout ≥ 375 mm FL were captured with lures (Appendix B). During this time, air temperatures ranged from -11°C to 4°C. In July 2002, 346 lake trout were examined for marks, of which 47 were recaptured from the seine-caught group, 13 were recaptured from the November lure-caught group, and 7 were recaptured from the March and April lure-caught group. No tag loss was observed.

Table 3.–Sample sizes and estimated recovery rates of lake trout ≥ 375 mm FL in Sevenmile Lake under four different natural mortality scenarios.

	Actual and adjusted numbers of marked fish, n_1, numbers of recaptured fish, m_2, and estimated recovery rates, $\hat{r}$ [a], corresponding to the following treatment groups			
	Fall 01 Seine	Fall 01 Lure	Spring 02 Lure	All Lure
n_1	172	24	21	45
m_2	47	13	7	20
$\hat{r}$	0.28	0.54	0.33	0.44
$n_{1(adjusted;}$ with constant mortality)	118	18	19	37
$n_{1(adjusted}$; with ¼ mortality at spawning)	115	19	19	38
$n_{1(adjusted}$; with ½ mortality at spawning)	112	21	20	41
$n_{1(adjusted}$; with ¾ mortality at spawning)	109	23	20	43
$\hat{r}$ (constant mortality)	0.42	0.73	0.37	0.55
$\hat{r}$ (¼ mortality at spawning)	0.43	0.67	0.36	0.52
$\hat{r}$ (½ mortality at spawning)	0.44	0.67	0.35	0.49
$\hat{r}$ (¾ mortality at spawning)	0.45	0.58	0.34	0.47

a $\hat{r}_i = \frac{m_{2,i}}{n_{1,i}}$ are the estimated recovery rates for each treatment group, *i*.

Pairwise comparisons of cumulative relative length frequency distributions using Kolmogorov-Smirnov tests between the three groups for fish ≥ 375 mm FL revealed no significant differences (Figure 4; Table 4). In addition, results from the Anderson-Darling test for homogeneity of pooled samples detected no significant differences in length distributions. Also, there was no significant difference in length distributions when comparing the marked fish and recaptured fish within each treatment group (Table 4). These results suggest that there was no size-selectivity by gear type for lake trout ≥ 375 mm FL. The average growth of marked fish ≥ 375 mm FL from the seine-caught group was 4.5 mm (SD = 5.3) and from the fall lure-caught group was -1.0 mm (SD = 5.6); therefore, growth was considered inconsequential to the results of the study.

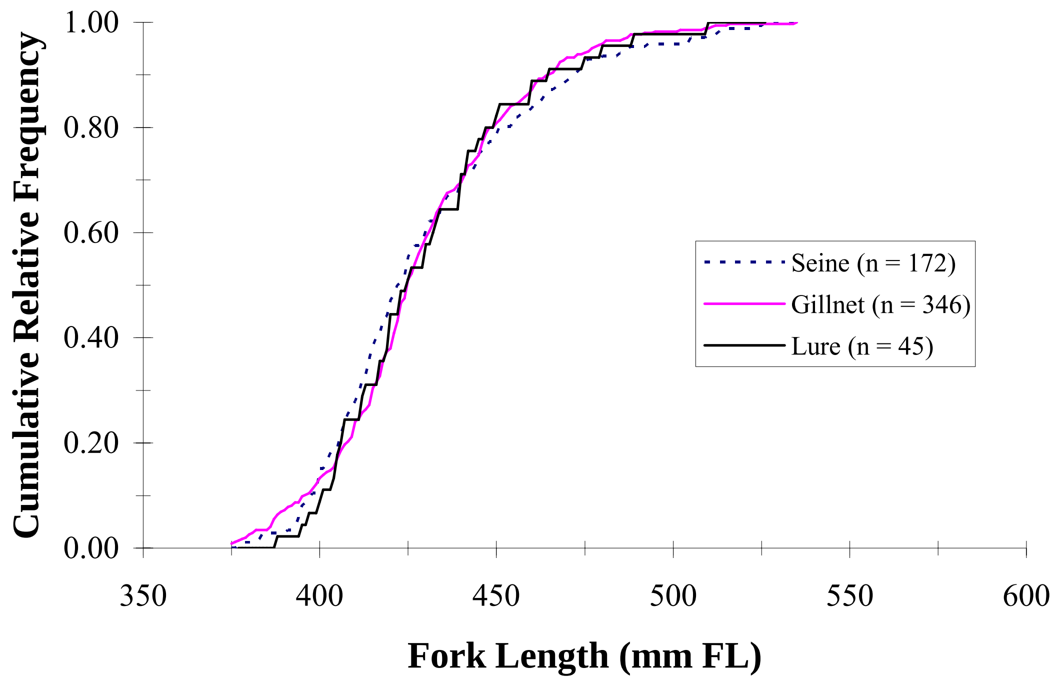

Figure 4.–Cumulative relative frequency distributions of all lake trout ≥ 375 mm FL captured with the seine, gill nets, and lures.

Table 4.–Kolmogorov-Smirnov and Anderson-Darling test results for comparison of length distributions between treatment groups for lake trout ≥ 375 mm FL.

All Lake Trout ≥ 375 mm FL			
Kolmogorov-Smirnov Tests	*D*-statistic	P-value	Result
Seine vs. Gill Net	0.09	0.27	Not Significant
Lure vs. Gill Net	0.09	0.88	Not Significant
Seine vs. Lure	0.07	0.99	Not Significant
Seine Marks vs. Seine Recaps	0.09	0.88	Not Significant
Lure Marks vs. Lure Recaps	0.16	0.85	Not Significant
Anderson-Darling Test	T_{akn}	P-value	Result
Pooled Data from All Groups	-0.50	0.58	Not Significant

TESTS OF HYPOTHESES

The low number of bait-caught fish precluded testing of all but the first hypothesis, which compared the survival rates of seine (control) and lure-caught fish. In addition, this remaining test was compromised by the low numbers of fish caught with lures, as only 45 fish (fall and spring events combined) were marked compared to the 134 lake trout estimated as necessary to achieve a power of 80% and a probability of Type I error of 20% or less. As a result, this test was expected to be susceptible to a high probability of Type I error (rejecting the null hypothesis when it is true), a high probability of Type II error (failing to reject the null hypothesis when the alternative is true), and low power (the probability of rejecting the null when the alternative is true). The recovery rate for the fall lure-caught fish (= 0.54) was greater than that for the seine-caught fish (= 0.28; Table 3), failing to reject the null hypothesis that the survival of the seine-caught fish would be less than or equal to that of the lure-caught fish. The recovery rate for spring lure-caught fish was = 0.33, but it is not known if this was different from the recovery rate of control fish because comparisons involving fish caught in the spring require adjustments for the effects of natural morality, and this was not possible.

The desire to use the fish caught by lure in the spring in the analysis and the unexpectedly high recovery rate for the fall lure-caught fish relative to that of the control led us to investigate the effects of natural mortality on the recovery rates. That the seine-caught fish had a much lower recovery rate than the fall lure-caught fish could be explained if the seine-caught fish had been subjected to natural mortality not experienced by the lure-caught fish. Post-spawning mortality of salmonids as a result of stress of spawning has been observed in other species (Ball and Cope 1961 and Moore 1975); therefore, this possibility was evaluated. Accurately adjusting for the effects of natural mortality was not possible given the lack of understanding concerning the magnitude of natural mortality and its seasonal distribution. Therefore, the effects of several mortality scenarios were modeled. For each scenario, adjusted recovery rates were calculated. Specifically, the number of marked fish in each treatment group ($n_{1,i}$) was decreased to a number of fish that was available at the time of the final event, $n_{1,i(adjust)}$, by accounting for mortality.

The adjusted recovery rates, $\hat{r}_{i,(adjust)} = \frac{m_{2,i}}{n_{1,i(adjust)}}$, exceeded those calculated without accounting for natural mortality because the numbers of recaptured tagged fish ($m_{2,i}$) were unaffected. Annual mortality rates were varied from 0.25 to 0.75 and varying percentages of that mortality (0, 25, 50 and 75%) were assigned to post-spawning mortality. Mortality not associated with spawning was distributed evenly throughout the rest of the year. Model results are presented in Figures 5-8 and are described below. The hypotheses test results reported in these figures were for 2-tailed tests at a significance level of 80%.

Without a spike in mortality associated with stress during spawning, the recovery rate of the fall lure-caught fish is significantly higher than that of the control group for all mortality rates (Figure 5). For this model, the recovery rate for the spring lure-caught fish is less than the control and remains nearly constant as annual mortality increases from 0.25 to 0.67. At an annual mortality rate of 0.67 the recovery rate of the control group is significantly higher than that of the spring lure-caught fish (Figure 5). As the proportion of mortality associated with post-spawning increases to 25, 50 and 75%, the curves for the lure treatment groups flatten while the slope of the curve for the seine control increases (Figures 6-8). Focusing on the annual mortality rate predicted using Shuter's model (= 0.38), the recover rate for the fall lure-caught fish is greater than that for the control with no spike in mortality associated with spawning but is no longer significantly greater when between 50 and 75% of the mortality is associated with the period immediately after spawning. This trend is more extreme at higher values for annual mortality with the point estimate for the seine control exceeding that for the fall lure event at mortality rates of 68% with 50% of the mortality associated with spawning (Figure 7).

Lake trout captured with lures in the spring and fall yield inconsistent results relative to the control for nearly the entire range of magnitude and distribution of annual mortality considered. Only for extreme annual mortality rates > 50%, with 50% or more occurring soon after spawning, were both the spring and fall adjusted recovery rates for lure-caught fish less than that for the control and only in the most extreme case considered were they both significantly less than the control. Pooling the lure-caught samples yields adjusted recovery rates that are significantly greater than the control for scenarios with moderate to low annual mortality with 0-25% associate with spawning, not significantly different than the control for moderate to high annual mortality rates with 0-75% associated with spawning, and significantly less than the control only for high annual mortality rates with most of the mortality associated with spawning.

EFFECTS OF GENDER AND HANDLING ON RECOVERY RATES

Recovery rates of lake trout captured with the seine (the only event where any sexual dimorphism could be observed) were not dependent on gender. Of the 127 males captured in the seine event, 35 (28%) were recaptured, and of the 64 females captured in the seine event, 16 (25%) were recaptured.

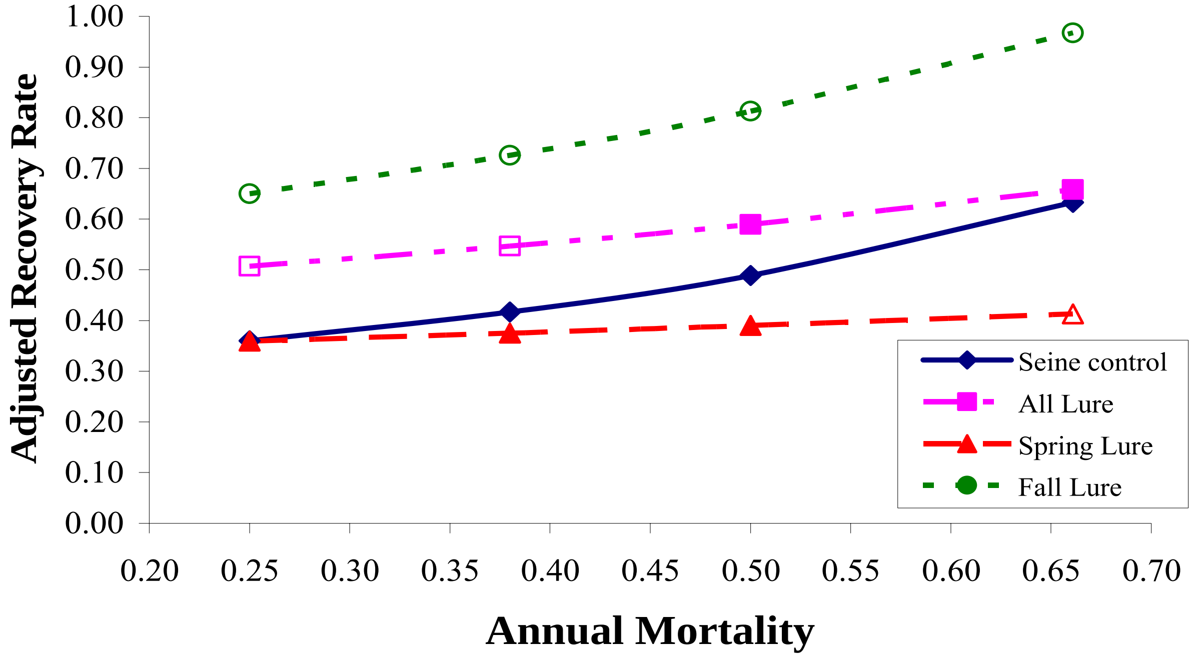

Figure 5. - Effect of annual natural mortality on recovery rates with a 0% spike after spawning (open symbols indicate difference relative to control significant at 80% significance level).

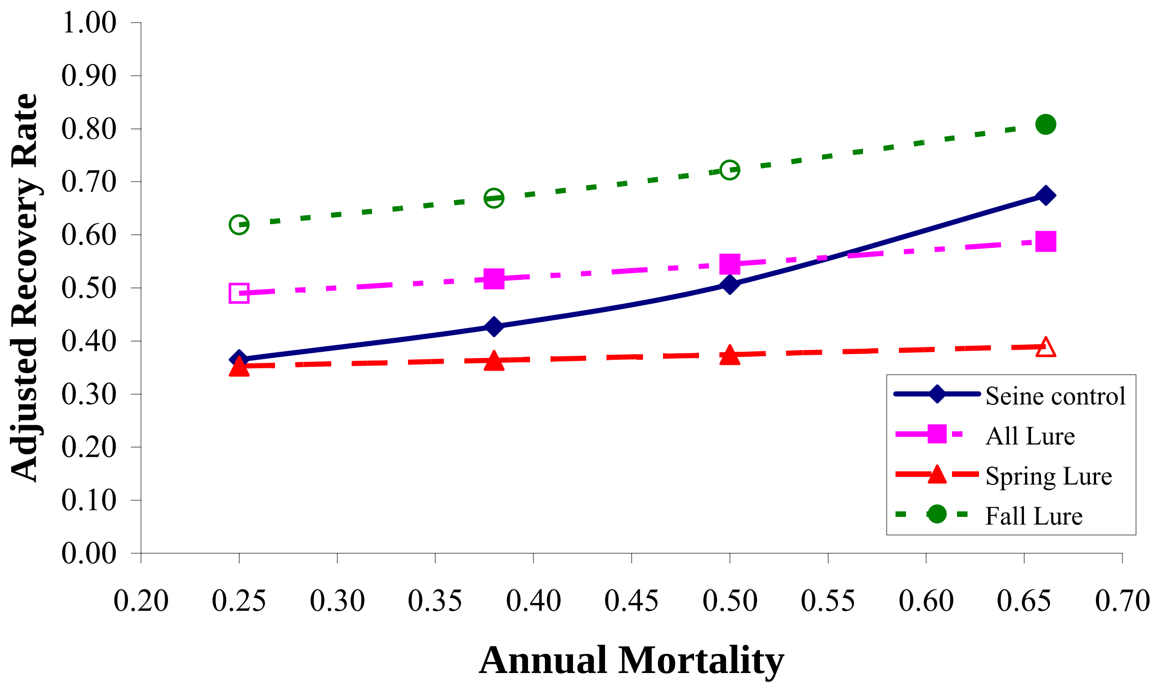

Figure 6. - Effect of annual natural mortality on recovery rates with a 25% spike after spawning (open symbols indicate difference relative to control significant at 80% significance level).

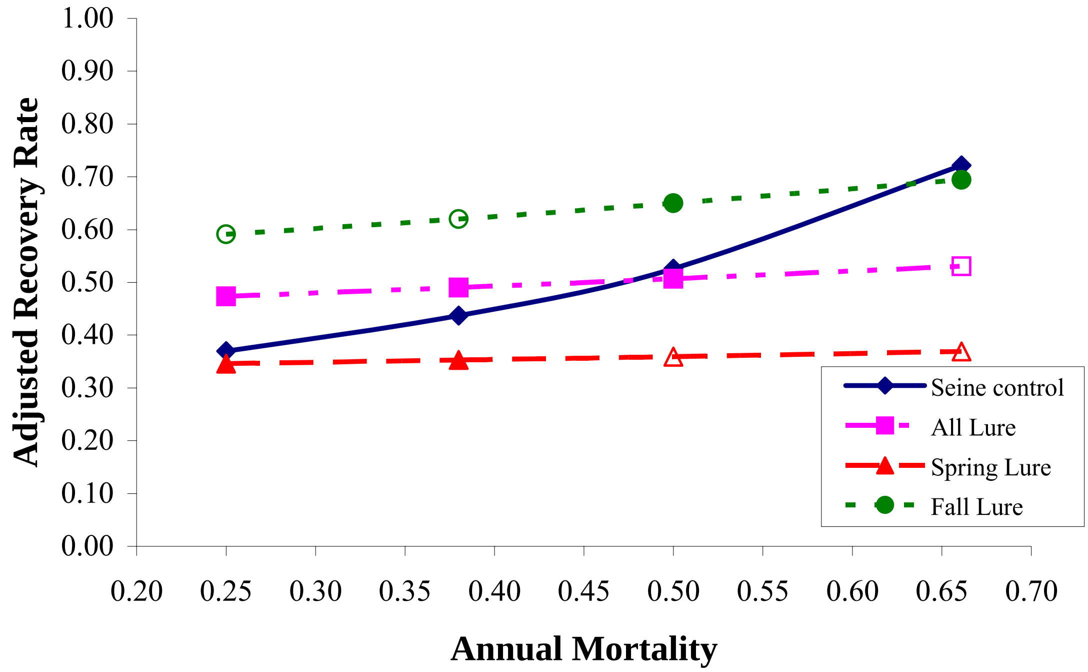

Figure 7.- Effect of annual natural mortality on recovery rates with a 50% spike after spawning (open symbols indicate difference relative to control significant at 80% significance level).

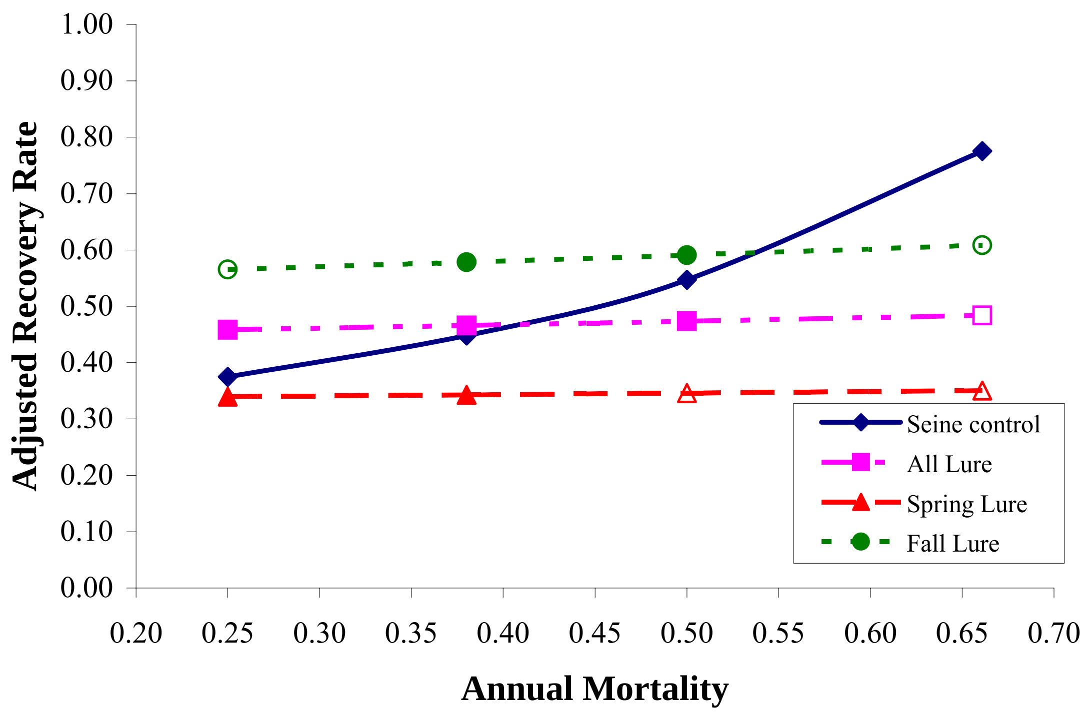

Figure 8.- Effect of annual natural mortality on recovery rates with a 75% spike after spawning (open symbols indicate difference relative to control significant at 80% significance level).

Although a comprehensive study of the potential effects of handling was not carried out, the incidence of bleeding and the length of time a fish was out of the water when sampled by hook-and-line were recorded. Chi-square tests were performed on a series of 2x2 contingency tables designed to evaluate the dependence of recovery rates on injuries resulting in bleeding and prolonged exposure to ambient air during the marking event. Of the 45 lake trout ≥ 375 mm FL caught with lures and released, 27 were bleeding at the time of release. Of these 27 fish, 13 (48%) were recaptured in the final event. Of the 18 fish that were not bleeding at the time of marking, 7 (39%) were recaptured in the final event. The data did not indicate a significant difference in recovery rates between fish that were bleeding and not bleeding ($\chi^2 = 0.38$; 1 df; P-value = 0.54).

Of the 45 lure-caught lake trout ≥ 375 mm FL, 28 were out of the water for 60 seconds or longer. Of these 28 fish, 13 (46%) were recaptured in the final event. Of the 16 fish that were exposed for less than 60 seconds, 7 (44%) were recaptured in the final event (for 1 recaptured fish ≥ 375 mm FL, the time the fish was out of the water was not recorded). The data did not indicate a significant difference in recovery rates based on length of time out of the water ($\chi^2 = 0.03$; 1 df; P-value = 0.86). Length of time that fish were out of the water during hook-and-line sampling ranged from 20 to 180 seconds, with an average of 68 seconds (SD = 30).

The combined effect of bleeding and spending ≥ 60 seconds out of the water on recovery rates was also examined. Of the 18 fish that were captured with lures and released that were also bleeding and held out of the water for ≥ 60 seconds, 8 (44%) were recaptured. Of the 8 fish that were captured with lures and released that were not bleeding and were held out of the water for < 60 seconds, 2 (25%) were recaptured. The data did not indicate a significant difference in recovery rates (Fisher's exact test; P-value = 0.42).

DISCUSSION

The high recovery rate for fall lure-caught fish compared to seine-caught fish was unexpected. Our ability to isolate the most plausible explanation for this was compromised by small sample sizes, particularly for lure-caught fish. Possible explanations include: 1) by chance the proportion of fall lure-caught fish in the final event was not representative of the proportion of fall lure-caught fish in the population, an artifact of small sample sizes; 2) the magnitude and seasonal distribution of natural mortality; in particular, that a spike in mortality associated with spawning rendered the seine-caught fish a poor control; 3) lake trout captured in a seine, during spawning, and held overnight have a greater post-release mortality than lure-caught fish; 4) a combination of factors; and, 5) another source of bias. Selective harvest of fish by anglers between time of seining and time of lure fishing could have rendered the seine-caught fish a poor control. However, knowledge of the fishery indicates this was not likely, nor was it likely that other anthropogenic disturbances were experienced by the spawning fish exclusively. Consistency table analysis showed no evidence of an affect on recovery rates of lure-caught fish that were bleeding and/or were subjected to lengthy (>60 s) exposure to ambient air during the marking events. In addition, the similarity in recovery rates by gender suggests that male and female lake trout sampled in the seine event were subject to similar mortality rates between the seine event and the final event.

It was possible that the unexpected result was due to a low probability random occurrence because the experiment was designed with relatively high probabilities of Type I and II errors and less than 20% of the samples estimated as necessary to meet the precision criteria were obtained during the fall event. It can be shown that the probability of having obtained a recovery rate of 54% or more for the fall lure caught fish just by chance (given the actual sample size and assuming the seine caught fish were a valid control) was relatively high, even if the lure caught fish experienced a relatively high mortality due to hooking (i.e., 20-30%). This analysis required that the true abundance of lake trout ≥ 375 mm FL (or the probability of capture in the recovery event) be estimated and, primarily as a result of the uncertainty in this parameter, the analysis does little to further that known about hooking mortality for lake trout. Finally, the inconsistency between the recovery rates for the lure-caught fish in the spring and fall events allows sampling error as a possible explanation for the unexpected result for the fall event.

It is also possible that the magnitude and seasonal distribution of mortality rendered the seine-caught fish a poor control. As stated above, post-spawning mortality of salmonids as a result of stress of spawning has been observed in other species. Moore (1975) found that the major cause of death for closely-related Arctic char *Salvelinus alpinus* in freshwater was probably due to physical deterioration during and after spawning. Ball and Cope (1961) found that cutthroat trout *Oncorhynchus clarki* in Yellowstone Lake had a high natural mortality after reproduction, and that post-spawners were a small component to the sport harvest. If a spike in annual natural mortality for lake trout ≥ 375 mm FL (the length at which lake trout in Sevenmile Lake become sexually mature) occurred soon after spawning (early to mid September) but before commencement of the hook-and-line sampling (mid November), there would have been a loss of tagged fish that would have biased the estimated recovery rate of fish from our control group low. If this were the case, the seine-caught fish did not experience a natural mortality common to all fish and therefore were not an appropriate control. Figures 5-8 demonstrate the potential for mortality to have substantial effects on recovery rates. It is important to note that annual natural mortality rates for lake trout greater than 0.50 are considered unreasonably high except in populations parasitized by lampreys *Lampetra spp*. (Martin and Olver 1980). That said, the possibility that handling may have exacerbated mortality associated with spawning or that handling induced mortality itself may have compromised the seine-caught fish as a control can not be ruled out; although, there was no obvious evidence to suggest such a handling effect (i.e., all fish sampled and released in the seine were green or ripe fish with excellent color and showing no outward signs of stress).

Based on the modeling results, it appears that natural mortality, on its own, is not a full explanation for the difference between the recovery rates for the seine and fall lure-caught lake trout or the difference between the recovery rates for the spring and fall lure-caught fish. The later result strongly argues against pooling the fall and spring lure-caught samples (e.g., for the purpose of attempting to place an upper bound on post-release mortality of lake trout angled through the ice) as the possibility that the sample was biased combined with uncertainty regarding the effects of natural mortality renders pooling imprudent. However, the modeling results did indicate that natural mortality could not be eliminated as contributing to the unexpected experimental results, especially if exacerbated by handling during spawning. By analogy, handling induced mortality, even without a spike in natural mortality during spawning, would yield similar experimental results and could not be eliminated as an explanation for the observed recovery rates. The need to know the effects of handling and natural mortality is important when designing similar experiments to assess hooking mortality for lake trout.

In summary, the possibility of having obtained a sample that was not representative of the population, a lack of understanding of the magnitude and seasonal distribution of natural mortality, and the absence of a precise estimate for the abundance of lake trout ≥ 375 mm FL in Sevenmile Lake at the time of the experiment precludes the use of these results for evaluating or effectively constraining the post-release mortality of lake trout angled through the ice.

The inability to reach the sample size goals for the hook-and-line treatment groups may be, in part, due to the feeding habits of lake trout in Sevenmile Lake and the type of terminal gear used. In this lake, lake trout and burbot *Lota lota* are the only 2 fish species present, and consequently the lake trout are rarely piscivorous. Here lake trout subsist primarily on insect larvae and small bivalves throughout their lives, rarely exhibiting predatory behavior. The lures and baits used in this study that mimicked live fish were likely ineffective at catching lake trout. It is possible that the study could be repeated in a larger lake where whitefish *Coregonus spp*. are present (such as Paxson Lake) and catches would be higher. However, because larger lakes like Paxson Lake that have higher abundances also have lower densities than Sevenmile Lake, it is not clear that the catch per unit effort would increase and, even if it did, more effort may be required to attain the required sample sizes.

CONCLUSIONS AND RECOMMENDATIONS

Uncertainty regarding the magnitude and temporal distribution of mortality and the possibility of not having obtained a representative sample precluded us from determining the post-release mortality of lake trout angled through ice and if a change in the regulations (e.g., gear type or minimum size restrictions) is warranted. In order to successfully complete a similar experiment to measure hooking mortality rates of lake trout, it is likely that the resource commitment in personnel and field supplies would need to be greater than for this experiment due to the low catch rates of lake trout when angled through ice.

The prevalence of post-spawning mortality of lake trout needs to be further researched. In Region III, mark-recapture experiments are often designed as multi-year experiments or experiments with a long hiatus between sampling events (e.g., fall until spring) and involve sampling large groups of lake trout on the spawning shoals. If marked fish experience an increase in mortality due to spawning or handling, biased abundance estimates may result. Understanding seasonal fluctuations in natural mortality and affects of handling may lead to improved estimates of abundance and composition for important lake trout fisheries in Alaska in future experiments. Recent research on Paxson Lake included multiple 2-event mark recapture experiments in which lake trout were caught and marked during the fall while spawning and during the spring (ADF&G *Unpublished*). Comparing abundance estimates may provide insight into both natural and handling mortality.

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APPENDIX A

Appendix A.–List of data files used and location of archived files**.**

Data file[a]	Description
2001-02Sevenmiledata.xls	Data files for Sevenmile Lake lake trout hooking mortality study, 2001 - 2002

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

APPENDIX B

Appendix B.–Capture history of lure-caught fish in Sevenmile Lake, 2001-02.

Date	Length	Hook Location	Bleeding	Time Out of Water (sec)
November 7	313	Lip	Yes	120
November 7	301	Roof	Yes	90
November 8	320	Lip	Yes	60
November 8	327	Lip/Eye	Yes	45
November 8	433	Outside of Mouth	No	45
November 8	321	Lip, left	Yes	60
November 8	211	Eye	Lots	60
November 8	404	Lower Lip	Little	60
November 8	328	Gill	Yes	60
November 8	320	Out	No	60
November 8	445	Eye/Upper Lip	Yes	60
November 8	346	Roof Mouth	Yes	60
November 8	397	Throat/Jaw	Yes	45
November 9	330	Lower Jaw/Isthmus	Little	45
November 9	310	Isthmus	Yes	45
November 9	325	Lower Jaw/Lip	No	45
November 9	335	Lower Jaw	Yes	60
November 9	423	Lip	No	45
November 9	356	Upper Lip/ Right Eye	Yes	60
November 9	412	Lower Jaw	No	50
November 9	310	Upper Lip	Yes	60
November 9	320	Lip	No	60
November 10	430	Upper Lip	No	60
November 10	430	Left Lip	Yes	60
November 10	450	Upper Lip	Yes	120
November 10	342	Lower Lip	Yes	60
November 10	475	Upper Lip	No	45
November 11	460	Upper Lip Left	Yes	60
November 11	295	Upper Lip	Yes	35

-continued-

Date	Length	Hook Location	Bleeding	Time Out of Water (sec)
November 11	355	Upper Lip	Yes	60
November 11	318	Upper Lip	Yes	60
November 12	234	Upper Mouth	Yes	60
November 12	322	Upper Mouth	Yes	90
November 12	432	Upper Mouth	Yes	90
November 12	406	Upper Lip	No	90
November 12	340	Upper Isthmus	Yes	60
November 12	420	Upper Isthmus	Yes	60
November 12	401	Lower	Little	90
November 13	336	Lower Mouth	Yes	60
November 13	322	Lower Mouth	Yes	30
November 13	373	Lower Mouth	Yes	30
November 13	325	Up and Lower Lip	Yes	120
November 14	407	Upper Lip	Yes	30
November 14	338	Upper Lip/Eye	Yes	90
November 14	307	Up and Lower Lip	Yes	60
November 14	210	Lower Mouth	No	--
November 14	407	Upper Mouth	No	30
November 14	417	--	Yes	30
November 14	331	Upper Lip	Yes	60
November 15	465	Upper Mouth	No	90
November 15	440	Upper Lip	No	90
November 15	335	Upper and Lower Lip	Yes	60
November 15	423	Lower Lip	Yes	90
November 15	440	Lower Lip	Yes	120
November 16	345	Upper Lip	Yes	90
November 17	320	Upper Mouth	Yes	120
November 18	323	Upper Mouth	Yes	90
November 27	420	Snag/Gill	No	120
November 28	426	Upper Front Lip	Yes	60

-continued-

Appendix B.–Page 3 of 4.

Date	Length	Hook Location	Bleeding	Time Out of Water (sec)
March 21	395	Deep Mouth	Yes	90
March 22	373	Mouth	Yes	30
March 22	420	Corner Mouth	Yes	100
March 23	442	Mouth	No	45
March 23	400	Mouth	Yes	90
March 24	434	Corner Mouth	Yes	--
March 24	440	Upper Mouth	No	90
March 24	320	Mouth	Yes	45
March 24	330	Tongue	Yes	120
March 24	320	--	No	30
March 25	405	Right Mouth	Little	45
March 25	388	Mouth	Yes	30
March 25	419	Corner Mouth	Yes	30
March 25	331	Lip/Mouth	Yes	35
March 25	331	Mouth	Yes	30
March 26	330	Left Maxillary	Yes	60
March 26	460	Right Maxillary	No	35
March 26	412	--	Yes	30
March 26	329	Upper Lip	No	30
March 26	315	Upper Left Mouth	Yes	60
March 26	295	Left Maxillary	Yes	45
March 26	331	Left Lip Low	Yes	60
March 26	331	Upper Left Lip	Yes	45
March 27	317	Left Maxillary	No	20
March 27	447	Top Lip	No	60
March 27	280	Lower Lip	Yes	45
March 28	489	Top Lip	No	120
March 28	350	Lower Lip	Yes	20
March 28	405	Lower Lip	Yes	45
March 30	417	Top Lip	Yes	120

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Date	Length	Hook Location	Bleeding	Time Out of Water (sec)
March 31	480	Top Lip	Yes	60
March 31	365	Lower Lip	Yes	120
March 31	330	Upper Lip	Yes	90
March 31	425	Lower Lip	No	60
March 31	320	Mouth	No	45
April 1	350	Top Front Lip	Yes	45
April 1	333	Bottom Lip	Little	60
April 1	330	Mouth	Little	45
April 1	451	--	Yes	90
April 2	442	Left up and lower	No	120
April 2	413	Under Chin	No	20
April 3	510	Top and Bottom	Little	90
April 3	327	Lower Lip	Yes	180
April 4	322	Hook fell out	Yes	60