Fishery Data Series No. 24-XX

Lake Trout Movement and Spawning Locations Within the Tangle Lakes System

by

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December 2024

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

Symbols and Abbreviations

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Mathematics, statistics

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

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ABSTRACT

This study used telemetric procedures to describe movement and locate spawning areas of lake trout *Salvelinus namaycush* within the 4 interconnected Tangle Lakes (Upper, Round, Shallow, and Lower Tangle Lakes). A total of 100 radio tags were deployed among the 4 lakes during spring 2022: 13 in Upper Tangle Lake, 25 in Round Tangle Lake, 22 in Shallow Tangle Lake, and 40 in Lower Tangle Lake. Fish were tracked with an airplane or boat 15 times between 23 June 2022 and 11 October 2023, and seasonally monitored with 3 fixed-tracking stations located between the lakes. The number of radiotagged fish deemed alive throughout the study was good, with 90 surviving through the first summer and gradually dropping to around 70 by the end of the following summer. Movement was detected between lakes a total of 129 times with the fixed-tracking stations. Movement occurred 20 times between Lower Tangle and Shallow Tangle Lake by 5 individual fish and 109 times between Round Tangle and Shallow Tangle Lakes by 28 individual fish. All 22 of the fish originally radiotagged in Shallow Tangle Lake traveled to Round Tangle Lake. Conversely, 6 of the 25 fish originally radiotagged in Round Tangle Lake moved to Shallow Tangle Lake, one of which continued to Lower Tangle Lake. Most fish radiotagged in Lower Tangle Lake stayed there, but 4 of the 40 fish did move to Shallow Tangle Lake at some point during this study. No fish moved between Upper Tangle Lake and Round Tangle Lake, but 2 fish did move from Upper Tangle Lake to Glacier Lake. Most movement was temporary. Radiotagged lake trout showed fidelity to the lakes they were radiotagged in seasonally. The percentage of alive lake trout radiotagged in Lower Tangle Lake and subsequently located there during 1 of the 15 airplane and/or boat tracking surveys ranged from 94% (SE=4%) to 100%. Shallow Tangle Lake had the least amount of fidelity, ranging from 6% (SE=6%) to 88% (SE=8%) during each survey; Round Tangle Lake had stronger fidelity, ranging from 88% (SE=8%) to 100%; and Upper Tangle Lake had 100% fidelity, except for the 2 fish that immigrated to Glacier Lake. Round Tangle Lake appears biologically significant to the fish radiotagged in Shallow Tangle Lake, and it is recommended that these two lakes be treated as a single population when addressing management concerns. Lower Tangle Lake and Upper Tangle Lake should be treated as independent populations.

Extensive radiotracking, visual monitoring and netting only affirmed a few spawning locations in the lake complex. A single deep water spawning area was confirmed in Lower Tangle Lake, and another suspected spawning area was identified. Two spawning locations were confirmed in Round Tangle Lake and two other areas had suspected spawning activity. One area had suspected spawning activity in Upper Tangle Lake and no evidence of spawning occurred at Shallow Tangle Lake.

Keywords: lake trout, Tangles Lakes, telemetry, distribution, spawning areas

INTRODUCTION

Lake trout *Salvelinus namaycush* support important recreational fisheries in Alaska. Lake trout are relatively long-lived and are slow to mature, meaning they can easily be overexploited when not managed conservatively (Martin and Olver 1980). In the Tanana River drainage, the most popular fishery for lake trout occurs in the Tangle Lakes system. The Tangle Lakes system is comprised of 4 interconnected lakes that are all connected by various reaches of the Tangle River (Figure 1), and Landlocked Tangle Lake, which is not connected to the river or other lakes. The Denali Highway intersects the lakes between Upper and Round Tangle Lakes near Mile Post 21. The interconnected lakes vary in size from 137 to 156 ha and vary morphometrically from predominately long and shallow to circular and deep. Two other nearby lakes, Glacier Lake and Landmark Gap Lake, drain into the Tangle Lakes through separate small streams. All 7 lakes contain lake trout. In addition to lake trout, other species found in the Tangle Lakes system include Arctic grayling *Thymallus arcticus*, burbot *Lota lota*, round whitefish *Prosopium cylindraceum* and longnose sucker *Catostomus catostomus*.

Due to concerns of overexploitation, the harvest limit for lake trout in Tangle Lakes was reduced in 1987 from 12 fish per day, only 2 of which could be 20 inches or larger, to 1 fish per day ≥18 in in total length. The regulation was changed to 1 lake trout of any size in 2008. The latest 5-year (2018–2022) mean of catch and harvest is 718 and 175, respectively (Table 1). ADF&G considers release mortality when estimating exploitation with the assumption that 10% of all released fish die. Total angler-based mortality is estimated annually as the sum of harvest and estimated release mortality, with estimated release mortality being 10% of the difference between catch and harvest. The 5-year mean of estimated angler-based mortality from Tangle Lakes is 232 (Table 1).

Lake trout associate with deep water in summer and typically occur in low densities; consequently, stock assessments are difficult and costly, particularly in large or remote lakes, and may result in biased or imprecise estimates. 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 Alaskan interior lakes to determine if annual harvests for 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. Upper Tangle Lake is an estimated 151.9 ha, Round Tangle Lake is 156.1 ha), Shallow Tangle Lake is 136.8 ha, and Lower Tangle Lake is 137.4 ha[1]. Combined, these sum to 582.2 ha. It should be noted that this combined estimate of surface area for the 4 interconnected lakes was calculated using satellite imagery and GIS tools, and differs from what Burr (2006) published (i.e., 620 ha). Applying the LA model to Tangle Lakes when considering the 4 lakes combined (one intermixing population of lake trout), YP is estimated at 390 kg/year. Burr (2006) estimated that the mean weight of lake trout of all sizes from the interconnected Tangle Lakes was approximately 1.7 kg, which estimates YP at 229 fish from the 4 lakes combined. The difficulty with this notion is that just because the lakes are connected does not mean that they should be considered a single population. If the lakes were treated as individual populations, and their YPs estimated individually and then summed, the result would be a YP of about 574 kg/year, or approximately 338 total fish. As previously stated, the most recent 5-year mean of angler-based mortality in the interconnected Tangle Lakes combined is 232 fish, which is at YP if the lakes are treated as a single population, but below YP if each lake has a separate population.

The notion of whether to treat the Tangle Lakes system as a single population or multiple populations has been previously examined. Scanlon (2010) radiotagged 40 lake trout from the interconnected Tangle Lakes in 2004 and tracked them for about 24 months to evaluate mixing and identify spawning areas. A total of 20 fish were radiotagged in Lower Tangle, 7 in Shallow Tangle, 12 in Round Tangle, and 1 in Upper Tangle Lakes. Low sample sizes constrained results of this study, but the main conclusions were that lake trout do periodically mix between Round and Shallow Tangle Lakes, and that mixing between Lower Tangle Lake and the other lakes is very limited. Scanlon (2010) documented no mixing of fish between Upper Tangle Lake and the other lakes, but sample sizes were very small. Secondary results of this study included the confirmation of a single spawning area in Round Tangle Lake, and a suspected, but unconfirmed spawning area near the south end of Lower Tangle Lake near the inlet river.

Studies prior to Scanlon (2010) are limited. Burr (1989) estimated an abundance of 211 lake trout ≥250 mm FL (SE = 33) in Upper Tangle Lake. In an attempt to identify spawning locations in 1991, Burr (1992) sampled 22 fish in Round Tangle Lake and 18 in Shallow Tangle Lake during the spawning season. He also documented spawning lake trout in the same area on Round Tangle Lake that Scanlon (2010) verified, and he suspected a spawning area in Lower Tangle Lake based on high catch rates of ripe fish from a single gillnet set. Of particular interest, one of the fish Burr (1992) tagged in Upper Tangle Lake was later recaptured in nearby Glacier Lake. The movement of this fish indicated that flows in Rock Creek were sufficient to serve as a migration corridor

[1] Alaska Lake Database (ALDAT). 2013–Alaska Department of Fish and Game, Division of Sport Fish. Available at http://www.adfg.alaska.gov/SF_Lakes/ (accessed October 15, 2024).

between Glacier and Upper Tangle Lake despite a relatively steep gradient (approximately 284 m over 19.5 rkm), but the degree of exchange between these lakes is uncertain. Exchange of lake trout between Landmark Gap and Tangle Lakes also appears likely based on the length and similar gradient (approximately 128 m over 10.5 rkm) of the interconnecting stream, but to date no exchange has been documented.

The primary goals of this project were to assess lake trout movement among the 4 interconnected lakes to determine if lake trout should be treated as separate or combined populations, to better assess spawning areas in all 4 lakes, and to collect information to help design an abundance estimation study. The resulting information was needed to better understand lake trout population dynamics and the effects of current exploitation rates. General catch rates, length composition of the population, locations of spawning areas, and fish movements among the lakes are all important factors when designing a mark-recapture experiment. A separate mark-recapture experiment to estimate abundance and length composition in the 4 interconnected Tangle Lakes commenced in April 2023 (Albert and Ocaña 2023).

OBJECTIVES

The objectives of the Tangle Lakes lake trout telemetry study were to:

1) Describe the seasonal (June 2022–October 2023) distributions of mature-sized lake trout ≥430 mm FL radiotagged in the interconnected Tangle Lakes during spring 2022 with an emphasis on movement among lakes; and,

2) Identify spawning areas of lake trout in the interconnected Tangle Lakes in September 2022.

METHODS

STUDY AREA

The Tangle Lakes system is comprised of 4 interconnected lakes: Upper Tangle Lake, Round Tangle Lake, Shallow Tangle Lake, and Lower Tangle Lake (Figure 1). Landlocked Tangle Lake shares the same last name, but as implied in the name, is not connected to the other 4 lakes. All radiotagging took place in the 4 interconnected Tangle Lakes, but occasional aerial surveys were flown over Glacier and Landmark Gap Lakes, as well as the Delta River. Glacier Lake and Landmark Gap Lake share the same drainage but are spatially separated and connected by relatively small creeks (Figure 1).

STUDY DESIGN

Overview

This study documented the seasonal distribution of lake trout in the 4 interconnected lakes in the Tangle Lakes system (Figure 1). A total of 100 radio tags were deployed during spring 2022 into lake trout ≥430 mm FL. Fish of this size were large enough to accommodate the radio tag (the tag must be <2% of the fish weight; Winter 1983), were expected to be mature (Burr 1993), and their behavior was expected to be representative of all mature-sized fish. Fish were tracked with airplane, boat, and fixed-tracking stations. An emphasis on tracking was placed in late September in an attempt to verify previously documented spawning areas and document undiscovered spawning areas.

Given the depth at which lake trout live, many radiotagged lake trout were expected to go undetected during surveys. A previous study with similar radio tags on humpback whitefish had variable detection rates below depths of 8 m (Schwanke 2024). All 4 of the interconnected Tangle Lakes have maximum depths exceeding 22 m. For this reason, the fixed-tracking stations were very important because aerial surveys would possibly not detect all movement between surveys.

Fish Capture

Lake trout were captured and radiotagged during 2 time periods during 2022: 4–7 April and 3–12 June. Lower Tangle Lake can be difficult to access in summer because of a stretch of shallow rocky water, so radio tags were deployed in that lake in April 2022. The other 3 lakes have easy open water access and were sampled in June 2022.

A total of 40 radio tags were deployed into Lower Tangle Lake during April 2022 (Table 2). A crew of 6 people accessed the lake via snowmachine and used hook-and-line gear to capture lake trout. Angling gear consisted of spoons, tube jigs, and swim shads, all tipped with bait.

The remaining 60 tags (22 for Shallow, 25 for Round, and 13 for Upper) were deployed in June 2022 (Table 2). Two or three 2-person crews captured lake trout from boats using hook-and-line gear and baited jug lines. Sampling with hook-and-line primarily consisted of trolling or casting spoons and vertically jigging soft baits such as tube jigs and swim shads. Hookless jug lines, which have been used successfully in other lake trout projects (Scanlon 2010; Schwanke and Albert 2019), were used in this study, primarily in Upper Tangle Lake, which required more effort to attain sample sizes. Jug lines were constructed from 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 foam float. A 15- to 25-mm piece of bait (whitefish) was tied to the line with a noose knot, and the bottom was weighted with a 28- to 85-gram sinker. Jug lines were opportunistically set on the windward side of a lake to minimize the chance of washing ashore. Jug lines were checked daily and were not left out overnight. All captured fish were gently guided into a rubber meshed dip net and temporarily placed in a tub filled with fresh water to examine their health (i.e., make sure they were not bleeding or injured in any other way). Surgeries followed within 10 minutes of this inspection.

Telemetric Procedures and Data Collection

At each tagging location, the first healthy fish ≥430 mm FL captured was radiotagged and all subsequent healthy captured fish of adequate size were radiotagged until the allotted number of radio tags for that location were deployed. Effort was put to disperse tags throughout each lake, although no stringent rules were used. Each lake trout was anesthetized using Aqui-S 20E and implanted with a radio tag following surgical methods detailed by Brown et al. (2002).

Anesthetized fish were measured to the nearest mm fork length (FL), placed ventral side up in a padded cradle, and the gills were irrigated with a water throughout the surgery. Surgical utensils were disinfected in a Nolvasan solution and rinsed with saline solution prior to each surgery. A 15-mm incision was made anterior to the pelvic girdle, along the left ventral side, about 5–10 mm from the midventral axis. A grooved director was placed into the coelomic cavity through the incision to direct a 16-gauge 25.4 cm hypodermic needle inserted from posterior of the pelvic girdle toward the incision (Brown et al. 2002). The tag antenna wire was routed from the incision past the pelvic girdle by threading the wire through the needle. Upon exit, the needle and grooved director were removed and the radio tag was fully inserted into the coelomic cavity. The incision was sutured with 3 to 4 simple interrupted stitches of monofilament suture material (Wagner et al. 2000) and treated with a surgical adhesive. After surgery, fish were immediately placed into a large recovery tote filled with fresh river water to regain equilibrium before they were released.

The tags were Lotek MCFT-3EM tags individually coded (1–100) on frequency 150.400 MHz. They were programmed to beep every 5–6.5 seconds, were turned off from 1 November 2022 through 30 March 2023, and then operated continuously until the batteries died sometime in early winter 2023. This encompassed 2 full open water seasons (summer of 2022 and 2023) and 2 spawning periods (fall 2022 and 2023). All radio tags had 24 h motion detectors programmed at the Lotek sensitivity level of 8 to help decipher mortalities. Each tag had ADF&G contact information to encourage self-reporting of harvested radiotagged fish.

Tracking flights were conducted using a fixed-wing aircraft or boat with a Lotek SRX 1200 receiver. Receivers were equipped with an internal GPS that recorded time and location data during each survey. Most surveys were aerial, but boat-based surveys were conducted when fixed-tracking stations were downloaded. Aerial surveys were conducted 100–300 m above the ground with a Piper Super Cub equipped with 2 H-antennas (148–152 MHz), 1 mounted on each wing, connected to a splitter and controlled by a selecting switch. This schematic allowed the pilot to more easily locate tags, which facilitated decoding. The same Lotek SRX 1200 receiver was used when boat tracking, but a single H antenna was used and manually pointed to detect as many fish as possible as the boat systematically covered the lake. Initially, the entire shoreline was tracked then transects across the lake were made. When 2 surveys were conducted within 10 days of each other, they were combined to maximize sample sizes for a single unit in time for data analysis. When this was done, the locations of all fish found during the first survey were used, and new fish found during the second survey were added to the results of the first survey.

During all aerial and boat surveys, the receiver (Lotek SRX 1200) automatically recorded date, time, and location (GPS decimal-degree, Datum WGS84) of radiotagged fish. The data was downloaded and saved as a text file then converted to a Microsoft Excel file. All data related to radiotelemetry was integrated into one master Excel spreadsheet compatible with ArcGIS® software.

A series of 3 fixed-tracking stations were set up between the 4 interconnected lakes (Figure 2). Lotek SRX 600 receivers were used along with a power source (two 12-volt batteries and a solar panel), an antenna switch box, a SunSaver solar controller, and 2 five-element Yagi antennas. The electrical components were stored in a locked metal box at the site. The receivers were programmed to continuously scan from both antennas simultaneously. When a signal of sufficient strength was encountered, the receiver paused for 15 seconds on each antenna, and then tag frequency, tag code, signal strength, date, time, and antenna number was recorded on the receiver. The pair of antennas allowed the determination of direction of travel (antenna 1 was pointed upstream and antenna 2 was pointed downstream). Based on signal strength and timestamps, a fish would be detected coming from one direction and leaving the other direction, or in some cases not actually passing the receiver.

Fixed tracking stations were functional during the majority of the open water season and during late spring when the lakes were still frozen. In 2022, the tracking stations between Lower and Shallow Tangle Lakes and between Shallow and Round Tangle Lakes both became functional on

25 April, and the tracking station between Round Tangle Lake and Upper Tangle Lake became functional on 11 June. The tracking stations stayed functional until mid to late October 2022, when solar power could not keep up with demand. In 2023, all 3 tracking stations were functional from 17 April until they were intentionally dismantled on 8 October.

Spawning Area Evaluation(s)

Radiotagged fish were tracked 16–25 September 2022 to identify spawning areas. Surveys were conducted with a boat at night when lake trout move to spawning areas. Two boats and 4–5 people worked night shifts. Each night, the entire shoreline of a lake was surveyed using high-powered, submersible lights, hand-held spotlights, and a Lotek SRX 1200 receiver connected to an H-antenna. The lights were used to visually spot aggregations of fish while simultaneously tracking the shoreline with the receiver. When a group of radiotagged fish was detected with the receiver but could not be seen due to either muddy or deep water, entanglement nets (2.54-mm bar mesh gillnets) were set to confirm spawning. All boat tracking results were combined and displayed on maps with locations of confirmed spawning areas and areas suspected to be spawning areas. The substrate type was documented where concentrations of fish were located.

Data Reduction and Analyses

In Season Data Reduction

To facilitate data reduction, a Master Excel file was constructed that contained all tagging, fixed-tracking station information, aerial tracking information, and catch/harvest reports for each radiotagged fish. After each aerial or boat tracking survey, the receiver was downloaded, sorted by frequency, code, and signal strength, and the data point with the strongest signal strength for each tag was recorded as that fish's location. An inseason initial fate was given based on the radio tag motion sensor, either "A" for Active, "I" for inactive, or "M" for missing for that date.

Fixed-tracking station data had to be treated differently because every fish could be detected on any day, and could move one of two directions (e.g., upstream or downstream). After each download of a fixed-tracking station, data was sorted by frequency, code, then signal strength. On a fish-by-fish basis, it was determined whether or not a fish passed a tracking station by examining the number of times it was located, signal strength, and antenna detections. Once it was determined a fish passed a tracking station, it was given a daily designation based on which lake it traveled to: LT for Lower Tangle Lake, ST for Shallow Tangle Lake, RT for Round Tangle Lake, and UT for Upper Tangle Lake. Only fish which passed a tracking station counted if they remained in the new lake for at least 24 h.

Data Analyses

After all the data was collected and initial reduction was complete, the first step in data analysis was revisiting each fish's aerial/boat tracking location via ArcMap and examining motion sensor results to determine the fate of each fish for each tracking survey. Reviewing the movement history of each radiotagged fish was required because the motion sensor sometimes did not accurately reflect the fate of a tagged fish during a given survey. The history of sensor recordings for each fish was examined to determine when and if the fish had died, and its fate was corrected for subsequent surveys. For example, a fish with an inactive signal for one or more surveys that later made substantial movements and emitted an active signal was considered alive for the inactive period. Conversely, a fish with an intermittent active signal, while exhibiting no detectable movement throughout the tracking history, was considered dead at the time of consecutive inactive signals. At the conclusion of aerial tracking flights, all fish were classified as follows:

1) Alive (A)- a fish with an active code and has shown movement since its previous location;

2) Non-fishing mortality (NFM) – a fish located within a lake but its tag was emitting an inactive signal;

3) Fishery mortality (FM) – a fish that was reported harvested or determined to be harvested based on unnatural movement at the fixed tracking stations (i.e., unreported fishing harvest); and,

4) At large (AL) –a fish that was not found during a survey.

The next step was going through each fish again, on a fish-by-fish basis, and determining the location of each fish deemed alive at the daily level. This included simultaneously examining all fixed-tracking station files and aerial survey files to determine where each fish was each day. At this point, fish that were missing for any aerial/boat surveys and subsequently located had their fates changed from AL to their respective lake designation (e.g., LT). This was possible because the tracking station data allowed us to determine what lake a fish was in at the time they were missing. The finished product was a final daily timeline for each live fish depicting what lake it was in for every day the tracking stations were functioning.

To describe movements, the proportion of fish moving among lakes was estimated semimonthly. The proportion of movement equations were as follows:

$$\hat{p}_{moved} = \frac{x_{moved}}{n} \tag{1}$$

$$\widehat{var}(\hat{p}_{moved}) = \frac{\hat{p}_{moved}(1-\hat{p}_{moved})}{n-1} \tag{2}$$

where:

$\hat{p}_{moved}$ = the proportion of lake trout that moved at least once among lakes semimonthly;

x_{moved} = all radiotagged fish whose location label changed semimonthly (does not include AL fish, or fish with NFM or FM subscripts); and,

n = includes x_{moved} and fish whose location label did not change semimonthly (does not include AL fish, or fish with NFM or FM subscripts).

Many movement scenarios were possible, making prescriptive analytical procedures impractical. Because movement among lakes was important to this study, contingency tables and related chi-square tests that were analogous to the mixing test used to test for consistency of the Petersen estimator (Seber 1982) were constructed. An s-by-(t+1) contingency table was constructed for each survey, in which s and t represent the numbers of tagging and observation strata, respectively. Numbers of radiotagged fish with unknown fate during the second period were recorded in column t+1 (i.e., analogous to "not observed" during the second event of a two-event mark-recapture experiment). This tested the null hypothesis that movement probabilities from lake to lake are the same among lakes. A significant P-value <0.05 would suggest otherwise and indicate that complete mixing does not occur among lakes and that the lakes should be treated as single populations. These chi-square tests were done considering movement among all 4 lakes (4x5 contingency tables) and considering only movement between adjacent lakes (2x3 contingency tables). Examining movement between adjacent lakes could be important for management of the interconnected Tangle Lakes. For example, evidence could show that 2 lakes exhibit complete mixing, while the other 2 do not, suggesting the interconnected Tangle Lakes should be treated as 3 populations.

RESULTS

SUMMARY OF FISH CAPTURED

A total of 100 lake trout were captured and surgically implanted with radio tags during 2 time periods. From 4 through 7 April 2022, 40 lake trout were captured and radiotagged from Lower Tangle Lake (Figure 2 and Table 2). An additional 22 lake trout were captured and radiotagged from Shallow Tangle Lake 8–10 June, 25 from Round Tangle Lake 3–12 June, and 13 from Upper Tangle Lake 9–11 June (Figure 2 and Table 2). Upper Tangle Lake had the largest mean size of lake trout (579 mm FL; SD=85), followed by Shallow Tangle Lake (563 mm FL; SD=72), Lower Tangle Lake (540 mm FL; SD=75), and Round Tangle Lake (485 mm FL; SD=40; Table 3). Length distribution box plots demonstrate that Round Tangle Lake generally had smaller fish captured and radiotagged (Figure 3).

DISTRIBUTION

Overview

A total of 15 tracking surveys were performed during this study: 10 exclusively by airplane, 3 exclusively by boat, and 2 that were combined (Table 4). The surveys spanned 17 months with the first survey occurring on 23 June 2022 and the last on 11 October 2023. The number of fish deemed alive throughout this study was good, ranging from 90 to 92 through the first summer and gradually dropping to below 80 by the fall. The final survey had constrained results because it is believed that some batteries in radio tags died, and previous surveys during the cold-water period revealed that many tags emitted an inactive code even though fish were subsequently found alive and exhibited movement. If additional surveys were conducted, many of the fish exhibiting inactive codes or were missing during the last survey would have likely been deemed alive and/or found.

Six of the 100 radiotagged fish were designated as sportfishing mortalities: 3 were reported and 3 were not. Unreported harvests were easy to detect as the tracking station located between Upper and Round Tangle Lakes detected these tags at high signal strengths (indicating the tag was out of the water), for a short period of time (indicating high speeds of travel), and then never detected them again. Interestingly, 3 of the harvested fish came from Upper Tangle Lake, a lake that only had 13 fish radiotagged.

Lake Distribution and Movements

The proportion of detected fish located in each lake on aerial survey dates are confounding because factors such as water depth (tag detectability), natural mortality, and fishing mortality affected lakes at different rates. Regardless, they are presented in Table 5 and do show trends. Distribution was fairly constant in Lower Tangle Lake, varying from 37% to 46% of all fish detected. Upper

Tangle Lake consistently had 13% of detected fish for the first 3 surveys but only 6% later in the study. Shallow and Round Tangle Lakes were the most dynamic and were mirror images of each other at times indicating movement between the lakes (Table 5; Figure 4). Of interest is that the distribution proportions for the surveys on 23 June 2022 and 23 June 2023 for Shallow and Round Tangle Lakes were nearly identical, suggesting fidelity to those respective lakes during that time-period.

Examining locations of fish originally tagged in a specific lake and found in that same lake during subsequent surveys was a more appropriate way to assess movement, or lack thereof (Table 6). The percentage of fish radiotagged in Lower Tangle Lake and subsequently located there during surveys ranged from 94% (SE=4%) to 100%. Shallow Tangle Lake had the least amount of fidelity; 6% (SE=6%) to 88% (SE=8%) of radiotagged fish were relocated in the lake during surveys (Table 6). Round Tangle Lake had strong fidelity; 88% (SE=8%) to 100% of fish remained in the lake during surveys. Upper Tangle Lake had 100% fidelity, except for 2 fish that immigrated to Glacier Lake (Table 6).

Contingency table chi-square tests for complete mixing gave strong evidence that movement probabilities from lake to lake were not the same among lakes, suggesting that individual lakes should be considered their own populations when estimating yield potentials. The null hypothesis of equal movement probabilities was rejected at every survey when considering movement among all 4 lakes (Table 7). Contingency table chi-square tests for adjacent lakes yielded similar results. Movement between Lower and Shallow Tangle Lakes was negligible and the null hypothesis of equal movement probabilities on every survey date was rejected. There was no movement observed between Upper Tangle and Round Tangle Lakes. Round and Shallow Tangle Lakes had the most movement between lakes, but when testing movement between just these 2 lakes (Table 7), all dates except 1 rejected the null hypothesis. The mixing test between tagging and 17 July 2023 gave only marginal evidence of unequal movement probabilities (P-value= 0.053), but it is likely that this result mainly reflects low test power.

Movement among lakes recorded by the fixed-tracking stations, which tracked fish continuously, provided the best information about lake trout distributions. Movement was detected between lakes a total of 129 times with the fixed-tracking stations. As stated earlier, the fixed-tracking stations performed nearly flawlessly. When comparing fixed-tracking and aerial survey locations, only one disparity was found in which aerial survey information did not agree with the lake designation from fixed-tracking station observations. This could have been an issue with the aerial survey information (e.g., false reading) or the fixed-tracking station missed a fish. Of the 129 detected movements, 83 occurred in 2022 and 46 occurred in 2023 (Figure 5). The number of times movement was detected by year and location is displayed in Figures 5–8. Movement occurred 20 times between Lower Tangle and Shallow Tangle Lake (5 individual fish) and 109 times between Round Tangle and Shallow Tangle Lakes (28 individual fish). Although this sums to 33 individual fish, technically only 32 unique fish moved among lakes because a single fish moved from Round Tangle Lake to Shallow Tangle and then to Lower Tangle Lake. For all lakes, the highest period of movement was in June 2022. In 2023, a more obvious movement trend existed when no fish moved to Shallow Tangle Lake between 1 July and 15 August, while that period encompassed peak movement to Round Tangle Lake (Figure 8).

Some fish moved many times over the course of a year, and many fish did not move at all. A total of 30 and 22 fish moved at least once in 2022 and 2023, respectively (Figure 9). Two fish moved in 2023 that did not move in 2022 bringing the total number of fish that moved during this study to 32. Ten fish moved at least 4 times in 2022 and a single fish moved 8 times in 2022. Looking at movement among lakes at a finer 2-week scale and converting to proportions of fish that moved at least once, revealed interesting results. In 2022, peak movement occurred during June and the first half of August (Table 8). In 2023, peak movement occurred during July and the second half of September. Possible explanations for these differences are outlined in the discussion.

Although tracking stations were not operational during the winter months, evidence suggested movement among lakes in winter was minimal to non-existent. No fish locations changed between the survey on 26 October 2022 and the next survey on 27 April 2023 (Tables 5–7). In addition, when the tracking stations were deployed on 17 April 2023, no fish were detected passing them until 20 May 2023, about the time the flowing connections between the lakes became ice free. For these reasons, it was assumed that none of our radiotagged fish moved during the winter of 2022/2023. Re-creating fish locations on a daily basis by using the fixed-tracking station information and aerial survey information showed obvious trends. The first is that most lake trout radiotagged in Lower Tangle Lake stayed there, but 4 of the 40 radiotagged fish did move to Shallow Tangle Lake (Figure 10 and Table 6). All 22 fish radiotagged in Shallow Tangle Lake moved to Round Tangle Lake in this study, but none went to Lower Tangle Lake (Figure 11 and Table 6). Fish radiotagged in Round Tangle Lake typically stayed there, but 6 of the 25 fish did migrate to Shallow Tangle Lake at one point, and 1 of those fish eventually went to Lower Tangle Lake (Figure 12 and Table 6). This fish crossed into Shallow Tangle Lake on 30 June 2023 and then into Lower Tangle Lake on 8 July 2023, where it remained for the duration of the study. No fish migrated from Upper Tangle Lake to interconnected Round Tangle Lake, but 2 out of the 13 fish originally tagged in Lower Tangle Lake were located in Glacier Lake on 27 September 2022. No fixed-tracking stations were set up on interconnecting Rock Creek, and Glacier Lake was not surveyed every time, but aerial information revealed movement occurred after 21 July for one fish, and after 10 August for the other.

Lastly, fidelity to lakes during June was assessed to aid in the upcoming mark-recapture study (Albert and Ocaña 2023). Tagging locations (lakes) were compared to lake distributions on 23 June 2023, which coincided with the timing of the first event of the mark-recapture experiment. A total of 31 lake trout originally tagged in Lower Tangle Lake were found, and 30 of those fish were located in Lower Tangle Lake (97%; SE=3%; Tables 6 and 7). Of the 17 fish originally radiotagged in Shallow Tangle Lake and found on 23 June 2023, 15 were located in Shallow Tangle Lake (88%; SE=8%). For fish originally radiotagged in Round Tangle Lake, 18 were located and 16 of them were found in Round Tangle Lake (89%; SE=8%; Tables 6 and 7). Of the 9 fish originally radiotagged in Upper Tangle Lake and detected on 23 June 2023, 7 were found in Upper Tangle Lake (78%; SE=14%) and the other 2 fish were found in Glacier Lake.

SPAWNING

Substantial effort was made to try and locate lake trout spawning areas in the interconnected Tangle Lakes system. Radiotagged fish were tracked at night with 2 boats equipped with lights 16–26 September 2022, and most nights the entire shoreline of any given lake was explored visually looking for fish. Despite this effort, only 2 shallow water spawning areas were visually confirmed in the interconnected lakes. Using entanglement nets to document fish spawning in deeper water proved difficult because catching a single fish, or a few fish, in spawning condition meant little if it could not be repeated.

Round Tangle Lake had only 1 known spawning area documented in previous studies (Burr 1992 and Scanlon 2010). This lake was surveyed on 8 out of 10 nights in September 2022. Visual confirmation of active spawning in shallow water was achieved at 2 locations (Figure 13). The most northern location was the previously documented area and was the prominent spawning area, with dozens of fish observed on it at times. The southern area (Figure 13) had never been documented and was less prominent, with no more than a dozen fish observed on it at once. Both locations had concentrations of radiotagged fish when all nightly surveys were combined. The other 2 areas on Round Tangle Lake were identified as possible spawning areas based on radiotagged fish distribution (Figure 13) and substrate type (i.e., small cobble), but spawning could not be confirmed visually or by setting entanglement nets. Regardless, these possible spawning areas were likely not substantial. Round Tangle Lake is surely an important lake for spawning as 100% of the fish originally radiotagged there and deemed alive were located in the lake on 27 September 2022 and 94% (SE= 6%) on 22 September 2023 (Table 6).

Shallow Tangle Lake surveys provided no evidence of spawning areas, but fish were detected in the lake during the spawning period on 18, 21, and 23 September 2022 (Figure 14). Most of the lake appears unsuitable for spawning, but some areas did have suitable substrate. Only 35% (SE=12%) of the fish originally tagged in Shallow Tangle Lake and deemed alive were located there on the 27 September 2022 survey and only 25% (SE=11%) were there on 22 September 2023 (Table 6).

Lower Tangle Lake spawning areas were challenging to detect despite having approximately 33 active radiotagged lake trout in the lake during the 2022 spawning period and conducting surveys on the nights of 18, 19, 23, and 25 September (Tables 6 and 7). All fish that were deemed alive and originally radiotagged from Lower Tangle Lake were located in the lake during the 27 September 2022 and the 22 September 2023 surveys. No aggregations of fish were visually seen in shallow water. This observation combined with past studies provides strong evidence that no shallow water spawning areas exist on this lake. However, a deep-water spawning area was confirmed based on high concentrations of radiotagged fish present and deepwater entanglement nets catching gravid fish at a relatively high rate (Figure 15). Also, concentrations of larger sized fish were observed on the depth/fish finder where the radio tags were located. During the day on 21 September, 5 ripe lake trout were sampled in an entanglement net set for 60 minutes at this location, 6 more ripe fish were captured over a 90-minute period on 23 September, while 11 other sets throughout the lake only yielded a total of 6 mature sized lake trout.

No spawning areas were confirmed on Upper Tangle Lake. Sample sizes were constrained at this lake; only 7 radiotagged fish were located and deemed alive during the spawning surveys (Table 7). The lake was surveyed on the nights of 17, 20, 21, and 24 September 2022. One suspected spawning area was identified next to Rock Creek based on a trend of fish visiting this area over time (Figure 16), but no spawning aggregations were visually confirmed and no concentrations of fish were found with netting efforts. Two ripe male lake trout were caught by Rock Creek on 22 September, but no others were caught to indicate spawning in the area.

There was some evidence of movement among lakes increasing during the spawning period (i.e., 15–30 September; Figures 5–8), but it was not substantial. It is likely that most lake trout were already in the lake they were going to spawn in as fall approached.

DISCUSSION

This study was a more comprehensive version of a previous study in which 40 lake trout were radiotagged among the 4 interconnected Tangle Lakes in August 2004 (20 in Lower Tangle Lake, 12 in Round Tangle Lake, 7 in Shallow Tangle Lake and 1 in Upper Tangle Lake; Scanlon 2010). Of the 40 fish radiotagged, 28 were located during the study, and there were issues with 2 of the tracking stations. Our study had a much larger sample size (n=100) and fish movements among the lakes were more thoroughly tracked. Tracking stations worked nearly flawlessly during the open water period and more airplane and boat tracking surveys were conducted. Although the previous study documented movement between Round and Shallow Tangle Lakes, this study documented substantially more movement of fish among the lakes, with higher rates of movement between Round and Shallow Tangle Lakes, as well as movement from Upper Tangle Lake to Glacier Lake. As with the previous study(s), this study again had trouble documenting spawning locations in all lakes, confirming that some spawning must occur in deeper portions (i.e., >3 m) of some of the lakes where visibility is limited.

Radio tags were deployed in Shallow, Round, and Upper Tangle Lakes during a time period in 2022 which coincided with an unusually high-water event from spring melt off. Rock Creek was flowing high and was spewing dirty water due to bank erosion. This severely reduced the water visibility in the northern portion of Upper Tangle Lake, all of Round Tangle Lake, and the flowing sections of Shallow and Lower Tangle Lakes for several days in June 2022. The higher water flow also possibly provided easier access among lakes, particularly between Round and Shallow Tangle Lakes. By late June, water conditions were back to normal. These conditions could explain some of the disparities in fish movements between the 2 years of this study.

Fish movement peaked during June in 2022, which coincided with high water, and during July 2023, which likely coincided with warming water temperatures (Figures 5–8; Table 8). During both years of the study, movement increased during the month of June with an obvious pattern of lake trout moving to Shallow Tangle Lake (Figures 7 and 8). We hypothesize that this movement was likely from lake trout seeking the warmer, more productive shallow water after ice-out. In both years of this study, Shallow Tangle Lake became ice-free a week before Round Tangle Lake, as did the flowing portions of Lower Tangle Lake. By July, the opposite movement occurred with lake trout departing Shallow Tangle Lake and traveling to Round Tangle Lake during mid-to-late summer (early-to-mid August). Table 6 documents this movement; 86% (SE=7%) of the lake trout originally radiotagged in Shallow Tangle Lake were there on 23 June 2022, but only 40% (SE=11%) resided there during the 2 August 2022 survey. In 2023, the contrast was even greater; 88% (SE=8%) of the live fish originally radiotagged in Shallow Tangle Lake were there during both June surveys, but by 15 August only 6% (SE=6%) of them remained in the lake (Table 6). Figure 8 shows that 15 fish moved to Round Tangle Lake during the month of July 2023, while no fish moved to Shallow Tangle Lake. Additionally, during this same time period, fish distribution in Lower Tangle Lake showed a trend of fish vacating the shallower flowing portion of the lake and residing in deeper areas, away from the presumable warm water current from Shallow Tangle Lake (Figure 17).

We can only assume that this documented movement is from fish seeking warmer more productive waters in June, then vacating these areas as summer progressed and water temperatures become too warm. An array of temperature loggers deployed at various suspected warm and cold water locations could prove or disprove our hypothesis. Either way, the observations support our hypothesis that lake trout in Tangle Lakes utilize the shallower more productive areas in early summer but then rely on the deeper portions of the basin during late summer when shallow areas may become too warm. This easy access to spring feeding areas and deep water refugia during late summer are probably key factors in the overall productivity of this lake trout population, particularly for those residing in Round, Shallow, and Lower Tangle Lakes.

This study documented movement from Upper Tangle Lake to Glacier Lake. Exact dates of emigration are not known but based on survey information, it is believed that 1 of these fish left after 21 July and the other after 10 August. At that time, 10 of the 13 lake trout originally tagged in Upper Tangle Lake were alive, meaning 20% of our radiotagged fish emigrated to Glacier Lake that summer. Although 2 fish is a small sample size, it is of interest why these fish traveled up a small, relatively high velocity creek that is approximately 19.5 rkm long and climbs 284 m in elevation. Meanwhile, no radiotagged lake trout traveled to Round Tangle Lake which is connected to Upper Tangle Lake by a much easier to travel 1.8-rkm stream with a moderate descent of 14.5 m. Round Tangle Lake also has 2 documented spawning areas and is known to have comprehensive mixing of fish from Shallow Tangle Lake. Burr (1992) documented a single Floy tagged fish that was caught and tagged in Upper Tangle Lake and then caught a year later in Glacier Lake, but similar to our study, no movement between Upper Tangle and Round Tangle Lakes was detected. One consideration is that juvenile lake trout conceived in Glacier Lake might descend into Upper Tangle Lake for rearing, only to return to Glacier Lake as maturity begins. Whatever the case, it is baffling that no movement between Upper Tangle and Round Tangle Lakes have been documented.

A separate mark-recapture experiment to estimate abundance and length composition in the 4 interconnected Tangle Lakes commenced in April 2023 and will conclude in June 2024 (Albert and Ocaña 2023). The initial results of this telemetry study were used in the design of that experiment (e.g., relative catch rates and movement expectations). This study documented movement among the 4 interconnected Tangle Lakes 129 times by 32 unique fish (Figures 5 and 9), but there appears to be a strong fidelity to distinct lakes during June when the bulk of the sampling for the mark-recapture study is occurring. On the 23 June 2023 survey, 31 of the 32 fish still alive and originally radiotagged in Lower Tangle Lake were found in Lower Tangle Lake (97%; SE=3%). Similarly, Shallow Tangle Lake had 88% (SE=8%) fidelity during this time and Round Tangle Lake had 89% (SE=8%; Table 6). This illustrates that, despite heavy mixing during other times of year between Round and Shallow Tangle Lakes, most fish were found in the respective lakes they were radiotagged in during the following June. The movement of 2 radiotagged fish between Upper Tangle Lake and Glacier Lake will pose a problem for the mark-recapture study, but those biases can be isolated if no movement to Upper Tangle Lake occurs. This study did not detect such movements, but diagnostic tests for the mark-recapture study will be more comprehensive in that more rigorous sampling procedures will take place and hundreds more fish will be handled. It is suggested that efforts be made sometime after the conclusion of that study to subsample Glacier Lake and see if any fish tagged in Upper Tangle Lake are recovered there.

Statistical tests for mixing suggest that all lakes should be treated as their own populations when applying the LA model. Contingency table chi-square test results were conclusive with the null hypothesis of equal movement probabilities being rejected for every survey date when considering all 4 lakes together, and all adjacent lake combinations for all survey dates except 1 date (Table 7). However, there was extensive movement documented from Shallow Tangle Lake to Round

Tangle Lake (22 of 22 fish). The null hypothesis was likely rejected for most surveys for this lake combination because most fish originally radiotagged in Round Tangle Lake never moved to Shallow Tangle Lake (only 6 of 25 moved to Shallow Tangle Lake). However, having 100% of the fish radiotagged in Shallow Tangle Lake move to Round Tangle Lake, and 24% of the fish radiotagged in Round Tangle move to Shallow Tangle Lake, it is recommended that they be treated as one population for management purposes.

Using the LA model to estimate YP as 3 populations (Lower Tangle Lake [137.4 ha], Upper Tangle Lake [151.9 ha], and Round and Shallow Tangle Lakes combined [292.9 ha]) results in an estimated yield of 524 kg. Using an overall estimated mean weight of 1.7 kg (Burr 2006) for the interconnected Tangle Lakes, YP was estimated at 308 fish for the 4 interconnected lakes. Mean weights from the Albert and Ocaña (2023) study for individual lakes and lake combinations should be used in future estimates of YP in numbers of fish.

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FIGURES AND TABLES

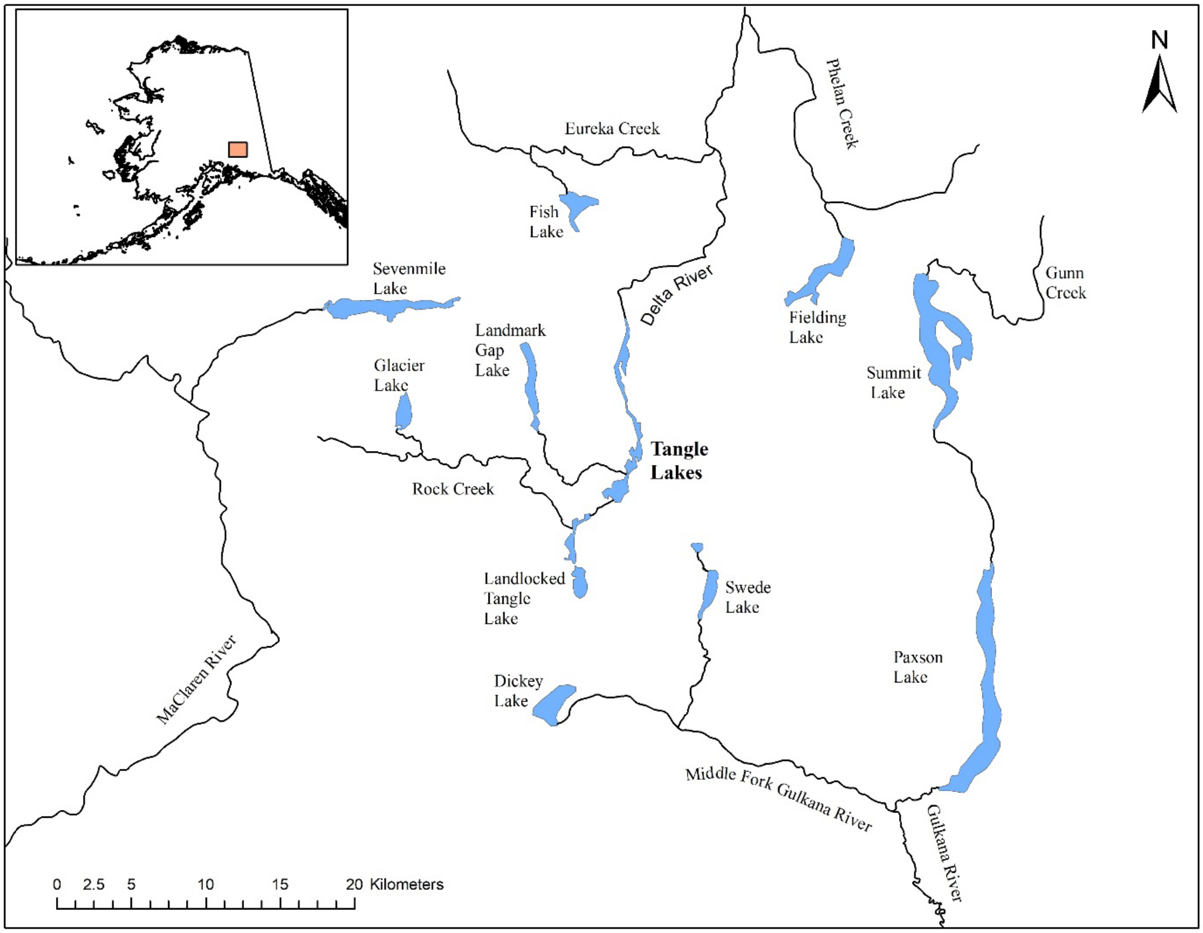

Figure 1.–Map depicting the location of Tangle Lakes.

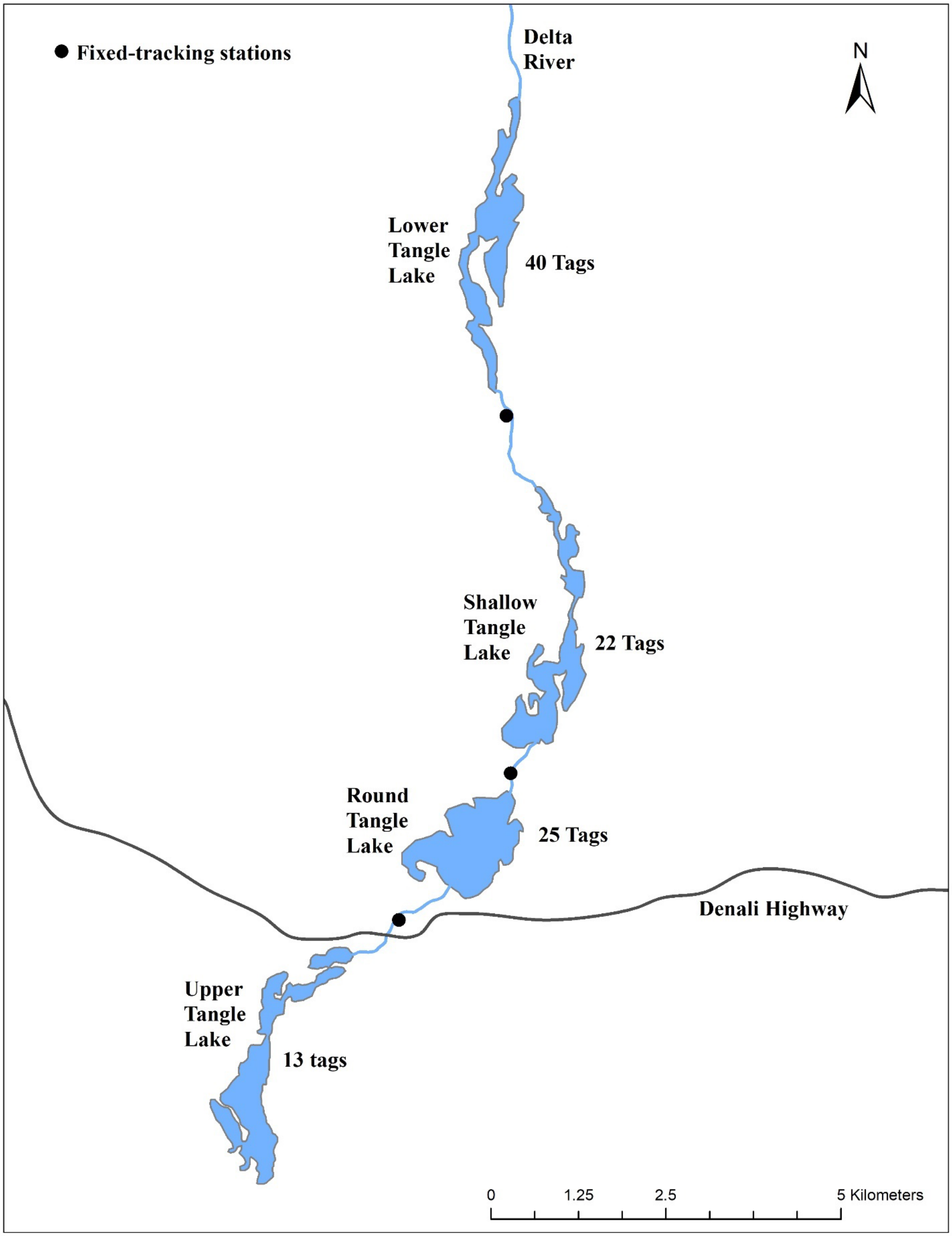

Figure 2.–Map of Tangle Lakes with radio tag deployment distribution and the location of the 3 fixed-tracking station locations (black dots).

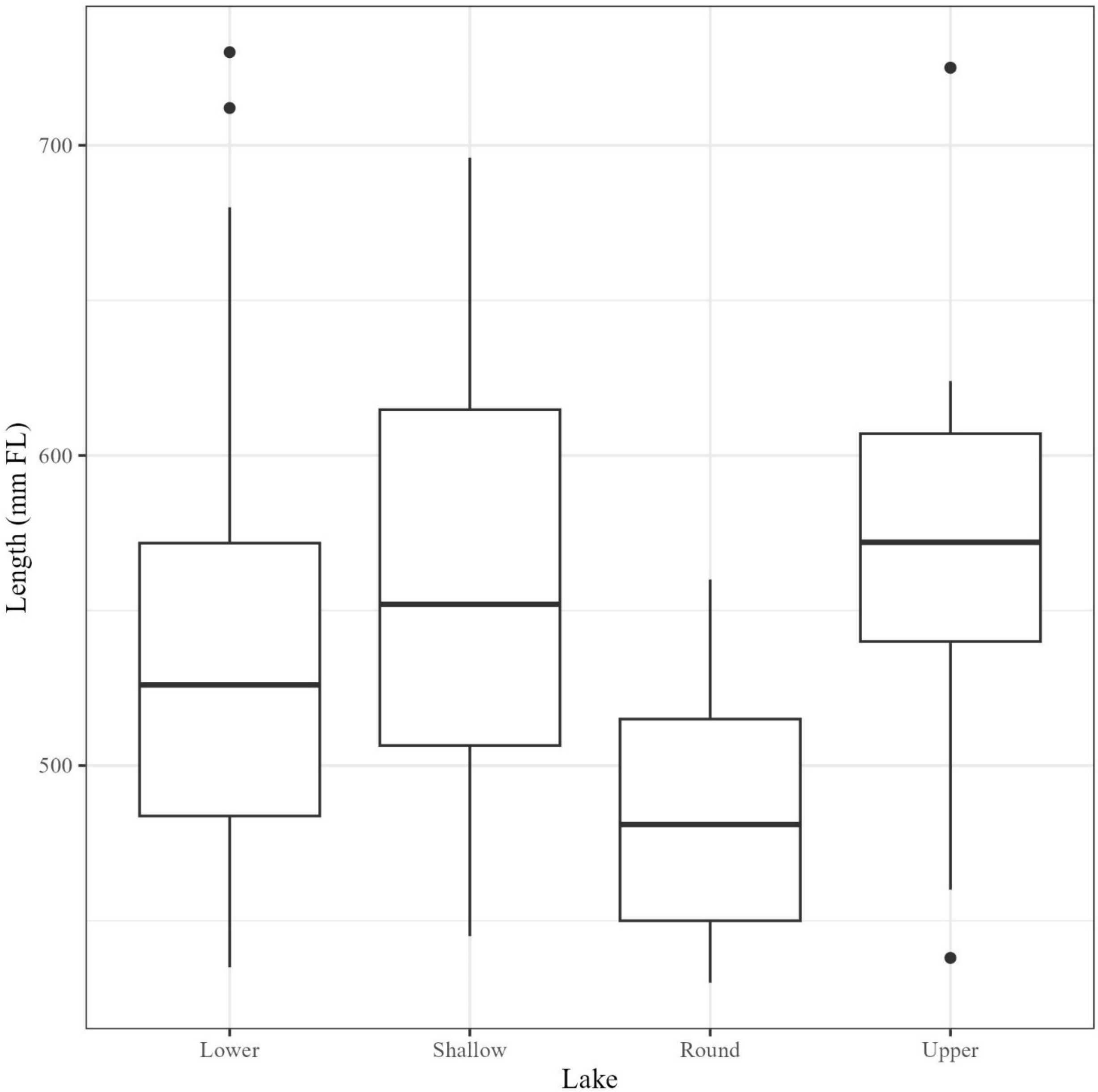

Figure 3.–Length summary of the radiotagged lake trout, Tangle Lakes. The heavy lines are the median length, the box represents the 25th to 75th quartile range, and the dots are outliers defined as >1.5 X inner quartile range.

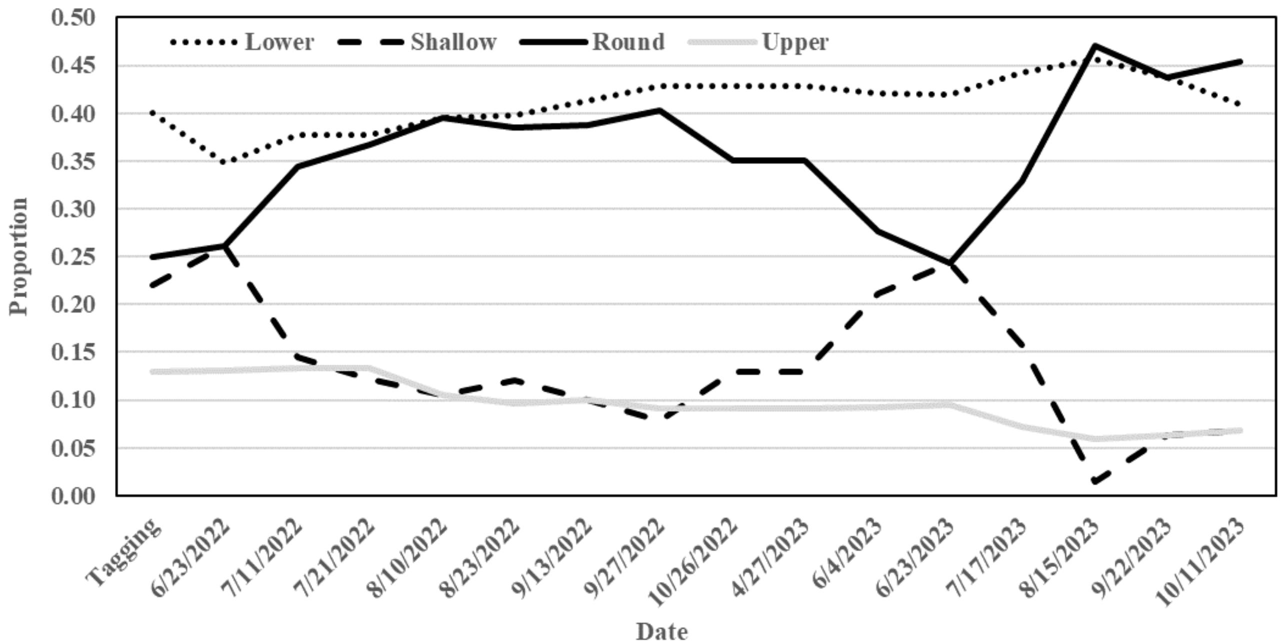

Figure 4.–Proportions of lake trout detected and deemed alive in each lake by survey, Tangle Lakes.

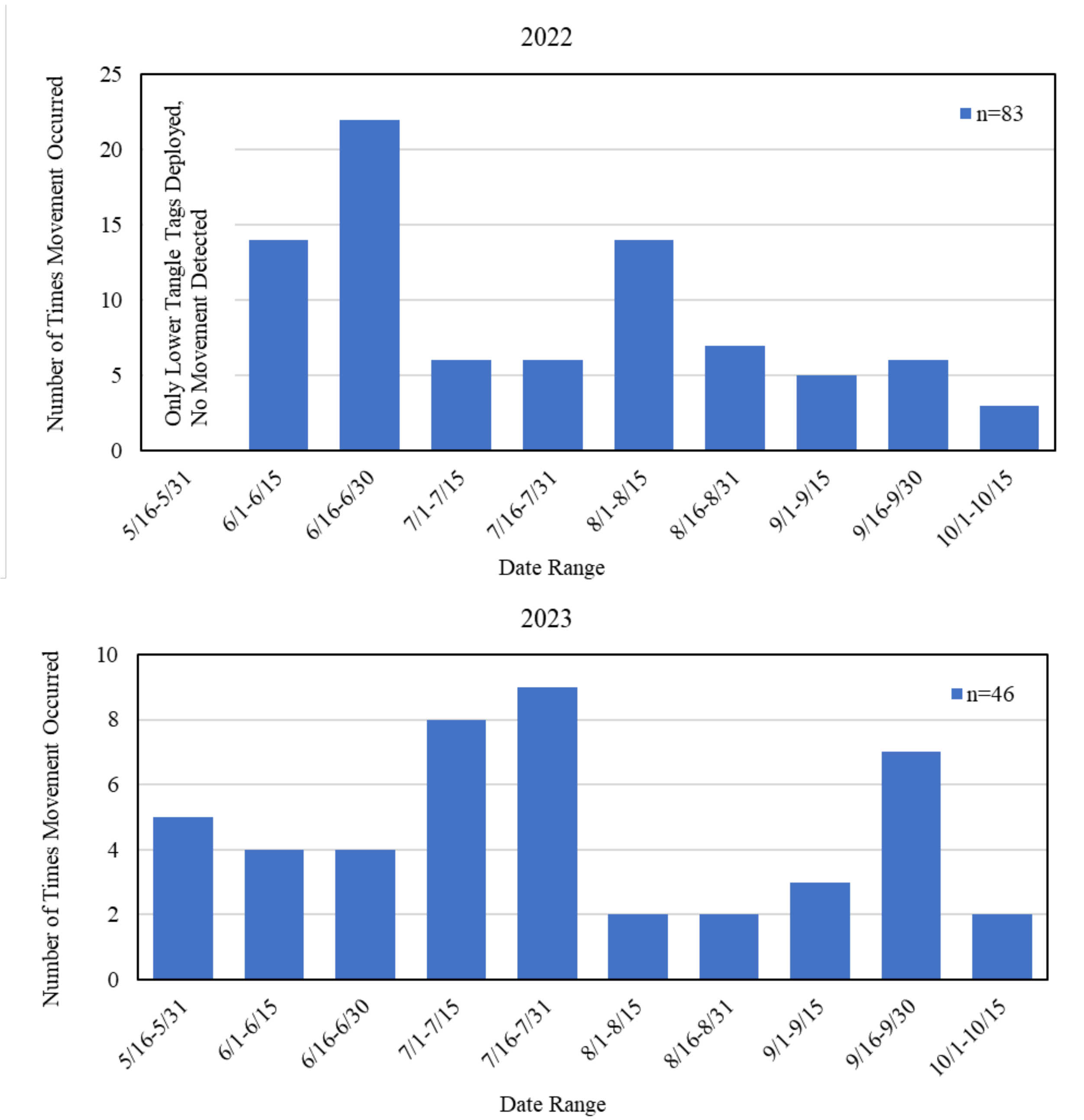

Figure 5.–Number of times lake trout were detected moving among lakes, Tangle Lakes 2022 and 2023.

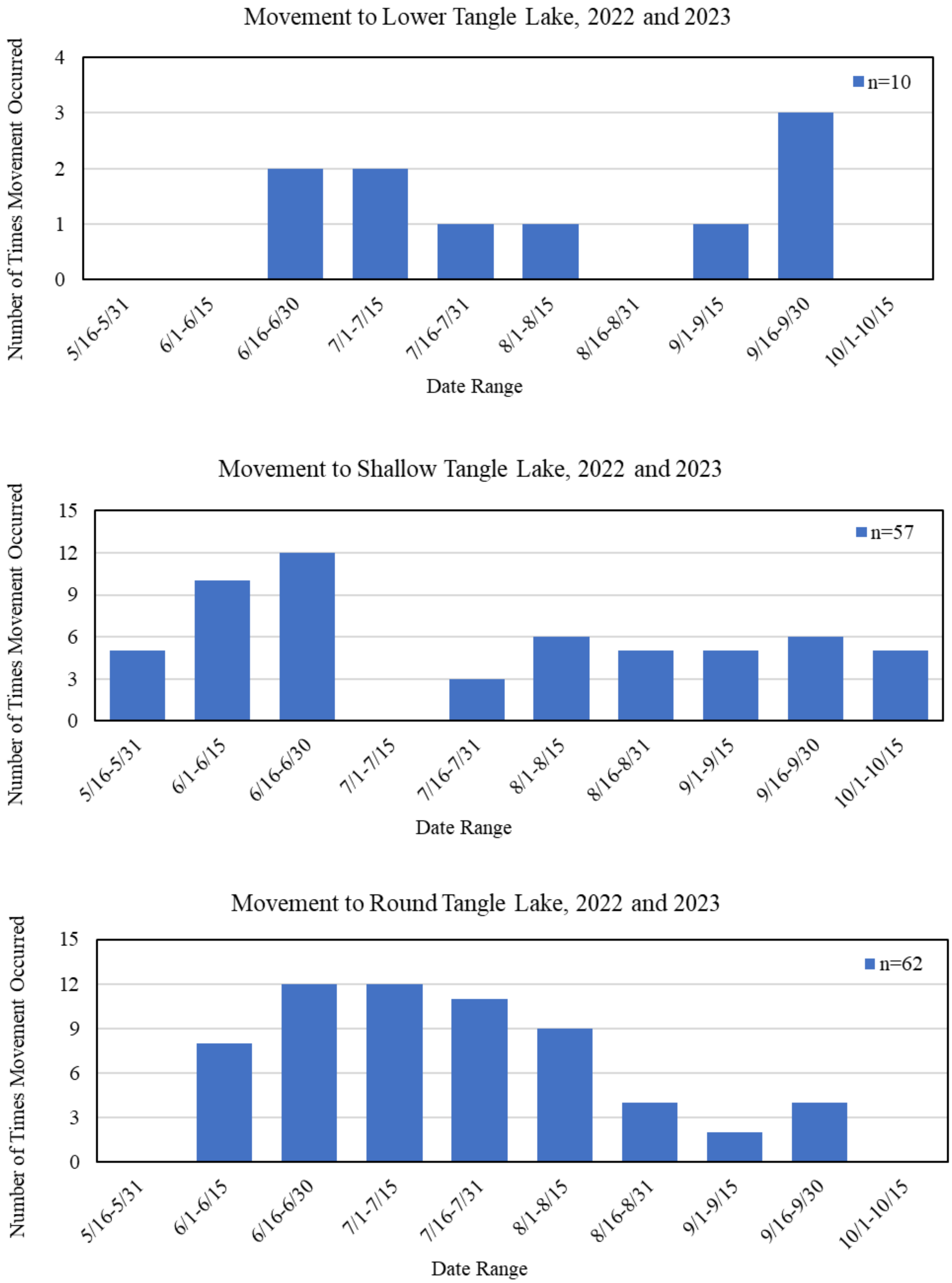

Figure 6.–Destination of lake trout detected moving among lakes, Tangle Lakes, 2022 and 2023.

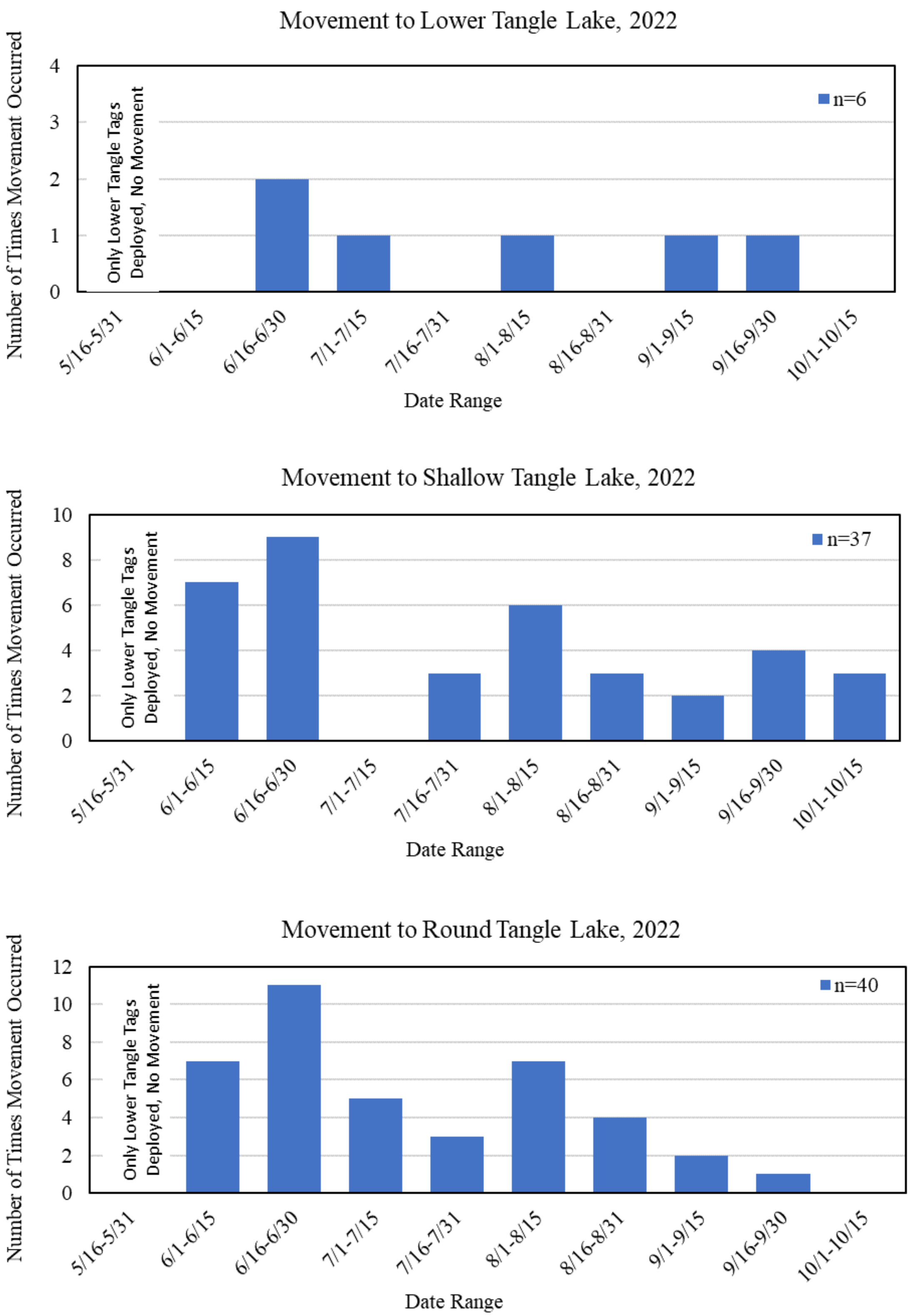

Figure 7.–Destination of lake trout detected moving among lakes, Tangle Lakes, 2022.

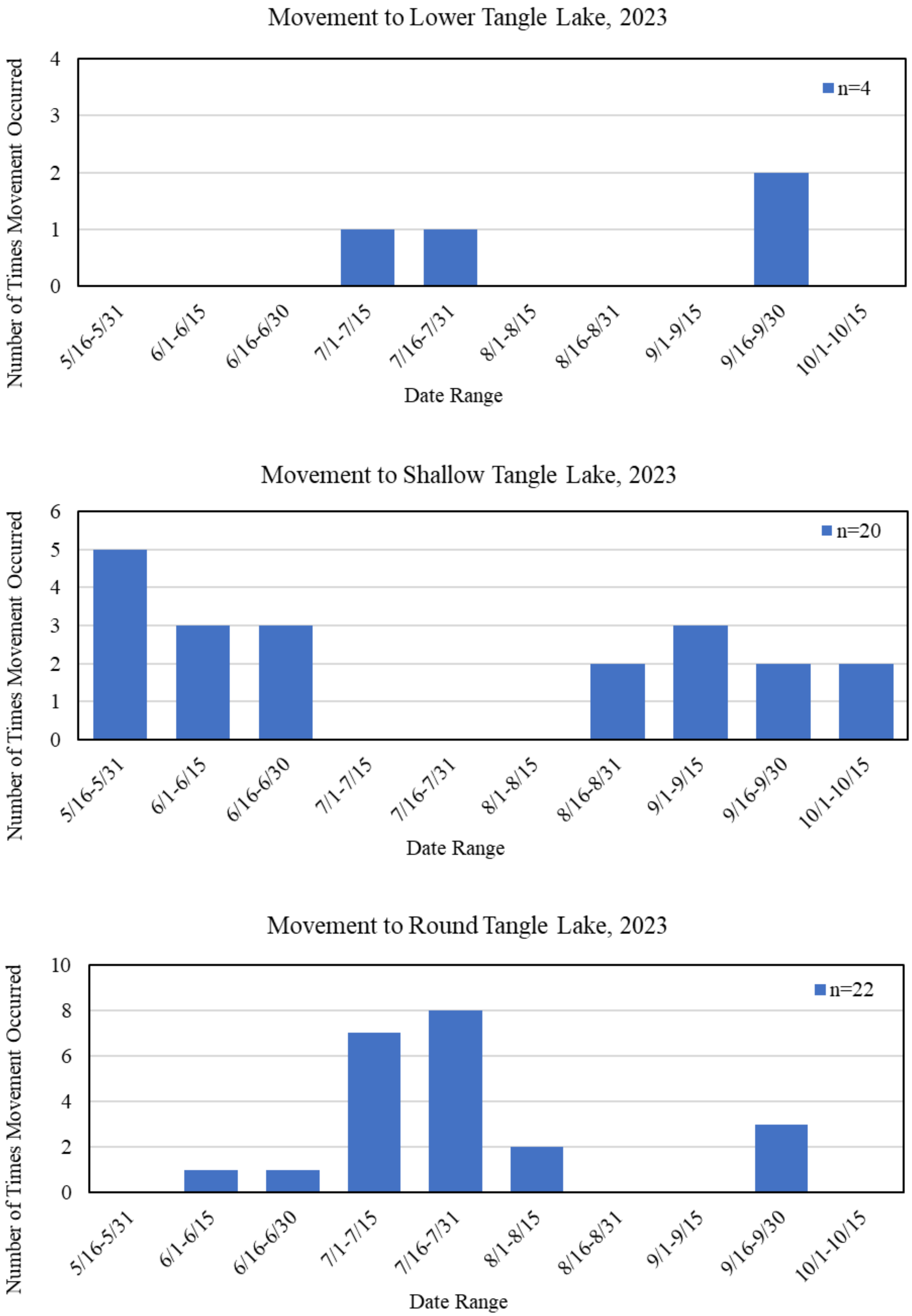

Figure 8.–Destination of lake trout detected moving among lakes, Tangle Lakes, 2023.

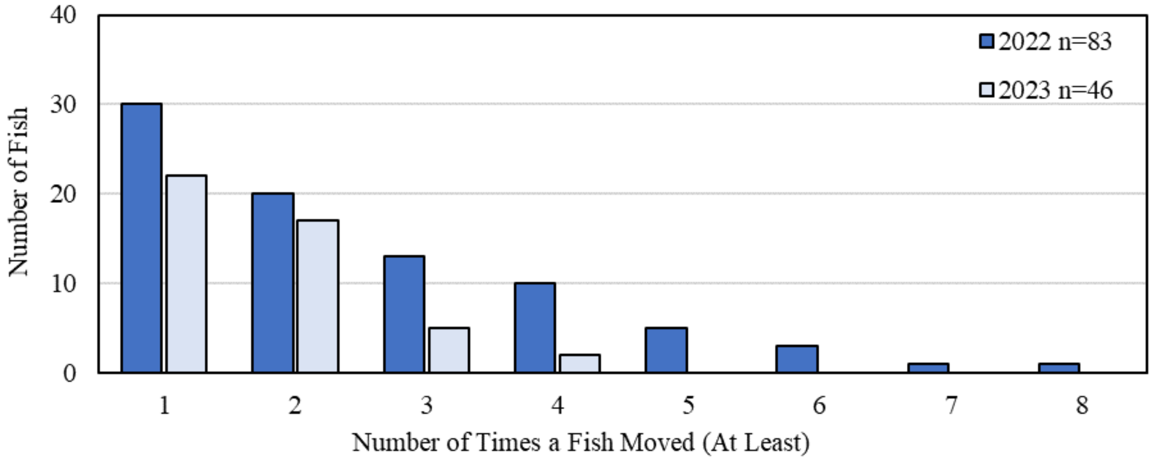

Figure 9.–The number of times individual fish moved among the 4 interconnected Tangle Lakes, 2022 and 2023.

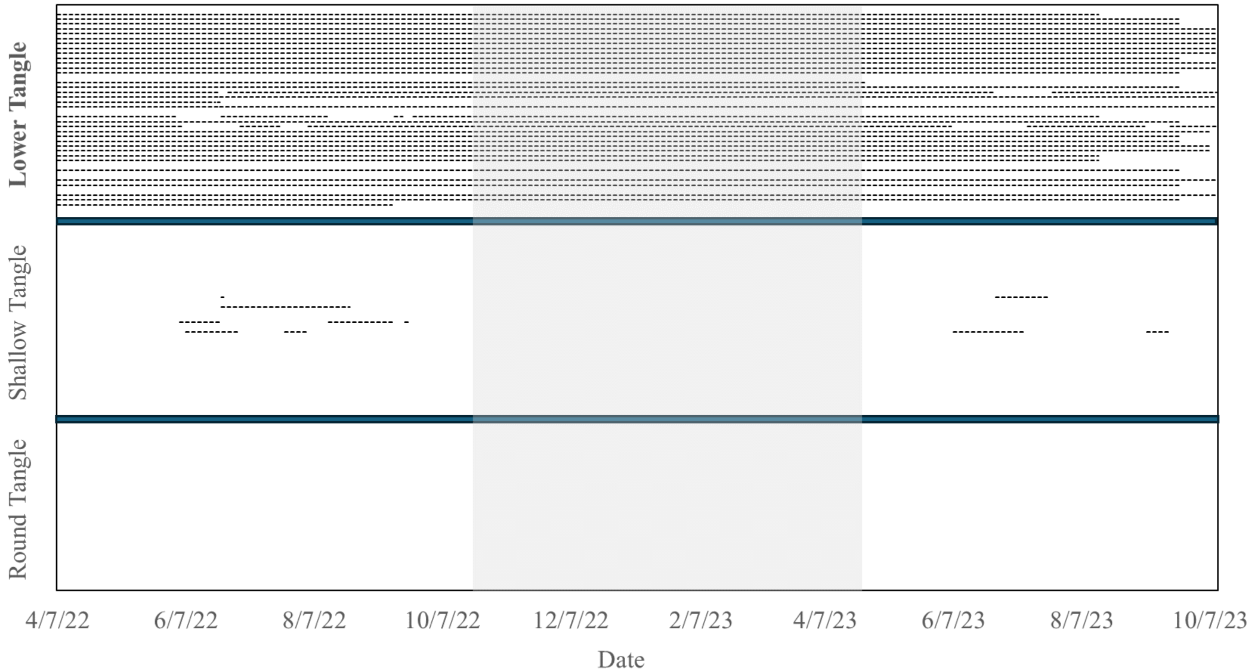

Figure 10.–Locations of individual fish radiotagged in Lower Tangle Lake. Shaded areas represent the time period the tracking stations were not functional.

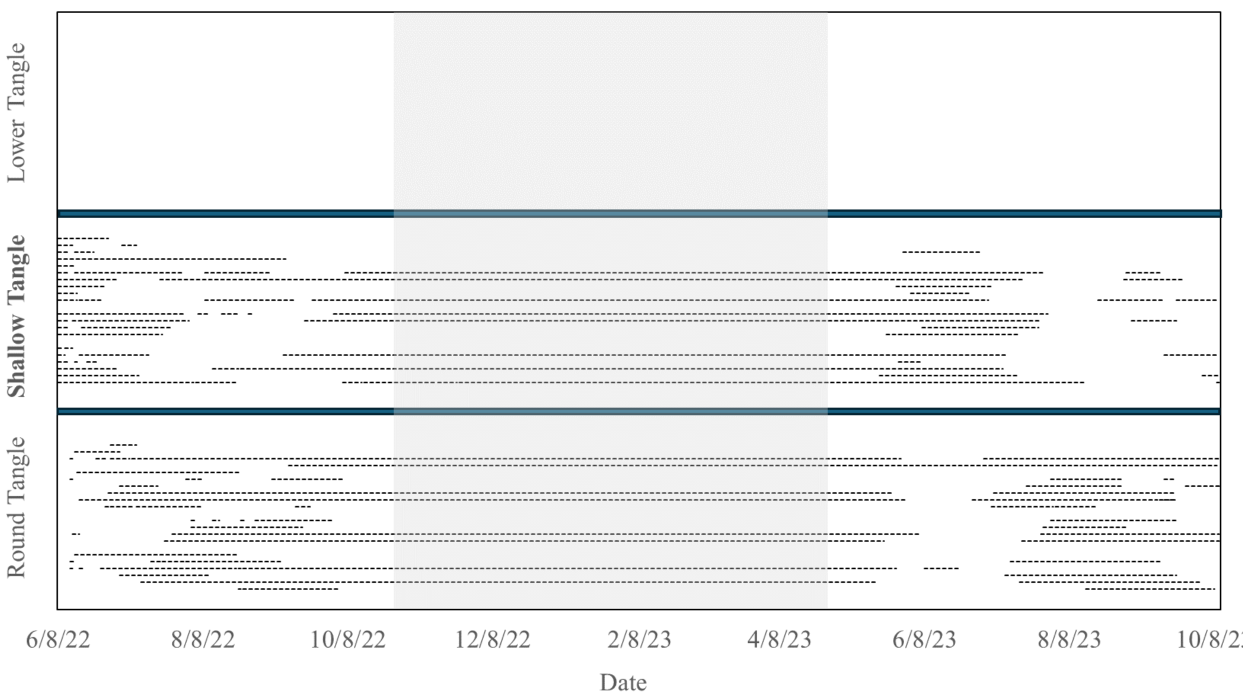

Figure 11.–Locations of individual fish radiotagged in Shallow Tangle Lake. Shaded areas represent the time period the tracking stations were not functional.

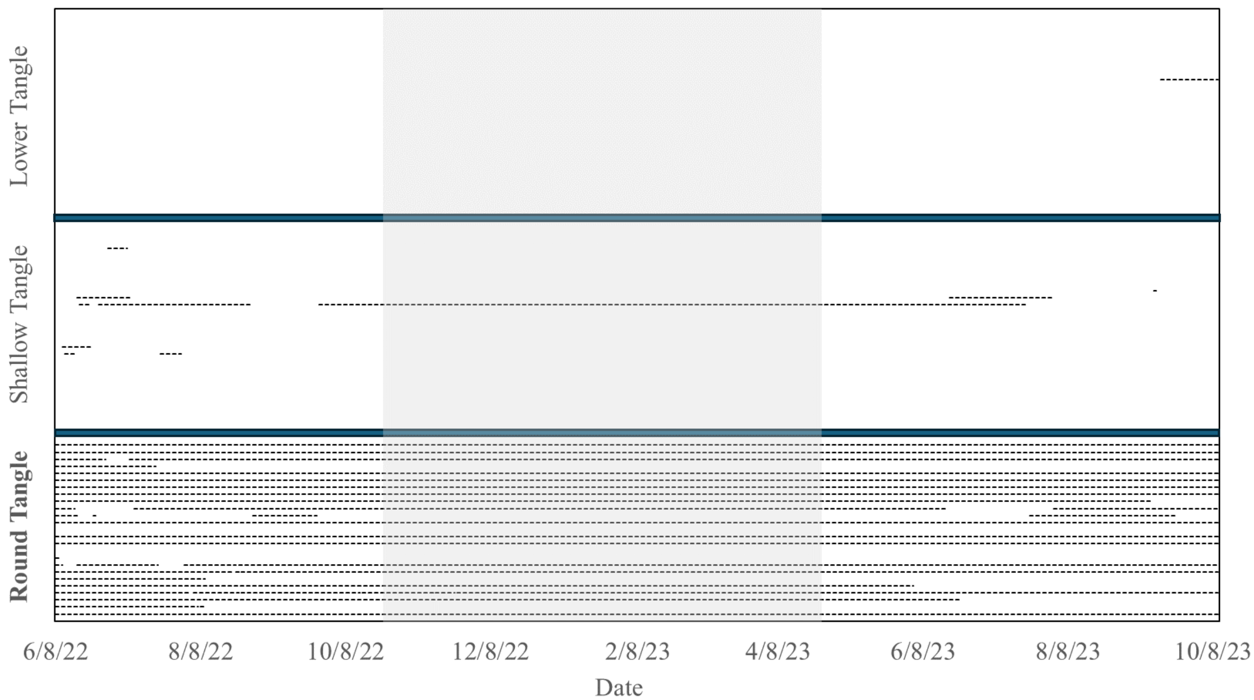

Figure 12.–Locations of individual fish radiotagged in Round Tangle Lake. Shaded areas represent the time period the tracking stations were not functional.

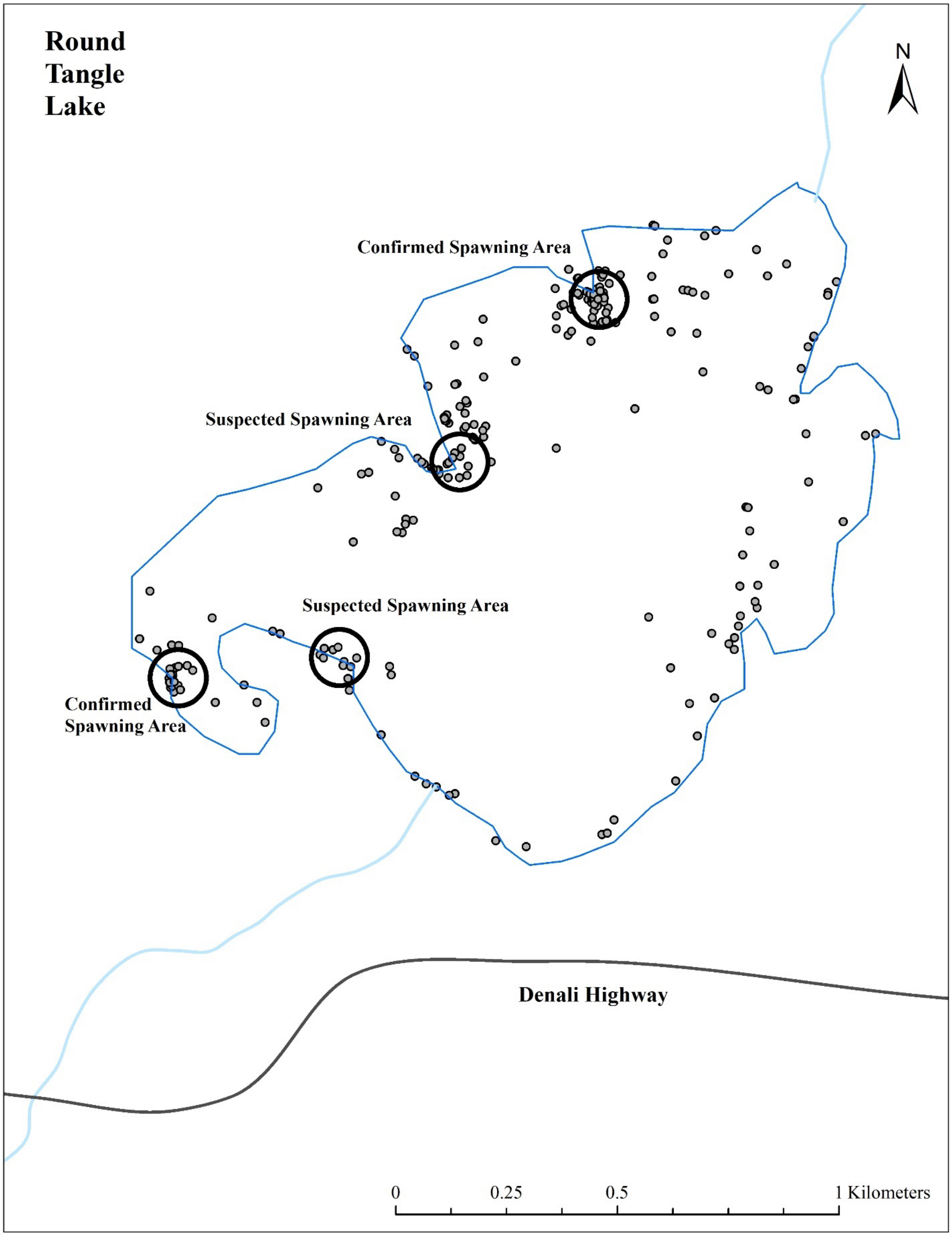

Figure 13.–Map of Round Tangle Lake with radiotagged fish locations (16, 17, 18, 20, 21, 22, 24, and 25 September) with documented and possible spawning areas, 2022.

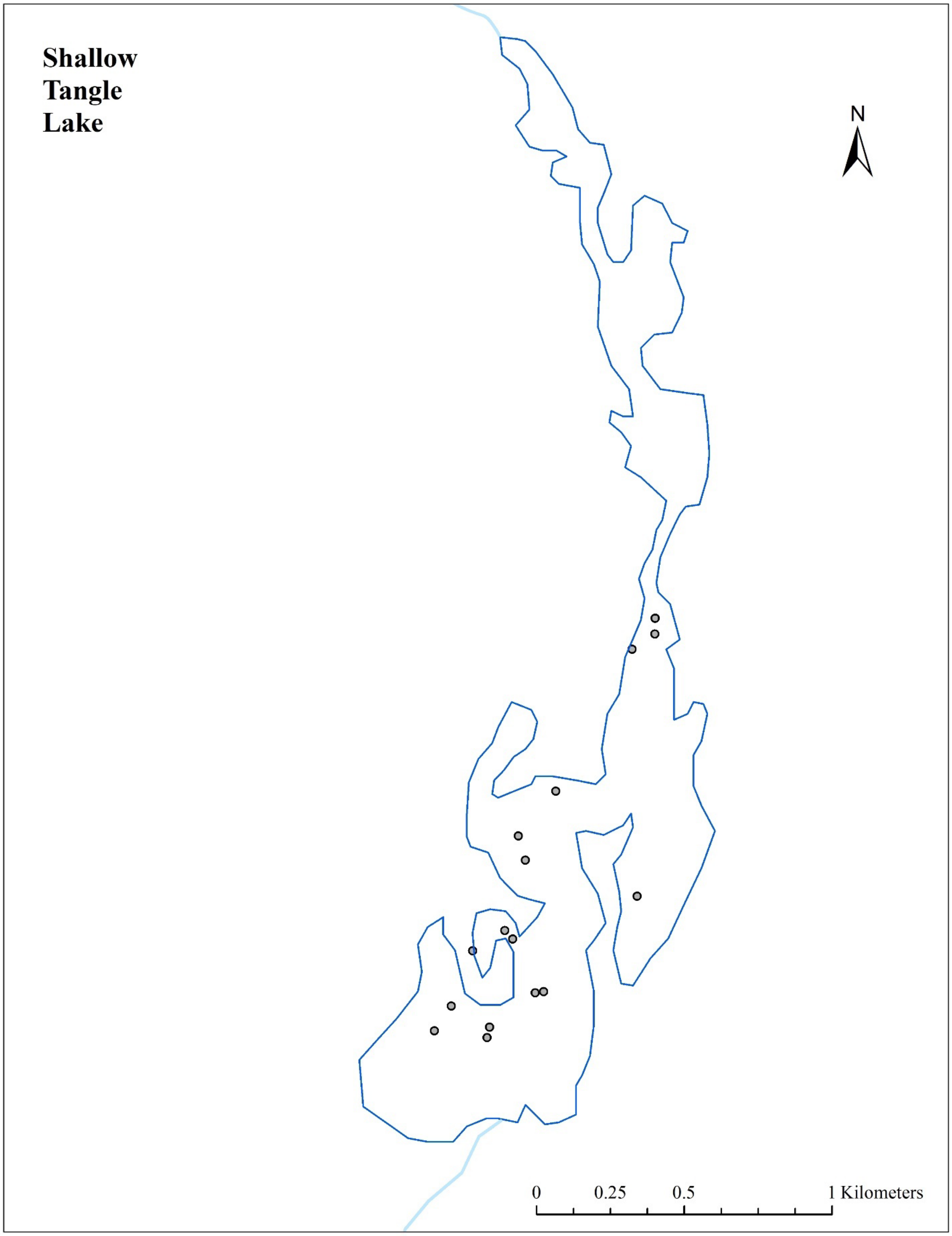

Figure 14.–Map of Shallow Tangle Lake with radiotagged fish locations (18, 21, and 23 September), 2022.

Figure 15.–Map of Lower Tangle Lake with radiotagged fish locations (18, 19, 23 and 25 September) with documented and possible spawning areas, 2022.

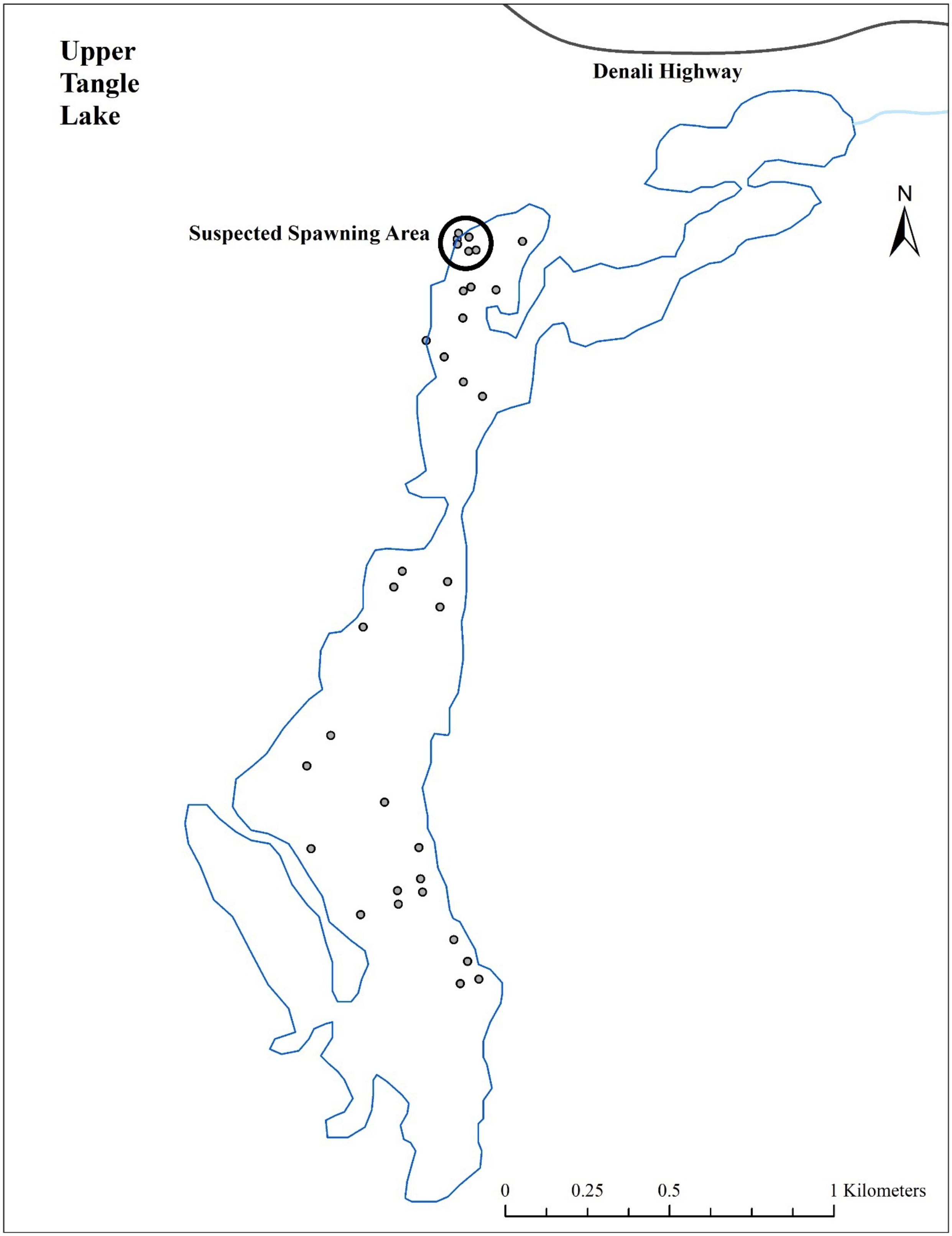

Figure 16.–Map of Upper Tangle Lake with radiotagged fish locations (17, 20, 21 and 24 September) and possible spawning areas, 2022.

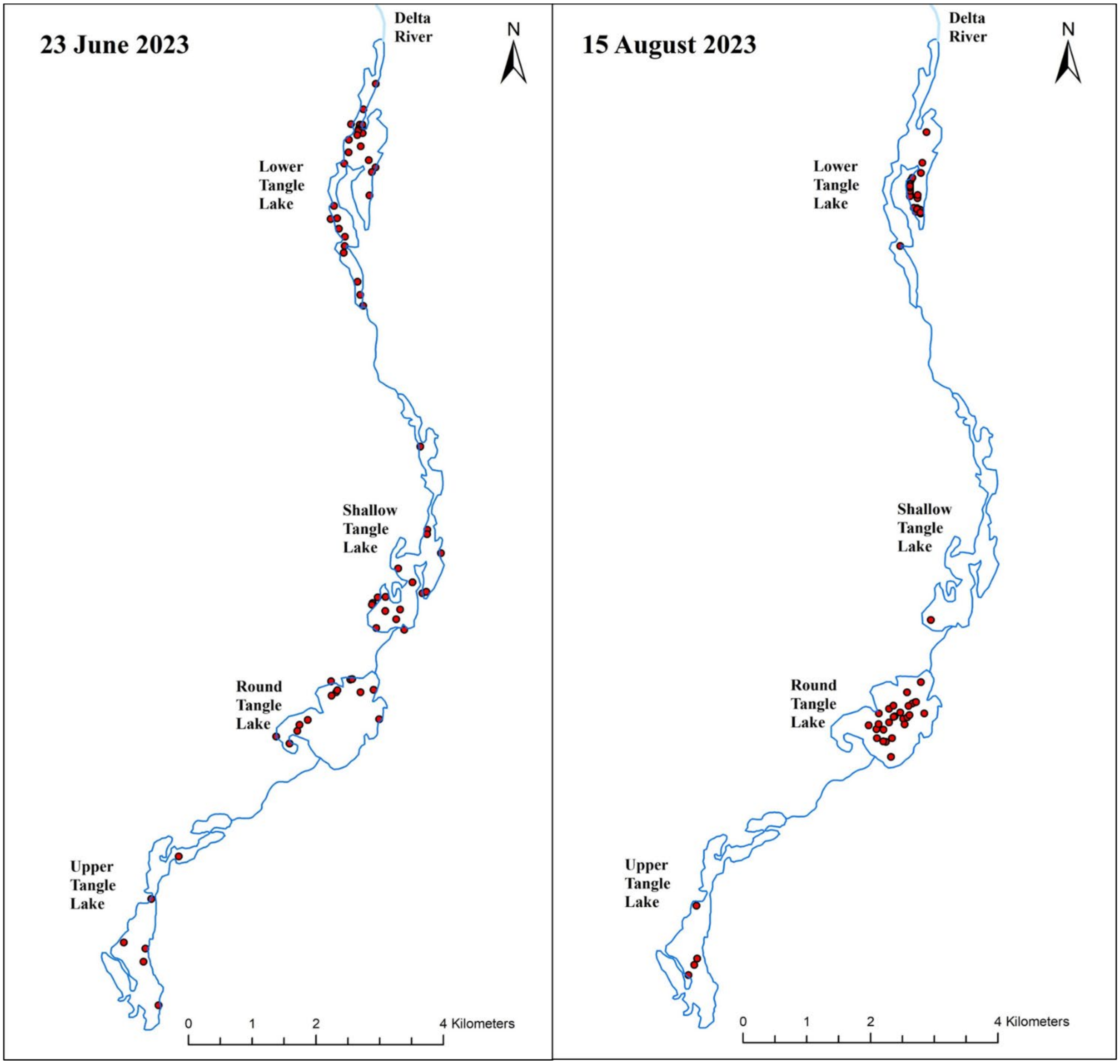

Figure 17.–Map of Tangle Lakes showing fish seeking presumably deeper/colder water in late summer.

Table 1.–Estimated catch, harvest, and angler mortality of lake trout from Tangle Lakes, 2003–2022.

Year	Respondents [a,b]	Catch [a]	Harvest [a]	Angling Mortality [c]
2003	109	1,631	505	618
2004	73	825	270	326
2005	74	1,781	224	380
2006	63	895	272	334
2007	78	1,580	383	503
2008	67	541	190	225
2009	68	1,140	333	414
2010	90	3,266	640	903
2011	58	1,216	300	392
2012	57	1,222	161	267
2013	63	590	401	420
2014	60	801	206	266
2015	46	1,121	72	177
2016	56	1,049	374	442
2017	59	851	205	270
2018	54	198	0	20
2019	51	599	316	354
2020	69	2,630	516	727
2021	35	75	36	40
2022	28	86	9	17
5-year average (2018–2022)	47	718	175	232
10-year average (2013–2022)	52	800	214	273

[a] Alaska Sport Fishing Survey database [Internet]. 2003–2022. Anchorage, AK: Alaska Department of Fish and Game, Division of Sport Fish. Available from http://www.adfg.alaska.gov/sf/sportfishingsurvey/.

[b] 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.

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

Table 2.–Lake, dates, and number of radio tags deployed in Tangle Lakes, 2022.

Lake	Dates	Number of Tags
Lower Tangle	5–7 April	40
Shallow Tangle	8–10 June	22
Round Tangle	3–12 June	25
Upper Tangle	9–11 June	13

Table 3.–Mean length (mm FL) of lake trout captured and radiotagged from Tangle Lake, 2022.

Lake	Statistic	Value
Lower Tangle	Sample Size	40
	Mean Length	540.1
	Standard Deviation	74.8
	Minimum Length	435
	Maximum Length	730
Shallow Tangle	Sample Size	22
	Mean Length	563.4
	Standard Deviation	71.7
	Minimum Length	445
	Maximum Length	696
Round Tangle	Sample Size	25
	Mean Length	484.9
	Standard Deviation	39.6
	Minimum Length	430
	Maximum Length	560
Upper Tangle	Sample Size	13
	Mean Length	579.0
	Standard Deviation	84.6
	Minimum Length	438
	Maximum Length	725

Table 4.–Tracking dates and the number of radiotagged lake trout by status category, Tangle Lakes, 2022–2023.

Survey Number	Survey Date	Survey Method	Number of Fish		
			Alive [a]	Dead	Missing
1	23 June 2022	Airplane	92	5	3
2	11 July 2022	Airplane	90	6	4
3	21 July 2022	Boat	90	6	4
4	10 August 2022	Airplane	87	9	4
5	23 August 2022	Boat	85	12	3
6	13 September 2022	Boat	82	13	5
7	27 September 2022	Airplane	79	14	7
8	26 October 2022	Airplane	79	16	5
9	27 April 2023	Airplane	79	16	5
10	4 June 2023	Airplane	78	16	6
11	23 June 2023	Airplane	76	18	6
12	17 July 2023	Airplane/Boat	72	21	7
13	15 August 2023	Airplane/Boat	70	21	9
14	22 September 2023	Airplane	66	21	13
15	11 October 2023	Airplane	46[b]	25	29

[a] Includes the 2 fish that moved to Glacier Lake during the summer of 2023.

[b] If additional surveys were conducted, many of the fish exhibiting inactive codes or were not found during the last survey would have likely been corrected to alive.

Table 5.–Proportions of detected fish deemed alive in each lake by survey, Tangle Lakes.

Date of Survey	Proportion of Lake Trout in Each Lake			
	Lower	Shallow	Round	Upper
Tagging Dates	0.40	0.22	0.25	0.13
23 June 2022	0.35	0.26	0.26	0.13
11 July 2022	0.38	0.14	0.34	0.13
21 July 2022	0.38	0.12	0.37	0.13
10 August 2022	0.40	0.10	0.40	0.10
23 August 2022	0.40	0.12	0.39	0.10
13 September 2022	0.41	0.10	0.39	0.10
27 September 2022	0.43	0.08	0.40	0.09
26 October 2022	0.43	0.13	0.35	0.09
27 April 2023	0.43	0.13	0.35	0.09
4 June 2023	0.42	0.21	0.28	0.09
23 June 2023	0.42	0.24	0.24	0.09
17 July 2023	0.44	0.16	0.33	0.07
15 August 2023	0.46	0.01	0.47	0.06
22 September 2023	0.44	0.06	0.44	0.06
11 October 2023	0.41	0.07	0.45	0.07

Table 6.–The number of lake trout tagged in each lake and deemed alive for each survey, and the proportion of those fish found in the lake they were originally radiotagged in.

	Lower			Shallow			Round			Upper [a]		
Spawning Location	n	prop	SE	n	prop	SE	n	prop	SE	n	prop	SE
23 June 2022	35	0.91	0.05	22	0.86	0.07	23	0.91	0.06	12	1.00	0.00
11 July 2022	35	0.97	0.03	20	0.60	0.11	23	1.00	0.00	12	1.00	0.00
21 July 2022	35	0.97	0.02	20	0.50	0.11	23	1.00	0.00	12	1.00	0.00
10 August 2022	35	0.97	0.03	20	0.40	0.11	22	1.00	0.00	10	0.90	0.09
23 August 2022	35	0.94	0.04	20	0.40	0.11	20	1.00	0.00	10	0.80	0.13
13 September 2022	34	0.97	0.03	18	0.39	0.11	20	1.00	0.00	10	0.80	0.13
27 September 2022	33	1.00	0.00	17	0.35	0.12	20	1.00	0.00	9	0.78	0.14
26 October 2022	33	1.00	0.00	17	0.53	0.12	20	0.95	0.05	9	0.78	0.14
27 April 2023	33	1.00	0.00	17	0.53	0.12	20	0.95	0.05	9	0.78	0.14
4 June 2023	32	1.00	0.00	17	0.88	0.08	20	0.95	0.05	9	0.78	0.14
23 June 2023	32	0.97	0.03	17	0.88	0.08	18	0.89	0.08	9	0.78	0.14
17 July 2023	32	0.97	0.03	16	0.50	0.13	17	0.88	0.08	7	0.71	0.17
15 August 2023	31	1.00	0.00	16	0.06	0.06	17	1.00	0.00	6	0.67	0.19
22 September 2023	27	1.00	0.00	16	0.25	0.11	17	0.94	0.06	6	0.67	0.19
11 October 2023	17	1.00	0.00	8	0.38	0.17	16	0.94	0.06	5	0.60	0.22

[a] The 2 fish that moved from Upper Tangle Lake to Glacier Lake during late summer 2022 are included in this table as part of n.

Table 7.–Contingency tables for chi-square tests used to assess complete mixing of radiotagged lake trout, Tangle Lakes 2022–2023.

Area Tagged	Area Located (23 June 2022)				
	Lower	Shallow	Round	Upper	Missing
Lower	32	3	0	0	5
Shallow	0	19	3	0	0
Round	0	2	21	0	2
Upper	0	0	0	12	1
Total	32	24	24	12	8

Area Tagged	Area Located (11 July 2022)				
	Lower	Shallow	Round	Upper	Missing
Lower	34	1	0	0	5
Shallow	0	12	8	0	2
Round	0	0	23	0	2
Upper	0	0	0	12	1
Total	34	13	31	12	10

Area Tagged	Area Located (21 July 2022)				
	Lower	Shallow	Round	Upper	Missing
Lower	34	1	0	0	5
Shallow	0	10	10	0	2
Round	0	0	23	0	2
Upper	0	0	0	12	1
Total	34	11	33	12	10

Area Tagged	Area Located (10 August 2022)				
	Lower	Shallow	Round	Upper	Missing
Lower	34	1	0	0	5
Shallow	0	8	12	0	2
Round	0	0	22	0	3
Upper	0	0	0	9	4
Total	34	9	34	9	14

Area Tagged	Area Located (23 August 2022)				
	Lower	Shallow	Round	Upper	Missing
Lower	33	2	0	0	5
Shallow	0	8	12	0	2
Round	0	0	20	0	5
Upper	0	0	0	8	5
Total	33	10	32	8	17

Area Tagged	Area Located (13 September 2022)				
	Lower	Shallow	Round	Upper	Missing
Lower	33	1	0	0	6
Shallow	0	7	11	0	4
Round	0	0	20	0	5
Upper	0	0	0	8	5
Total	33	8	31	8	20

Area Tagged	Area Located (27 September 2022)				
	Lower	Shallow	Round	Upper	Missing
Lower	33	0	0	0	7
Shallow	0	6	11	0	5
Round	0	0	20	0	5
Upper	0	0	0	7	6
Total	33	6	31	7	23

Area Tagged	Area Located (26 October 2022)				
	Lower	Shallow	Round	Upper	Missing
Lower	33	0	0	0	7
Shallow	0	9	8	0	5
Round	0	1	19	0	5
Upper	0	0	0	7	6
Total	33	10	27	7	23

Area Tagged	Area Located (27 April 2023)				
	Lower	Shallow	Round	Upper	Missing
Lower	33	0	0	0	7
Shallow	0	9	8	0	5
Round	0	1	19	0	5
Upper	0	0	0	7	6
Total	33	10	27	7	23

Area Tagged	Area Located (4 June 2023)				
	Lower	Shallow	Round	Upper	Missing
Lower	32	0	0	0	8
Shallow	0	15	2	0	5
Round	0	1	19	0	5
Upper	0	0	0	7	6
Total	32	16	21	7	24

Area Tagged	Area Located (23 June 2023)				
	Lower	Shallow	Round	Upper	Missing
Lower	31	1	0	0	8
Shallow	0	15	2	0	5
Round	0	2	16	0	7
Upper	0	0	0	7	6
Total	31	18	18	7	26

Area Tagged	Area Located (17 July 2023)				
	Lower	Shallow	Round	Upper	Missing
Lower	31	1	0	0	8
Shallow	0	8	8	0	6
Round	0	2	15	0	8
Upper	0	0	0	5	8
Total	31	11	23	5	30

Area Tagged	Area Located (15 August 2023)				
	Lower	Shallow	Round	Upper	Missing
Lower	31	0	0	0	9
Shallow	0	1	15	0	6
Round	0	0	17	0	8
Upper	0	0	0	4	9
Total	31	1	32	4	32

Area Tagged	Area Located (22 September 2023)				
	Lower	Shallow	Round	Upper	Missing
Lower	27	0	0	0	13
Shallow	0	4	12	0	6
Round	1	0	16	0	8
Upper	0	0	0	4	9
Total	28	4	28	4	36

Area Tagged	Area Located (11 October 2023)				
	Lower	Shallow	Round	Upper	Missing
Lower	17	0	0	0	23
Shallow	0	3	5	0	14
Round	1	0	15	0	9
Upper	0	0	0	3	10
Total	18	3	20	3	56

Note: All P-values for the 4x5 (among all lakes) contingency table chi-square tests were <0.05. All P-values for the 2x3 (between 2 adjacent lakes) contingency table chi-square tests were <0.05, except the 17 July 2023 survey between Round and Shallow Tangle Lakes, which had a P-value of 0.053.

Table 8.–Proportions of alive fish that moved among lakes at least once, Tangle Lakes 2022–2023.

Date Range	2022			2023		
	n	Prop	SE	n	Prop	SE
16–31 May	NA	NA	NA	5	0.06	0.03
1–15 June	11	0.12	0.03	4	0.05	0.03
16–30 June	18	0.20	0.04	3	0.04	0.02
1–15 July	6	0.07	0.03	8	0.11	0.04
16–31 July	6	0.07	0.03	9	0.13	0.04
1–15 August	10	0.12	0.03	2	0.03	0.02
16–31 August	3	0.04	0.02	2	0.03	0.02
1–15 September	6	0.08	0.03	3	0.04	0.03
15–30 September	4	0.05	0.03	6	0.09	0.04
1–15 October	3	0.04	0.02	2	0.03	0.02

APPENDIX A

Appendix A1.–Date of capture, length, tag information, capture location, final fate, date last found alive, and days alive, for each radiotagged lake trout, Tangle Lakes, 2022–2023.

Date	FL (mm)	Radio Tag Frequency (MHz)	Radio Tag Code	Lake Tagged In	Latitude Decimal Degrees	Longitude Decimal Degrees	Final Fate [a]	Last Date Found Alive	Days Alive
4/5/2022	555	150.400	1	Lower	63.1333	-145.961	AL	8/15/2023	497
4/5/2022	529	150.400	2	Lower	63.1345	-145.956	AL	9/22/2023	535
4/5/2022	523	150.400	3	Lower	63.1333	-145.961	AL	9/22/2023	535
4/5/2022	514	150.400	4	Lower	63.1345	-145.956	A	10/11/2023	554
4/5/2022	485	150.400	5	Lower	63.1345	-145.956	A	10/11/2023	554
4/5/2022	455	150.400	6	Lower	63.1333	-145.961	A	10/11/2023	554
4/5/2022	450	150.400	7	Lower	63.1333	-145.961	A	10/11/2023	554
4/5/2022	440	150.400	8	Lower	63.1399	-145.958	A	10/11/2023	554
4/5/2022	561	150.400	9	Lower	63.1333	-145.961	A	10/11/2023	554
4/5/2022	553	150.400	10	Lower	63.1399	-145.958	A	10/11/2023	554
4/5/2022	547	150.400	11	Lower	63.1345	-145.956	AL	9/22/2023	535
4/5/2022	479	150.400	12	Lower	63.1333	-145.961	A	10/11/2023	554
4/5/2022	451	150.400	13	Lower	63.1399	-145.958	AL	7/17/2023	468
4/6/2022	619	150.400	14	Lower	63.1399	-145.958	NFM	4/6/2022	0
4/6/2022	577	150.400	15	Lower	63.1399	-145.958	NFM	4/27/2023	386
4/6/2022	480	150.400	16	Round	63.1399	-145.958	AL	9/22/2023	534
4/6/2022	636	150.400	17	Round	63.1345	-145.956	A	10/11/2023	553
4/6/2022	435	150.400	18	Round	63.1399	-145.958	A	10/11/2023	553
4/6/2022	514	150.400	19	Round	63.1333	-145.961	AL	8/23/2022	139
4/6/2022	730	150.400	20	Round	63.1399	-145.958	A	10/11/2023	553
4/6/2022	633	150.400	21	Round	63.1379	-145.961	FM	4/6/2022	0
4/6/2022	680	150.400	22	Round	63.1379	-145.961	AL	8/15/2023	496
4/6/2022	512	150.400	23	Round	63.1379	-145.961	AL	9/22/2023	534
4/6/2022	555	150.400	24	Round	63.1379	-145.961	A	10/11/2023	553
4/6/2022	557	150.400	25	Round	63.1379	-145.961	A	10/11/2023	553

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Date	FL (mm)	Radio Tag Frequency (MHz)	Radio Tag Code	Lake Tagged In	Latitude Decimal Degrees	Longitude Decimal Degrees	Final Fate [a]	Last Date Found Alive	Days Alive
4/6/2022	472	150.400	26	Lower	63.1379	-145.961	NFM	9/22/2023	534
4/6/2022	500	150.400	27	Lower	63.1379	-145.961	AL	9/22/2023	534
4/6/2022	477	150.400	28	Lower	63.1379	-145.961	A	10/11/2023	553
4/6/2022	577	150.400	29	Lower	63.1379	-145.961	A	10/11/2023	553
4/6/2022	492	150.400	30	Lower	63.1379	-145.961	AL	8/15/2023	496
4/7/2022	712	150.400	31	Lower	63.1379	-145.961	AL	8/15/2023	496
4/6/2022	503	150.400	32	Lower	63.1379	-145.961	NFM	4/6/2022	0
4/6/2022	680	150.400	33	Lower	63.1333	-145.961	AL	9/22/2023	534
4/6/2022	492	150.400	34	Lower	63.1379	-145.961	AL	4/6/2022	0
4/6/2022	515	150.400	35	Lower	63.1379	-145.961	A	10/11/2023	553
4/7/2022	578	150.400	36	Lower	63.1379	-145.961	AL	9/22/2023	533
4/6/2022	450	150.400	37	Lower	63.1379	-145.961	AL	4/6/2022	0
4/7/2022	560	150.400	38	Lower	63.1379	-145.961	A	10/11/2023	552
4/7/2022	557	150.400	39	Lower	63.1379	-145.961	AL	9/22/2023	533
4/6/2022	570	150.400	40	Lower	63.1379	-145.961	NFM	9/13/2022	160
6/3/2022	436	150.400	41	Round	63.0528	-145.997	A	10/11/2023	495
6/4/2022	469	150.400	42	Round	63.0515	-145.991	A	10/11/2023	494
6/4/2022	495	150.400	43	Round	63.0515	-145.991	A	10/11/2023	494
6/5/2022	560	150.400	44	Round	63.0578	-145.998	FM	7/21/2022	46
6/5/2022	463	150.400	45	Round	63.0558	-145.998	A	10/11/2023	493
6/5/2022	434	150.400	46	Round	63.0558	-145.998	A	10/11/2023	493
6/6/2022	476	150.400	47	Round	63.0558	-145.998	A	10/11/2023	492
6/6/2022	538	150.400	48	Round	63.0558	-145.998	A	10/11/2023	492
6/6/2022	550	150.400	49	Round	63.0558	-145.998	A	10/11/2023	492
6/8/2022	686	150.400	50	Shallow	63.0747	-145.972	NFM	6/23/2022	15

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Date	FL (mm)	Radio Tag Frequency (MHz)	Radio Tag Code	Lake Tagged In	Latitude Decimal Degrees	Longitude Decimal Degrees	Final Fate [a]	Last Date Found Alive	Days Alive
6/10/2022	514	150.400	51	Upper	63.0211	-146.060	A	10/11/2023	488
6/11/2022	540	150.400	52	Upper	63.0387	-146.054	A	10/11/2023	487
6/9/2022	725	150.400	53	Upper	63.0191	-146.061	A	10/11/2023	489
6/10/2022	570	150.400	54	Upper	63.0257	-146.061	A	10/11/2023	488
6/9/2022	725	150.400	55	Upper	63.0172	-146.061	FM	9/13/2022	96
6/9/2022	438	150.400	56	Upper	63.0172	-146.061	AL	6/23/2023	379
6/10/2022	592	150.400	57	Upper	63.0200	-146.060	AL	7/17/2023	402
6/9/2022	460	150.400	58	Upper	63.0191	-146.061	NFM	6/9/2022	0
6/9/2022	595	150.400	59	Upper	63.0225	-146.058	A	10/11/2023	489
6/9/2022	565	150.400	60	Upper	63.0225	-146.058	AL	9/22/2023	470
6/8/2022	526	150.400	61	Shallow	63.0711	-145.977	NFM	6/23/2022	14
6/8/2022	530	150.400	62	Shallow	63.0711	-145.977	A	10/11/2023	490
6/9/2022	557	150.400	63	Shallow	63.0709	-145.977	A	10/11/2023	490
6/9/2022	590	150.400	64	Shallow	63.0709	-145.977	NFM	8/23/2022	75
6/9/2022	611	150.400	65	Shallow	63.0709	-145.977	NFM	9/22/2023	470
6/9/2022	487	150.400	66	Shallow	63.0709	-145.977	A	10/11/2023	489
6/9/2022	636	150.400	67	Shallow	63.0709	-145.977	AL	9/22/2023	470
6/9/2022	654	150.400	68	Shallow	63.0709	-145.977	AL	9/22/2023	470
6/9/2022	541	150.400	69	Shallow	63.0709	-145.977	A	10/11/2023	489
6/9/2022	596	150.400	70	Shallow	63.0709	-145.977	AL	9/22/2023	470
6/9/2022	493	150.400	71	Shallow	63.0695	-145.972	AL	9/22/2023	470
6/9/2022	616	150.400	72	Shallow	63.0709	-145.977	AL	9/22/2023	470
6/10/2022	516	150.400	73	Round	63.0585	-145.997	A	10/11/2023	488
6/9/2022	481	150.400	74	Shallow	63.0695	-145.972	A	10/11/2023	488
6/9/2022	500	150.400	75	Shallow	63.0695	-145.972	A	10/11/2023	489

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Date	FL (mm)	Radio Tag Frequency (MHz)	Radio Tag Code	Lake Tagged In	Latitude Decimal Degrees	Longitude Decimal Degrees	Final Fate [a]	Last Date Found Alive	Days Alive
6/9/2022	546	150.400	76	Shallow	63.0711	-145.977	NFM	9/13/2022	96
6/9/2022	696	150.400	77	Shallow	63.0711	-145.977	AL	8/23/2022	75
6/9/2022	454	150.400	78	Shallow	63.0695	-145.972	A	10/11/2023	489
6/9/2022	622	150.400	79	Shallow	63.0711	-145.977	AL	6/23/2023	379
6/9/2022	581	150.400	80	Shallow	63.0695	-145.972	NFM	9/22/2023	470
6/12/2022	439	150.400	81	Round	63.0556	-145.980	NFM	9/22/2023	467
6/11/2022	502	150.400	82	Round	63.0576	-145.977	A	10/11/2023	487
6/11/2022	555	150.400	83	Round	63.0609	-145.986	NFM	6/11/2022	0
6/11/2022	481	150.400	84	Round	63.0556	-145.980	A	10/11/2023	487
6/11/2022	462	150.400	85	Round	63.0559	-145.979	A	10/11/2023	487
6/10/2022	445	150.400	86	Shallow	63.0756	-145.960	AL	9/22/2023	469
6/11/2022	445	150.400	87	Round	63.0609	-145.986	AL	6/4/2023	359
6/11/2022	496	150.400	88	Round	63.0609	-145.986	NFM	6/11/2022	0
6/10/2022	547	150.400	89	Shallow	63.0787	-145.962	A	10/11/2023	488
6/11/2022	515	150.400	90	Round	63.0548	-145.982	A	10/11/2023	487
6/12/2022	481	150.400	91	Round	63.0609	-145.986	A	10/11/2023	486
6/12/2022	496	150.400	92	Round	63.0537	-145.983	NFM	8/10/2022	59
6/12/2022	449	150.400	93	Round	63.0580	-145.995	FM	6/4/2023	357
6/12/2022	430	150.400	94	Round	63.0609	-145.986	A	10/11/2023	486
6/11/2022	607	150.400	95	Upper	63.0401	-146.050	NFM	7/21/2022	40
6/12/2022	461	150.400	96	Round	63.0607	-145.979	FM	6/23/2023	376
6/12/2022	450	150.400	97	Round	63.0545	-145.982	NFM	8/10/2022	59
6/11/2022	624	150.400	98	Upper	63.0371	-146.052	FM	6/23/2023	377
6/12/2022	523	150.400	99	Round	63.0609	-145.986	A	10/11/2023	486
6/11/2022	572	150.400	100	Upper	63.0211	-146.060	FM	7/21/2022	40

[a] A= alive, AL= at large (missing), NFM= non-fishing mortality (presumed natural mortality) and FM= fishing mortality