Fishery Data Series No. 19-30

Estimation of Abundance and Yield Potential of Lake Trout in Chandler Lake, 2017–2018

Final Report for Study 16-107

USFWS Office of Subsistence Management

Fishery Information Service

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 2-year mark–recapture experiment was conducted on lake trout *Salvelinus namaycush* in Chandler and Little Chandler lakes. Intensive hook and line sampling occurred throughout both lakes for a 3-week period shortly after ice out in 2017 and 2018. The first event spanned 3–21 July 2017 and the second event spanned 28 June–22 July 2018. A length-stratified Chapman estimator was used to estimate lake trout abundance. Estimated abundance for lake trout 450–599 mm FL was 5,287 (SE = 683; 95% CI = 3,948–6,626), estimated abundance for fish ≥600 mm FL was 472 (SE = 94; 95% CI = 288–655), and the combined estimate of lake trout ≥450 mm FL was 5,759 (SE = 689; 95% CI = 4,407–7,110). Lake trout 500–549 mm represented 56% (SE = 1.5%) of the estimated population. Fish ≥600 mm FL accounted for 8% (SE = 1.6%) of the estimated population and 2% (SE = 0.4%) were ≥800 mm FL. A total of 305 lake trout were weighed in 2017 and their mean weight of 2.03 kg was used in the lake area (LA) model to estimate a yield potential (YP) of 400 lake trout annually from Chandler and Little Chandler lakes combined.

Key words: lake trout, *Salvelinus namaycush,* Chandler Lake, Little Chandler Lake, mark–recapture, abundance, length composition

INTRODUCTION

The Chandler Lake system is located on the north side of the central Brooks Range at approximately 68.231° N and 152.705° W. Lake trout *Salvelinus namaycush*, Arctic grayling *Thymallus arcticus*, Arctic char *S. alpinus*, round whitefish *Prosopium cylindraceum* and slimy sculpin *Cottus cognatus* inhabit these lakes, and burbot *Lota lota* have been reported by anglers. The system contains 6 lakes: Amiloyak, unnamed lakes 1 and 2, Chandler, Little Chandler, and Round lakes (Figure 1). Chandler Lake is the largest of these lakes, lying at 888 m in elevation with a surface area of 1,300 hectares and a maximum depth of 22 m (LaPerrire et al. 2003). Chandler Lake is connected at the north end to Little Chandler Lake (317 hectares) by a 200 m section of the Chandler River. Round Lake (170 hectares) is 4 km downriver from Little Chandler Lake and is 12 m lower in elevation. Chandler and Little Chandler lakes have the highest density of lake trout (Troyer and Johnson 1994) in this system and were the focal points of this study.

The sport fishery at Chandler Lake has traditionally been considered small. An onsite creel survey performed in the summer of 1987 estimated that 20 anglers fished the lake and harvested 10 lake trout and 18 Arctic grayling (Troyer and Johnson 1994). Harvest estimates are also intermittently available from the ADF&G annual mail survey to estimate sport fishing participation; however, these estimates are considered unreliable for Chandler Lake because too few respondents (0–2) report fishing this location. Nevertheless, the estimates are sufficient to demonstrate that sport harvests are minimal. From 1996–2017, the average number of estimated days fished by sport anglers was 24, and the annual estimated catch and harvest was 17 and 12 fish, respectively.[1]

The Chandler Lake system supports an important subsistence fishery for lake trout, as well as Arctic char and Arctic grayling. The primary subsistence users are from the village of Anaktuvuk Pass, which in 2017 had a community population of 355 residents (Robinson et al. 2018). The travel distance between Anaktuvuk Pass and Chandler Lake is approximately 50 km. This fishery traditionally occurs through the ice in April and May as the amount of daylight and air temperatures increase. The first study to assess subsistence harvest was a comprehensive creel survey conducted in 1989, which estimated that 57 lake trout and 66 Arctic char were harvested from Chandler Lake from March to April (Troyer and Johnson 1994). In 2011 and 2014, the ADF&G Division of Subsistence conducted a household survey of residents of Anaktuvuk Pass to estimate annual

[1] Alaska Sport Fishing Survey database [Internet]. 1996–2017. Anchorage, AK: Alaska Department of Fish and Game, Division of Sport Fish. http://www.adfg.alaska.gov/sf/sportfishingsurvey/. (Accessed August 27, 2019).

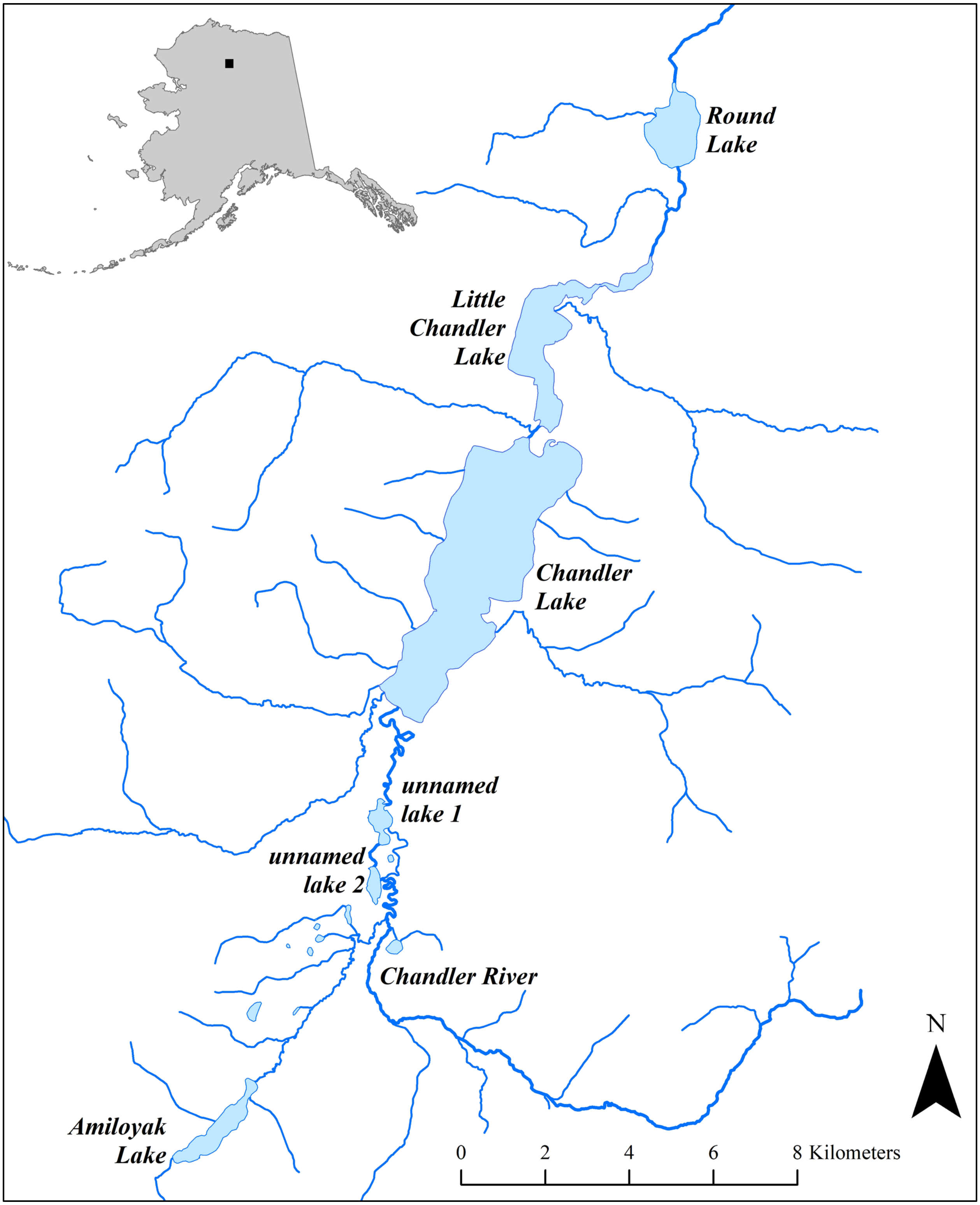

Figure 1.–Map of the Chandler lakes system.

harvest of fish and wildlife by village residents. This study estimated that 691 (95% CI = 525–856) lake trout were harvested in 2011 and 915 (95% CI = 479–1,461) were harvested in 2014[2]. These estimates were not apportioned by lake, and it is unknown what proportion was harvested from Chandler and Little Chandler lakes.

A rigorous investigation of lake trout in the Chandler Lake system was conducted in 1987 (Troyer and Johnson 1994). Gill nets were deployed in nearshore areas to mark and recapture fish to obtain abundance estimates and assess fish movement. Biological samples were collected to determine age, growth, length-weight relationships, fecundity, maturity, and food habits. An abundance estimate was attained for Chandler and Little Chandler lakes of 1,737 (95% CI 1,090–3,524) lake trout ≥234 mm FL. The investigators concluded that harvest levels were low relative to the population size and that there was no evidence of overexploitation. Other major findings of this study were that lake trout mix between Chandler and Little Chandler lakes and should be treated as a single population during future abundance and exploitation assessments. They also found that lake trout from Chandler Lake(s) are slow growing (6 mm annually for mature sized fish), long lived (max age recorded was 28 years old), likely exhibit non-consecutive spawning, and feed primarily on Arctic grayling. Other samples of lake trout from Chandler Lake revealed fish exceeding 40 years of age (Furniss 1974; Black et al. 2013).

Lake trout are often managed conservatively because they are long lived and slow to mature. Troyer and Johnson (1994) established a threshold yield of 0.14 kg/hectare for lake trout in Chandler and Little Chandler lakes, which was 10% of their standing crop estimate of 1.41 kg/ha. This translated to a recommended harvest level of 227 kg/year for both lakes combined. The calculated mean weight of lake trout during their study was 1.25 kg per fish, which would correspond to a sustainable harvest of approximately 182 lake trout annually for both lakes.

In the absence of updated stock assessments to determine sustained yields, the lake area (LA) model developed by Evans et al. (1991) has been applied to many interior Alaska lakes to determine if annual harvests of lake trout exceed the estimated yield potential (YP). The model estimates the total mass of fish that can be sustainably harvested from a lake based on its surface area. The mean weight of harvested fish is needed to convert LA model estimates of total mass to numbers of fish. Creel surveys garner the best information for this, but they are often cost prohibitive and it is generally difficult to attain adequate sample sizes using these techniques, especially in remote lakes. Because of this, various capture methods (e.g., hook and line, entanglement nets, beach seines, etc.) have been employed and successfully used to estimate lake trout yield potential from the LA model (Burr 1993). Applying the LA model to Chandler and Little Chandler lakes (1,617 ha) results in an estimated yield potential of 813 kg/year, or 0.50 kg/ha, which is nearly 4 times the amount recommended by Troyer and Johnson (1994), and very close to the 2011 estimate of subsistence harvest by the residents of Anaktuvuk Pass (using an average weight of 1.25 kg per fish).

Given a higher level of potential harvest and the lapse since the last population assessment (30 years), a reexamination of the lake trout population in Chandler and Little Chandler lakes was warranted. This study specifically addressed the U.S. Fish and Wildlife Service, Office of Subsistence Management (USFWS-OSM), 2016 Priority Information Need to examine the longevity and abundance of lake trout in the Upper Anaktuvuk River drainage. The study was

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2 Community Subsistence Information System (CSIS) Harvest by Community. [Internet]. 1990–2014. Anchorage, AK: Alaska Department of Fish and Game, Division of Subsistence. https://www.adfg.alaska.gov/sb/CSIS (Accessed August 27, 2019).

designed to estimate the abundance of lake trout in Chandler and Little Chandler lakes, estimate length composition, and estimate mean weight of lake trout vulnerable to hook and line sampling to more accurately convert biomass yield from the LA model to sustainable numbers of harvested fish.

OBJECTIVES

The objectives of this project were to

1. estimate the abundance of lake trout ≥450 mm FL in Chandler and Little Chandler lakes such that the estimate is within 25% of the true value 95% of the time;
2. estimate the length composition in 25 mm length categories of the lake trout population in Chandler and Little Chandler lakes such that the estimates are within 7.5 percentage points of the true values 95% of the time; and,
3. update and estimate the annual yield potential (YP), in numbers of fish, of lake trout from Chandler and Little Chandler lakes, such that the estimate is within 10% of the true value 95% of the time, with the lake area (LA) model-estimated YP in kg treated as a constant.

An associated task was to

1. collect otoliths from sampling mortalities for the United States Geological Survey (USGS) staff to age for an independent study.

METHODS

OVERVIEW

This study used mark–recapture techniques to estimate abundance of lake trout in Chandler and Little Chandler lakes (Figure 1). Lake trout were captured and tagged during summer 2017 for the marking event and captured and examined during summer 2018 for the recapture event. Similar study designs for Alaskan lake trout, with relatively long hiatuses between capture events, have been successfully employed during previous projects (Parker et al. 2001; Wuttig 2010; Schwanke 2013). In addition to standard mark–recapture practices, a subsample of captured lake trout were weighed during 2017 sampling to update lake trout YP based on the LA model.

The sampling strategy for this project was to 1) sample the entire study area attempting to subject all fish to an equal probability of capture during the first event (i.e., to the extent possible, distribute marks in proportion to abundance throughout the study area); 2) rely on mixing between events to better ensure an even marked to unmarked ratio throughout the study area; and 3) repeat sampling strategy 1 for the second event. In order to reduce potential biases, the entire study area was sampled during both events to ensure pockets of fish were not isolated from the experiment. Effort was increased in high density areas attempting to create a uniform marked to unmarked ratio.

Assumptions needed to garner an unbiased estimate of abundance using Chapman's modification of the Petersen estimator (Chapman 1951; Seber 1982) are listed below.

1. The population was closed (lake trout did not enter the population, via growth or immigration, or leave the population, via death or emigration, during the experiment);
2. all lake trout had a similar probability of capture in the first event or in the second event, or marked and unmarked lake trout mixed completely between events;

3. marking of lake trout did not affect the probability of capture in the second event;
4. marked lake trout were identifiable during the second event; and
5. all marked lake trout were reported when recovered in the second event.

The experiment was designed to allow the validity of these assumptions to be ensured or tested because failure to satisfy these assumptions could result in biased results. In some cases, the assurance of some assumptions slightly compromised another. In these cases, the scale of the potential biases influenced the study design in a manner to keep the associated biases negligible. These compromises are discussed throughout this report.

SAMPLING METHODS

Summer 2017 (Marking Event)

In 2017, a crew of 5 people sampled lake trout from 3–21 July (Table 1). A partial crew trade out occurred on 13 July. Four people fished from 2 inflatable rafts while the fifth person fished from shore. Hook and line gear consisted mostly of spoons (1/2 to 1 oz) trolled at 1.25–3.0 km per hour, and soft baits (e.g., tube jigs) with 1/2–2 oz jig heads and 4–8 in long bodies jigged vertically in the water column. The shore fisherman primarily fished spoons and flies. Up to 5 hookless jug lines were also periodically deployed to target the larger fish in the population. These were constructed with a 45-cm section of PVC pipe encased in marine foam with a 10- to 20-m section of braided line hanging from the bottom of the float. A relatively large section of bait (whitefish) was secured to each line with a noose knot, and each line had a 1–3 oz weight tied to it to limit drift. Jug lines were periodically checked multiple times a day.

When a fish was brought to the surface, either by hook and line or jug line, it was landed with a knotless landing net, unhooked (or the bait was removed if it was a jug line fish), and temporarily placed in a holding tote. Fish were measured for FL to the nearest mm, marked with an individually numbered FloyFD-94 internal anchor tag (primary mark), and given a partial left-pectoral fin clip (secondary mark) in case tag loss occurred. Every other sampled lake trout in 2017 was weighed to the nearest 1/10th kg. GPS coordinates were recorded for every fish tagged and clipped. The shore sampler followed the same process excluding the holding tote; fish were immediately sampled and released.

Table 1.–Sampling dates, crew sizes, and gear used to capture lake trout at Chandler and Little Chandler lakes, 2017–2018.

Year	Dates	Crew Size	Gear
2017	7/3–7/21	5-person crew	hook and line and minimal jug lines
2018	6/28–7/2	2-person crew	hook and line
	7/3–7/22	6-person crew	hook and line and minimal jug lines

Summer 2018 (Capture Event)

Sampling procedures for the second event were very similar to those employed during the first event. One exception was that effort was increased to bolster sample sizes. Two people flew into Little Chandler Lake and sampled from 28 June to 3 July out of an inflatable raft (Table 1). On 3 July, 4 additional crew members arrived, and a crew of 6 people sampled for the next 10 days until 13 July. On 13 July a partial crew trade out occurred and sampling with 6 people continued until 22 July. A total of 3 rafts were used during the second event and 2 people sampled from each raft. Sampling gear and methods were identical to the first event.

Captured fish were measured for FL to the nearest mm, inspected for a tag or partial left-pectoral fin clip, tag number was recorded if applicable, and each fish was given a partial right-pectoral fin clip to ensure it was not double counted if caught later in the event. GPS coordinates were recorded for every fish examined in the second event. No fish were weighed in the second event.

EVALUATION OF ASSUMPTIONS

Assumption 1: Based on previous sampling, it was believed that Chandler and Little Chandler lakes were essentially a closed system for lake trout. Inlet and outlet streams exist but were not thought to be utilized by a significant number of lake trout. Troyer and Johnson (1994) did not detect lake trout movement between Chandler Lake(s) and nearby Round, unnamed #1 and #2, and Amiloyak lakes. Immigration due to growth recruitment was expected to be insignificant. Troyer and Johnson (1994) estimated mean annual growth of lake trout in Chandler lake(s) to be 6 mm annually. The presence of growth recruitment was evaluated during this study, and, if of practical significance, attempts were made to minimize its overall effect (e.g., increase minimum length size for the population of inference).

Emigration may have occurred due to fishing and natural mortality. The magnitude of emigration due to natural mortality was considered inconsequential because lake trout are very long lived. The magnitude of harvest between events may have ranged from inconsequential (e.g., 10 fish) to significant (e.g., 500 fish). If harvest was significant, the abundance estimate was germane to the first event (2017).

Assumption 2: Differences in capture probability related to fish size, location, and time were examined. Size-selective sampling was tested using 2 Kolmogorov-Smirnov (KS) tests. The tests and possible actions for data analysis are outlined in Appendix A1. If stratification by size or location was required, capture probabilities were examined for each stratum, and total abundance (and its variance estimate) was calculated by summing strata estimates. The assumption of equal probability of capture was sought because sampling occurred throughout the entire lake during both events. In addition, the year long hiatus promoted mixing of lake trout between summers. Capture probabilities and mixing were tested with contingency tables (Appendix A2). For these tests, Chandler Lake was divided into 4 equal size strata, and a fifth equally sized stratum was Little Chandler Lake (Figure 2). A matrix was made to evaluate movement of recaptured fish between events (Appendix A2) and capture probabilities for each event were examined by these geographic strata.

Assumption 3: No handling and marking induced behavioral effects were anticipated due to the year-long hiatus between events. During the first event, fish that were overly stressed due to poor hook placement were released untagged. During the second event, every fish was examined for a tag and a partial pectoral fin clip.

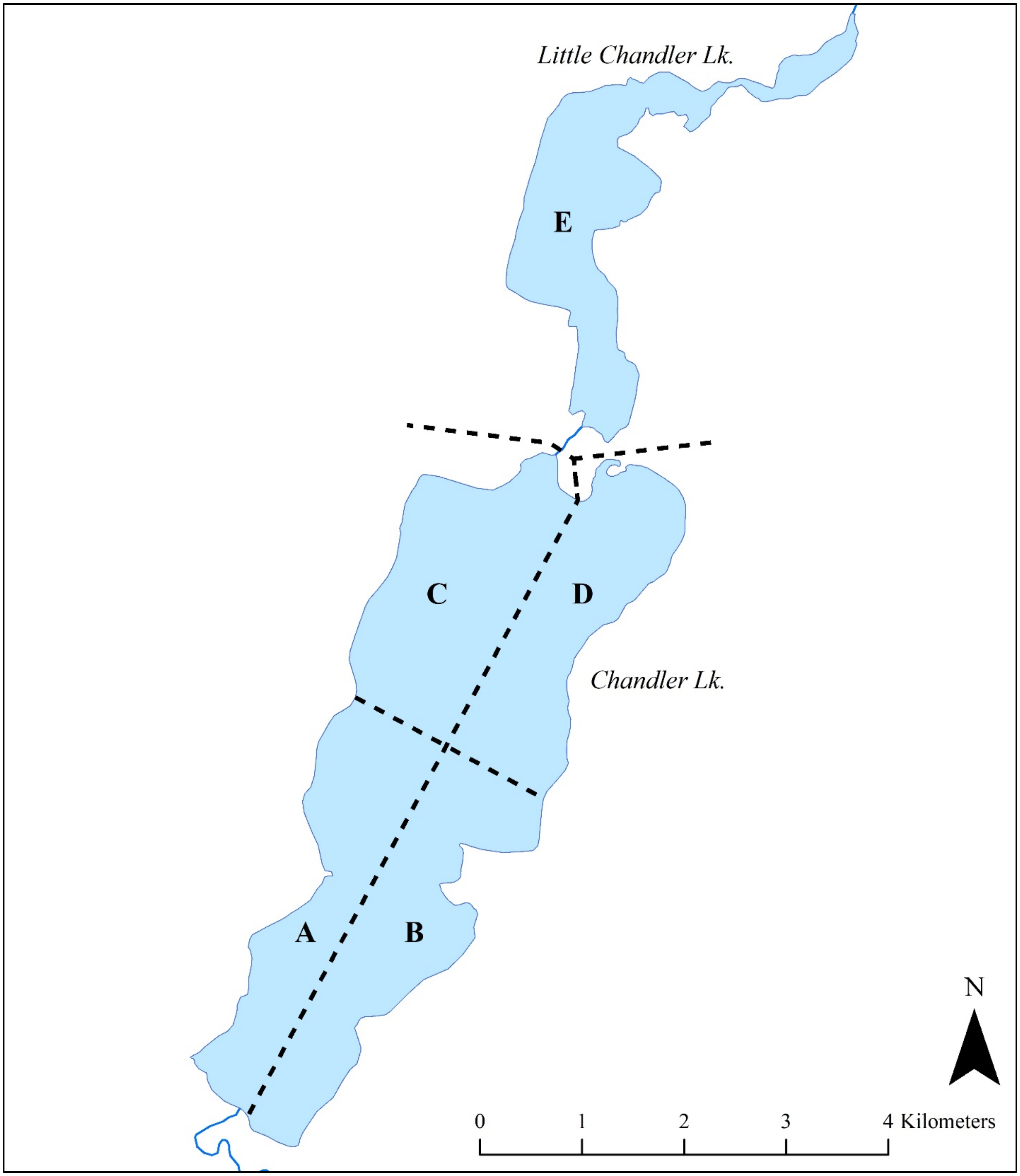

Figure 2.–Map of Chandler and Little Chandler lakes with section boundaries indicated by dashed lines.

Assumption 4: This assumption was addressed by using a standardized tagging procedure and double marking each lake trout captured during the first event. Tag loss was identifiable if a fish was captured with a partial left-pectoral fin clip and no Floy tag.

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

DATA ANALYSIS

Abundance

A two-step approach was used to determine whether size- or spatial-stratification was necessary, and to determine the appropriate abundance estimator. First, differences in capture probability related to fish size were examined using KS tests (Appendix A1). Once these tests were performed and prescribed results were achieved, 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 throughout this report, the nomenclature of the corresponding reference cited is used; notation will vary depending on the analyses discussed (e.g., M = n_1, C = n_2 and R = m_2).

First, before KS tests were performed, annual growth of lake trout was accounted for. To accommodate for growth, second event recapture (R_2) lengths were used in the captured versus recaptured "C vs R" KS test and first event recapture lengths (R_1) were used in the marked versus recaptured "M vs R" KS test.

Size-selective sampling was tested using KS tests. These tests and possible size-stratification decisions 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. This was performed by choosing a length breakpoint where the KS D-statistic was the highest (where the most separation occurred between the 2 cumulative length distribution curves). The KS tests were then reevaluated for each stratum until either a Case I, II, or III scenario was achieved.

Once it was determined whether to size-stratify or not, consistency tests were performed to determine if spatial-stratification was needed and to determine which abundance estimator was appropriate (i.e., Chapman's modification of the Petersen two-sample approach (Chapman 1951), or the methods used by Darroch (1961)). Spatial violations of assumption 2 were tested using consistency tests described by Seber (1982; Appendix A2). Chandler and Little Chandler lakes were divided into 5 geographic strata for diagnostic testing (Figure 2). Section A included the primary inlet stream to Chandler Lake and the sole outlet stream was included in Section E. Assumption 2 was satisfied if at least 1 of the 3 consistency tests outlined in Appendix A2 failed to reject the associated null hypothesis. In this case, the Chapman's modification of the Petersen two-sample approach was appropriate. If all 3 of these tests rejected the null hypothesis, and no movement of marked lake trout between geographic strata was observed, a spatially stratified abundance estimate was computed using the methods of Chapman (1951). If there was movement of marked lake trout between strata, the methods of Darroch (1961) were used to compute a partially stratified abundance estimate.

If size-stratification and spatial-stratification were not necessary, a pooled abundance estimate was calculated using Chapman's modification of the Petersen two-sample model (Chapman 1951):

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

where:

$\widehat{N}$ = the abundance of lake trout in the study area;

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 lake trout recaptured in the second event.

The variance of this estimator was calculated as:

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

If size- or spatial-stratification was necessary, equations 1 and 2 were used for each size/space stratum, and the abundance estimates and associated variances were summed to achieve an overall abundance estimate.

Length Composition

Kolmogorov-Smirnov test outcomes were used to determine if size stratification was necessary and if data from the first, second, or both events would be used for estimating length composition (Appendix A1). For cases I–III, size stratification was not necessary and length proportions and variances of proportions for lake trout were estimated using samples from the event(s) without size-selectivity using:

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

where:

$\hat{p}_k$ = the proportion of lake trout that were within length category k (25 mm increments);

n_k = the number of lake trout sampled that were within length category k; (25 mm increments); and

n = the total number of lake trout sampled.

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

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

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

Lake Area Model

The LA model was used to estimate yield potential, expressed in kg biomass/year; therefore, a random sample of fish weights was needed to infer yield potential in terms of numbers of fish. The results of the KS tests using length data (Appendix A1) were used to evaluate bias. If no size selectivity took place in either event, a random sample of fish from either or both events could be used to estimate the length composition of the sample. If size-selectivity was detected, only the weights from the sampling event determined to be unbiased could be used. Because lake trout were only weighed in the first event, if it was determined that size selectivity took place in the first event but not the second, a length/weight relationship could be calculated from the first event weights and applied to the second event lengths.

The LA model was used to estimate yield potential as:

$$log_{10}\hat{Y}P = 0.60 + 0.72\, log_{10}(Area) \tag{5}$$

where

$\hat{Y}P$ = estimated yield potential (kg biomass/year); and

Area = the area of Chandler and Little Chandler lakes combined in hectares.

The unbiased yield potential (delta-method from Seber 1982) for the combined lakes, in terms of number of lake trout, was calculated as:

$$\hat{Y}P_n = \frac{\hat{Y}P}{\hat{W}} + \frac{\hat{Y}P}{\hat{W}^3}\hat{V}(\hat{W}) \tag{6}$$

where

$\hat{Y}P_n$ = estimated yield potential (number of lake trout);

$\hat{W}$ = estimated mean weight of lake trout (kg per fish) determined from sampling; and,

$\hat{V}(\hat{W})$ = estimated variance of the mean weight.

Treating $\hat{Y}P$ as a constant, the variance of the yield potential due to sampling was estimated as:

$$\hat{V}(\hat{Y}P_n) = \frac{\hat{Y}P^2}{\hat{W}^4}\hat{V}(\hat{W}) \tag{7}$$

RESULTS

SUMMARY OF FISH CAPTURED

A total of 606 unique lake trout of all lengths were sampled 3–21 July 2017 and a total of 700 were sampled 28 June–22 July 2018. Sixty-five of the fish captured in 2017 were recaptured in 2018. Considering just fish ≥450 mm FL, a total of 546 unique lake trout were sampled in 2017 and 636 were examined in 2018, 62 of which were recaptured from the first event. Hook and line gear captured >98% of the fish during both events, with the remaining fish captured with jug lines.

Summary information of captured fish lengths were nearly identical between years (Table 2). Sampled lake trout ranged from 346 to 955 mm FL. The mean length of all fish sampled was 537 mm FL (SD = 84) in 2017 and 537 mm FL (SD = 87) in 2018. The mean length of lake trout ≥450 mm FL was 549 mm FL (SD = 78) in 2017 and was 549 mm FL (SD = 81) in 2018 (Table 2).

GROWTH AND THE EFFECTS OF GROWTH RECRUITMENT

Annual estimated growth was minimal, averaging 6.1 mm per year for 64 of the recaptured fish (one fish had unreasonable growth). Smaller fish generally grew more than the larger fish (Figure 3). To minimize the effects of growth recruitment, the population of inference was set to fish ≥450 mm FL (despite the smallest recap being marked at a length of 385 mm). This eliminated the smaller faster growing fish from the population of inference and reduced estimated growth to

5.0 mm. Growth recruitment still existed, but was considered negligible (i.e., <4%) for fish ≥450 mm FL (see Discussion).

Table 2.–Mean length (mm FL) of lake trout captured during sampling events at Chandler and Little Chandler lakes, 2017 and 2018.

Year	Dates	Statistic	All Fish	≥450 mm FL
2017	7/3–7/21	Mean	537	549
		SD	84	78
		Sample Size	606	546
2018	6/28–7/22	Mean	537	549
		SD	87	81
		Sample Size	700	636

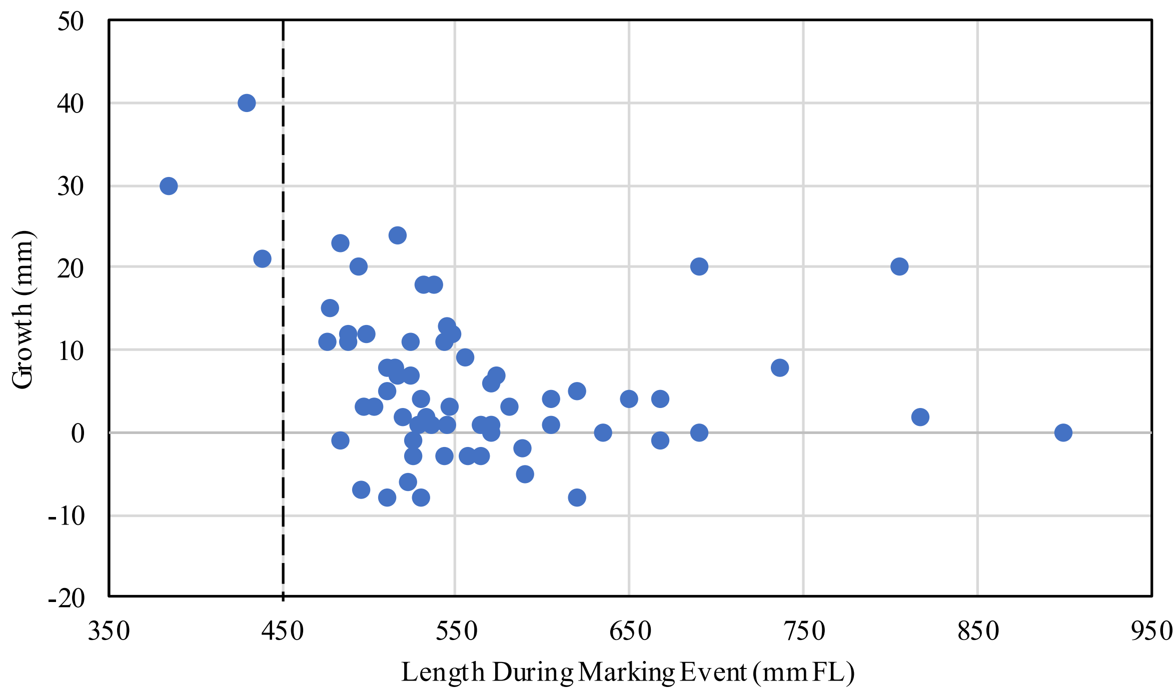

Figure 3.–Estimated growth (recapture length-marking length) of lake trout between sampling events, Chandler and Little Chandler lakes, 2017–2018. The dashed line represents the minimum length for the abundance estimate (450 mm FL).

ABUNDANCE ESTIMATES

KS tests on all lengths of fish ≥450 mm FL did not provide strong evidence that size stratification was necessary, however, an obvious separation in cumulative length frequency curves was present around 600 mm FL for both marked versus recaptured (M vs R) and captured versus recaptured (C vs R) fish. Additional KS tests were performed, in which length was stratified at 600 mm FL, resulting in substantially larger test p-values, and effectively no evidence of a need to further size-stratify. (Case I in Appendix A; Figures 4 and 5).

Consistency tests (Appendix A2) indicated that geographic stratification was not necessary for either length strata. For small fish (450–599 mm FL), capture probabilities by geographic area (Figure 2) were considered different in the first event, but equal during the second event, and complete mixing was not achieved (Tables 3–5). For the large length stratum (≥600 mm FL), tests indicated that equal probability of capture was achieved in both events and that complete mixing occurred (Tables 6–8).

Figures 6 and 7 show the distribution of fish marked (n_1) and examined (n_2) for both length strata. These figures illustrate the efforts made to distribute tags throughout the lake. Mixing, displayed by the movements of recaptured fish (m_2), is illustrated in Figure 8. Some fish moved completely across the lakes, several moved between the lakes, while others had no detectable movement, which indicated seasonal fidelity to a specific area in the lake(s).

The abundance estimate for all lake trout ≥450 mm FL in Chandler and Little Chandler lakes was 5,759 (SE = 689; 95% CI = 4,407–7,110). This estimate had a relative precision of 0.235, exceeding the objective goal of 0.25. The estimated abundance of small fish (450–599 mm FL) was 5,287 (SE = 683; 95% CI = 3,948–6,626) and for large fish (≥600 mm FL) was 472 (SE = 94; 95% CI = 288–655). Because both growth recruitment and mortality occurred between events, there is probably a slight positive bias associated with these estimates (see *Discussion*).

LENGTH COMPOSITION

KS tests indicated a case I scenario (no selectivity occurred during either sampling event) for both length strata (Figures 4 and 5); therefore, length composition was estimated for each stratum using data from both events. Data from each stratum were combined to make an estimate of the overall length composition of lake trout ≥450 mm FL. Lake trout from 500–549 mm represented an estimated 56% (SE = 1.5%) of the population (Figure 9). Large fish were present, but not in large numbers; just 8% (SE = 1.6%) of the estimated population was in the large length strata (≥600 mm FL), and 2% (SE = 0.4%) of the population was estimated to be ≥800 mm FL.

LAKE AREA MODEL

Mean lengths (and assumed mean weights) were similar between events (Table 2; Figures 4–5), therefore, the weights of fish captured during only the first event were used to estimate the mean weight of lake trout in the population. A total of 305 random fish were weighed to the nearest 1/10th kg in 2017 resulting in a mean weight of 2.03 kg (SD = 1.2). The lake area model indicates a yield potential of 813 kg for both Chandler and Little Chandler lakes combined, resulting in an estimated sustainable yield of 400 fish (95% CI = 373–427) annually. Weight distribution is displayed as a length-weight relationship in Figure 10.

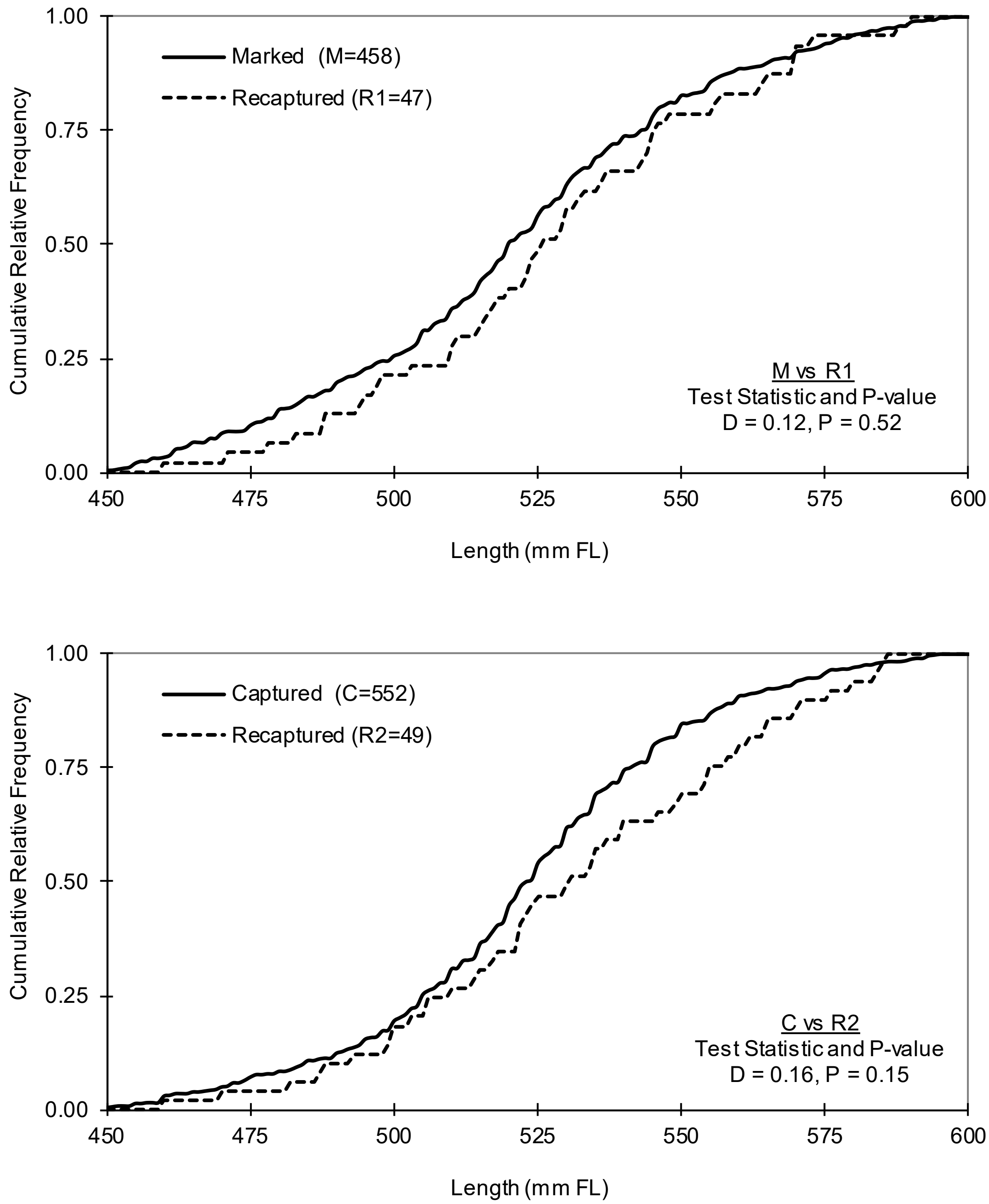

Figure 4.–Cumulative relative frequency of lake trout 450–599 mm FL marked and recaptured (top) and captured and recaptured (bottom), 2017 and 2018.

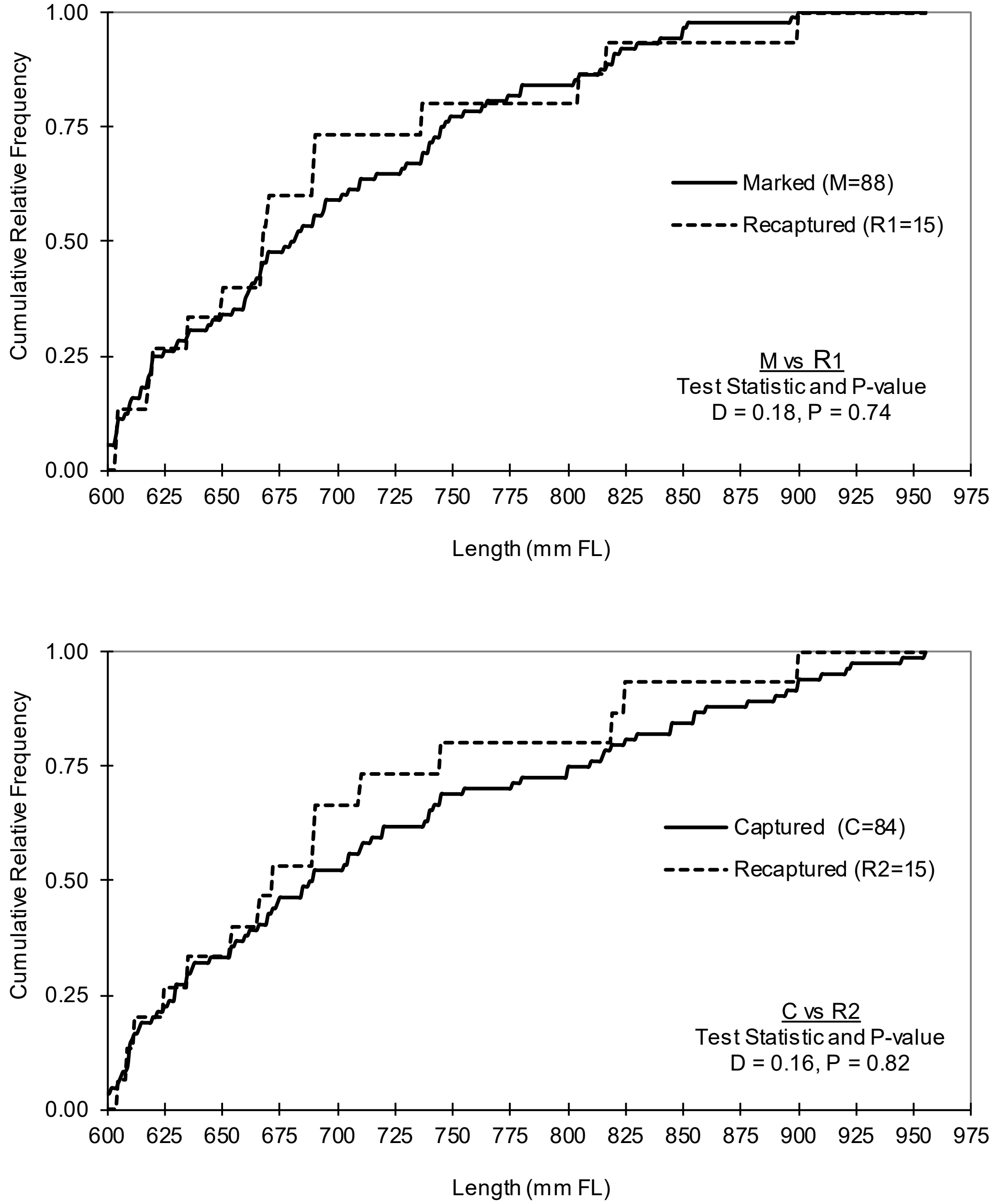

Figure 5.–Cumulative relative frequency of lake trout ≥600 mm FL marked and recaptured (top) and captured and recaptured (bottom), 2017 and 2018.

Table 3.–Test for complete mixing. Number of lake trout 450–599 mm FL marked in each lake section (A–E) and recaptured or not recaptured in each section of Chandler and Little Chandler lakes, 2017–2018.

Section Where Marked	Section Where Recaptured					Not Recaptured (n_1-m_2)	Total Marked (n_1)
	A	B	C	D	E		
A	6	0	0	2	0	82	90
B	2	3	0	2	1	83	91
C	3	2	2	3	1	71	82
D	1	0	0	2	0	63	66
E	0	0	0	0	17	112	129
Total	12	5	2	9	19	411	458

χ^2 = 67.6, df = 20, P-value < 0.001, reject H_o.

Table 4.–Test for equal probability of capture during the first event for lake trout 450–599 mm FL. Number of marked and unmarked lake trout examined during the second event by section (A–E) in Chandler and Little Chandler lakes, 2017–2018.

Category	Section Where Examined					All Sections
	A	B	C	D	E	
Marked (m_2)	12	5	2	9	19	47
Unmarked (n_2-m_2)	103	63	52	194	93	505
Examined (n_2)	115	68	54	203	112	552
$P_{capture}$ 1st event (m_2/n_2)	0.10	0.07	0.04	0.04	0.17	0.085

χ^2 = 16.8, df = 4, P-value = 0.002, reject H_o.

Table 5.–Test for equal probability of capture during the second event for lake trout 450–599 mm FL. Number of lake trout marked by section (A–E) during the first event that were recaptured and not recaptured during the second event in Chandler and Little Chandler lakes, 2017–2018.

Category	Section Where Marked					All Sections
	A	B	C	D	E	
Recaptured (m_2)	8	8	11	3	17	47
Not Recaptured (n_1-m_2)	82	83	71	63	112	411
Marked (n_1)	90	91	82	66	129	458
$P_{capture}$ 2nd event (m_2/n_1)	0.08	0.05	0.07	0.02	0.13	0.066

χ^2 = 4.8, df = 4, P-value = 0.31, fail to reject H_o.

Table 6.–Test for complete mixing. Number of lake trout ≥600 mm FL marked in each section (A–E) and recaptured or not recaptured in each section in Chandler and Little Chandler lakes, 2017–2018.

Section Where Marked	Section Where Recaptured					Not Recaptured (n_1-m_2)	Total Marked (n_1)
	A	B	C	D	E		
A	1	0	1	0	0	8	10
B	0	1	0	0	0	14	15
C	1	1	0	0	0	12	14
D	1	1	0	0	0	6	8
E	0	0	1	1	6	33	41
Total	3	3	2	1	6	73	88

χ^2 = 0.22, df = 20, *P*-value = 0.33, fail to reject H_o.

Table 7.–Test for equal probability of capture during the first event for lake trout ≥600 mm FL. Number of marked and unmarked lake trout examined during the second event by section (A–E) in Chandler and Little Chandler lakes, 2017–2018.

Category	Section Where Examined					All Sections
	A	B	C	D	E	
Marked (m_2)	3	3	2	1	6	15
Unmarked (n_2-m_2)	18	13	11	4	23	69
Examined (n_2)	21	16	13	5	29	84
$P_{capture}$ 1st event (m_2/n_2)	0.14	0.19	0.15	0.20	0.21	0.18

χ^2 = 0.42, df = 4, *P*-value = 0.98, fail to reject H_o.

Table 8.–Test for equal probability of capture during the second event for lake trout ≥600 mm FL. Number of lake trout marked by section (A–E) during the first event that were recaptured and not recaptured during the second event in Chandler and Little Chandler lakes, 2017–2018.

Category	Section Where Marked					All Sections
	A	B	C	D	E	
Recaptured (m_2)	2	1	2	2	8	15
Not Recaptured (n_1-m_2)	8	14	12	6	33	73
Marked (n_1)	10	15	14	8	41	88
$P_{capture}$ 2nd event (m_2/n_1)	0.20	0.07	0.14	0.25	0.20	0.17

χ^2 = 1.81, df = 4, *P*-value = 0.77, fail to reject H_o.

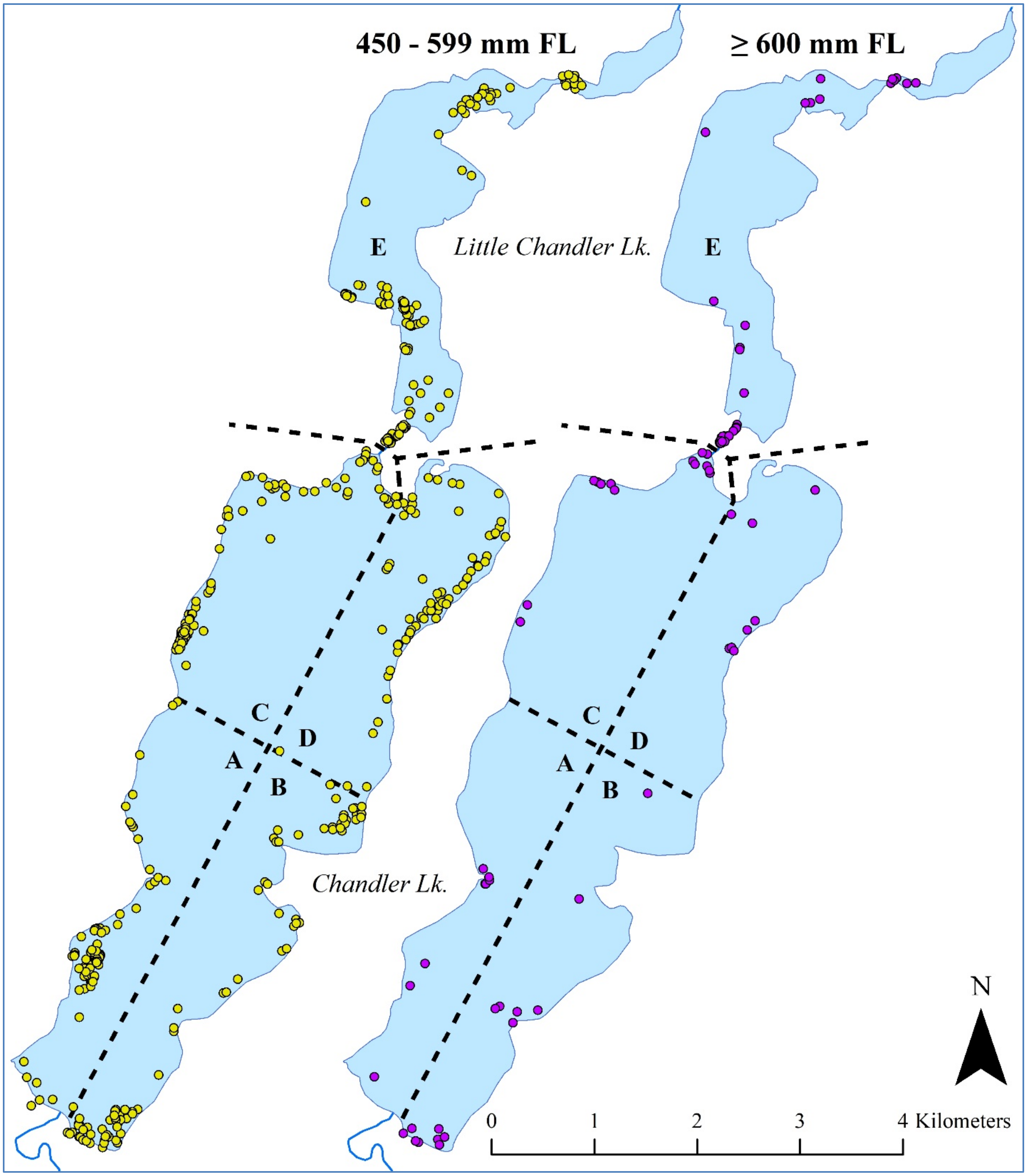

Figure 6.–Map of Chandler and Little Chandler lakes with locations of fish captured and tagged during the first event (M) from 3–21 July 2017. A dot may represent more than one fish.

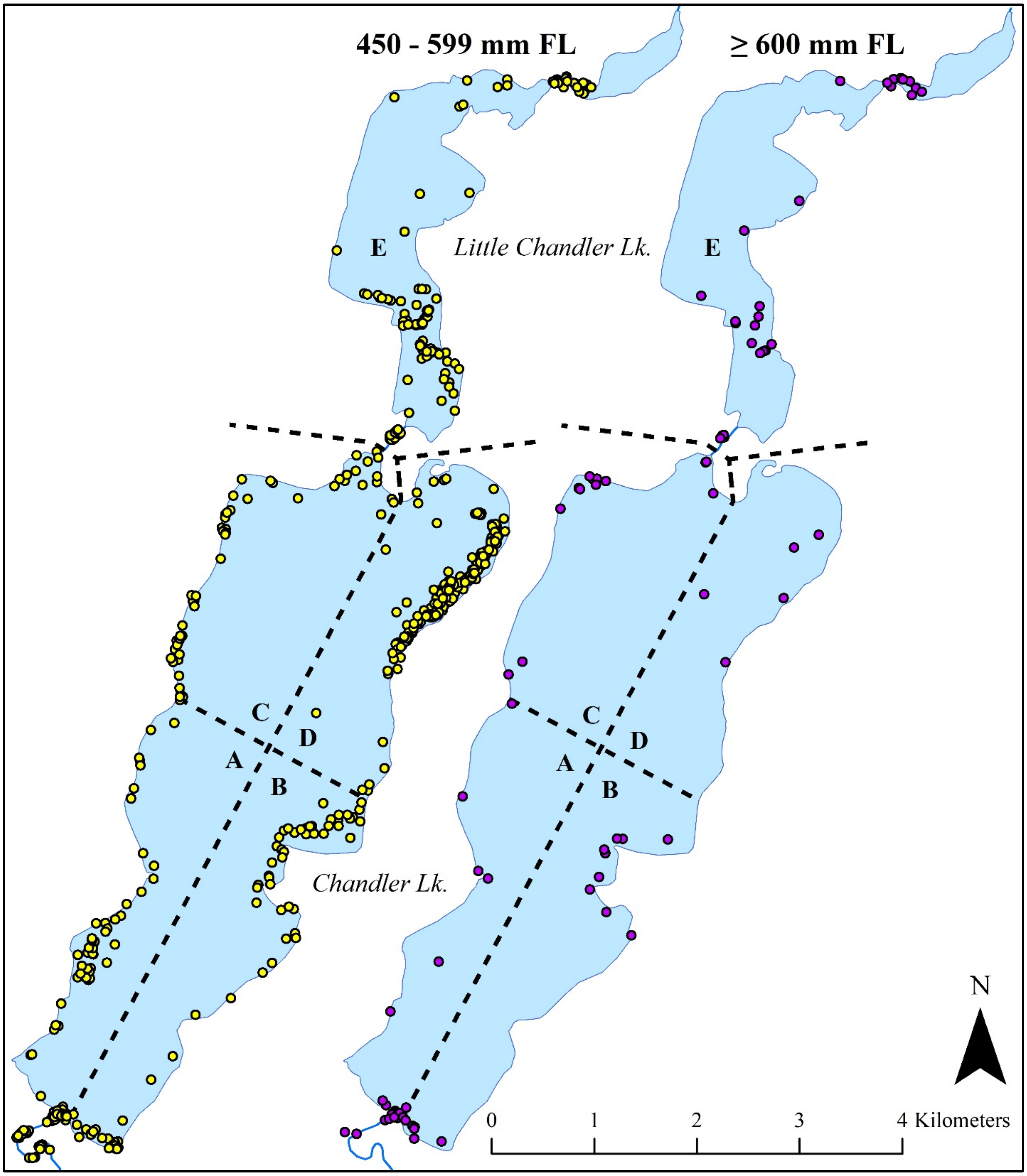

Figure 7.–Map of Chandler and Little Chandler lakes with locations of fish captured and examined during the second event (C) from 28 June–22 July 2018. A dot may represent more than one fish.

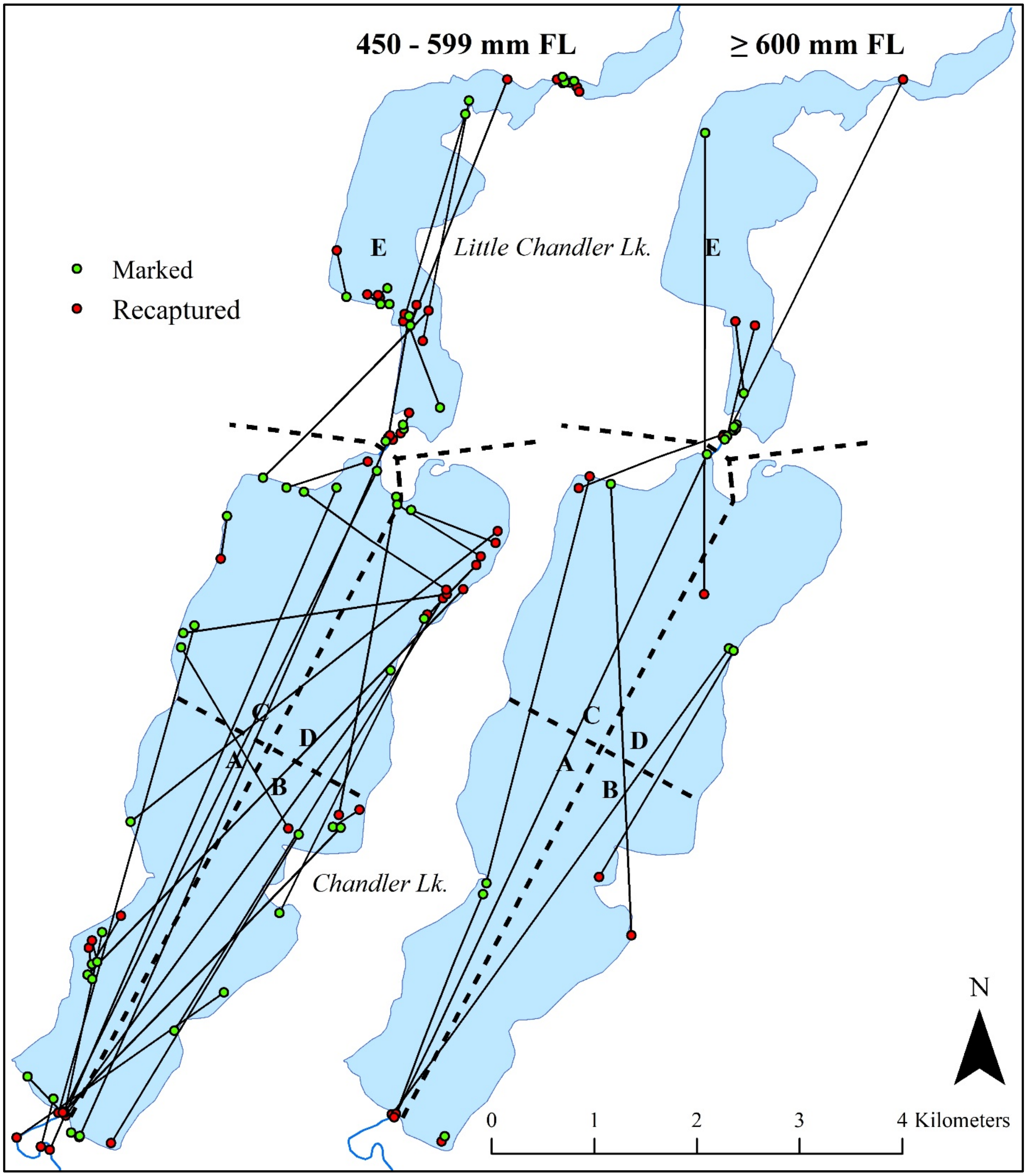

Figure 8.–Map of Chandler and Little Chandler lakes with locations of fish captured and tagged during the first event (M) and recaptured during the second event (R) and the distance between those two locations.

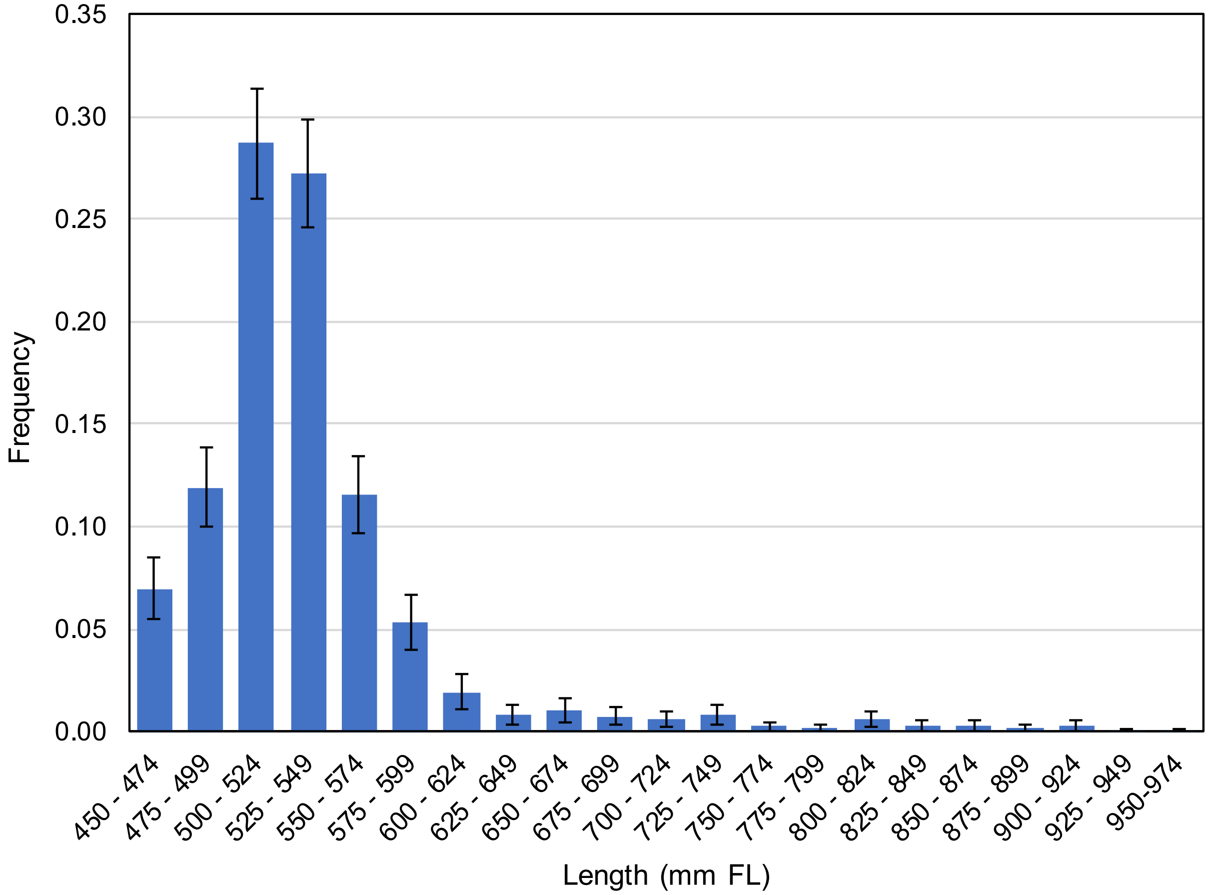

Figure 9.–Estimated length composition of lake trout ≥450 mm FL, Chandler and Little Chandler lakes, 2017–2018.

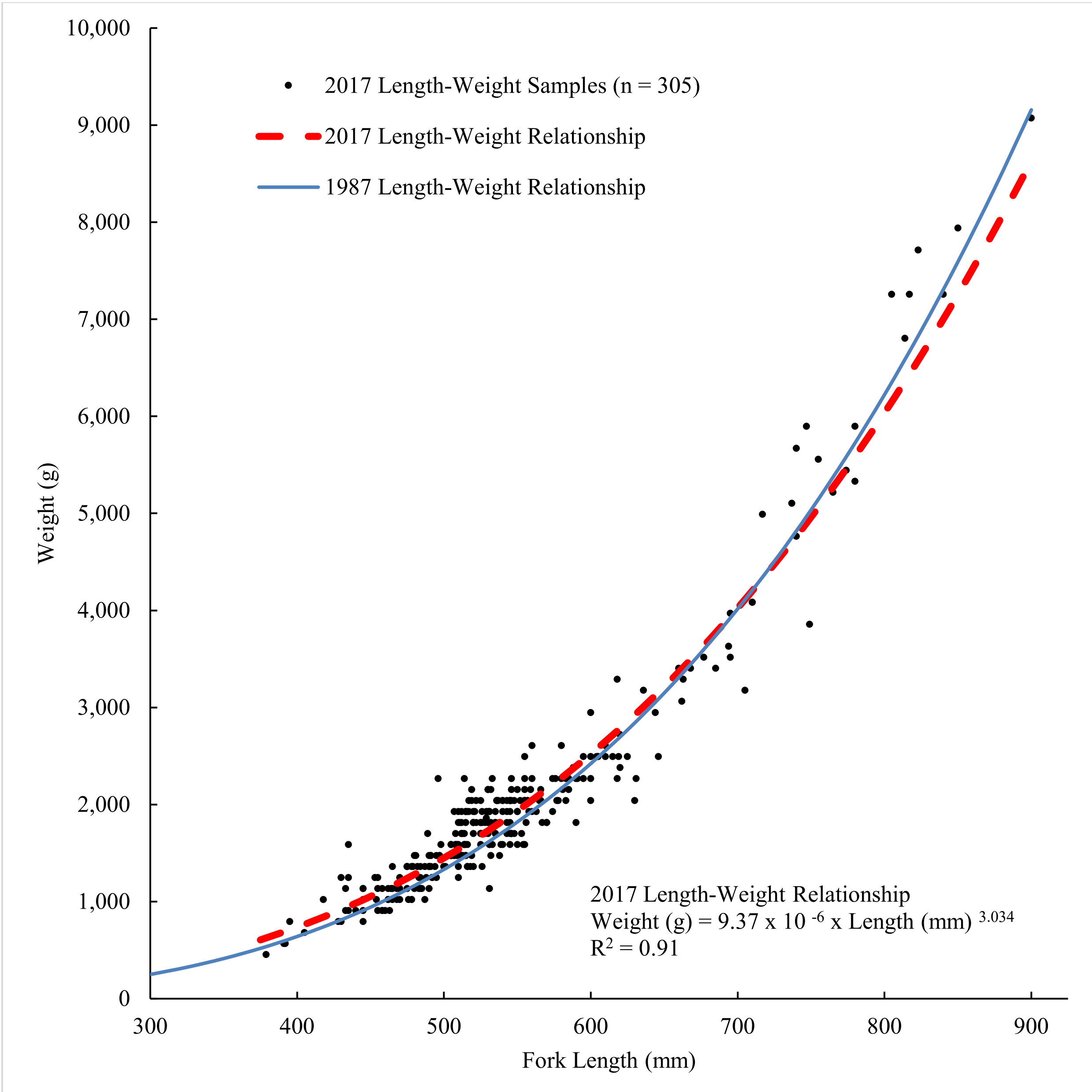

Figure 10.–Length-weight relationships for lake trout sampled from Chandler and Little Chandler lakes, 2017 and 1987 (fitted line only; Troyer and Johnson 1994).

DISCUSSION

This study was performed 30 years after the previous study and had very different results. In 1987, Troyer and Johnson (1994) estimated a combined abundance of lake trout in Chandler and Little Chandler lakes of 1,737 fish ≥234 mm FL (95% CI = 1,090–3,524). This study estimated the abundance of lake trout ≥450 mm FL in Chandler and Little Chandler lakes combined to be 5,759 (95% CI = 4,407–7,110). Despite the population of inference of this study being much more constrained, the point estimate was 4,000 fish higher. Three possible factors contributed to this discrepancy. First, the lake trout population might be substantially larger now. Second, the 1987 abundance estimate might be biased low. Lastly, the abundance estimate of this study might be biased high. These 2 studies were both two-event mark–recapture experiments, but each used a different approach for sampling. Potential biases of each need to be explored.

There was potential for negative bias during the 1987 project. Gillnets were the primary sample gear and a small crew deployed 1 or 2 gillnets a day and moved them around throughout the day. Limited hook and line sampling occurred as gillnets were deployed. Despite relatively long sampling events of about 3 weeks each, their coverage of the lake was not complete for an approach using passive sampling gear (e.g., only 18 gillnet sites were fished in the upper half of Chandler Lake and only 9 sites in all of Little Chandler Lake). If fish remained localized during their single season study, some areas of the lake were over sampled and other areas were under sampled. This would lead to an estimate that is biased low (underestimating the population size). There is also concern that their population of inference (≥234 mm FL) was erroneous because 234 mm was the smallest fish captured (not recaptured), and it did not appear that KS tests were used to determine capture probabilities by size.

This study focused on distributing sampling effort throughout Chandler and Little Chandler lakes during both events and used a long hiatus to reduce handling concerns and promote mixing. However, the long hiatus between events did allow for both growth recruitment and mortality to occur causing a positive bias in the abundance estimate. The Petersen estimator can garner an unbiased estimate if only recruitment or mortality occur, but not when both are present. Lake trout, especially in high latitudes, are slow growing and long lived. Both traits suggest that biases associated with annual recruitment and mortality would be low. The positive bias due to growth recruitment was explored by modeling the relationship between second-event lengths and growth in recaptured fish. Four models were considered (linear, exponential, logistic, and hockey-stick) with error assumed to be normally distributed around the trend line. Each modeled relationship was then used to adjust both the lengths of fish captured in the second event (i.e., subtracting growth), the length stratum each fish belonged to (if necessary), and to cull individuals that had recruited into the population of inference. The estimated bias due to growth recruitment was small, ranging from a 1% to 4% reduction in the abundance estimate depending on the growth model considered. The combination of these growth effects and harvest levels of several hundred fish would add negligible bias. As such, the discrepancy between this abundance estimate and the 1987 study is likely explained by negative bias in the 1987 abundance estimate and/or a dramatic increase in the abundance of lake trout.

The data collected during this study was more than adequate to meet precision criteria and allowed for exploration with alternative analyses while maintaining acceptable power for diagnostic testing. For example, results of KS tests (Appendix A1) and consistency tests (Appendix A2) indicated it would have been appropriate to pool all fish ≥450 mm FL for the abundance estimate. We explored this option which resulted in an estimate that was 229 fish fewer than the size-stratified estimate, a difference of just 4%. Although the relative precision of 0.22 was slightly better for the pooled estimate, the minute loss of precision was acceptable in this case. We chose to present the size-stratified estimate because there was an obvious separation in the cumulative relative length frequencies (KS tests) at 600 mm FL, and size-stratifying at this length resulted in KS and consistency test results with higher p-values. Size stratification was also justified biologically. In 2017, large fish were concentrated in the creek between Chandler and Little Chandler lakes. A total of 53 fish were sampled there with a mean length of 628 mm FL, half of which were >600 mm FL. In 2018, these large fish never fully materialized at the creek. We believe that the large fish marked in the creek in 2017 contributed to the high D-statistic around the 600 mm FL mark in the pooled KS tests (i.e., fish between 550 and 650 mm FL were marked at a higher rate than they were recaptured). This plausible explanation of the data reinforced the decision to size-stratify.

The LA model, combined with the mean weight (2.03 kg) of sampled fish during this study, resulted in an estimated yield potential of 400 lake trout annually from Chandler and Little Chandler lakes. This number is approximately 7% of the abundance point estimate of 5,759 fish ≥450 mm FL. It is believed that this level of harvest would amount to a lower percentage of the population susceptible to harvest. Although suffering from a small sample size of recaptured fish <450 mm FL and the concerns of biases, data did allow to make an abundance estimate of 6,570 fish ≥385 mm FL. This estimate is very likely biased high to an unknown extent because growth recruitment would be proportionally higher when smaller fish are considered. Although biased, it does serve to illustrate that a harvest of 400 fish annually likely would not exceed 6% of the targeted population.

Every other lake trout sampled in 2017 was weighed resulting in a mean weight of 2.03 kg. Lake trout sampled by Troyer and Johnson (1994) in Chandler and Little Chandler Lakes had a mean weight of 1.27 kg in 1987. Gillnet catches of lake trout have been shown to be negatively biased towards both small and large individuals (Hansen et al. 1997). Since the fish in 1987 were sampled primarily with gill nets (half of the length of their nets had a bar mesh ≤2.5 cm), it is not appropriate to compare the weight samples between these studies. However, comparisons of length-weight relationships are more appropriate, especially when considering samples were collected during the same general season. Length-weight relationships visually appear similar between studies (Figure 10). It is likely that any discrepancies between the 1987 and 2017 length-weight relationships are due to differences in fish sizes represented by the two data sets (e.g., in 2017 only 1% of the fish weighed were <400 mm FL, whereas in 1987 about 10% of their sample was <400 mm FL).

Although the population appears healthy during this study period, potential harvest levels should be discussed. The household surveys conducted in 2011 and 2014 reveal the importance of lake trout as a subsistence resource to the residents of Anaktuvuk Pass. The estimated mean annual harvest from community members during these 2 years was 803 total lake trout from unspecified lakes. If the majority of these fish are being harvested from Chandler and Little Chandler lakes, concerns of overexploitation would be warranted. Future household surveys should focus on clarifying the specific harvest locations of lake trout by the residents of Anaktuvuk Pass.

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APPENDIX A

Appendix A1.–Detection and mitigation of selective sampling during a two-event mark–recapture experiment.

Size-selective sampling may cause bias in two-event mark–recapture estimates of abundance and size and sex composition. Kolmogorov-Smirnov (KS) two sample tests are used to detect size-selective sampling.

Results of the tests will dictate whether the data needs to be stratified to obtain an unbiased estimate of abundance. The nature of the detected selectivity will also determine whether the first, second, or both event samples are used for estimating size compositions.

DEFINITIONS

M = Lengths of fish marked in the first event

C = Lengths of fish inspected for marks in the second event

R = Lengths of fish marked in the first event and recaptured in the second event

SIZE-SELECTIVE SAMPLING: KS TESTS

Three KS tests are used to test for size-selective sampling.

KS Test 1	C vs R	Used to detect size selectivity during the 1st sampling event. H_o: Length distributions of populations associated with C and R are equal
KS Test 2	M vs R	Used to detect size selectivity during the 2nd sampling event. H_o: Length distributions of populations associated with M and R are equal
KS Test 3	M vs C	Used to corroborate the results of the first two tests. H_o: Length distributions of populations associated with M and C are equal

Table A1-1 presents possible results of selectivity testing, their interpretation, and prescribed action.

-continued-

Table A1-1.–Possible results of selectivity testing, interpretation, and action.

Case	KS or χ^2 Test M vs. R (2^{nd} event test)	 C vs. R (1^{st} event test)	 M vs. C (1^{st} vs 2^{nd} event)	Interpretation and Action
I	Fail to reject H_o	Fail to reject H_o	Fail to reject H_o	**Interpretation**: No selectivity during either sampling event. **Action**: Abundance: Use a Petersen-type model without stratification. Composition: Use all data from both sampling events.
II	Reject H_o	Fail to reject H_o	Reject H_o	**Interpretation:** No selectivity during the 1st event but there is selectivity during the 2nd event. **Action**: Abundance: Use a Petersen-type model without stratification. Composition: Use data from the 1st sampling event without stratification. 2^{nd} event data only used if stratification of the abundance estimate is performed, with weighting according to Equations 1–3 below.
III	Fail to reject H_o	Reject H_o	Reject H_o	**Interpretation:** No selectivity during the 2nd event but there is selectivity during the 1st event. **Action**: Abundance: Use a Petersen-type model without stratification. Composition: Use data from the 2nd sampling event without stratification. 1st event data may be incorporated into composition estimation only after stratification of the abundance estimate and appropriate weighting according to Equations 1–3 below.
IV	Reject H_o	Reject H_o	Either result	**Interpretation:** Selectivity during both 1st and 2nd events. **Action:** Abundance: Use a stratified Petersen-type model, with estimates calculated separately for each stratum. Sum stratum estimates for overall abundance. Composition: Combine stratum estimates according to Equations 1–3 below.
V	Fail to reject H_o	Fail to reject H_o	Reject H_o	**Interpretation:** The results of the 3 tests are inconsistent. **Action:** Need to determine which of Cases I–IV best fits the data. Inconsistency can arise from high power of the M vs. C test or low power of the tests involving R. Examine sample sizes (generally M or C from <100 fish and R from <30 are considered small), magnitude of the test statistics (D_{max}), and the *P*-values of the three tests to determine which Cases I–IV best fits the data.

-continued-

COMPOSITION ESTIMATION FOR STRATIFIED ESTIMATES

An estimate of the proportion of the population in the k^{th} size category for stratified data with I strata is calculated as follows:

$$\hat{p}_k = \sum_{i=1}^{I} \frac{\hat{N}_i}{\hat{N}} \hat{p}_{ik}\,, \tag{1}$$

with variance estimated as:

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

where:

$\hat{p}_{ik}$ = estimated proportion of fish belonging to category k in stratum i;

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

$\hat{N}$ = estimated total abundance $= \sum_{i=1}^{I} \hat{N}_i$

TESTS OF CONSISTENCY FOR PETERSEN ESTIMATOR

Three contingency table analyses are used to determine if the Petersen estimate can be used (Seber 1982). If any of the null hypotheses are not rejected, then a Petersen estimator may be used. If all three of the null hypotheses are rejected, a temporally or spatially stratified estimator (Darroch 1961) should be used to estimate abundance.

Seber (1982) describes 4 conditions that lead to an unbiased Petersen estimate, some of which can be tested directly:

1. Marked fish mix completely with unmarked fish between events.
2. Equal probability of capture in event 1 and equal movement patterns of marked and unmarked fish.
3. Equal probability of capture in event 2.
4. The expected number of marked fish in recapture strata is proportional to the number of unmarked fish.

In the following tables, the terminology of Seber (1982) is followed, where *a* represents fish marked in the first event, *n* fish captured in second event and *m* marked fish recaptured; $m_{\bullet j}$ and $m_{i\bullet}$ represent summation over the i^{th} and j^{th} indices, respectively.

I. Mixing Test

Tests the hypothesis (condition 1) that movement probabilities (θ_{ij}), describing the probability that a fish moves from marking stratum *i* to recapture stratum *j*, are independent of marking stratum: H_o: $\theta_{ij} = \theta_j$ for all *i* and *j*.

Area/Time Marking Strata *(i)*	Area/Time Recapture Strata *(j)*				Not Recaptured
	1	2	…	t	$a_i - m_{i\bullet}$
1	m_{11}	m_{12}	...	m_{1t}	$a_1 - m_{1\bullet}$
2	m_{21}	m_{22}	...	m_{2t}	$a_2 - m_{2\bullet}$
...	...	...	...	...	…
s	m_{s1}	m_{s2}	...	m_{st}	$a_s - m_{s\bullet}$

II. Equal Proportions Test[a] (SPAS[b] terminology)

Tests the hypothesis (condition 4) that the marked to unmarked ratio among recapture strata is constant: H_o: $\Sigma_i a_i\theta_{ij}/U_j = k$, where k = a constant, U_j = unmarked fish in stratum *j* at the time of 2[nd] event sampling, and a_i = number of marked fish released in stratum *i*. Failure to reject H_o means the Petersen estimator should be used only if the degree of closure among tagging strata is constant, i.e. $\Sigma_j\theta_{ij} = \lambda$ (Schwarz and Taylor 1998; p 289). A special case of closure is when all recapture strata are sampled, such as in a fishwheel to fishwheel experiment, where $\Sigma_j\theta_{ij} = 1.0$; otherwise biological and experimental design information should be used to assess the degree of closure.

	Area/Time Recapture Strata *(j)*			
	1	2	…	t
Marked ($m_{.j}$)	$m_{\bullet 1}$	$m_{\bullet 2}$	…	$m_{\bullet t}$
Unmarked (n_j - $m_{.j}$)	n_1 - $m_{\bullet 1}$	n_2 - $m_{\bullet 2}$	…	n_t - $m_{\bullet t}$

-continued-

III. Complete Mixing Test[a] (SPAS[b] terminology)

Tests the hypothesis that the probability of re-sighting a released animal is independent of its stratum of origin: H_o: $\Sigma_j \theta_{ij} p_j = d$, where p_j is the probability of capturing a fish in recapture stratum j during the second event, and d is a constant.

	Area/Time Marking Strata *(i)*			
	1	2	…	s
Recaptured (m_i)	$m_{1\bullet}$	$m_{2\bullet}$	…	$m_{s\bullet}$
Not Recaptured (a_i - $m_{i\bullet}$)	a_1 - $m_{1\bullet}$	a_2 - $m_{2\bullet}$	…	a_s - $m_{s\bullet}$

[a] There is no 1:1 correspondence between Tests II and III and conditions 2–3 above. It is pointed out that equal probability of capture in event 1 will lead to (expected) non-significant Test II results, as will mixing, and that equal probability of capture in event 2 along with equal closure ($\Sigma j \theta ij = \lambda$) will also lead to (expected) non-significant Test III results.

[b] Stratified Population Analysis System (Arnason, A. N., C. W. Kirby, C. J. Schwarz and J. R. Irvine. 1996. Computer Analysis of Data from Stratified Mark-Recovery Experiments for Estimation of Salmon Escapements and Other Populations, Canadian Technical Report of Fisheries and Aquatic Sciences 2106).