Fishery Data Series No. 24-14

Stock Assessment and Yield Potential of Lake Trout in Fielding Lake, 2021–2022

by

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and

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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)

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

A population assessment of lake trout *Salvelinus namaycush* in Fielding Lake was conducted in 2021–2022. Mark–recapture techniques were used to estimate the abundance and length composition for 2 populations of inference: (1) lake trout recruited to hook-and-line gear, and (2) all sexually mature lake trout. Marking events occurred 15–30 June and 15 September–4 October 2021, and a combined recapture event occurred 16–29 June 2022. Both populations of inference were estimated using Chapman's modification of the 2-event Petersen mark–recapture model for abundance estimation. Data from the June 2021 and June 2022 sampling events were used to evaluate fish recruited to hook-and-line gear. The estimated abundance for this population was 1,637 (SE = 240; 95% CI = 1,166–2,108) lake trout ≥353 mm fork length (FL) and 380 (SE = 79; 95% CI = 224–535) lake trout ≥600 mm FL. Lake trout 353–499 mm FL represented 49.3% (SE = 3.0%) of the estimated population, fish 375–599 mm FL accounted for 54.8% (SE = 3.0%), and 26.1% (SE = 2.7%) of the population was ≥600 mm FL. Data from the September 2021 and June 2022 events were used to evaluate sexually mature lake trout. For this population, 824 (SE = 140; 95% CI = 550–1,098) fish were ≥474 mm FL and 382 (SE = 80; 95% CI = 225–538) were ≥600 mm FL. Lake trout 474–599 mm FL represented 48.8% (SE = 3.9%) of the estimated spawning population and 51.2% (SE = 3.9%) were ≥600 mm FL. A total of 148 lake trout captured with unbaited hook-and-line gear during the June sampling events were weighed and their mean weight of 1.3 kg (SE = 0.09 kg) was used in the Lake Area (LA) model to estimate an annual yield potential of 91 lake trout under the current sport fishing regulations (daily bag and possession limit of 1 fish ≥26 in total length). Based on the estimated abundance and conservative (5%) and typical (10%) exploitation rates, it is recommended that total fishing mortality remain below 82–164 lake trout annually.

Keywords: lake trout, *Salvelinus namaycush*, Fielding Lake, mark–recapture, abundance, length composition, sustainable harvest level, length-weight relationship, lake area model, yield potential, Floy tag, PIT tag

INTRODUCTION

The purpose of this project was to obtain information on the lake trout *Salvelinus namaycush* population in Fielding Lake to evaluate current harvest levels and sport fishing regulations. Lake trout in Fielding Lake were last assessed during 2010–2011 (Schwanke 2013). Current estimates of abundance, length composition, and an updated determination of the allowable sustainable harvest level of lake trout in Fielding Lake were needed to address and evaluate regulatory proposals that fishery managers expected at the January 2023 Alaska Board of Fisheries (BOF) Arctic-Yukon-Kuskokwim (AYK) Finfish meeting.

Fielding Lake is in the Upper Delta River drainage and is a popular recreational destination (Figure 1). Anglers at Fielding Lake target Arctic grayling *Thymallus arcticus*, burbot *Lota lota*, and lake trout. Other fish species present include round whitefish *Prosopium cylindraceum,* and slimy sculpin *Cottus cognatus*. Access to the lake is from the Richardson Highway at milepost 200.5 via a 2-mile gravel road. A campground, public use cabin, and boat launch operated by the Alaska Department of Natural Resources are located on the north end of the lake. Numerous private cabins are along the northern and eastern shores. Situated within the Alaska Range at 906 m in elevation, the 538-hectare lake has several small inlets, a maximum depth of 23 m, and a single outlet that drains into the glacially fed Delta River. The lake begins to freeze by the middle of October and is usually ice-free by mid-June.

The sport fishery for lake trout in Fielding Lake is managed under the *Wild Lake Trout Management Plan* (5 AAC 74.040; Burr 2006). The overall objective of this plan is to maintain harvests of lake trout below defined maximum sustained yield thresholds and, where practical, promote simplicity and uniformity in regulations. For a given lake trout population, total fishing mortality is estimated from the annual Alaska Sport Fishing Survey (commonly known as the Statewide Harvest Survey [SWHS]) and compared to predicted allowable yields based on either location-specific studies or the Lake Area (LA) model (Evans et al. 1991). The LA model is believed to estimate sustainable annual harvest or yield potential (in kg of lake trout/year) based on lake surface area. The resulting biomass is converted to numbers of fish using an estimated average weight for harvested fish. When the annual guideline harvest level is consistently exceeded (e.g., 3 out of 5 years), the management plan recommends (1) further restricting the fishery without additional information, or (2) assessing the status of the spawning population to help gauge if the predicted yield potential is too conservative (i.e., harvest trends are in fact sustainable). Under current sport fishing regulations, the LA model recommends that annual harvests of lake trout in Fielding Lake should not exceed 91 fish ≥26 in total length (TL; ADF&G 2018).

Fielding Lake is one of the most intensively managed lake trout fisheries in Interior Alaska. Since 1985, progressively more restrictive regulatory actions have been enacted (Table 1). The current bag and possession limit is 1 lake trout ≥26 in TL (~600 mm FL), only 1 unbaited single-hook artificial lure or fly may be used, and fishing for lake trout and burbot is not permitted from 1–30 September.[1] Sport fishing effort in Fielding Lake has been relatively constant, averaging 1,002 angler-days annually from 2007–2021.[2] However, the annual SWHS does not apportion estimates of angler effort by fish species. Estimated catch, harvest, and total fishing mortality of lake trout during the same period has been more variable, with annual means of 234 fish caught, 28 fish harvested, and an estimated total fishing mortality of 49 fish (Table 1). Total fishing mortality includes harvest plus 10% of catch, which is believed to be a conservative estimate of catch and release mortality. The observed annual variability in catch and harvest estimates is likely due to the low number of anglers (i.e., responses) who report fishing this location.[3]

Assessments of the spawning male lake trout population in Fielding Lake were conducted during 1998–2000 and 2010–2011 (Table 2; Parker et al. 2001; Schwanke 2013). Schwanke (2013) believed the 1998–2000 abundance estimate was biased low because sampling did not occur throughout the entire spawning period; and after accounting for differences in study design and sampling, concluded that the population of spawning males did not undergo substantial changes in abundance between the 2 studies. Neither of the prior population assessments estimated spawning female abundance because lake trout males are present at spawning sites for a longer duration than females, and because some females may not spawn each year (i.e., skip-spawning; Martin and Olver 1980; Burr 1991, 1992; Binder et al 2015; Pinheiro et al. 2017). Estimating the number of spawning female lake trout would require increased sampling frequency and an experimental design that accounts for potential violations of the mark–recapture model assumptions (i.e., closure due to either skip-spawning or temporal variations in female spawning behavior; Schwanke 2013).

Although no change was apparent between the previous 2 lake trout abundance estimates in Fielding Lake, and recent catch and harvest data exhibited no discernable trend, public interest to liberalize the fishing regulations prompted the need for updated population information. The Fairbanks Fish and Game Advisory Committee (AC) submitted a proposal for consideration during the January 2023 BOF AYK Finfish meeting to remove the size limit restriction for lake trout in Fielding Lake. To evaluate this proposal and assess the efficacy of current and proposed

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[1] ADF&G. 2021. 2022 Northern Alaska sport fishing regulations summary. Alaska Department of Fish and Game, Juneau.

[2] Alaska Sport Fishing Survey database [Internet]. 1996– . Anchorage, AK: Alaska Department of Fish and Game, Division of Sport Fish (cited August 19, 2024). Available from: http://www.adfg.alaska.gov/sf/sportfishingsurvey/.

[3] Alaska Sport Fishing Survey estimates based on fewer than 12 responses are not used other than to document that sport fishing occurred at a location; estimates based on 12–29 responses can be useful in indicating relative orders of magnitude and for assessing long term trends; and estimates based on 30 or more responses are generally representative of levels of effort, catch, and harvest.

regulations, managers requested updated estimates of abundance, length composition, and yield potential for lake trout in Fielding Lake. This study aimed to provide this information and examine a broader portion of the population than was previously examined (i.e., lake trout recruited to hook-and-line gear and all sexually mature fish).

OBJECTIVES

The research objectives for this study were as follows:

1) Estimate the abundance of lake trout susceptible to capture with common sport fishing tackle during June 2021.
2) Estimate the length composition (in 25 mm length categories) of the lake trout population susceptible to capture with common sport fishing tackle during June 2021.
3) Estimate the abundance of sexually mature lake trout during September 2021.
4) Estimate the length composition (in 25 mm length categories) of the sexually mature lake trout population during September 2021.
5) Estimate the yield potential of lake trout in Fielding Lake, in terms of the number of fish.

METHODS

OVERVIEW

This study consisted of 2 independent abundance estimation experiments using 2-event Petersen mark–recapture techniques for a closed population: a June 2021–June 2022 experiment and a September 2021–June 2022 experiment (Seber 1982). The population of inference for the June–June abundance estimate was composed of lake trout large enough to be recruited into the sport fishery, which included immature and mature fish of both sexes. For the June sampling events, fish were captured using sport fishing gear and baited hookless jug lines immediately following ice-out, when angling for lake trout is generally considered to be "good." Length and weight data collected during the June–June experiment were used to estimate the lake trout yield potential for Fielding Lake using the LA model. The September–June experiment estimated the abundance of mature spawning lake trout. During the September marking event, fish were captured by beach seining at their spawning site periodically throughout the spawning period. The June 2022 sampling event served as the recapture event for both experiments.

Both experiments were designed to obtain unbiased abundance estimates by satisfying the following assumptions:

1) The population is closed (lake trout do not enter the population, via growth or immigration, or leave the population, via death or emigration, during the experiment).
2) All lake trout have a similar probability of capture in the first event or in the second event, or marked and unmarked fish mix completely between events.
3) Marking of lake trout does not affect the probability of capture in the second event.
4) Marked lake trout are identifiable during the second event.
5) All marked lake trout will be reported when recovered in the second event.

The experiments were designed to allow the validity of these assumptions to be ensured or tested. Diagnostic tests were used to identify heterogeneous capture probabilities (i.e., violations of

Assumption 2), and prescribed model selection procedures were followed in the event of such violations (Appendix A). Diagnostic tests are not available to evaluate Assumptions 1, 3, 4, and 5; instead, the experiments were designed to ensure that these assumptions were met, thereby avoiding potential biases. Sample sizes required for estimating abundance (Objectives 1 and 3) were determined using the methods of Robson and Regier (1964). The sample sizes to estimate length composition (Objectives 2 and 4) were determined using the methods of Thompson (1987).

SAMPLING METHODS

June 2021 and September 2021 (Marking Events)

During the June 2021 marking event, lake trout were captured from boats, using hook-and-line gear and baited hookless jug lines. Three 2-person crews captured and tagged fish over a 16-day period from 15 through 30 June. Hook-and-line sampling primarily consisted of trolling or casting spoons and vertically jigging soft baits (e.g., artificial tube or baitfish imitations). Up to 12 hookless jug lines, which have been used successfully in other lake trout projects (Scanlon 2010; Schwanke and Albert 2019), were deployed throughout the lake daily. The jug lines were constructed from a 45 cm section of PVC pipe encased in marine foam with a 10–20 m section of braided line hanging from the bottom of the foam float. A 15–25 cm piece of bait (herring or whitefish) was tied to the line with a noose knot. Jug lines were set each morning, checked periodically throughout the sampling day, and retrieved at the end of the day. Captured fish were gently guided into a rubber meshed dip net, placed in a tub filled with fresh water, and sampled immediately.

The September 2021 marking event consisted of 4 sampling periods conducted between 15 September and 4 October. A crew of 3–5 people captured lake trout using a beach seine (120 m long and 2.5 m deep) with a large bag in the center (3.7 m wide). One end of the seine was anchored to shore while the rest was deployed from a boat around an aggregation of lake trout, and then brought back to shore in a semicircle. To limit the disturbance to spawning fish, only 1–2 beach seine hauls were made per night. Captured fish were removed from the seine and held in a partially submerged net pen for sampling.

During both the June and September marking events, each unmarked captured lake trout was marked with an individually numbered internal anchor tag (primary mark; Model FD-94 Anchor Tag, Floy Tag Inc., Seattle, WA). A partial left pectoral (June) or left pelvic (September) fin clip was given as a secondary mark in case of tag loss. Additionally, a subset of 51 fish marked in June 2021 and all 114 fish marked in September 2021 received an individually numbered passive integrated transponder (PIT) tag (APT12 PIT tag, Biomark, Boise, ID). PIT tags were implanted in a standardized location in the left opercular musculature (i.e., cheek).

For each captured lake trout, the following information was recorded: date, capture location, gear type, length (mm FL), weight (June only), sex (September only), tag number and color, secondary mark type, recapture status (Y or N), and any other pertinent comments. Fish were weighed to the nearest 0.1 kg using a handheld scale and rubber mesh net bag, and in September, the sex of captured fish was determined through the expulsion of eggs or milt.

June 2022 (Recapture Event)

Sampling procedures for the June 2022 event were very similar to those employed during June 2021. Sampling occurred from 16–29 June for 14 days total. All captured lake trout were measured (mm FL), weighed, and examined for primary and secondary marks (Floy tags, PIT tags, and fin clips), and fish capture locations were recorded. All captured fish were also given a right pectoral fin clip to prevent resampling.

Evaluation of Assumptions

Assumption 1 (Population Closure)

Fielding Lake is a closed system for lake trout. Inlet and outlet streams exist but are not believed to be utilized by lake trout. The inlet streams are considered too small to serve as migration corridors for non-juvenile lake trout, and the outlet stream is generally shallow (i.e., <0.5 m in depth) and only flows for 3 km before its confluence with the heavily glaciated Phelan Creek (Figure 1).

Immigration through growth recruitment over the time frame of this study was expected to be negligible and within the range of measurement error. Previous population assessments did not report significant growth between sampling events (Parker et al. 2001; C. Schwanke, ADF&G, Division of Sport Fish Biologist, Glennallen, unpublished data). However, growth was evaluated in this study by comparing first and second event lengths for recaptured fish and, if significantly different, second event lengths were corrected to account for growth (see *Data Analysis* section).

Fish may have left the population of inference through fishing and natural mortality. Both sources of emigration were expected to occur at the same rate for marked and unmarked lake trout; therefore, abundance estimates were considered germane to the first event of each experiment.

Assumption 2 (Bias in Capture Probabilities)

The length of each captured fish was recorded along with the time and location to detect and correct for unequal probabilities of capture related to fish size, location, or time. Size-selective sampling was tested using Kolmogorov-Smirnov (KS) tests. The tests and possible actions for data analysis are outlined in Appendix A1. Capture probabilities relative to location or time were evaluated using consistency tests of the Petersen estimator (Seber 1982) and are outlined in Appendix A2. If stratification by size was required, capture probabilities were examined for each stratum, and total abundance and its variance estimate were calculated by summing strata estimates (Seber 1982). If stratification by location was required, a Darroch estimator was used (Darroch 1961).

Relative to the June–June experiment, the assumption of equal probability of capture was likely satisfied because sampling effort occurred throughout the entire lake using a wide variety of hook-and-line gear and baited hookless jug lines during both events. To distribute sampling effort, the lake was divided into 3 equal sized spatial strata (~180 ha each; Figure 2).

Relative to the September–June experiment, it was expected that not all mature lake trout in Fielding Lake would be subject to capture during the first event, which occurred during the spawning period (September–October 2021). However, this was negated because all mature fish were subject to capture during the second event (June 2022) when fish were captured using hook-and-line gear and baited hookless jug lines fished throughout the entire lake.

Assumption 3 (Handling Effects on Probability of Capture in the Second Event)

No handling or marking induced behavioral effects were anticipated due to the long hiatuses between events and because each fish was carefully handled during sampling. During the first event, if a fish appeared injured or overly stressed, it was measured but not tagged. During the second event, every fish was examined for a tag and partial pectoral or pelvic fin clips (i.e., primary and secondary marks). Hooking or capture mortality was considered low (i.e., ≤1%) because captured fish that showed signs of injury or stress were not tagged.

Assumptions 4 and 5 (Marked Fish are Identifiable Upon Recapture and Correctly Reported)

These assumptions were addressed by double marking each lake trout captured during the first event and instructing the sampling crews to closely examine all captured fish for tags and fin clips. Tag loss was identifiable if a fish was captured with an event specific secondary mark and no tag.

DATA ANALYSIS

Abundance (Objectives 1 and 3)

The following methods were used for each experiment. Prior to diagnostic testing (Appendix A), the marking and recapture lengths of all recaptured lake trout were examined for growth recruitment using paired t-tests at a significance level of 0.05. If significant growth was detected and the magnitude of the growth was more than what was allowable for measurement error, lengths of sampled fish in the second event were adjusted using a regression between the marking and recapture lengths that allowed growth to vary with fish size.

A 2-step approach was then used to determine whether size or spatial stratification was necessary and the appropriate method to estimate abundance. First, differences in capture probability related to fish size were examined using KS tests (Appendix A1). Once these tests were performed, spatial selectivity and mixing were examined using contingency table analyses (Appendix A2). These series of tests are described below and were also used to evaluate Assumption 2. Note: for statistical analyses discussed through this report, the nomenclature of the corresponding reference cited is used; notation will vary depending on the analysis discussed (e.g., marked fish in the first event = M = n_1, captured fish in the second event = C = n_2, tagged fish recaptured in the second event = R = m_2).

KS tests to examine size-selective sampling and possible outcomes of this testing are outlined in Appendix A1. Cases I–III call for no stratification by size. If stratification by size was required (Case IV), different stratification schemes were evaluated to determine the appropriate length strata. Length strata were selected by stratifying where the KS D-statistic was the highest (i.e., where the most separation occurred between 2 cumulative length frequency distribution curves). The KS tests were then reevaluated for each stratum until either Case I, II, or III was achieved.

Consistency tests to determine if a spatially stratified estimator was needed and which abundance estimator was appropriate (i.e., Chapman's [1951] estimator or the Darroch [1961] estimator) are outlined in Appendix A2. Fielding Lake was divided into 3 spatial strata for diagnostic testing (Figure 2). Assumption 2 was satisfied if at least 1 of 3 consistency tests outlined in Appendix A2 failed to reject the associated null hypothesis. In this case, Chapman's (1951) estimator was appropriate. If all 3 of the consistency tests rejected the null hypothesis, the methods of Darroch (1961) were used to compute an abundance estimate.

If size stratification and spatial stratification were not necessary, a pooled abundance estimate was calculated using Chapman's (1951) estimator (Seber 1982). This was calculated using:

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

where:

$\widehat{N}$ = the estimated abundance of lake trout in Fielding Lake;

n_1 = the number of lake trout marked and released during the first event;

n_2 = the number of lake trout examined for marks during the second event; and

m_2 = the number of marked lake trout recaptured in the second event.

The variance of this estimator was calculated as (Seber 1982):

$$\hat{V}(\widehat{N}) = \frac{(n_1+1)(n_2+1)(n_1-m_2)(n_2-m_2)}{(m_2+1)^2(m_2+2)} \tag{2}$$

If size or complete spatial stratification were necessary, Equations 1 and 2 were used for each size or spatial stratum. The resulting abundance estimates and associated variances were then summed to obtain an overall abundance estimate (Seber 1982).

Length composition (Objectives 2 and 4)

To estimate length compositions, results from the diagnostic KS tests for size-selective sampling (Appendix A1) were used to determine if stratification was necessary and if data from the first, second, or both events should be used. For Cases I–III (Appendix A1), stratification was not necessary and length proportions (25 mm FL categories) and variances of proportions were estimated from the event(s) without size selectivity using (Cochran 1977):

$$\hat{p}_k = \frac{n_k}{n} \tag{3}$$

where:

$\hat{p}_k$ = the estimated proportion of lake trout that are within length category k;

n_k = the number of lake trout sampled that are within length category k; and

n = the total number of lake trout sampled.

The unbiased variances of these proportions were estimated as (Cochran 1977):

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

If diagnostic tests indicated Case IV (Appendix A1), where size selectivity was present during both events, the data were stratified to eliminate variability in capture probabilities within strata for one or both sampling events. Formulae to adjust length composition estimates are presented in Appendix A1 (Equations 1–2).

Lake area model (Objective 5)

The LA model (Evans et al. 1991) was used to estimate yield potential of Fielding Lake as:

$$\log_{10}(\widehat{YP}) = 0.60 + 0.72\log_{10}(a) \tag{5}$$

where:

$\widehat{YP}$ = estimated yield potential in kg biomass per year; and

a = lake area in ha.

Assuming yield potential in kg biomass per year is a constant and that the average weight of lake trout is normally distributed, the approximate average yield potential (delta-method; Seber 1982; Casella and Berger 2002) for Fielding Lake, in terms of number of lake trout, was calculated as:

$$\widehat{YP}_n \approx \frac{\widehat{YP}}{\widehat{W}} \tag{6}$$

where:

$\hat{W}$ = estimated sample mean of the weights of lake trout (in kg per fish).

The approximate variance was estimated as:

$$\hat{V}(\widehat{YP_n}) \approx \frac{\widehat{YP}^2}{\widehat{W}^4}\,\hat{V}(\widehat{W}) \tag{7}$$

RESULTS

SUMMARY OF FISH CAPTURED

There were 204 unique lake trout sampled during June 2021, 114 during September 2021, and 332 during June 2022. Thirty-two (32) fish marked in June 2021 were recaptured in June 2022, and 22 of the fish marked in September 2021 were recaptured in June 2022 (Table 3). Lengths of all lake trout sampled during the June 2021 and 2022 events ranged between 296 and 845 mm FL. The mean lengths of sampled fish in June 2021 and 2022 were 532 mm FL (SD = 123) and 505 mm FL (SD = 118), respectively (Figure 3). Fish sampled in September 2021 ranged between 476 and 827 mm FL, with a mean FL of 626 mm (SD = 84; Figure 3). In June 2022, lengths of recaptured fish marked in June 2021 ranged from 385 to 831 mm FL, and fish marked in September 2021 ranged from 474 to 802 mm FL. A sub-sample of 48 lake trout captured in June 2022 were measured for both FL and TL to establish a stock specific linear regression to convert between these units of measure (Figure 4).

In both experiments, loss of the primary mark (Floy tag) was insignificant. One recaptured fish lost its Floy tag. The fish was identified as a recapture by the presence of the September 2021 secondary mark, and it had a PIT tag. An additional fish that was also marked with both tags was recaptured and found to have lost the PIT tag but not the Floy tag. No other evidence of tag loss was observed by sampling crews.

During the June sampling events, 86% of fish were captured with hook-and-line gear and 14% with baited hookless jug lines. All September 2021 fish were captured at the spawning area with a beach seine. Only fish sampled during the June events were weighed. A Kruskal-Wallis rank sum test showed that there was at least one significant difference between the median weights of fish caught with different gear types (i.e., unbaited lure, baited lure, or baited hookless jug line; $\chi^2 = 106.09$, df = 2, $P < 0.001$).[4] Results of a nonparametric multiple comparisons test indicated

[4] The R project for statistical computing. Version 4.0.4. Vienna, Austria. https://www.R-project.org/.

that fish captured with different gear had significantly different median weights (Siegel and Castellan 1988).[5,6] Box plots of the data show that the median weight of fish captured with baited hookless jug lines was greater than that of fish captured with baited lures, which in turn was greater than that of fish captured with unbaited lures (Figure 5).

ABUNDANCE (JUNE 2021–2022, OBJECTIVES 1–2, 5)

Growth Recruitment

Evidence of significant growth between sampling events was detected ($t = -5.03$, $df = 31$, $P < 0.001$; Figure 6). Growth between events was accounted for by adjusting the lengths of fish captured during the June 2022 event using a linear regression fit to paired first and second event lengths of recaptured fish (Figure 7; Gulland 1969). Adjusted second event lengths reflect the size of the fish at the time of the first event in June 2021. First event and adjusted second event lengths were used for all subsequent diagnostic testing and analysis. No adjustments for growth were necessary for recaptured fish, because first event lengths were available.

Diagnostic Tests Relative to Size and Spatial Stratification

KS tests on fish ≥353 mm FL (the first event length of the smallest recaptured fish) and KS tests on fish ≥390 mm FL (18 in TL) did not provide sufficient evidence for size stratification. A Case III scenario (i.e., size selectivity in the first event) was concluded for fish ≥353 mm FL, and a Case I scenario (no size selectivity) was concluded for fish ≥390 mm FL (Table 4, Appendix A1). However, a clear separation was present near 500 mm FL in the cumulative length frequency distributions of both marked versus recaptured (M vs. R) and captured versus recaptured (C vs. R) fish (Figure 8). Additional KS tests were performed for fish ≥500 mm, and these tests concluded a Case I scenario with no size selectivity detected in either event (Table 4, Appendix A1). Based on prior studies, 500 mm FL is the length at which most lake trout in Fielding Lake are sexually mature (Parker et al. 2001; Schwanke 2013). Finally, fish ≥600 mm FL were also examined. This stratum corresponded to the current sport fishing minimum length limit of 26 in TL. KS test results for fish ≥600 mm FL had larger P-values and didn't provide sufficient evidence for further size stratification (Case I scenario; Table 4).

Consistency tests indicated that spatial stratification was also unnecessary for the examined length strata (Appendix A2). The complete mixing test was examined for all cases. However, these tests failed to meet the assumptions for chi-square tests due to small sample sizes, and therefore had inconclusive results. The tests for equal probability of capture indicated that equal probabilities of capture were achieved in both events for all cases (Tables 5–7), except for chi-square tests for fish ≥600 mm FL, which had inconclusive results because of small sample sizes.

The geographic distribution of fish marked in the first event (n_1), examined in the second event (n_2), and the movement of recaptured fish (m_2), illustrate the efforts made to distribute tags and sampling effort throughout the lake (Figure 9). Some recaptured fish moved completely across the lake, while others had almost no detectable movement.

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5 The R project for statistical computing. Version 4.0.4. Vienna, Austria. https://www.R-project.org/.

6 Package pgirmess: Spatial analysis and data mining for field ecologists. R package version 1.7.1. https://cran.r-project.org/web/packages/pgirmess/index.html.

Abundance Estimate (Objective 1)

Results from diagnostic tests indicated that neither size nor spatial stratification was necessary for most size categories. Therefore, Chapman's (1951) estimator, using the pooled data from both sampling events, was used to estimate abundance. Estimated abundance of lake trout ≥353 mm FL was 1,637 fish (SE = 240) with a 95% confidence interval (CI) of 1,166–2,108 fish. Table 8 presents abundance estimates and 95% CI for lake trout ≥390, ≥500, and ≥600 mm FL.

Because the chi-square tests for fish ≥600 mm FL had inconclusive results, we also estimated abundance for this category using the methods of Darroch (1961) and by combining spatial strata (Areas-B and -C). The resulting abundance estimate was very similar to Chapman's (1951) estimator. Chapman's (1951) estimator provided a more conservative point estimate and was simpler to compute; therefore, we deemed geographic stratification unnecessary.

Length Composition (Objective 2)

Because diagnostic tests detected size selectivity for lake trout ≥353 mm FL during the first event but not in the second event (i.e., Case III scenario; Table 4), an overall estimate of the length composition for lake trout ≥350 mm FL was made using the corrected lengths from the second event (Figure 10). Fish with lengths 353–499 mm FL composed an estimated 49.3% (SE = 3.0%) of the population, and fish ≥600 mm FL made up 26.1% (SE = 2.7%). Lake trout ≥800 mm FL were present but only composed 2.6% (SE = 1.0%) of the estimated population. All proportion estimates attained the absolute precision goal of 0.10.

YIELD POTENTIAL (OBJECTIVE 5)

The LA model indicated a lake trout annual yield potential of 368.27 kg from Fielding Lake. This biomass estimate was converted to numbers of fish using the mean weight of fish captured with unbaited hook-and-line gear during the June 2021 and 2022 sampling events. Only fish captured with unbaited hook-and-line gear were used because current sport fishing regulations prohibit the use of bait at Fielding Lake. A total of 148 lake trout were captured by this means and weighed; fish had a mean weight of 1.3 kg (SE = 0.09) and 11 fish were at least 26-inch TL. The length-weight relationship for these fish is shown in Figure 11. Under the current sport fishing regulations of a bag and possession limit of 1 fish ≥26 in TL (~600 mm FL), and making assumptions of normality, the estimated annual yield potential for lake trout in Fielding Lake was 91 fish. With no minimum size limit, the estimated annual yield potential increased to 284 lake trout (Table 9; Evans et al. 1991; Casella and Berger 2002).

ABUNDANCE (SEPTEMBER 2021)

Growth Recruitment

No evidence was found that significant growth occurred between the September 2021 and June 2022 sampling events for recaptured fish ($t = -1.91$, $df = 21$, $P = 0.07$). Therefore, correcting second event lengths for growth was not required. Average growth between the sampling events was 2 mm FL (SE = 1).

Diagnostic Tests Relative to Size and Spatial Stratification

KS tests on lake trout ≥474 (the first event length of the smallest recaptured fish), ≥500, and ≥600 mm FL were performed using first event recapture lengths (Table 10, Appendix A1). All size categories had KS test results that may indicate a Case IV scenario (i.e., size selectivity during both sampling events, further stratification required). However, further stratification was not possible due to small sample sizes, so a Case III scenario was deemed the most appropriate. First event capture methods (i.e., beach seining the spawning area), undoubtedly selected for larger, sexually mature individuals. Additionally, size selectivity was not detected for fish ≥500 or ≥600 mm FL during the second event of the June 2021–June 2022 experiment, which also served as the second event for the September 2021–June 2022 experiment (Table 4).

Some of the consistency tests to examine mixing and capture probabilities could not be conducted because all fish were marked in the same location (i.e., the spawning area is in section B) during the first event (Figure 2). This rendered the chi-square tests inconclusive due to empty matrix cells (Appendix A2), so chi-square goodness-of-fit tests were performed in their place (Tables 11–13). Consistency tests indicated that spatial stratification was not necessary for fish ≥474 mm FL because equal probability of capture was achieved during the first event (Table 12). However, chi-square test results indicated that spatial stratification was necessary for fish ≥500 mm FL, and results for fish ≥600 mm FL were inconclusive because test assumptions were not met (Table 12). No evidence was found that equal probability of capture was achieved for any of the size categories in the second event (Table 13). Use of Darroch's (1961) estimator for fish ≥500 and ≥600 mm FL did not provide more reasonable abundance estimates, primarily because the movement matrices were non-invertible. Consequently, spatial stratification was deemed unnecessary for all length strata.

Mixing of marked and unmarked fish between sampling events was also assessed by examining the proportions of fish examined (n_2) and recaptured (m_2) in each spatial strata during the second event as well as plotting the capture locations of examined and recaptured fish (Table 14, Figure 12). Both methods indicated that incomplete mixing likely occurred between sampling events.

Abundance Estimate (Objective 3)

Results from diagnostic tests indicated that neither size nor spatial stratification was necessary, or in some cases, possible to perform. Therefore, Chapman's (1951) estimator, using the pooled data from both sampling events, was used to estimate abundance. Estimated abundance of lake trout ≥474 mm FL was 824 fish (SE = 140) with a 95% CI of 550–1,098 fish. Table 15 presents abundance estimates and 95% CI for lake trout ≥500 and ≥600 mm FL.

Length Composition (Objective 4)

Based on the KS test results, a Case III scenario (i.e., size selectivity detected in the first event) was deemed appropriate for fish ≥474 mm FL (Table 10). To make an overall estimate of the length composition of mature lake trout ≥475 mm FL, only data from the second sampling event was used (Figure 13). Lake trout from 474–599 mm FL composed an estimated 48.8% (SE = 3.9%) of the population, with fish ≥600 mm FL making up 51.2% (SE = 3.9%). Fish ≥800 mm FL only accounted for 3.0% (SE = 1.3%) of the population. All proportion estimates attained the absolute precision goal of 0.10.

DISCUSSION

This study produced the first abundance estimates for lake trout fully recruited to the sport fishery (June–June experiment) and for all sexually mature lake trout (September–June experiment) in Fielding Lake. Although previous studies by Parker et al. (2001) and Schwanke (2013) provided valuable estimates of male spawning abundance, this study's estimates of abundance and size composition were germane to a substantially larger portion of the population. These data can be used to assess the sustainability of future catch and harvest trends and proposed regulatory changes, and provide managers with more and better information to evaluate the sustainability of the lake trout fishery in Fielding Lake under the guidelines outlined in the *Wild Lake Trout Management Plan* (5 AAC 74.040; Burr 2006).

Abundance estimates were compared to current SWHS data to explore lake trout exploitation. The estimated abundance of lake trout ≥353 mm FL (i.e., fish fully recruited to hook and line) in Fielding Lake was 1,637 fish (SE = 240). Total fishing mortality was estimated using the SWHS estimates of harvest plus 10% of the reported catch after subtracting harvest (Table 1). Using these data, the average annual exploitation rate for 2017–2021 was 1.7% and ranged between 0.8–3.4%. Fishery managers believe that the lake trout sport fishery is sustainable if the total exploitation rate remains below 10% annually (ADF&G 2022). However, caution should be used when interpreting or basing management decisions on exploitation rates derived from SWHS data because, since 2016, too few people (i.e., <12 respondents) reported fishing at Fielding Lake to generate reliable estimates. SWHS estimates for resident fish species require a minimum of 12 respondents to achieve acceptable precision levels (Clark 2009). The SWHS data was used in this instance because no alternative data describing sport fishing effort, catch, and harvest of lake trout was available for Fielding Lake.

Neither the June nor September abundance estimates attained the relative precision goals of 0.25 (Tables 8 and 15). This occurred because of insufficient sample sizes in the first events (June 2021 and September 2021) of both experiments. Specific to the June abundance estimate, post-hoc analysis indicated that if the first event sample size was closer to that of the second event (approximately 100 additional fish), the relative precision goal would have been achieved or exceeded. Relative to the September 2021 sampling event, prolonged periods of strong northerly winds and below freezing temperatures prevented beach seining at the spawning site regularly, impacting the total number of fish captured and marked.

Length-weight data collected during this study and the LA model were used to generate updated estimates of yield potential. Only data for fish captured with unbaited hook-and-line gear were used in the LA model, because it provided the best approximation of the size composition of fish captured by anglers at Fielding Lake. Under the regulatory scenario of 1 lake trout of any size bag and possession limit (the regulation outlined in the recent BOF proposal), LA model annual yield estimates for Fielding Lake were 368.27 kg or 284 fish. This yield is inappropriately high when compared to the abundance estimates from this study. If total fishing mortality were to reach that predicted yield, it would result in an exploitation rate of 17.3%, which is much higher than the 10% exploitation rate preferred by managers. Annual harvests of this magnitude would likely be unsustainable at Fielding Lake given the abundance estimates provided by this study.

Although it is beyond our ability to directly assign causation, the length frequency distribution of fish captured during this study suggested a possible recruitment failure corresponding to the timing of the 2010–2011 ADF&G sampling project at Fielding Lake. An unexpectedly low number of fish 425–575 mm FL were captured during the June sampling events (Figure 3). This anomaly was identified after the 2021 field season and was most pronounced for fish 450–499 mm FL. Lake trout in some Alaskan lakes can reach 400 mm FL in just 5 years; however, on average, they require more than 10 years to reach 400 mm FL (Burr 1997). This raised concerns that the previous stock assessment completed in 2010–2011 may have negatively affected spawning success.

Sampling only occurred at the spawning area during the spawning period (September) in those years, and progeny from the 2010–2011 spawning seasons would have been 10–11 years old at the onset of this study, and most likely in the size range most underrepresented in our June 2021 sample. Further examination of a limited number of length-at-age samples collected from Fielding Lake and other lakes in the vicinity (i.e., Lower Tangle and Sevenmile Lakes) indicated that age-10 through age-12 lake trout had a mean length of 481 mm FL (M. L. Albert, ADF&G, Division of Sport Fish Biologist, Fairbanks, unpublished data), which also directly corresponded to the 450–499 mm FL length class (Figures 3 and 10). Because of this, and out of an abundance of caution, spawning abundance for this study was estimated using sampling events conducted in September 2021 and June 2022 instead of during 2 consecutive spawning seasons as was typically done during previous assessments.

Comparisons between assessments should be made with caution because of the differing study designs, but estimates of sexually mature fish produced by this study were substantially higher than previous estimates (Parker et al. 2001; Schwanke 2013). The observed differences may exist for several reasons. First, prior spawning abundance estimates may have been biased low. This is possible if spawning occurred at additional unknown locations within Fielding Lake or at the known spawning site in water that was too deep for effective fish capture with the sampling gear (i.e., beach seine). Under this scenario, a substantial proportion of the spawning population would have been excluded from the experiment, violating a key assumption of a 2-event Petersen mark–recapture model for closed populations and resulting in a biased low estimate. However, it was unlikely that any fish were excluded from sampling during this study because at least 1 sampling event from both experiments occurred in June, which was well outside of the spawning period. A second explanation for the observed difference is that spawning abundance did indeed increase since the 2010–2011 stock assessment. At Fielding Lake, overall sport fishing effort, lake trout harvest, and total fishing mortality have decreased in recent years, while catch has remained similar (Table 1). This indicates that the number of fish caught at Fielding Lake per unit of effort has increased without any concurrent changes to the sport fishing regulations that would make anglers more effective (e.g., allowing the use of bait), which is evidence that the lake trout population has likely increased. The improved methodology used in this study (i.e., June–June experiment timing and expanding the population of inference to include all fish susceptible to hook-and-line gear) and the similar abundance estimates of sexually mature fish generated between the June–June and September–June experiments lend greater confidence to this conclusion.

This study provided new insights that will be useful when selecting future lake trout regulations and assessment methodologies. During the September 2021 marking event of the September–June experiment, sex was determined for all sampled fish. This allowed for the calculation of second event (June 2022) capture probabilities by sex (Appendix A2). Interestingly, all female lake trout recaptures in June 2022 from the September 2021 marking event occurred on or after the summer solstice, and we found that female lake trout ≥600 mm FL may have a higher probability of capture than similarly sized males in June after the summer solstice (Table 16). This observation is supported by a Canadian study examining the seasonal dynamics of lake trout gonad development (J. M. Casselman, Adjunct Professor, Queen's University, Kingston, Ontario, 2002, unpublished data and manuscript). The study found gonad development and associated activity and feeding increased after the summer solstice, resulting in mature female lake trout being caught and harvested at a much higher rate than their relative abundance within the population. Sport fishing regulations that restrict retention to larger lake trout (e.g., ≥26 in TL), like those currently in place for Fielding Lake, may inadvertently result in a disproportionate harvest of large sexually mature female fish during much of the open-water season. However, more study is required to conclude this for Alaska's lake trout populations because we had small sample sizes of larger fish in this study, the September sampling event during spawning was biased towards males, and only data from Fielding Lake was examined.

Finally, our study explored the use of PIT tags as a primary marking method for lake trout. Recaptured lake trout could have had 1 of 3 possible capture histories: (1) June 2021–June 2022; (2) June 2021/September 2021–June 2022; or (3) September 2021–June 2022. All PIT tagged fish that were recaptured retained their PIT tags except for 1 fish that followed the third capture history. Similarly, only 1 Floy tagged fish that followed the second capture history lost its tag. In both cases, the fish were identified because they had been double marked with uniquely identifiable tags (i.e., Floy and PIT) and retained 1 of the marks. While a more detailed examination of the efficacy and retention rates of PIT tags implanted in the opercular musculature of lake trout would be useful, these initial observations strongly suggest that PIT tags are an acceptable alternative to Floy tags in some scenarios.

RECOMMENDATIONS

Based on applying both conservative (5%) and typical (10%) exploitation rates to the abundance estimate of lake trout ≥353 mm FL recruited to the sport fishery in Fielding Lake, it is recommended that total fishing mortality remain below 82–164 fish annually. The most recent 5-year (2017–2021) average of total fishing mortality was 28 fish (Table 1). Although this estimate is unreliable because too few anglers report fishing at Fielding Lake for meaningful analysis, the low level of effort compared to previous years indicates that there is opportunity to liberalize the sport fishing regulations for lake trout.

The abundance estimates produced by this study provide information for fishery managers to identify conservative population management thresholds (i.e., a maximum allowable exploitation rate) and should be used to assess the sustainability of future effort, catch, and harvest trends as well as any proposed regulatory changes. Typically, the LA model provides a conservative approach for managing a lake trout population when abundance information is not available. For example, at Chandler and Little Chandler Lakes, the LA model yield potential estimate equated to an exploitation rate of ≤7% based on a recent abundance estimate (Schwanke and Albert 2019). However, at Fielding Lake, the LA model yield potential estimate resulted in an exploitation rate that would be unsustainable in the long term (17.3%). This illustrates the importance of not relying solely on the LA model when making decisions about popular lake trout fisheries.

The use of bait and baited lures can affect the average size of lake trout caught in a sport fishery. This study showed that the use of bait or baited lures captures larger lake trout on average than unbaited lures (Figure 5). Where allowed, the use of bait and baited lures would likely result in increased average weights of harvested fish and thus a decrease in the total number of fish that can be sustainably harvested according to the LA model. Fishery managers should consider this when examining the potential effects of regulations that allow or prohibit the use of bait and baited lures in a sport fishery.

Regular assessments of the lake trout population in Fielding Lake should continue. These will become especially important if the sport fishing regulations are liberalized. Due to the slow growing nature of lake trout, and the already restrictive sport fishing regulations currently in place at Fielding Lake, a reasonable interval between population estimates is 10 years. Population assessments should be conducted sooner if total fishing mortality from SWHS estimates regularly exceed a 10% exploitation rate, or if there are frequent angler reports of large changes in perceived abundance and size composition.

Future population assessments should follow the June–June study design. This will provide data to identify population changes much sooner than if the population of inference is limited to sexually mature fish. It will also eliminate any negative effects to the population caused by sampling fish during the spawning period. Lake trout population assessments at Fielding Lake or elsewhere should also incorporate the use of hookless baited jug lines as a sampling gear to help ensure adequate sample sizes of larger fish. Additionally, researchers should be aware of the potential biases that may be related to differences in the capture probabilities of male and female lake trout, especially when baited sampling gears are employed.

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TABLES AND FIGURES

Table 1.–Estimated sport fishing effort (angler-days), lake trout harvest and catch, total fishing mortality, and sport fishing regulations for lake trout in Fielding Lake, 1981–2021.

Year	Respondents[a,d]	Effort[b,d]	Harvest[d]	Catch[d]	Total fishing mortality[c]	Sport fishing regulations
1981	48	1,369	295	–	–	- 10 fish bag and possession limit, only 2 fish larger than 20 inches - setlines permitted
1982	56	2,764	364	–	–	
1983	36	1,737	294	–	–	
1984	16	871	169	–	–	
1985	14	1,023	347	–	–	- 10 fish bag and possession limit, only 2 fish larger than 20 inches - setlines prohibited - bait allowed
1986	25	1,682	136	–	–	
1987	12	1,032	127	–	–	
1988	21	1,728	364	–	–	
1989	37	1,664	195	–	–	- 2 fish bag and possession limit, 18-inch minimum size - setlines prohibited - bait allowed
1990	33	1,255	186	321	200	
1991	34	1,572	295	870	353	
1992	41	1,910	170	247	178	
1993	41	1,827	276	939	342	
1994	40	2,129	52	213	68	- 1 fish bag and possession limit, 22-inch minimum size - setlines prohibited - bait allowed
1995	46	3,575	44	486	88	
1996	23	960	42	260	64	
1997	23	1,259	55	270	77	
1998	25	1,601	19	300	47	
1999	25	1,154	43	279	67	
2000	20	827	18	221	38	
2001	17	525	12	106	21	- Open season, 1 Oct–31 Aug - 1 fish bag and possession limit, 26-inch minimum size - setlines prohibited - bait allowed - single-hook only
2002	18	826	0	137	14	
2003	17	840	83	423	117	
2004	15	1,010	101	520	143	
2005	17	1,248	112	862	187	
2006	16	1,065	108	634	161	
2007	16	1,139	40	227	59	- Open season, 1 Oct–31 Aug - 1 fish bag and possession limit, 26-inch minimum size - setlines prohibited - bait prohibited - single-hook artificial lures only
2008	17	1,203	7	103	17	
2009	15	788	18	552	71	
2010	20	1,548	48	309	74	
2011	7	422	2	12	3	
2012	14	1,163	64	299	88	
2013	9	1,545	161	335	178	
2014	9	714	0	145	15	
2015	15	1,732	32	291	58	
2016	14	992	21	117	31	
2017	10	1,108	29	286	55	
2018	8	551	0	165	17	
2019	7	805	0	134	13	
2020	10	726	0	315	32	
2021	7	595	0	220	22	

-continued-

Table 1.–Page 2 of 2.

Year	Respondents[a,d]	Effort[b,d]	Harvest[d]	Catch[d]	Total fishing mortality[c]	Sport fishing regulations
2007–2021 Average	12	1,002	28	234	49	
2017–2021 Average	8	757	6	224	28	

[a] Estimates based on fewer than 12 respondents are only used to document that sport fishing occurred; estimates based on 12–29 respondents can be useful in indicating relative orders of magnitude and assessing long term trends; and, estimates based on 30 or more respondents are generally representative of levels of effort, catch, and harvest.

[b] Sport fishing effort is measured in number of days fished and is not apportioned by species.

[c] Total fishing mortality includes estimated catch-and-release mortality and equals harvest + 10% of the catch after subtracting the harvest.

[d] Alaska Sport Fishing Survey database [Internet]. 1996– . Anchorage, AK: Alaska Department of Fish and Game, Division of Sport Fish. Available from http://www.adfg.alaska.gov/sf/sportfishingsurvey/.

Table 2.–Historical estimates of lake trout abundance in Fielding Lake, 1999 and 2010.

Year	Population of inference	Estimated abundance	SE	95% CI
1999[a]	mature males	193	35	124–262
2010[b]	mature males	299	25	250–347
	males ≥500 mm FL	270	23	225–315
	males ≥600 mm FL	125	12	102–148
	mature males; truncated 2010–2011 data to 1998–2000 sampling dates	189	29	132–245

[a] Parker, J. F., B. Scanlon, and K. Wuttig. 2001. Abundance and composition of lake trout in Fielding (1999) and Island Lakes. Alaska Department of Fish and Game, Fishery Data Series No. 01-31, Anchorage.

[b] Schwanke, C. J. 2013. Stock assessment of lake trout in Fielding Lake, 2010–2011. Alaska Department of Fish and Game, Fishery Data Series No. 13-55, Anchorage.

Table 3.–Summary of lake trout captured in each sampling event at Fielding Lake, 2021–2022.

	Captured and sampled			Recaptured from June 2021			Recaptured from September 2021		
Event	All fish	≥500 mm FL	≥600 mm FL	All fish	≥500 mm FL	≥600 mm FL	All fish	≥500 mm FL	≥ 600 mm FL
June 2021	204	125	73	–	–	–	–	–	–
September 2021	114	111	62	–	–	–	–	–	–
June 2022	332	149	84	32	22	15	22	20	13

Table 4.–Results of diagnostic Kolmogorov-Smirnov (KS) tests used to detect and correct for size-selective sampling (Appendix A1) for estimating abundance and length composition of lake trout in Fielding Lake, June 2021–June 2022.

		Comparison		
Size strata		M vs. R (2nd event test)	C vs. R (1st event test)	M vs. C (1st vs. 2nd event test)
≥353 mm FL	Test statistic *D*	0.142	0.261	0.153
	P-value	0.636	0.040	0.009
	Interpretation	No size selectivity detected	Size selectivity detected	Size selectivity detected
	Overall interpretation and recommended action	Case III: Size selectivity detected in the 1st event but not in the 2nd event. Calculate abundance using entire data set without stratification. Estimate composition parameters using 2nd event data.		
≥390 mm FL	Test statistic *D*	0.195	0.244	0.095
	P-value	0.335	0.119	0.369
	Interpretation	No size selectivity detected	No size selectivity detected	No size selectivity detected
	Overall interpretation and recommended action	Case I: No size selectivity detected in either the 1st or 2nd event. Calculate abundance using entire data set without stratification.		
≥500 mm FL	Test statistic *D*	0.153	0.197	0.087
	P-value	0.773	0.453	0.697
	Interpretation	No size selectivity detected	No size selectivity detected	No size selectivity detected
	Overall interpretation and recommended action	Case I: No size selectivity detected in either the 1st or 2nd event. Calculate abundance using the entire data set without stratification.		
≥600 mm FL[a]	Test statistic *D*	0.254	0.157	0.132
	P-value	0.475	0.949	0.556
	Interpretation	No size selectivity detected	No size selectivity detected	No size selectivity detected
	Overall interpretation and recommended action	Case I: No size selectivity detected in either the 1st or 2nd event. Calculate abundance using the entire data set without stratification.		

Note: FL = fork length.

[a] This size category might not have enough power. Case I or Case II seem reasonable looking at the cumulative length frequency curves. No size strata seem appropriate if interpreted as Case IV. Therefore, abundance was calculated using the entire data set without stratification.

Table 5.–Test for complete mixing. Number of lake trout ≥353, ≥390, ≥500, and ≥600 mm fork length (FL) marked, recaptured, or not recaptured in each section (A–C) in Fielding Lake, June 2021–June 2022.

Length strata	Section marked	Section recaptured A	B	C	Not recaptured (n_1-m_2)	Total marked (n_1)
≥353 mm FL	A	12	6	2	98	118
	B	3	8	0	47	58
	C	0	1	0	20	21
	Total	15	15	2	165	197
	χ^2 = 8.92, df = 6, P-value = 0.178, fail to reject H_0					
		A	B	C	Not recaptured (n_1-m_2)	Total marked (n_1)
≥390 mm FL	A	11	6	2	93	112
	B	3	5	0	39	47
	C	0	0	0	16	16
	Total	14	11	2	148	175
	χ^2 = 6.09, df = 6, P-value = 0.413, fail to reject H_0					
		A	B	C	Not recaptured (n_1-m_2)	Total marked (n_1)
≥500 mm FL	A	10	4	1	72	87
	B	3	4	0	22	29
	C	0	0	0	9	9
	Total	13	8	1	103	125
	χ^2 = 5.46, df = 6, P-value = 0.487, fail to reject H_0					
		A	B	C	Not recaptured (n_1-m_2)	Total marked (n_1)
≥600 mm FL	A	4	3	1	35	43
	B	1	4	0	18	23
	C	0	0	0	7	7
	Total	5	7	1	60	73
	χ^2 = 4.52, df = 6, P-value = 0.607, fail to reject H_0					

Table 6.–Test for equal probability of capture during the first event for lake trout ≥353, ≥390, ≥500, and ≥600 mm fork length (FL). Number of marked and unmarked lake trout examined during the second event by lake section (A–C) in Fielding Lake, June 2021–June 2022.

		Section where fish examined			
Size strata	Category	A	B	C	All sections
≥353 mm FL	Recaptured (m_2)	15	15	2	32
	Unmarked (n_2-m_2)	82	125	33	240
	Examined (n_2)	97	140	35	272
	P(capture) 1st event (m_2/n_2)	0.155	0.107	0.057	0.118
	χ^2 = 2.66, df = 2, *P*-value = 0.264, fail to reject H_0				
		A	B	C	All sections
≥390 mm FL	Recaptured (m_2)	14	11	2	27
	Unmarked (n_2-m_2)	64	87	22	173
	Examined (n_2)	78	98	24	200
	P(capture) 1st event (m_2/n_2)	0.179	0.112	0.083	0.135
	χ^2 = 2.31, df = 2, P-value = 0.316, fail to reject H_0				
		A	B	C	All sections
≥500 mm FL	Recaptured (m_2)	13	8	1	22
	Unmarked (n_2-m_2)	43	56	17	116
	Examined (n_2)	56	64	18	138
	P(capture) 1st event (m_2/n_2)	0.232	0.125	0.056	0.159
	χ^2 = 4.22, df = 2, P-value = 0.121, fail to reject H_0				
		A	B	C	All sections
≥600 mm FL[a]	Recaptured (m_2)	5	7	1	13
	Unmarked (n_2-m_2)	19	32	7	58
	Examined (n_2)	24	39	8	71
	P(capture) 1st event (m_2/n_2)	0.208	0.179	0.125	0.183
	χ^2 = 0.29, df = 2, P-value = 0.867, fail to reject H_0				

[a] This test does not meet assumptions for a chi-square test, test results are inconclusive.

Table 7.–Test for equal probability of capture during the second event for lake trout ≥353, ≥390, ≥500, and ≥600 mm fork length (FL). Number of lake trout by lake section (A–C) during the first event and recaptured during the second event in Fielding Lake, June 2021–June 2022.

		Section where fish marked			
Size strata	Category	A	B	C	All sections
≥353 mm FL	Recaptured (m_2)	20	11	1	32
	Not recaptured (n_1-m_2)	98	47	20	165
	Marked (n_1)	118	58	21	197
	P(capture) 2nd event (m_2/n_1)	0.169	0.190	0.048	0.162
		χ^2 = 2.39, df = 2, *P*-value = 0.302, fail to reject H_0			
		A	B	C	All sections
≥390 mm FL	Recaptured (m_2)	19	8	0	27
	Not recaptured (n_1-m_2)	93	39	16	148
	Marked (n_1)	112	47	16	175
	P(capture) 2nd event (m_2/n_1)	0.170	0.170	0.00	0.154
		χ^2 = 3.21, df = 2, P-value = 0.201, fail to reject H_0			
		A	B	C	All sections
≥500 mm FL	Recaptured (m_2)	15	7	0	22
	Not recaptured (n_1-m_2)	72	22	9	103
	Marked (n_1)	87	29	9	125
	P(capture) 2nd event (m_2/n_1)	0.172	0.241	0.000	0.176
		χ^2 = 2.78, df = 2, P-value = 0.249, fail to reject H_0			
		A	B	C	All sections
≥600 mm FL[a]	Recaptured (m_2)	8	5	0	13
	Not recaptured (n_1-m_2)	35	18	7	60
	Marked (n_1)	43	23	7	73
	P(capture) 2nd event (m_2/n_1)	0.186	0.217	0.000	0.178
		χ^2 = 1.78, df = 2, P-value = 0.411, fail to reject H_0			

[a] This test does not meet assumptions for a chi-square test, test results are inconclusive.

Table 8.–Estimated abundances of lake trout recruited to the sport fishery at Fielding Lake, June 2021–June 2022.

Size strata	Abundance	SE	95% CI	Relative precision
≥353 mm FL	1,637	240	1,166–2,108	0.29
≥390 mm FL	1,262	200	871–1,654	0.31
≥500 mm FL	760	128	509–1,012	0.33
≥600 mm FL	380	79	224–535	0.41

Table 9.–Lake area model estimates of yield potential in numbers of lake trout and 95% confidence intervals at varying minimum length limits for Fielding Lake, June 2021–June 2022.

	Minimum length limit			
	None	18 in	24 in	26 in
Estimated yield potential (95% CI)	284 (245–323)	246 (211–281)	113 (94–131)	91 (70–112)

Table 10.–Results of diagnostic Kolmogorov-Smirnov (KS) tests used to detect and correct for size-selective sampling (Appendix A1) for estimating abundance and length composition of spawning lake trout in Fielding Lake, September 2021–June 2022.

		Comparison		
Size strata		M vs. R (2nd event test)	C vs. R (1st event test)	M vs. C (1st vs. 2nd event test)
≥474 mm FL	Test statistic *D*	0.247	0.308	0.133
	P-value	0.166	0.038	0.183
	Interpretation	No size selectivity detected	Size selectivity detected	No size selectivity detected
	Overall interpretation and recommended action	Case III: Size selectivity detected in the 1st event but not in the 2nd event. Calculate abundance using entire data set without stratification. Estimate composition parameters using 2nd event data.		
≥500 mm FL	Test statistic *D*	0.294	0.338	0.082
	P-value	0.082	0.025	0.784
	Interpretation	No size selectivity detected	Size selectivity detected	No size selectivity detected
	Overall interpretation and recommended action	Case III: Size selectivity detected in the 1st event but not in the 2nd event. Calculate abundance using entire data set without stratification.		
≥600 mm FL	Test statistic *D*	0.375	0.459	0.150
	P-value	0.066	0.011	0.333
	Interpretation	No size selectivity detected	Size selectivity detected	No size selectivity detected
	Overall interpretation and recommended action	Case III: Size selectivity detected in the 1st event but not in the 2nd event. Calculate abundance using entire data set without stratification.		

Table 11.–Chi-square goodness-of-fit test for complete mixing. Number of lake trout ≥474, ≥500, and ≥600 mm fork length (FL) marked in lake section B and recaptured or not recaptured in each section (A–C) in Fielding Lake, September 2021–June 2022.

Length strata	Section marked	Section recaptured A	B	C	Not recaptured (n_1-m_2)	Total marked (n_1)
≥474 mm FL	B	6	15	1	92	114
		$\chi^2 = 192.18$, df = 3, P-value <0.001, reject H_0				
		A	B	C	Not recaptured (n_1-m_2)	Total marked (n_1)
≥500 mm FL	B	6	14	0	91	111
		$\chi^2 = 195.77$, df = 3, P-value <0.001, reject H_0				
		A	B	C	Not recaptured (n_1-m_2)	Total marked (n_1)
≥600 mm FL	B	3	10	0	49	62
		$\chi^2 = 99.935$, df = 3, P-value <0.001, reject H_0				

Table 12.–Test for equal probability of capture during the first event for lake trout ≥474, ≥500, and ≥600 mm fork length (FL). Number of marked and unmarked lake trout examined during the second event by lake section (A–C) in Fielding Lake, September 2021–June 2022.

		Section where fish examined			
Size strata	Category	A	B	C	All sections
≥474 mm FL	Recaptured (m_2)	6	15	1	22
	Unmarked (n_2-m_2)	59	62	21	142
	Examined (n_2)	65	77	22	164
	P(capture) 1st event (m_2/n_2)	0.092	0.195	0.045	0.134
		χ^2 = 4.91, df = 2, P-value = 0.086, fail to reject H_0			
		A	B	C	All sections
≥500 mm FL	Recaptured (m_2)	6	14	0	20
	Unmarked (n_2-m_2)	55	54	20	129
	Examined (n_2)	61	68	20	149
	P(capture) 1st event (m_2/n_2)	0.098	0.206	0.000	0.134
		χ^2 = 6.78, df = 2, P-value = 0.034, reject H_0			
		A	B	C	All sections
≥600 mm FL[a]	Recaptured (m_2)	3	10	0	13
	Unmarked (n_2-m_2)	27	34	10	71
	Examined (n_2)	30	44	10	84
	P(capture) 1st event (m_2/n_2)	0.100	0.227	0.000	0.155
		χ^2 = 4.29, df = 2, P-value = 0.117, fail to reject H_0			

[a] This test does not meet assumptions for a chi-square test, test results are inconclusive.

Table 13.–Test for equal probability of capture during the second event for lake trout ≥474, ≥500, and ≥600 mm fork length (FL). Number of lake trout marked during the first event and recaptured during the second event in Fielding Lake, September 2021–June 2022.

Size strata	Category	Section where fish marked
		B
≥474 mm FL	Recaptured (m_2)	22
	Not recaptured (n_1-m_2)	92
	Marked (n_1)	114
	P(capture) 2nd event (m_2/n_1)	0.193
		χ^2 = 42.982, df = 1, P-value<0.001, reject H_0
		B
≥500 mm FL	Recaptured (m_2)	20
	Unmarked (n_2-m_2)	91
	Marked (n_1)	111
	P(capture) 2nd event (m_2/n_1)	0.180
		χ^2 = 45.414, df = 1, P-value<0.001, reject H_0
		B
≥600 mm FL	Recaptured (m_2)	13
	Unmarked (n_2-m_2)	49
	Marked (n_1)	62
	P(capture) 2nd event (m_2/n_1)	0.210
		χ^2 = 20.903, df = 1, P-value=0.001, reject H_0

Table 14.–Summary of the numbers of lake trout examined and recaptured in Fielding Lake by geographic strata during the September 2021–June 2022 experiment.

Geographic strata	Length strata											
	≥474 mm FL				≥500 mm FL				≥600 mm FL			
	Examined		Recaptured		Examined		Recaptured		Examined		Recaptured	
	n_2	$P(n_2)$	m_2	$P(m_2)$	n_2	$P(n_2)$	m_2	$P(m_2)$	n_2	$P(n_2)$	m_2	$P(m_2)$
A	65	0.40	6	0.27	61	0.41	6	0.30	30	0.36	3	0.23
B	77	0.47	15	0.68	68	0.46	14	0.70	44	0.52	10	0.77
C	22	0.13	1	0.05	20	0.13	0	0.00	10	0.12	0	0.00
Total	164		22		149		20		84		13	

Note: All fish were marked at the spawning site in lake section B. P(n2) is the probability of being examined in each geographic strata, and P(m2) is the probability of being recaptured in each geographic strata. FL = fork length.

Table 15.–Estimated abundances of sexually mature lake trout in Fielding Lake, September 2021–June 2022.

Size strata	Abundance	SE	95% Confidence interval	Relative precision
≥474 mm FL	824	140	550–1,098	0.33
≥500 mm FL	799	143	520–1,078	0.35
≥600 mm FL	382	80	225–538	0.41

Table 16.–Test for equal probability of capture during the second event for lake trout ≥474, ≥500, ≥600, ≥650, ≥700, and ≥750 mm fork length (FL). Numbers of lake trout by sex marked during the first event and recaptured during the second event in Fielding Lake, September 2021–June 2022.

		Sex		
Size Strata	Category	Female	Male	All fish
≥474 mm FL	Recaptured (m_2)	8	14	22
	Not recaptured (n_1-m_2)	22	70	92
	Marked (n_1)	30	84	114
	P(capture) 2nd event (m_2/n_1)	0.267	0.167	0.193
		χ^2 = 0.85, df = 1, *P*-value = 0.357, fail to reject H_0		
		Female	Male	All fish
≥500 mm FL	Recaptured (m_2)	7	13	20
	Not recaptured (n_1-m_2)	21	70	91
	Marked (n_1)	28	83	111
	P(capture) 2nd event (m_2/n_1)	0.250	0.157	0.180
		χ^2 = 0.68, df = 1, *P*-value = 0.408, fail to reject H_0		
		Female	Male	All fish
≥600 mm FL[a]	Recaptured (m_2)	7	6	13
	Not recaptured (n_1-m_2)	11	38	49
	Marked (n_1)	18	44	62
	P(capture) 2nd event (m_2/n_1)	0.389	0.136	0.210
		Odds ratio = 3.92, P-value = 0.040, reject H_0		
		Female	Male	All fish
≥650 mm FL[a]	Recaptured (m_2)	6	6	12
	Not recaptured (n_1-m_2)	4	22	26
	Marked (n_1)	10	28	38
	P(capture) 2nd event (m_2/n_1)	0.600	0.214	0.316
		Odds ratio = 5.21, P-value = 0.045, reject H_0		
		Female	Male	All fish
≥700 mm FL[a]	Recaptured (m_2)	4	3	7
	Not recaptured (n_1-m_2)	2	14	16
	Marked (n_1)	6	17	23
	P(capture) 2nd event (m_2/n_1)	0.667	0.176	0.304
		Odds ratio = 8.20, P-value = 0.045, reject H_0		
		Female	Male	All fish
≥750 mm FL[a,b]	Recaptured (m_2)	3	2	5
	Not recaptured (n_1-m_2)	0	9	9
	Marked (n_1)	3	11	14
	P(capture) 2nd event (m_2/n_1)	1.000	0.182	0.357
		Odds ratio = Inf, P-value = 0.027, reject H_0		

[a] Fisher's Exact Test was used instead of a chi-square test. The chi-square test failed to reject but doesn't have chi-square assumptions met. Fisher's Exact Test rejects but an odds ratio of 1 is within the 95% confidence interval.

[b] It is hard to conclude anything for this test since the odds ratio is infinite.

Figure 1.–Location of Fielding Lake.

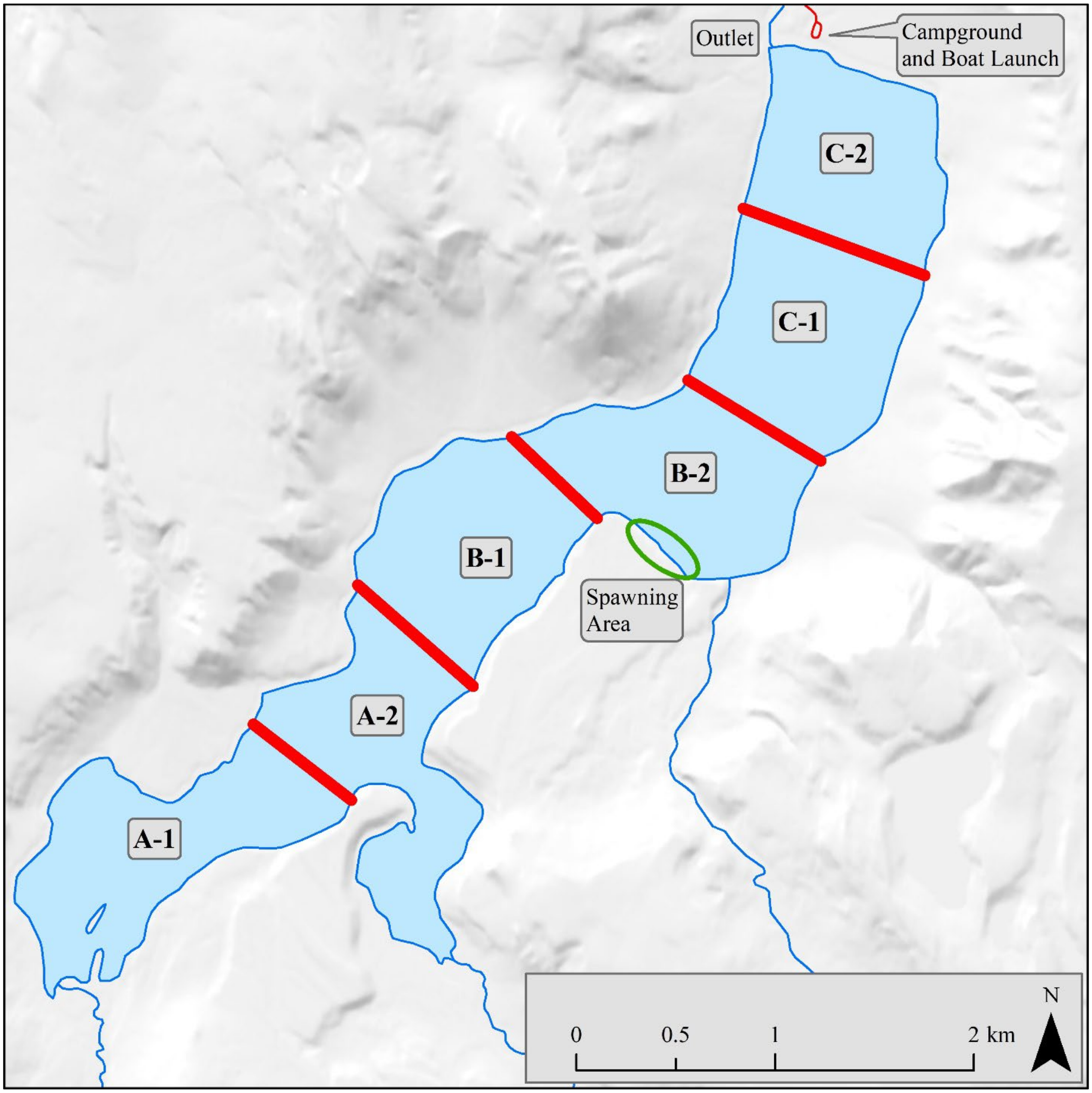

Figure 2.–Fielding Lake study section boundaries (red lines) and lake trout spawning area (green oval), 2021–2022.

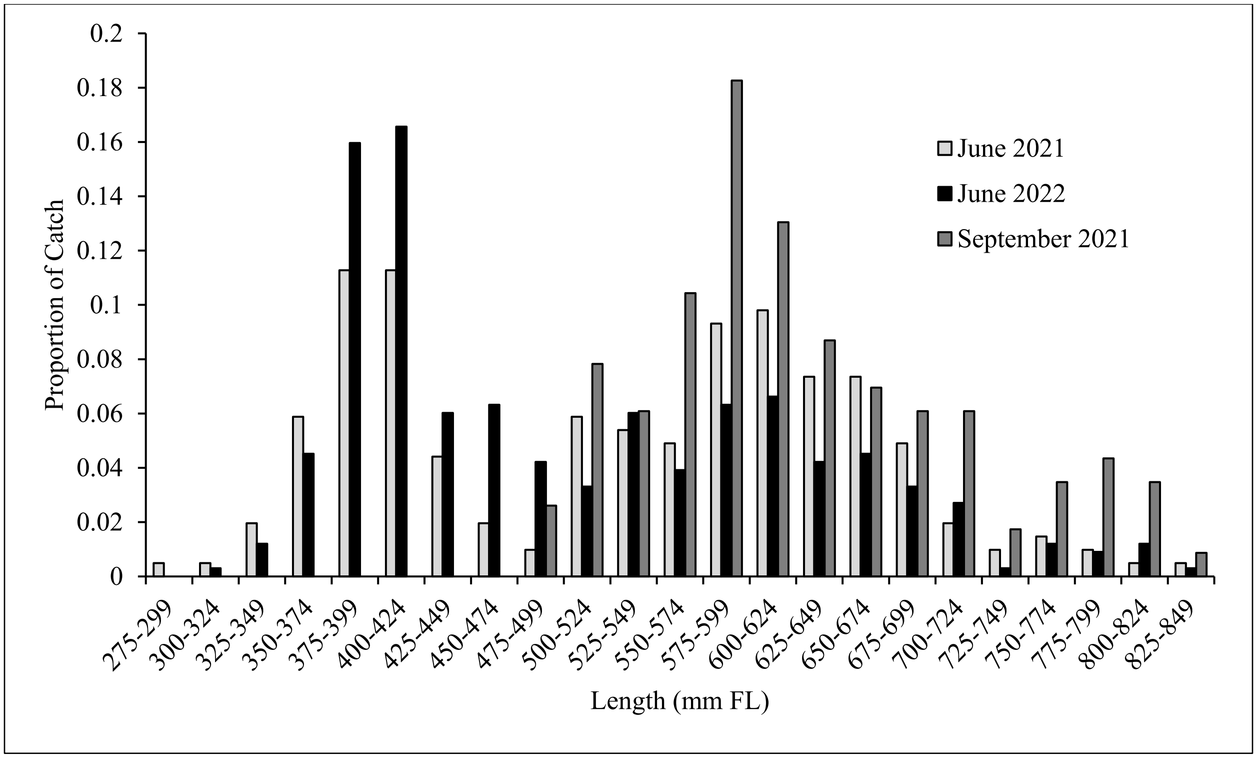

Figure 3.–Length (fork length [FL]) distribution of all captured lake trout during the June and September 2021 and June 2022 sampling events at Fielding Lake.

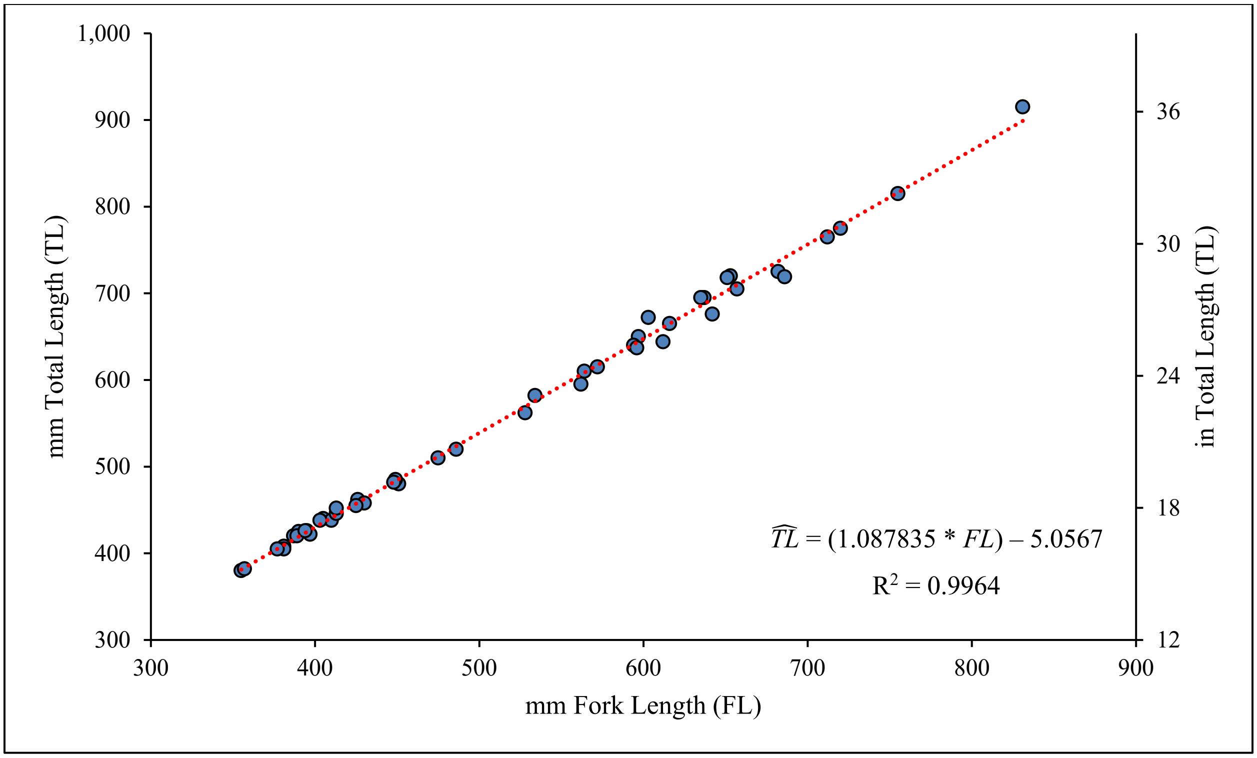

Figure 4.–Relationship between fork length (FL) and total length (TL) of lake trout at Fielding Lake, June 2022.

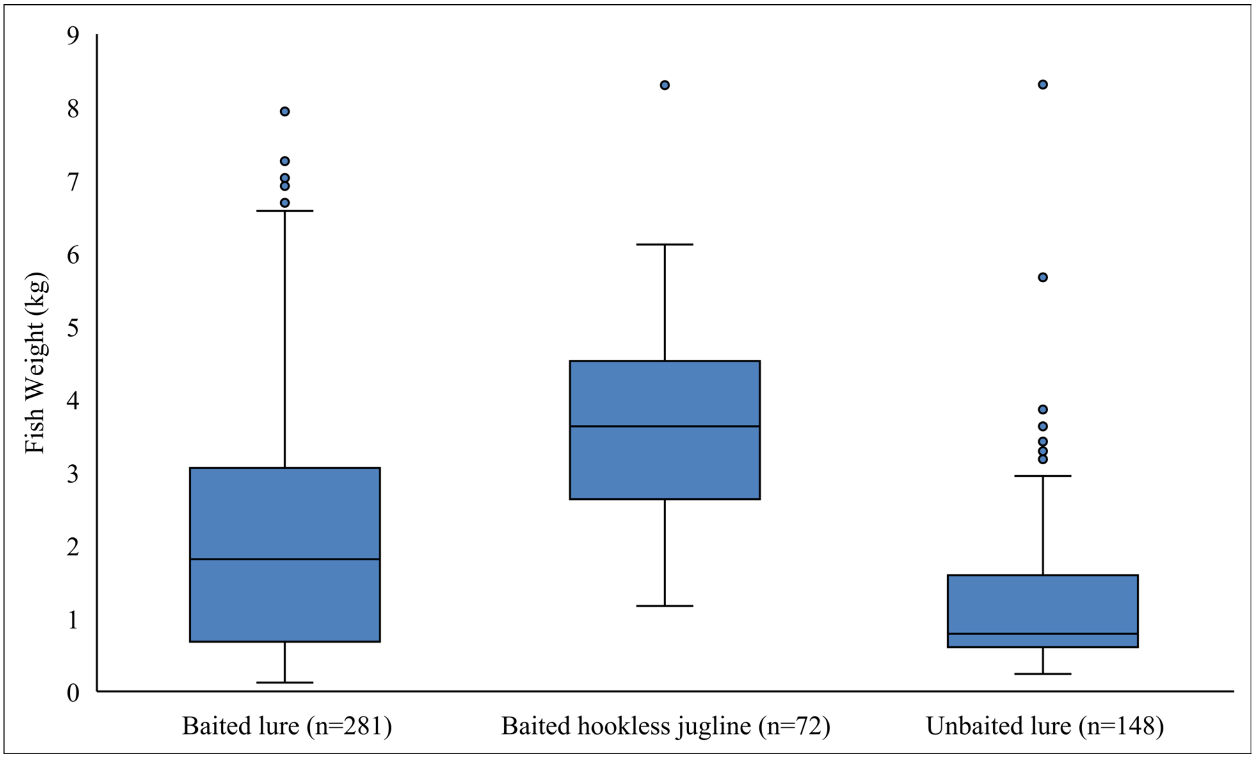

Figure 5.–Boxplots of fish weights captured with baited lures, baited hookless jug lines, and unbaited lures at Fielding Lake during the June 2021 and June 2022 sampling events.

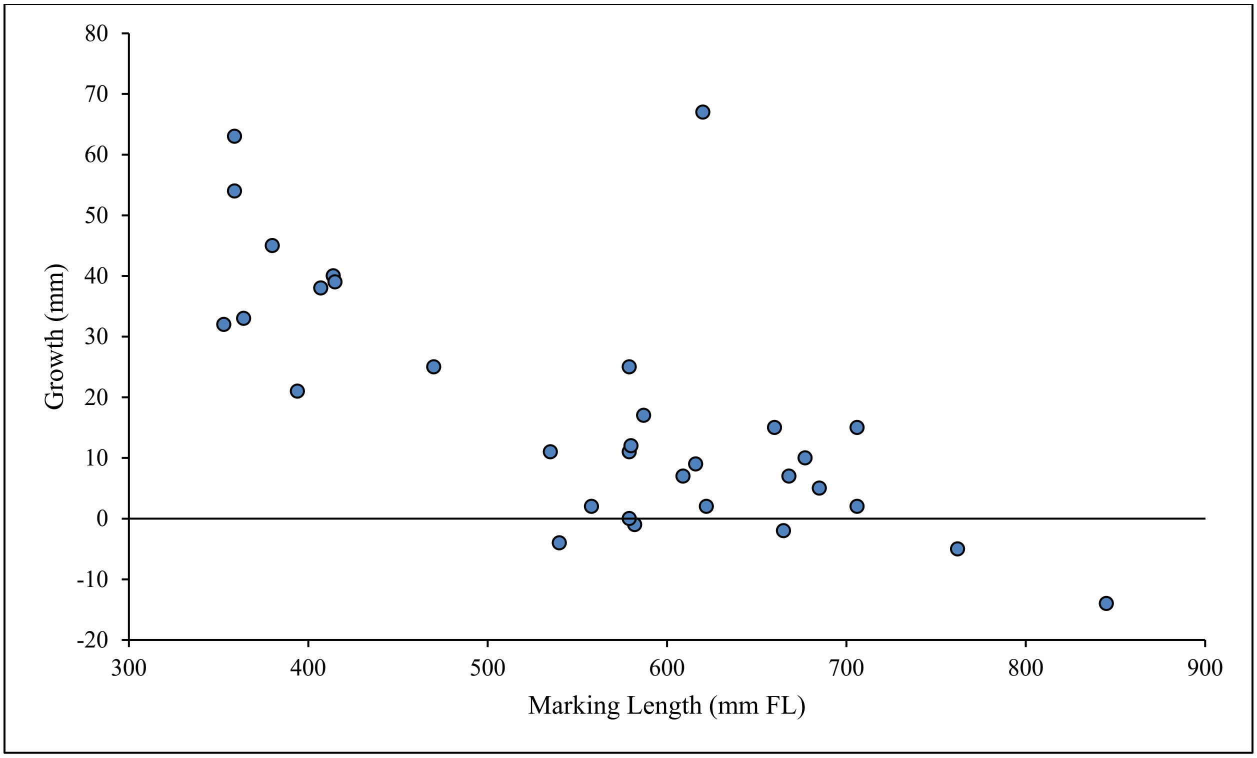

Figure 6.–Growth (recapture length-marking length) of lake trout between the June 2021 and June 2022 sampling events at Fielding Lake.

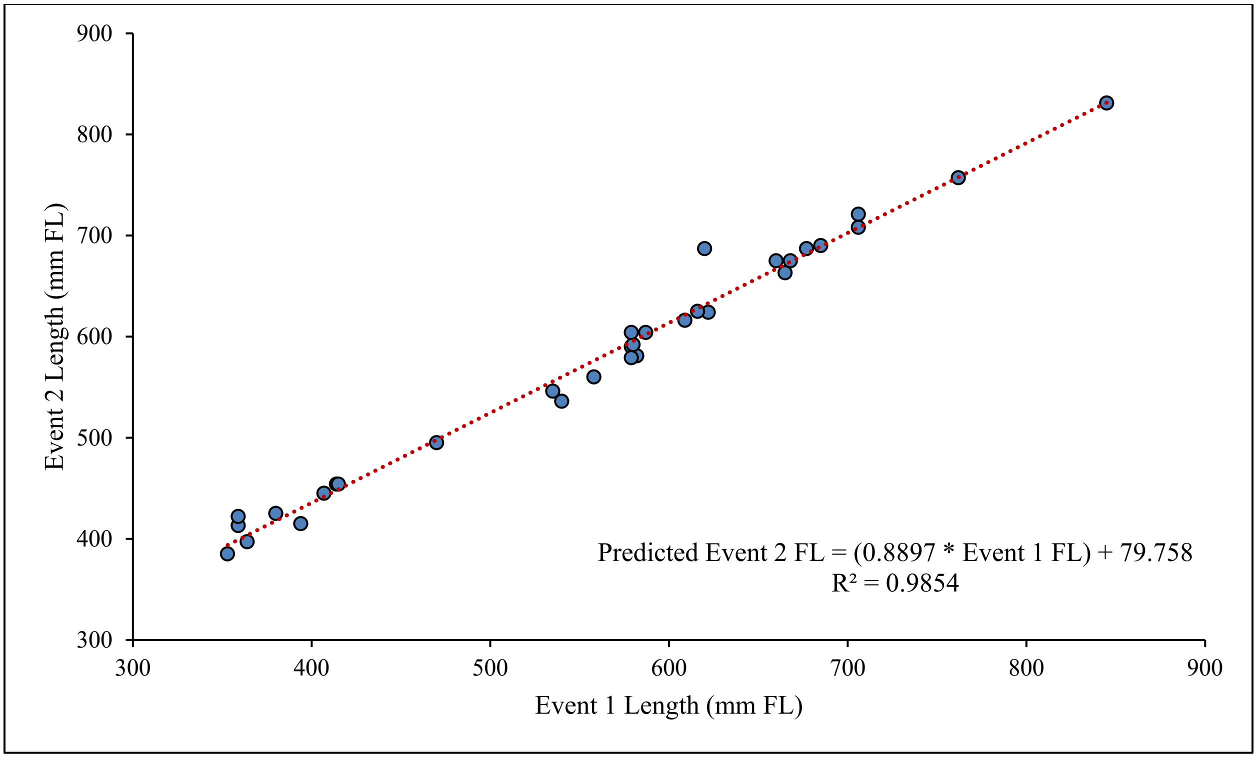

Figure 7.–Linear regression of paired first (June 2021) and second (June 2022) event lengths of recaptured lake trout at Fielding Lake.

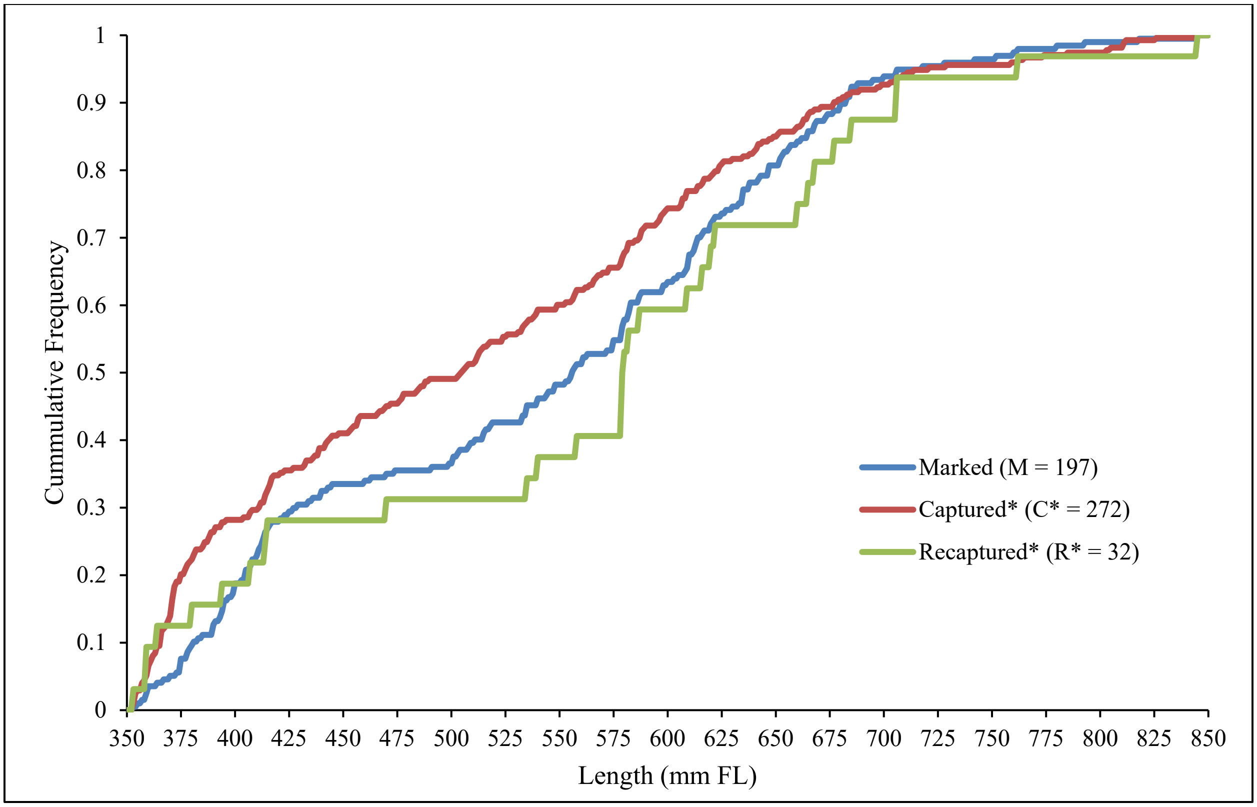

Figure 8.–Cumulative length frequency distributions of lake trout ≥353 mm fork length (FL) marked during the first event (June 2021) and examined or recaptured during the second event (June 2022) at Fielding Lake. The asterisk (i.e., *) indicates that second event fish lengths were adjusted for growth.

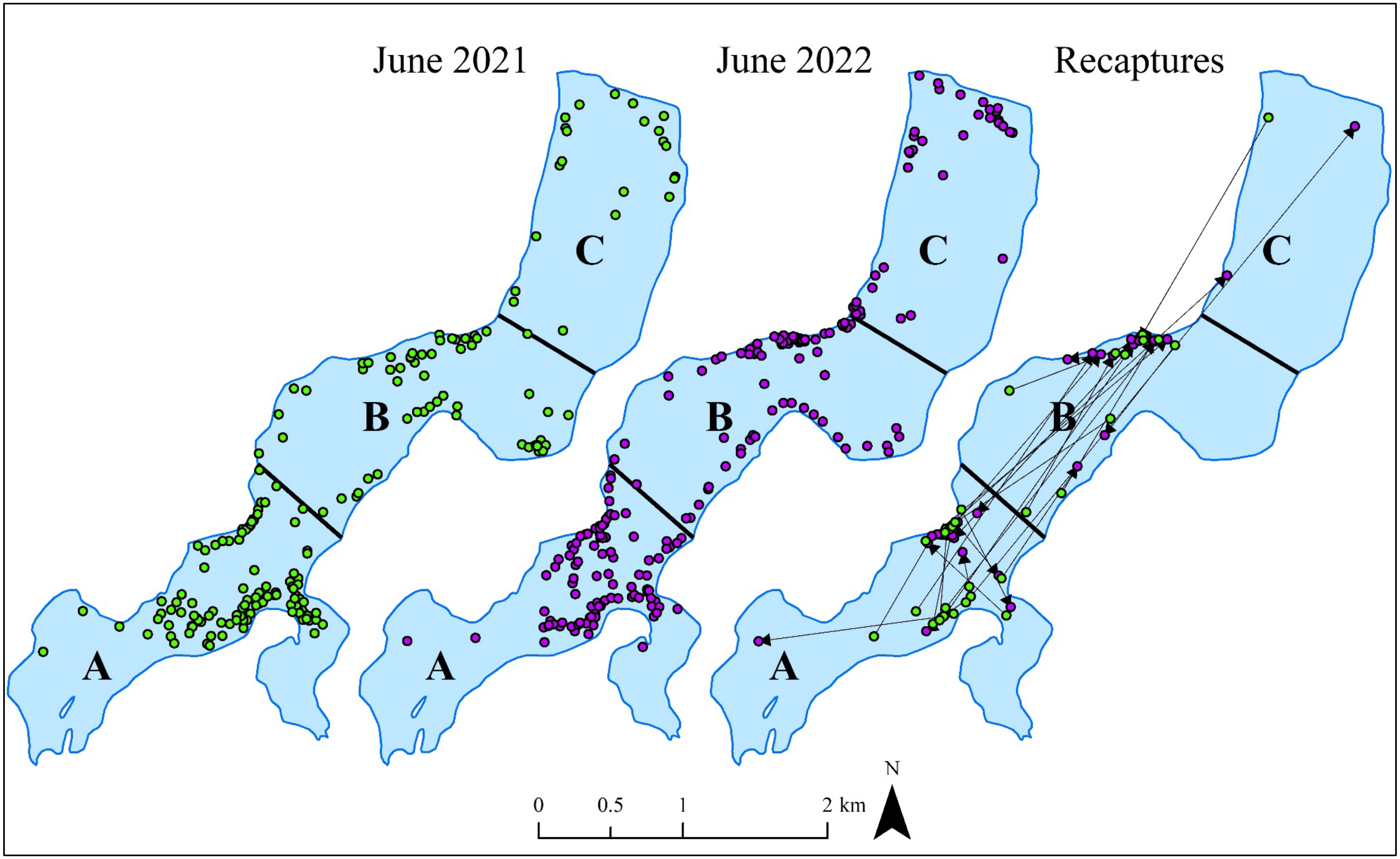

Figure 9.–Capture locations of lake trout marked in June 2021 and examined or recaptured in June 2022 at Fielding Lake.

Note: some dots may represent more than 1 fish. Green dots represent first event capture locations and purple dots represent second event capture locations. The arrows denote movement of recaptured fish between marking and second event capture locations.

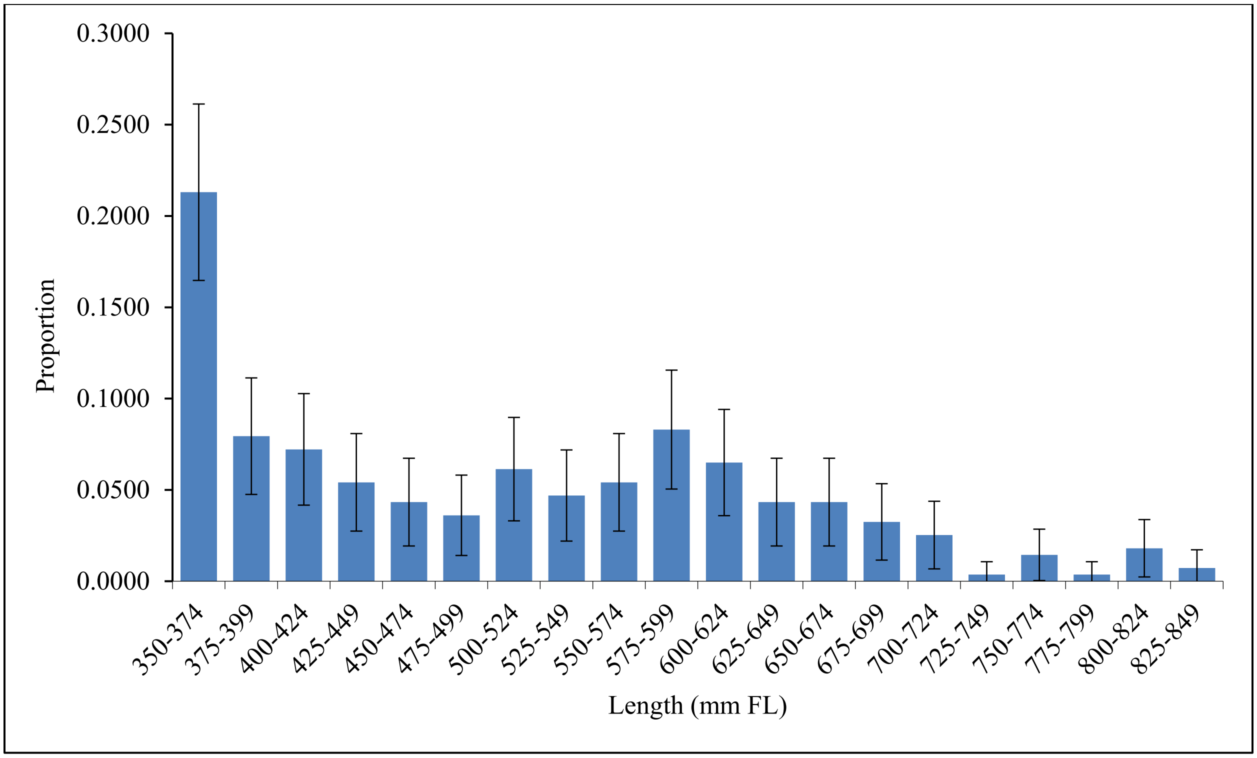

Figure 10.–Estimated length composition of lake trout ≥350 mm fork length (FL) at Fielding Lake, June 2022. Error bars represent 95% CIs.

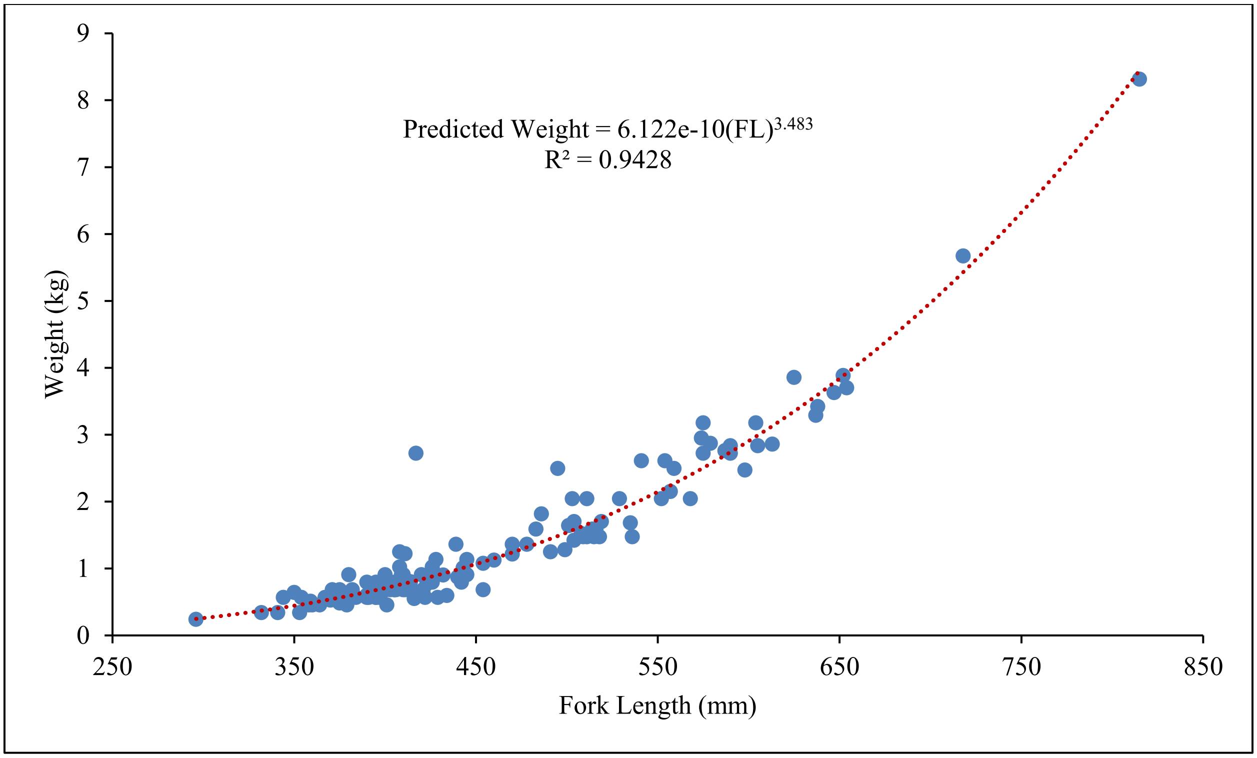

Figure 11.–Length-weight relationship for lake trout sampled at Fielding Lake, June 2021 and June 2022.

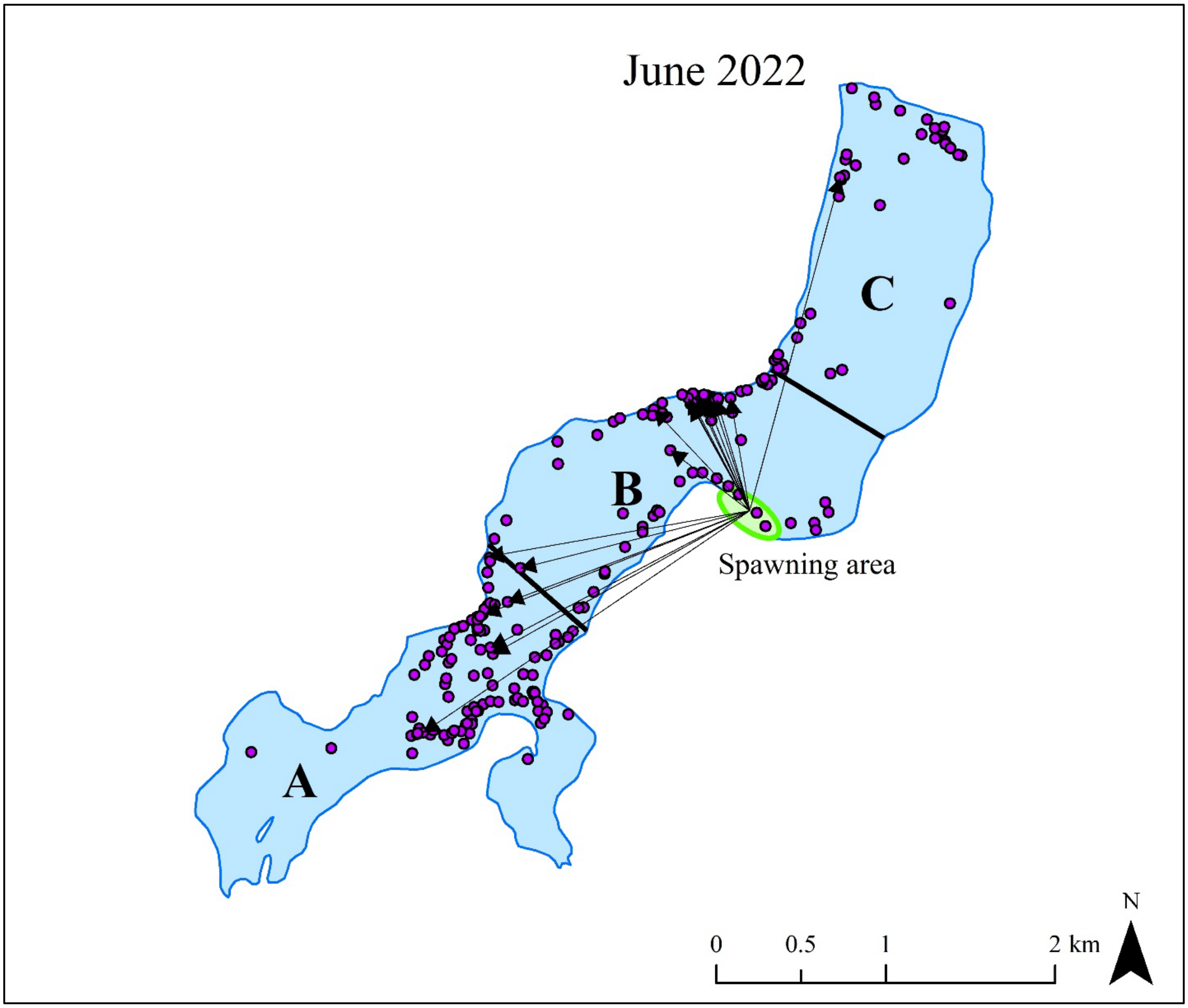

Figure 12.–Capture locations of lake trout marked in September 2021 in the spawning area (green oval) and examined or recaptured (purple dots) in June 2022 at Fielding Lake. The arrows denote movement of recaptured fish between marking and second event capture locations. Note that some dots may represent more than 1 fish.

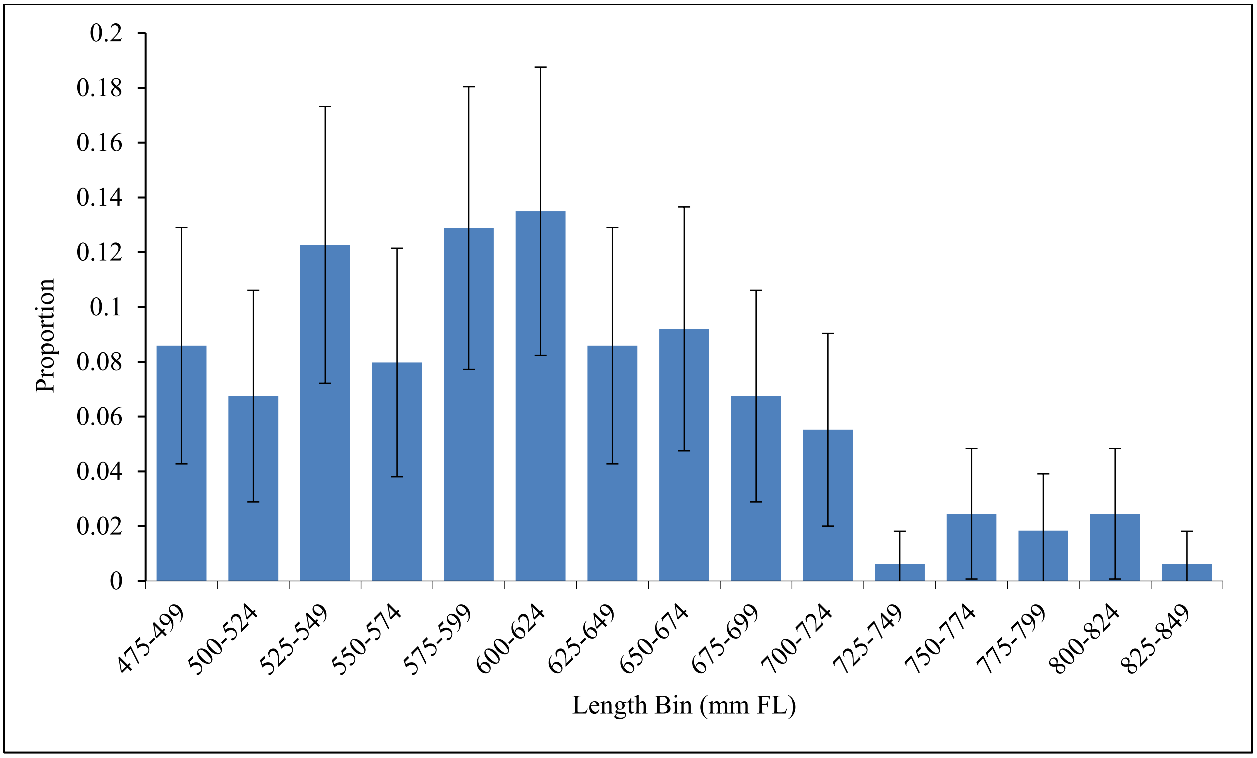

Figure 13.–Estimated length composition of sexually mature lake trout ≥475 mm fork length (FL) at Fielding Lake, June 2022. Error bars represent 95% CIs.

APPENDIX A:
STATISTICAL TESTS FOR ANALYZING DATA FOR SIZE AND SEX BIAS

Appendix A1.–Detection and mitigation of length or sex selective sampling during a 2-event mark–recapture study.

Length selective sampling: The 2-sample Kolmogorov-Smirnov test (Conover 1980) is used to detect significant evidence that length selective sampling occurred during the first or second sampling events (Seber 1982). The second sampling event is evaluated by comparing the length frequency distribution of all fish marked during the first event (M) with marked fish recaptured during the second event (R), using the null 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 marked fish recaptured during the second event (R). A third test, comparing M and C, is conducted and used to evaluate the results of the first 2 tests when sample sizes for M or C are small (<100) or when the sample size for R is small (<30).

Sex selective sampling: Contingency table analysis (chi-square test) is generally used to detect significant evidence that sex selective sampling occurred during the first or second sampling events (Seber 1982). The counts of observed males to females are compared between M and R, C and R, and M and C as described, using the null hypothesis that the probability that a sampled fish is male or female is independent of sample. When the proportions by sex are estimated for a subsample (usually from C), rather than observed for all fish in the sample, contingency table analysis is not appropriate, and the proportions of females (or males) are compared using a 2-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 length/sex selectivity detected during either sampling event.		
Case II:		
Reject H_o	Fail to reject H_o*	Reject H_o
There is no length/sex selectivity detected during the first event but there is during the second event.		
Case III:		
Fail to reject H_o*	Reject H_o	Reject H_o
There is no length/sex selectivity detected during the second event but there is during the first event.		
Case IV:		
Reject H_o	Reject H_o	Reject H_o
There is length/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 that 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 length/sex selectivity during the second event that the M vs. R test was not powerful enough to detect. *Case I* may be considered but *Case II* is the recommended, conservative interpretation.

Note: * If power is suspect in this test because sample sizes for M or C are small, the sample size for R is also small, the p-value is not large (≤ 0.20), and the D-statistic is large (≥ 0.20), then Case IV may be more appropriate.

-continued-

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 length/sex selectivity during the first event that 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 length/sex selectivity during both events that 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.

Case I. Abundance is calculated using a Petersen-type estimator 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 estimator 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 estimator 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 estimator 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, overall composition parameters (p_k) are estimated by combining within stratum composition estimates using (Goodman 1960; Cochran 1977; Seber 1982):

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

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

where:

j	=	the number of sex/length strata;
$\hat{p}_{ik}$	=	the estimated proportion of fish that were age or length 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 1 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.
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). If any of the null hypotheses are not rejected, then a Petersen estimator (Chapman 1951) may be used. If all 3 tests are rejected, a temporally or geographically stratified estimator (Darroch 1961) should be used to estimate abundance.

In the following tables, recall that n_1 refers to the number of fish marked in the first event for each time or area *i*. In addition, n_2 refers to the number of fish examined in the second event for each section *j*. Lastly, m_2 refers to the number of fish marked in time or area *i* and recaptured in section *j*.

I.-Test for complete mixing[a]

Area/time where marked (*i*)	Area/time where recaptured (*j*)				Not recaptured
	1	**2**	**…**	**t**	(n_1-m_2)
1					
2					
…					
s					

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

	Area/time where examined (*j*)			
	1	**2**	**…**	**t**
Marked (m_2)				
Unmarked (n_2-m_2)				

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

	Area/time where marked (*i*)			
	1	**2**	**…**	**s**
Recaptured (m_2)				
Not recaptured (n_1-m_2)				

[a] This tests the hypothesis that movement probabilities (θ_{ij}) from time or area *i* (*i* = 1, 2, ...s) to section *j* (*j* = 1, 2, ...t) are the same among sections: H_0: $\theta_{ij} = \theta_j$ for all *i* and *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 time or area designations: H_0: $\Sigma_i a_i \theta_{ij} = kU_j$ for all *i* and *j*, where *k* = a constant, U_j = total unmarked fish in stratum *j* at the time of second event 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-*i* contingency table with respect to recapture probabilities among time or area designations: H_0: $\Sigma_j \theta_{ij} p_j = d$ for all *i* and *j*, where p_j is the probability of capturing a fish in section *j* during the second event, and d is a constant.