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Stock Assessment and Yield Potential of Lake Trout in the Tangle Lakes System, 2023–2024

by

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and

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

Symbols and Abbreviations

The following symbols and abbreviations, and others approved for the Système International d'Unités (SI), are used without definition in the following reports by the Divisions of Sport Fish and of Commercial Fisheries: Fishery Manuscripts, Fishery Data Series Reports, Fishery Management Reports, and Special Publications. All others, including deviations from definitions listed below, are noted in the text at first mention, as well as in the titles or footnotes of tables, and in figures or figure captions.

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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SIGNATURE PAGE

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ABSTRACT

The primary objectives of this study are to estimate the abundance and length composition of lake trout *Salvelinus namaycush* in the Tangle Lakes system and to update the sustainable harvest level using the Lake Area model. Abundance and length composition will be estimated for the portion of the population that is susceptible to capture with hook-and-line sampling gear. To estimate abundance, two-event mark-recapture experiments for closed populations will be conducted on lakes within the Tangle Lakes system. Fish will be captured and marked in Lower Tangle Lake in April 2023 and in Upper, Round, Shallow, and Lower Tangle Lakes in June 2023. Recapture events will occur at the respective lakes in April and June 2024. The weights of fish captured with common sport fishing gear during the June sampling events will be used to estimate the number of fish that can be sustainably harvested on an annual basis using the Lake Area model. Abundance estimates will be generated for individual lakes or groups of lakes based on the movements of recaptured fish and results from a concurrent telemetry study. Abundance estimates will be compared to the updated estimate of sustainable harvest level and to estimates of catch and harvest generated by the Alaska Sport Fishing Statewide Harvest Survey to determine if current harvest limits and regulations are appropriate.

Key words: Lake trout, *Salvelinus namaycush*, abundance, mark-recapture, Tangle Lakes, Lower Tangle Lake, Shallow Tangle Lake, Round Tangle Lake, Upper Tangle Lake, Lake Area model, sustainable yield, effort, catch, harvest.

PURPOSE

This study is designed to evaluate current harvest levels and fishing regulations by collecting information on the lake trout *Salvelinus namaycush* population in the Tangle Lakes system. No system-wide stock assessment of lake trout has been completed to date. Current estimates of abundance and length composition, and an updated determination of the allowable sustainable harvest level are needed to assess the sustainability of recent trends in sport fishing catch and harvest of lake trout from the Tangle Lakes system.

BACKGROUND

Lake trout support important recreational fisheries in Alaska. They are relatively long lived and slow to mature, which can result in over exploitation of a population if not managed conservatively (Martin and Olver 1980; Burr 1997). In the Tanana River Management Area (TRMA), the most popular sport fishery for lake trout occurs in the Tangle Lakes system, located in the Upper Delta River drainage (Figures 1 and 2; Scannell and Baker 2021). In addition to lake trout, anglers fishing in the system target Arctic grayling *Thymallus arcticus* and burbot *Lota lota*. The system is comprised of 4 lakes connected by short segments of the Tangle River (Upper, Round, Shallow, and Lower Tangle Lakes) and 1 unconnected lake (Landlocked Tangle Lake). All 5 lakes support populations of lake trout. The interconnected lakes vary in size, with surface areas ranging from 140–200 ha, and morphometrics, from long and shallow to circular and deep. Two other nearby lakes (Glacier and Landmark Gap Lakes) both contain lake trout and drain into the Tangle Lakes system via separate small streams. The Denali Highway intersects the system between Upper and Round Tangle Lakes near milepost 21. There is a campground and boat launch located at Round Tangle Lake, and a day-use wayside and boat launch at Upper Tangle Lake. Both facilities are operated by the U. S. Department of the Interior Bureau of Land Management, and the entire Tangle Lakes system lies within the Delta Wild and Scenic River corridor.

Lake trout in the Tangle Lakes system are managed under the Wild Lake Trout *Management Plan* (5 AAC 74.040; Burr 2006). The overall objectives of this plan are 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 (harvest plus 10% catch-and-release mortality applied to the catch after harvest has been subtracted) is estimated from the annual Alaska Sport Fishing Statewide Harvest Survey (SWHS) and compared to predicted allowable yields based on either location specific studies or the Lake Area (LA) model (Table 1; Evans et al. 1991; Burr 2006). Due to concerns of overexploitation, the sport fishing harvest limit for lake trout in the Tangle Lakes system (including Glacier and Landmark Gap lakes) was reduced in 1987 from 10 per day, only 2 of which could be ≥20 in total length (TL), to 1 fish ≥ 18 in TL per day (Arvey et al. 1991). In 2008, the regulation was changed to 1 fish per day of any size (Parker 2009).

Lake trout inhabit deep water, typically occur in low densities, and are often found in large or remote lakes. These factors frequently result in difficult and costly stock assessment research, with resulting estimates that are imprecise or biased (Burr 2006). As described by Burr (2006), in the absence of updated stock assessments to determine sustainable yields, the LA model is used to estimate sustainable annual harvest or yield potential (in kg of lake trout per 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). Burr (2006) also cautions fishery managers to be aware of limitations resulting from the inherent variability of yield potential estimates of the LA model and the generally poor precision of lake specific estimates by the SWHS. Burr (2006) states, "Implementing drastic regulatory changes to curtail fishing opportunity based only on the [LA] model's yield potential threshold target and results from the mail survey [SWHS] is inappropriate.".

Using the LA model and considering the 4 connected Tangle Lakes combined (i.e., 1 intermixing population of lake trout), Burr (2006) estimated that 235 fish can be sustainably harvested annually. However, the interconnectedness of the 4 lakes does not justify acceptance of the assumption that the lake trout inhabiting those lakes are a single population. If the lakes are considered as 4 individual lake trout populations (i.e., complete population closure between them), and yield potential is estimated for each lake individually and then summed, the resulting yield potential would be 353 fish annually. From 2012–2021[1], the annual estimates of lake trout catch, harvest, and total fishing mortality averaged 1,308, 241, and 348 fish, respectively (Table 1). The 10-year average of estimated annual total fishing mortality is well above yield potential if the lake trout inhabiting the Tangle Lakes system are considered a single population, but slightly below the yield potential if the lakes are treated as separate populations.

The question of how to treat lake trout in the Tangle Lakes system, either as a single population or multiple populations, has been previously examined. Scanlon (2010) radiotagged 40 lake trout and tracked them for approximately 24 months. The study concluded that lake trout do periodically mix between Round and Shallow Tangle Lakes, limited mixing occurs between Lower Tangle Lake and the other lakes, and no movement occurs between Upper Tangle Lake and the other Tangle Lakes.

Because a small number of radio tags were deployed in 2010, constraining the study's results and conclusions, a second telemetry study was conducted in spring 2022 to provide a more thorough examination of lake trout movements in the Tangle Lakes system (Schwanke 2022). This study

[1] Alaska Sport Fishing Survey database [Internet]. 1996–. Anchorage, AK: Alaska Department of Fish and Game, Division of Sport Fish (cited April 3, 2023). Available from http://www.adfg.alaska.gov/sf/sportfishingsurvey/.

deployed 100 radio tags apportioned between the 4 interconnected lakes and is currently ongoing. Data collection will continue through October 2023. Forty (40) fish were radiotagged in Lower Tangle Lake, 22 in Shallow Tangle Lake, 25 in Round Tangle Lake, and 13 in Upper Tangle Lake. Preliminary study results are similar to those reported by Scanlon (2010), but with one notable exception. Of the fish radiotagged in Upper Tangle Lake in June 2022, 11 were believed to have survived capture and tagging, and by September 2022, 2 of these fish were detected in Glacier Lake (C. Schwanke, Sport Fish Biologist, ADF&G, Glennallen, personal communication).

Based on the preliminary results of the current radiotelemetry study (Schwanke 2022) and the work completed by Scanlon (2010), the lake trout inhabiting the Tangle Lakes system should be treated as 3 populations: 1) Lower Tangle Lake; 2) Round and Shallow Tangle lakes; and, 3) Upper Tangle Lake. When applied to these 3 populations of fish, the LA model estimates a yield potential of 324 lake trout. An additional point to consider, which was suggested by Scanlon (2010), is whether Upper Tangle Lake should be included in estimates of sustainable yield for the Tangle Lakes system. Upper Tangle Lake appears to have a relatively small population with no or very minimal mixing with the other 3 lakes, and fish from this lake likely constitute a small component of the lake trout caught and harvested in the sport fishery.

Studies completed prior to Scanlon (2010) were limited in their scope and conclusions. Using primarily gill nets, Burr (1989) estimated an abundance of 211 lake trout ≥250 mm FL (SE=33) in Upper Tangle Lake. Later, Burr (1992b) conducted sampling in 1991 that documented growth and size composition of lake trout in the 4 connected Tangle Lakes, and lake trout spawning in Lower and Round Tangle Lakes. One lake trout that was marked in Upper Tangle Lake was later recaptured in Glacier Lake. This observation and the preliminary results of the current radiotelemetry study are evidence that there is some level of exchange between the populations inhabiting Upper Tangle and Glacier Lakes (Schwanke 2022). Because the observed exchange was minimal, it is believed that Upper Tangle and Glacier Gap Lakes should not be included in estimates of sustained yield. However, future investigation of the lake trout population in Glacier Gap Lake and the movements of fish between it and Upper Tangle Lake are warranted.

The information provided by the current radiotelemetry study has allowed for the design and implementation of a Tangle Lakes system-wide lake trout stock assessment (Schwanke 2022). Recent trends of catch and harvest of lake trout from the sport fishery in the Tangle Lakes system, while relatively constant, indicate annual total fishing mortality is near or exceeding sustainable annual LA model yield potential estimates. A stock assessment is needed to ensure that exploitation rates remain at sustainable levels in this popular and accessible sport fishery.

OBJECTIVES

The primary objectives for this study are to:

1. estimate the abundance of lake trout susceptible to capture with common sport fishing tackle during April and June 2023 in the connected Tangle Lakes such that the estimate is within 25% of the true abundance 95% of the time;

2. estimate the length composition (in 25-mm length categories) of the lake trout population susceptible to capture with common sport fishing tackle during April and June 2023 and 2024 such that the estimated proportions are within 10% of the true proportions 95% of the time; and,

3. estimate the yield potential of lake trout in the connected Tangle Lakes, in number of fish, such that the estimate is within 200% of the true value 95% of the time.

METHODS

This study is designed to estimate the abundance of lake trout in the connected Tangle Lakes using two-event Petersen mark-recapture techniques for closed populations (Seber 1982). The population of inference for the experiment will include both immature and mature fish that are susceptible to capture with hook-and-line gear. Fish will be captured using common sport fishing gear and baited hookless juglines. The timing of the sampling events was chosen to occur immediately following ice-out in June, when fishing for lake trout is generally considered to be "good". Lower Tangle Lake will also be sampled in April for reasons stated in the Marking Event section below. Length and weight data collected during the experiment will be used to estimate the yield potential of the interconnected Tangle Lakes using the LA model. Sampling will closely follow methods successfully employed to estimate lake trout abundances at Chandler, Little Chandler, and Fielding Lakes (Schwanke and Albert 2019; Albert and Ocaña *In prep*). Abundance estimates will be generated for individual lakes or groups of lakes pending examination of movements of recaptured fish and results from a concurrent telemetry study.

MARK-RECAPTURE EXPERIMENT (OBJECTIVES 1–2)

Using two-event Petersen mark-recapture techniques for closed populations (Seber 1982), the experiment will rely on the following assumptions to obtain an unbiased estimate of abundance:

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 will have a similar probability of capture in either the first or second event, or marked and unmarked lake trout will mix completely between events;
3. marking of lake trout will not affect the probability of capture in the second event;
4. marked lake trout will be identifiable during the second event; and,
5. all marked lake trout will be reported when recovered in the second event.

Failure to satisfy these assumptions may result in biased estimates; therefore, the experiment is designed to allow the validity of these assumptions to be ensured or tested. Sufficient data will be collected to perform diagnostic tests to identify heterogeneous capture probabilities (violations of Assumption 2) and prescribed model selection procedures will be followed in the event of such violations. Diagnostic tests are not available to evaluate Assumptions 1, 3, 4, and 5; instead, the experiment is designed to ensure that these assumptions will be met thereby avoiding potential biases. The design will ensure that sample sizes will be adequate to meet objective precision criteria and to perform reliable diagnostic tests.

Marking Event (April and June 2023)

Marking events will occur during April and June 2023 at Lower Tangle Lake and June 2023 at Upper, Round, and Shallow Tangle Lakes. Lower Tangle Lake is easier to access during winter and can be sampled effectively in late spring prior to break-up. Sampling Lower Tangle Lake in April will allow for more effort to be expended towards the remaining 3 lakes during June 2023.

During the April 2023 marking event at Lower Tangle Lake, lake trout will be captured by ice-fishing with baited and unbaited soft plastic jigs and spoons over a period of 6 days by a crew of 6–8 people. Captured fish will be placed in an insulated cooler filled with fresh water and sampled immediately.

The June 2023 marking event will utilize three 2-person crews in boats, powered by outboard motors, to capture and mark fish over a 15-day period in mid to late June. Hook-and-line gear and baited hookless jug lines will be used for fish capture. Hook-and-line sampling will primarily consist of trolling or casting spoons and vertically jigging soft baits (e.g. artificial tube or baitfish imitations). Captured fish will be gently guided into a rubber meshed dip net, placed in a tub filled with fresh water, and sampled immediately.

Hookless jug lines, which have been used successfully in other lake trout projects, will be deployed throughout the lake (Scanlon 2010; Schwanke and Albert 2019, Albert and Ocaña *In prep*). Approximately 30 jug lines will be available for use. Jug lines will be constructed from a 45-cm long bullet-shaped foam buoy with a 10- to 20-m section of heavy braided fishing line hanging from the buoy. A 15- to 25-cm piece of bait (herring or whitefish) will be tied to the line with a noose knot, and the bottom will be weighted with a 28- to 85-g lead weight. Jug lines will be opportunistically set on the windward side of the lake to minimize the chance of the gear washing ashore, and additional weight may be added if considerable drifting occurs. Jug lines will be checked several times daily. Captured fish will be gently guided into a rubber meshed dip net, placed in a tub filled with fresh water, and sampled immediately.

During both marking periods, each unmarked lake trout captured will be marked with an individually numbered Floy™ FD-94 internal anchor tag (primary mark; model FD-94 Anchor Tag, Floy Tag and Manufacturing Inc., Seattle, Washington). All marked fish will receive a partial lake-specific fin clip as a secondary mark to ensure they are still identifiable in case of tag loss (Table 2). Additionally, all lake trout captured during June 2023 will also be marked with an individually numbered passive integrated transponder (PIT) tag (APT12 PIT tag, Biomark, Boise, Idaho). PIT tags will be implanted in a standardized location in the left opercular musculature (i.e., cheek).

Recapture Event (April and June 2024)

Recapture events will occur during April and June 2024 at Lower Tangle Lake and June 2024 at Upper, Round, and Shallow Tangle Lakes. Both recapture periods will closely follow the methods used in the respective marking periods. If feasible, capture techniques and equipment will be refined from the marking event. Ideally, this will improve sampling efficiency and increase sample sizes during the recapture events. Examined fish will receive a partial right pectoral fin clip to prevent sampling with replacement during the recapture event.

Evaluation of Assumptions

Assumption 1 (population closure)

For the purposes of this experiment, the connected Tangle Lakes system will be considered a closed population with one exception. Based on a prior mark-recapture experiment and an ongoing radiotelemetry study, there is evidence that some exchange of fish occurs between Upper Tangle Lake and nearby Glacier Lake via Rock Creek. One of the lake trout tagged by Burr (1992a-b) in Upper Tangle Lake was later recaptured in Glacier Lake. Additionally, 2 fish from the current radiotelemetry study that were radiotagged in Upper Tangle Lake in June 2022, were located in

Glacier Lake in September 2022 (C. Schwanke, Sport Fish Biologist, ADF&G, Glennallen, personal communication). The degree of exchange between the 2 lakes is still uncertain, but the results of the current radiotelemetry study are expected to provide further clarity. If exchange of fish between Upper Tangle and Glacier Lakes occurs during this experiment, it is expected to be at a relatively low rate. The available radiotelemetry data will be utilized to frame the degree to which the assumption of closure may be violated (i.e., movements out of Upper Tangle Lake to Glacier Lake) in this experiment. Separately, the likelihood of exchange between Landmark Gap Lake and the Tangle Lakes system appears to be unlikely because the connecting stream is small and intermittent, with a steep descent (~120 m over 16 km). None of the past or presently radiotagged lake trout have emigrated downstream of Lower Tangle Lake. Nor were any lake trout captured during Arctic grayling studies in the Delta River downstream of Lower Tangle Lake (A. Gryska, Sport Fish Biologist, ADF&G, Fairbanks, personal communication).

Relative to lake trout movements within the connected Tangle Lakes system, preliminary results from the current radiotelemetry experiment were used to identify which lake's populations should be considered closed and in which lakes an exchange of fish is likely to occur. There is minimal movement of fish to or from Lower Tangle Lake. However, Round and Shallow Tangle Lakes have a moderate level of fish exchange, and there have been no observed movements of fish between Round and Upper Tangle Lakes (C. Schwanke, Sport Fish Biologist, ADF&G, Glennallen, personal communication). Based on this, we anticipate that 3 abundance estimates will likely result from this study: one for Lower Tangle Lake, one for Shallow and Round Tangle Lakes, and one for Upper Tangle Lake.

Growth recruitment over the timeframe of the experiment is expected. A similar lake trout population assessment at nearby Fielding Lake found evidence of significant fish growth between sampling events (average=18 mm FL; Albert and Ocaña *In prep*). First and second event lengths of marked fish captured in the second event will be examined for growth. If evidence of significant growth is found, the lengths of all fish captured in the second event will be adjusted to account for growth.

Fish may also leave the population of inference through fishing and natural mortality. Because natural and fishing related mortality is not expected to be selective towards marked individuals, the two-event Peterson mark-recapture model is still appropriate. In the event of mortality, abundance estimates will be germane to the first event. The natural mortality rate is believed to be inconsequential because mature lake trout are very long-lived once mature. Catch and harvest estimates from the SWHS are for the entire Tangle Lakes system and not specific to the individual lakes. However, the magnitude of harvest is expected to be substantial (e.g., 200–400 fish annually; Table 1). This level of harvest necessitates assuming that marked and unmarked fish will be caught by anglers at the same rate and, therefore, removed from the population proportionally.

Assumption 2 (bias in capture probabilities)

The assumption of equal probability of capture will be satisfied because sampling will occur throughout the entire study area during both events. To distribute sampling effort, Upper Tangle, Round Tangle, and Shallow Tangle Lakes will be sampled at least every other day. While Lower Tangle Lake will receive less sampling in June, the April sampling effort ensures it will receive a similar amount sampling effort as the other 3 lakes. Field crews will distribute sampling effort throughout their assigned lake each day to ensure all fish are subject to capture. The year-long hiatus between the marking and recapture events will promote mixing of marked and unmarked lake trout.

The length and capture location of each fish captured will be recorded to detect and correct for unequal probabilities of capture related to fish size or location. Size-selective sampling will be examined using two-sample Kolmogorov-Smirnov (KS) tests. The tests and possible actions for data analysis are outlined in Appendix A1. If stratification by size or sex is required, capture probabilities will be examined for each stratum, and total abundance and its variance estimate will be calculated by summing strata estimates.

Geo-temporal violations of Assumption 2 will be evaluated using consistency tests (Appendix A2). Potential violations will be assessed spatially by dividing the study area into 4 geographic strata (i.e., by lake; Figure 2). Round and Shallow Tangle Lakes will likely be combined into 1 stratum for consistency testing because significant exchange of fish between them is expected. If diagnostic tests indicate stratification by location or time is required, the possible actions for data analysis are outlined in Appendix A2.

Assumption 3 (handling effects on probability of capture in the second event)

No handling or marking induced behavioral effects are anticipated due to the long hiatus between events and because each fish will be carefully handled during sampling. During the first event, if a fish appears injured or overly stressed, it will be measured but not tagged. During the second event, every fish will be examined for a tag (Floy™ and PIT) and a partial fin clip. Hooking or capture mortality will be assumed to be very low (i.e., ≤1%), particularly because any captured fish showing any signs of injury or major stress will not be tagged.

Assumption 4 (marked lake trout are identifiable upon recapture)

This assumption will be satisfied by double marking each lake trout captured during the first event of the experiment. Unique secondary marks (e.g., partial fin clips) will be used for each lake (Table 2). Tag loss will be noted on the field data collection form when a fish is recaptured during the second event with a secondary mark (partial fin clip), but without a Floy™ or PIT tag. Additionally, for both Floy™ and PIT tags, tag placement will be standardized, which will allow verification of tag loss by locating recent tag wounds, marks, or scars. Tag loss is anticipated but expected to be minimal. For example, during the 2021–2022 Fielding Lake study, evidence of Floy™ or PIT tag loss was observed for only 2 out of 54 lake trout (Albert and Ocaña *In prep*). Similarly, no tag loss was observed during the 2017–2018 Chandler and Little Chandler Lakes study (Schwanke and Albert 2019).

Assumption 5 (all fish are correctly reported)

All fish will be thoroughly examined for tags or recent fin clips. All markings (tag number, tag color, fin clip, and tag wound if present) on each fish will be accurately recorded by field crews.

Estimation of Annual Allowable Harvest (Objective 3)

The LA model relies on the mean weight of harvested fish. In the absence of a creel survey in which mean weights of harvested fish can be calculated, estimating these weights through sampling is necessary. During this mark-recapture experiment, hook-and-line gear will be the primary sampling method and is assumed to effectively mirror the size composition of lake trout caught in the sport fishery. Therefore, only the mean weight of fish sampled with hook-and-line gear will be used to estimate yield potential using the LA model (Evans et al. 1991).

SAMPLE SIZE

Abundance Estimates (Objective 1)

Information to approximate the population of lake trout large enough to be susceptible to hook-and-line gear in each of the 4 lakes is limited. The sample sizes presented in this section are based upon initial estimates of lake trout abundance derived primarily from observations of catch-per-unit-effort and perceived relative abundance reported by field crews in April and June 2022 while deploying radio tags (C. Schwanke, Sport Fish Biologist, ADF&G, Glennallen, personal communication; J. Spencer, Sport Fish Biologist, ADF&G, Fairbanks, personal communication). Additional factors taken into consideration were the proximity of a lake to access points (i.e., amount of potential sport fishing effort), lake size (i.e., surface area), amount of suitable thermal habitat (i.e., depth), and results of prior field studies (Burr 1989, 1992a, 1992b; Scanlon 2010, Schwanke 2022). Because substantial exchange of fish between Round and Shallow Tangle Lakes is expected, the required sample size reflects conducting a pooled estimate of abundance for those lakes. Using the methods of Robson and Regier (1964), required sample sizes, assuming 3 stratum, to attain the desired precision criteria for Objective 1 (within 25% of the true abundance 95% of the time) were determined (Table 3). Additionally, required sample sizes to attain abundance estimates within 25% of the true abundance 90% of the time were also calculated to provide context.

Based upon field crew observations from sampling completed in 2022, it is believed that all the sample sizes required to meet the objective precision criteria are attainable (J. Spencer, Sport Fish Biologist, ADF&G, Fairbanks, personal communication). However, if those samples sizes cannot be met, fishery management staff have indicated that abundance estimates meeting the lower precision criteria, while not preferable, will be sufficient. The project leader will adjust sampling effort between the lakes as needed to ensure adequate sample sizes are attained in each stratum. Adjustments will be based on daily and cumulative catches, within-event recapture rates, environmental conditions (i.e., water clarity or weather), and perceived relative abundance of lake trout in each lake.

Length Compositions (Objective 2)

The methods of Thompson (1987) for multinomial proportions, with finite population corrections, were used to calculate sample size requirements for length composition estimates. To achieve the desired precision criteria (within 10% of the true values 95% of the time), at least 113 lake trout from Lower Tangle Lake and at least 115 fish from Shallow and Round Tangle Lakes must be sampled. The sample sizes required for the associated abundance estimates (Objective 1, Table 3) for these 3 lakes are larger and will be sufficient to satisfy all length composition sample size requirements even if diagnostic tests find evidence of length selectivity and require data from only one sampling event to be used for the analysis (Appendix A1). For Upper Tangle Lake, at least 64 fish will need to be sampled in each event to satisfy precision criteria for estimating length composition. This is greater than the sample size for the associated abundance estimate (Table 3). However, the sample size for Upper Tangle Lake is 57 fish in each event for the estimate to be within 10% of the true values 90% of the time. Further lowering the precision criteria to within 15% of the true values 90% of the time requires sampling 34 fish per event.

Lake Area Model and Yield Potential Estimates (Objective 3)

A sample of at least 100 lake trout caught with hook-and-line gear from both events will yield an estimate of the mean weight that is within 25% of the true value 95% of the time, assuming the mean and standard deviation of weights is similar to those observed in a comparable summer sample (n=148) of lake trout from Fielding Lake (Albert and Ocaña *In prep*). This conclusion was reached using a bootstrap to approximate mean weight and the variance of mean weight using the Fielding Lake data over sample sizes (n) from 30 to 150 with 5,000 iterations and the critical t-value associated with a 95% confidence level and n – 1 degrees of freedom.

Treating the estimated yield potential from the LA model as constant (that is, only incorporating the sampling variance due to estimation of the mean weight), using the Fielding Lake data to approximate the mean and standard deviation of weights, and using mean weight as an approximate normal distribution, a sample size of 100 fish will satisfy the precision criteria of yield potential in numbers of lake trout to be within 25% of the true value 95% of the time.

It is important to recognize the variance due to prediction from the LA model. The LA model reported in Evans et al. (1991) is expressed on the log-log scale, with an R^2 of 0.69 and a sample size of 43 lakes. Sampling from the lake area data reported in this publication and simulating yield potential values such that estimated regression parameters are equivalent to those reported, provide an approximate estimate of the model residual variances and thereby prediction variances for new lakes with the same areas as the 4 interconnected Tangle Lakes. Simulating values using these prediction variances and sampling with replacement from the Fielding Lake weight data, yield potential in kg is expected to be within 450% of the true value 95% of the time. Note that this relative precision is based on a 95% prediction interval, which is typically wider than confidence intervals. Also note, there is likely extra variance because all lakes were used in the bootstrap without replacement to estimate prediction variance instead of the 43 specific lakes used by Evans et al. (1991). Considering both the variance in mean weight and the variance in yield potential in kg, yield potential in number of lake trout is expected to be within 200% of the true value 95% of the time. Because Fielding Lake and the Tangle Lakes system are close in location, we expect the lakes to have similar populations of lake trout. However, Fielding Lake is larger than any one of the Tangle Lakes, but smaller than the combined surface area of the 4 connected Tangle Lakes. The bootstrap and Monte Carlo simulation showed that relative precision tends to increase with the size of the lake. The relative precision chosen is the maximum relative precision for lakes ranging in size from 140 to 800 ha. Thus, we can be confident the relative precision will hold no matter the lake size.

Differences in the mean and standard deviation of fish weights between the lake trout populations in Fielding Lake and the Tangle Lakes system could change the maximum relative precision, as seen in the bootstrap. If the Tangle Lakes system has a smaller mean weight and a smaller standard deviation of weight than Fielding Lake, it is expected that the relative precision for mean weight will remain the same or decrease. Therefore, the desired precision criteria may be reached with a sample size smaller than 100 fish. If the Tangle Lakes system has a larger mean weight and a larger standard deviation of weight than Fielding Lake, it is likely that the relative precision will stay the same. By examining weight data collected during the marking event it will be possible to determine if and how the given relative precision and sample size may be adjusted for the Tangle Lakes system. It is expected that the Tangle Lakes system will have a smaller mean weight and a smaller standard deviation of weight than those observed at Fielding Lake. The Tangle Lakes system experiences higher levels of sport fishing effort, and lake trout catch and harvest than

Fielding Lake, likely resulting in a population with a higher composition of smaller (i.e., ≤500 mm FL) fish. Regardless of differences between Fielding Lake and the Tangle Lakes system, we expect that the relative precision for yield potential in kg and yield potential in number of lake trout will stay the same. The yield potential in number of lake trout will have a smaller relative precision if yield potential in kg is taken as a constant and the Tangle Lakes system has a smaller mean weight and a smaller standard deviation of weight than Fielding Lake.

The sample sizes required for the associated abundance estimates (Objective 1; Table 3) for these 4 lakes are larger than 100 when including both events and will be sufficient to satisfy all yield potential sample size requirements.

DATA COLLECTION AND REDUCTION

Data collected from all sampled fish will include:

1. date of capture;
2. crew member names;
3. water and weather conditions;
4. time of capture;
5. general description of capture location;
6. GPS coordinates of capture location (WGS84 decimal degrees latitude and longitude);
7. capture gear;
8. measurement of fish FL to nearest mm;
9. measurement of fish TL to nearest mm;
10. weight of fish to nearest 0.1 kg (using a handheld scale);
11. sex of fish (if known);
12. Floy™ tag number and color (if tagged);
13. PIT tag number (if tagged);
14. fin clip type (secondary mark);
15. recapture status (Y or N); and,
16. any applicable notes to include but not limited to observations of capture, significant wounds (already present or due to capture), overall condition of fish, presence of an old tag, or tag or fin clip scars.

Data items 1–16 will be recorded onto data forms printed on water resistant paper (Rite in the Rain® Paper, JL Darling LLC, Tacoma, Washington; Appendix B). Weights will only be collected during the June sampling periods. Fish will be weighed in a rubber meshed net bag with the weight of the net subtracted.

Mark-recapture data will be transferred from data forms to Excel worksheets for analysis and archival. Column headings will correspond to headings on attendant data forms (Appendix B). Additional columns may be added for clarity. Data will be entered, examined for obvious errors, and corrected immediately following each field collection period. The final reviewed dataset will be archived in the Alaska Lake Database (ALDAT): http://www.adfg.alaska.gov/SF_Lakes/.

DATA ANALYSIS

ABUNDANCE ESTIMATES (OBJECTIVE 1)

Prior to diagnostic testing (Appendix A), the marking and recapture lengths of all recaptured lake trout in an experiment will be examined for growth-recruitment using paired t-tests at a significance level of 0.05. If significant growth is detected, lengths of sampled fish in the second event will be corrected. If growth is constant between all sizes of fish, growth correction will be done by subtracting the mean growth of recaptured fish from the lengths of all fish captured in the second event. If growth varies by fish size, a regression that allows growth to vary by fish size will be used for second event length corrections (Gulland 1969).

For abundance estimates, size- and sex-selective sampling will be tested using Kolmogorov-Smirnov tests. If stratification by size or sex is required, capture probability will be examined for each stratum, and total abundance and its variance estimate will be calculated by summing strata estimates. These tests and possible actions for data analysis are outlined in Appendix A1. Spatio-temporal violations of Assumption 2 will be evaluated using consistency tests described by Seber (1982; Appendix A2). If some movement of marked lake trout between geographic strata is observed, but mixing is incomplete, the methods of Darroch (1961) will be used to compute a partially stratified abundance estimate. If no movement of marked fish between geographic strata is observed, a completely stratified abundance estimate will be computed using a modification of the methods of Chapman (1951) or Darroch (1961). More details for possible actions if stratification by location or time is required are outlined in Appendix A2.

If no stratification is required, abundance estimates will be calculated using Chapman's (1951) modification of the Petersen estimator. This Chapman estimator will be calculated for each of the geographic strata of the Tangle Lakes system using:

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

where:

$\hat{N}$= the estimated abundance of lake trout;

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 will be calculated as:

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

LENGTH COMPOSITIONS (OBJECTIVE 2)

Results from the diagnostic tests for size-selective sampling (Appendix A1) will be used to determine if stratification is necessary and if data from the first, second, or both events should be used. An estimated length composition is required for each of the populations or geographic strata of the Tangle Lakes system. For cases I-III (Appendix A1), stratification is not necessary. Length proportions (in 25-mm categories) will be estimated using samples from event(s) without size selectivity and calculated using:

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

where:

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

n_k= the number of lake trout sampled within length category *k*; and,

n= the total number of lake trout sampled.

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

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

If diagnostic tests indicate case IV (Appendix A1), where size-selectivity is present during both events, the data will be 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.

Comparisons between length distributions will be made using Kolmogorov-Smirnov tests at a significance level of 0.05. For examination of length distributions by sampling gear type, the lengths of captured fish will not be corrected for growth. This will reflect the actual sizes of fish captured by each sampling gear.

LAKE AREA MODEL AND YIELD POTENTIAL ESTIMATES (OBJECTIVE 3)

The LA model (Evans et al. 1991) will be used to estimate yield potential for each population/geographic strata of the Tangle Lakes system as:

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

where:

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

a = lake area in ha.

Assuming yield potential in kg of biomass per year is a constant for each stratum, the approximate average yield potential (delta method; Seber 1982; Casella and Berger 2002), in terms of number of lake trout, will be estimated as:

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

where:

$\overline{\mathrm{W}}$ = estimated sample mean of the weights of lake trout (in kg per fish) from both events.

The approximate variance will be estimated as:

$$\hat{\mathrm{V}}(\overline{YP}_n) \approx \frac{\widehat{\mathrm{YP}}^2}{\overline{\mathrm{W}}^4}\ \hat{\mathrm{V}}(\overline{\mathrm{W}}) \tag{8}$$

where:

$\widehat{V}(\overline{W}) = \frac{\widehat{V}(W)}{n}$ = estimated variance of the sample mean;

$\widehat{V}(W)$= estimated sample variance of the weights (in kg) of lake trout from both events; and,

n= the total number of lake trout sampled in both events.

SCHEDULE AND DELIVERABLES

Research findings from 2023–2024 will be summarized in a Fishery Data Series (FDS) Report. Important project dates to be completed annually, unless specified by year, are given below.

Date(s)	Activity
March–May 2023	Complete staffing plan; organize and purchase supplies.
11–18 April 2023	First sampling period of the marking event at Lower Tangle Lake.
15–30 June 2023	Second sampling period of the marking event at all 4 lakes.
March–May 2024	Complete staffing plan; organize and purchase supplies.
11–18 April 2024	First sampling period of the recapture event at Lower Tangle Lake.
15–30 June 2024	Second sampling period of the recapture event at all 4 lakes.
November 2024	Data analysis completed.
January 2025	Draft FDS report submitted to project biometrician.
March 2025	Draft FDS report submitted to research supervisor.
April 2025	Completed final report.

RESPONSIBILITIES

Matthew Albert	Fishery Biologist 2, Project Leader Responsible for authoring project operational plan, supervise and assist with field project preparation, purchasing, and sampling, perform data analysis, and author final report.
Mackenzie Ocaña	Biometrician 2 Provide biometric assistance for study design, project operational plan, data analysis, and final report.
James Savereide	Fishery Biologist 4, Research Coordinator Review project operational plan and final report.
April Behr	Fishery Biologist 3, Resident Species Research Supervisor Review project operational plan and final report.
Klaus Wuttig	Fishery Biologist 4, AYK Management Coordinator Review project operational plan and final report.
Andy Gryska	Fishery Biologist 3, Fairbanks Area Management Biologist Review project operational plan, final report, and assist with field sampling.
Brandy Baker	Fishery Biologist 2 Assist with field logistics and sampling.
Corey Schwanke	Fishery Biologist 2 Assist with field logistics and sampling.
Brian Collyard	Fish and Wildlife Technician 4 Assist with purchasing, field project preparation, logistics, and sampling.
Joseph Spencer	Fishery Biologist 1 Assist with field logistics and sampling.
Mike McNulty	Fish and Wildlife Technician 3 Assist with field logistics and sampling.
Barry Willard	Fish and Wildlife Technician 3 Assist with field logistics and sampling.

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TABLES AND FIGURES

Table 1.–Annual estimates of sport fishing effort in angler days and lake trout harvest, catch, and total fishing mortality in numbers of fish at Tangle Lakes, 2002–2021.

Year	Respondents[a]	Effort[b]	Harvest	Catch	Total Fishing Mortality[c]
2002	111	4,994	414	2,464	619
2003	116	5,820	516	2,037	668
2004	81	3,737	270	976	341
2005	81	4,299	224	2,327	434
2006	66	3,600	292	1,076	370
2007	83	5,463	482	1,890	623
2008	70	3,443	232	1,119	321
2009	74	4,065	333	1,559	456
2010	93	7,050	657	3,317	923
2011	62	4,478	337	1,278	431
2012	60	4,326	161	1,254	270
2013	66	6,199	444	761	476
2014	61	5,519	206	801	266
2015	52	3,999	72	1,121	177
2016	62	4,619	374	1,049	442
2017	64	4,696	228	3,932	598
2018	57	4,431	16	214	36
2019	59	4,732	316	798	364
2020	73	6,252	560	2,851	789
2021	39	3,706	36	295	62
5-year average (2017–2021)	58	4,763	231	1,618	370
10-year average (2012–2021)	59	4,848	241	1,308	348

Source: Alaska Sport Fishing Survey database [Internet]. 1996–. Anchorage, AK: Alaska Department of Fish and Game, Division of Sport Fish (cited April 3, 2023). Available from http://www.adfg.alaska.gov/sf/sportfishingsurvey/.

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 plus 10% of the catch after subtracting harvest.

Table 2.–Event- and lake-specific partial fin clips to be used as secondary marks to identify tag loss and prevent sampling with replacement during the recapture event at Tangle Lakes, 2023–2024.

Event	Lake	Fin Clip
Mark (2023)	Lower	Left pectoral
	Shallow	Left pelvic
	Round	Right pelvic
	Upper	Adipose
Recapture (2024)	All lakes	Right pectoral

Table 3.–Initial approximations of the abundance of lake trout large enough to be susceptible to hook-and-line gear and sample sizes required to attain desired objective precision criteria.

Lake	Initial abundance approximation	Required sample size per sampling event to attain estimate ± 25% of true value	
		90% of the time	95% of the time
Upper	125	50	54
Round and Shallow	1,150	191	227
Lower	1,000	176	209

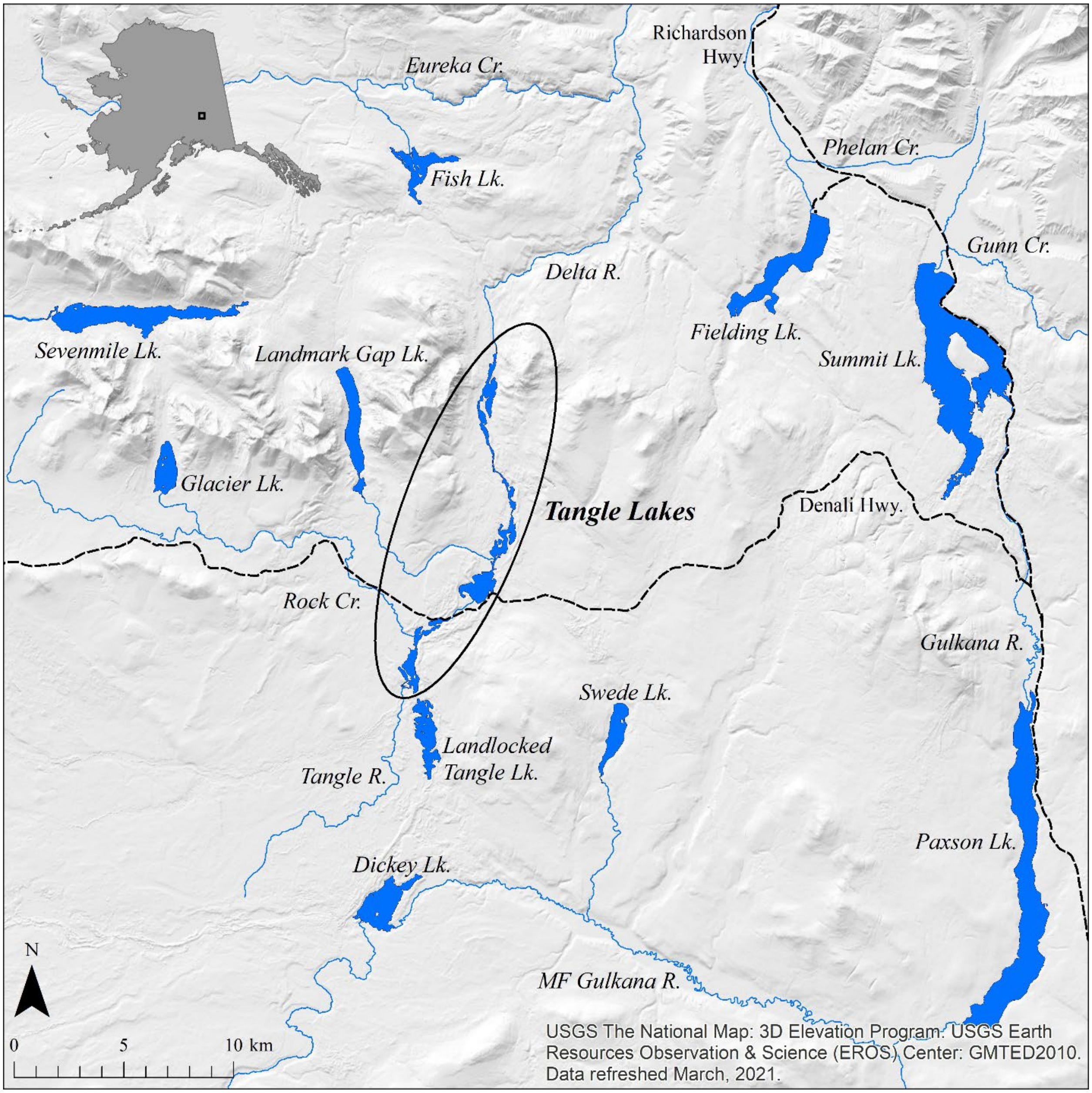

Figure 1.–Map depicting the location of Tangle Lakes.

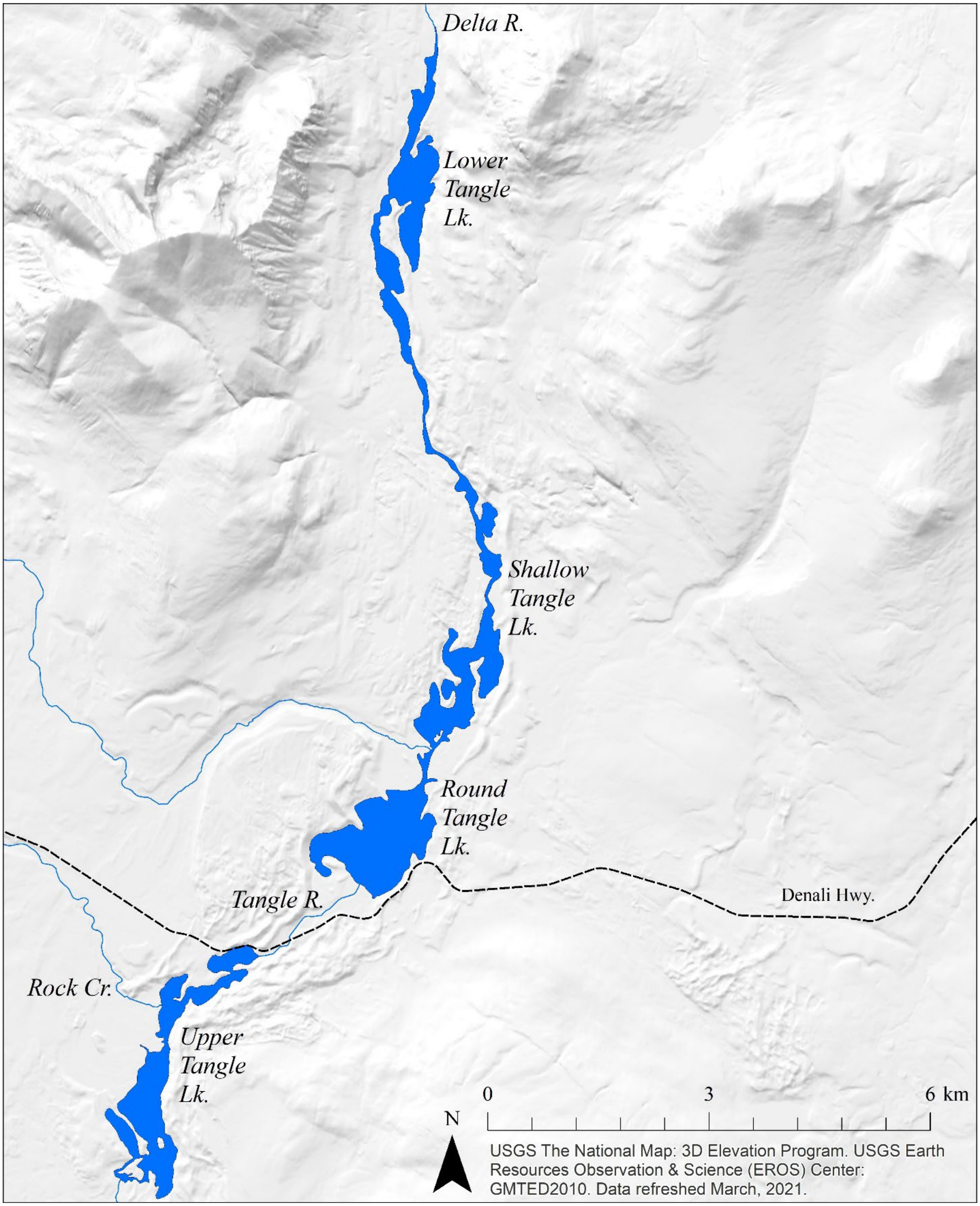

Figure 2.–Map of Tangle Lakes.

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 two-event mark recapture experiment.

Length selective sampling: The two-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 two 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&R, C&R, and M&C as described above, using the null hypothesis that the probability that a sampled fish is male or female is independent of sample. When the proportions by gender 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 two-sample test (e.g., Student's t-test).

M vs. R	**C vs. R**	**M vs. C**
Case I:		
Fail to reject H_o	Fail to reject H_o	Fail to reject H_o
There is no 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.

* 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 which the C vs. R test was not powerful enough to detect. *Case I* may be considered but *Case III* is the recommended, conservative interpretation.

D. If a) sample sizes for C vs. R and M vs. R are both small; and, b) both the C vs. R and M vs. R p-values are not large (~0.20 or less), the rejection of the null in the M vs. C test may be the result of 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 one must be fulfilled to meet assumptions of a Petersen estimator:

1. Marked fish mix completely with unmarked fish between events;
2. Every fish has an equal probability of being captured and marked during event 1; or,
3. Every fish has an equal probability of being captured and examined during event 2.

To evaluate these three assumptions, the chi-square statistic will be used to examine the following contingency tables, as recommended by Seber (1982). If any of the null hypotheses are not rejected, then a Petersen estimator (Chapman 1951) may be used. If all three 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	Area/Time Where Recaptured (*j*)				Not Recaptured
Where Marked (*i*)	**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.

APPENDIX B: DATA FORMS

Appendix B1.–Field data collection form for sampling lake trout during mark-recapture events.

Date:	**Lake:**	**Weather & Water Conditions:**	**Crew:**	**Daily Page:**	**Data Page:**

Fish #	**Time**	**Lat**	**Long**	**Gear**	**FL (mm)**	**TL (mm)**	**Wt. (kg)**	**Floy #**	**PIT #**	**Fin Clip**	**R-C?**	**Notes**