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Abundance and Length Composition of Cutthroat Trout at Neck Lake, Southeast Alaska, 2018

by

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and

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December 2023

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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ABUNDANCE AND LENGTH COMPOSTION OF CUTTHROAT TROUT AT NECK LAKE, SOUTHEAST ALASKA, 2018

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ABSTRACT

The population status of cutthroat trout *Oncorhynchus clarkii* at Neck Lake in Southeast Alaska that was last examined from 1996 through 1998 was reexamined in 2018. Mark–recapture was used to estimate abundance, length composition, and catch per unit effort (CPUE) for fish captured in baited hoop traps, baited funnel traps, and with hook and line. The 2 studies were compared to assess changes to the cutthroat trout population since 1996, when hatchery coho salmon *O. kisutch* fry commenced rearing in the lake. Estimated abundance of cutthroat trout >180 mm fork length (FL) in 2018 was 4,959 fish (95% CI 4,325–5,726), ~1,800 fish more than estimated in 1998. Length composition estimates of fish >180 mm FL showed larger fish in 2018 with mean lengths of 230 mm FL (SE = 1.3) in 2018 and compared to 219 mm FL (SE = 0.9) in 1998. In 2018, CPUE estimates by gear type for cutthroat trout >180 mm FL were 2.9 and 5.4 fish per overnight set for baited hoop and funnel traps, respectively. Hook and line CPUE was 3.8 fish per hour. Hook and line captured the largest mean size of fish (250 mm FL, SE = 1.6), whereas baited funnel traps caught the smallest mean size of fish (219 mm FL, SE = 1.5) >180 mm FL. Catch data were also used to examine the utility of conducting rapid stock assessments for monitoring cutthroat trout populations in lakes throughout Southeast Alaska.

Estimating the proportion of the population above the regionwide minimum size limit and other length composition estimates would probably be possible with a single trip of significantly shorter duration than the 10-day period conducted in 2018. An estimate of abundance will continue to require 2 trips, although both trips could be of shorter duration with refined capture gear and techniques.

Keywords: Southeast Alaska, Prince of Wales Island, Neck Lake, cutthroat trout, *Oncorhynchus clarkii*, abundance, mark–recapture, length composition, coho salmon, *Oncorhynchus kisutch*, stocking

INTRODUCTION

Cutthroat trout *Oncorhynchus clarkii* are distributed throughout Southeast Alaska (SEAK), including Neck Lake on Prince of Wales Island (POW), and provide an important resource for sport anglers. Since 1994, trout populations throughout SEAK have been managed conservatively by Alaska Department of Fish and Game (ADF&G) with a regionwide bag limit of 2 and minimum size and bait-use restrictions. Minimum size limits for the region are currently 11 inches total length (279 mm) or 10.75 inches fork length (273 mm), with some exceptions provided as special regulations. The minimum size limits were identified by past research on cutthroat trout maturity (Harding 2013) and intended to allow cutthroat trout to spawn at least once before they are susceptible to harvest.

The Neck Lake Hatchery on eastern POW has produced summer run coho salmon *O. kisutch* that have been reared in Neck Lake since 1996. The facility is operated by Southern Southeast Regional Aquaculture Association (SSRAA) and until 2017 was permitted to rear up to 2.2 million summer coho salmon fry in net pens located in Neck Lake. In 2017, the facility was permitted to rear an additional 2.2 million fall run coho salmon in Neck Lake. Until 2005, a portion of the coho salmon fry were released directly from net pens into Neck Lake during the fall to rear until they would leave the drainage as smolt in the spring (J. R. Parsley, Neck Lake Hatchery Manager, SSRAA, Whale Pass, personal communication). Since 2006 the fry have been raised in the lake net pens for 12 months with a May release date as smolts into Neck Lake. During 2017–2018, 1.8 million coho salmon fry were raised by the facility with a release of 1.7 million. Adult coho salmon cannot return to Neck Lake due to barrier falls in Neck Creek.

When the rearing of coho salmon fry in Neck Lake commenced in 1996, there were concerns regarding the potential impacts of rearing coho salmon with cutthroat trout. Concerns included coho salmon fry competition with juvenile cutthroat trout and the potential for adult trout predation on juvenile coho salmon. In addition, restrictive trout sport harvest limits were implemented in 1994 throughout SEAK. In response to both issues, ADF&G conducted a cutthroat trout population study during 1996–1998. Results of the project included estimates of abundance in 1997 and 1998 and length distributions of cutthroat trout ≥180 mm fork length (FL) from 1996 through 1998.

A combination of baited hoop traps (BHTs) and hook and line (H&L) were used to capture cutthroat trout throughout Neck Lake. Estimates indicated an abundance of ~3,000 cutthroat trout ≥180 mm FL in Neck Lake during 1997 and 1998 (Harding, Chadwick, and Freeman 1999). Most fish (76%) sampled during the study were <240 mm FL and only 6% of the cutthroat trout sampled were longer than the 12-inch (287 mm FL) minimum size limit established at that time (Harding, Chadwick, and Freeman 1999). The regionwide minimum size limit was changed in 2000 to 11 inches (279 mm) total length (TL) or 10.75 inches FL (273 mm).

It had been approximately 20 years since the last study and there was evidence that the size structure of cutthroat trout has changed. Reports from the public and H&L sampling by staff indicate that the length frequency of cutthroat trout in the lake has shifted toward larger fish. Coho salmon fry are reared in net pens and released as smolt into Neck Lake and may be prey to cutthroat trout for a short period of time in May. Cutthroat trout appear to concentrate at the net pens, probably feeding on commercial pellet food that filters through the net pens. This supplemental source of high-quality food may have increased the growth rates of cutthroat trout in Neck Lake and affected population size.

The catch and effort data from this study was also examined to develop recommendations for the rapid assessment of lake populations of cutthroat trout. Rapid assessment refers to sampling lakes over a short period of time, 1 to 3 days depending on size of lake, to assess cutthroat trout populations. Assessments may include estimating length composition, abundance, or an index of abundance.

The results of this study provided ADF&G with 2 deliverables: (1) The 2018 study duplicated the previous studies' capture techniques and sampling design to document and compare cutthroat trout abundance and length composition 20 years after implementation of restrictive trout fishing regulations regionwide and hatchery coho salmon rearing in the lake; and (2) the data collected from this study was analyzed to assess gear types and reductions in sampling effort that can be effectively used as an abundance and length-composition index for rapid assessments of cutthroat trout populations in lakes.

OBJECTIVES

1. Estimate abundance of cutthroat trout ≥180 mm FL in Neck Lake during 2018 within ± 15% of the true value 95% of the time using a closed population estimator.
2. Estimate length composition of the cutthroat trout ≥180 mm FL in Neck Lake in 20 mm increments during 2018 such that each multinomial proportion is within ±5 percentage points of the true value 90% of the time.

STUDY AREA

Prince of Wales Island is the largest island of the Alexander Archipelago in SEAK. The island is 217 km long and 72 km wide, with an area of 6,674 km^2. There are numerous lakes on POW that support cutthroat trout, including Neck Lake which is a relatively large (373 ha) roadside lake (Figure 1). Its location on northern POW, road access, a boat ramp, and proximity to the community of Whale Pass make Neck Lake a popular destination for trout anglers. A barrier falls on Neck Creek prevents anadromous fish from entering Neck Lake, and therefore the cutthroat trout population is only composed of potamodromous fish. Other species present are kokanee *O. nerka*, Dolly Varden *Salvelinus malma*, sculpin *Cottus*, and threespine stickleback *Gasterosteus aculeatus*. Currently, regionwide trout regulations apply to Neck Lake cutthroat trout sport angling.

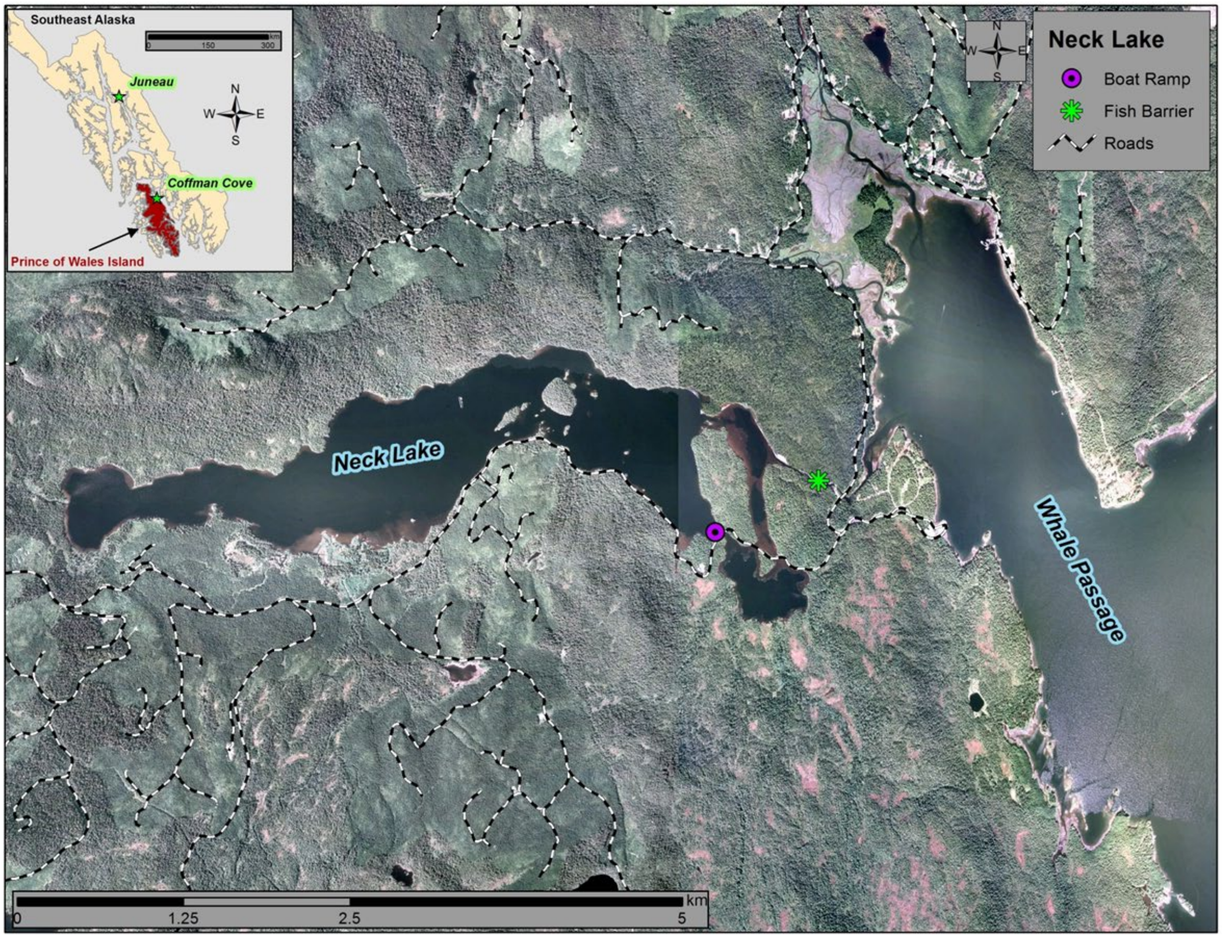

Figure 1.–Location of Neck Lake on Prince of Wales Island in southern Southeast Alaska.

METHODS

A 2-event closed population (Petersen) model was used to estimate abundance in 2018. Sampling dates were selected similar to the previous study to avoid sampling during spawning, when cutthroat trout are likely to be in tributary streams. In the 1998 study, sampling events 1 and 2 were separated by 8 days.

This study also duplicated the sampling methods and effort conducted in 1998 (Harding, Chadwick, and Freeman 1999) with baited funnel traps (BFTs) as an additional gear type. Similar levels of effort were maintained with BHTs and H&L capture techniques with BFTs in smaller numbers than BHTs. This design minimized compensatory effects on the catch rate between the BFT and BHT gear types and provided length and catch per unit effort (CPUE) data from both gear types for comparison.

FIELD SAMPLING

A 2- to 3-person crew conducted two 10-day trips to Neck Lake, which included 1 day of setting traps and 9 days of checking traps and sampling fish, to capture and mark cutthroat trout ≥180 mm FL with uniquely numbered anchor T-bar tags. The first sampling period (marking event) was 22 May to 31 May; a second 10-day sampling period (recapture event) was 2 July to 11 July.

Cutthroat trout were captured with BHTs (Appendix A), BFTs (Appendix A), and H&L. BHTs are 1.4 m long and consist of four 0.6-m-diameter steel hoops and 9 cm throats attached to the first and third hoops. BFTs were newly designed for this study and were based on the dimensions of large minnow traps used by ADF&G in past cutthroat trout studies. They are constructed of the same materials as BHTs and, unlike the large minnow traps, are collapsible for ease of transport and storage. BFTs are 0.9 m long and 0.6 m wide with a 6.35 cm entrance. Knotless nylon netting with a mesh size of 1 cm covered the BHTs and BFTs. Bait for the BFTs and BHTs consisted of whole and or crushed salmon eggs disinfected in betadine solution. H&L was conducted by casting small spoons, spinners, jigs, and other lures in a manner such that all shoreline areas were fished with similar effort.

The lake was divided into 3 areas (A, B, and C) to aid in evaluation of assumptions during data analysis (Figure 2). The 3 sampling areas (A, B, and C) were each further subdivided into 3 sections (numbered 1 through 9; see Figure 2). Area A consisted of sections 1–3, Area B consisted of sections 4–5, and Area C consisted of sections 7–9. Effort was uniformly distributed across each of the 9 sections of the lake in direct proportion to the amount of lake surface area present ≤40 m. The distribution of effort based on surface area was 130 BHT days, 34 BFT days, and 81 rod hours during each of the two 9-day sampling events (Table 1). Rod hours were calculated based on 3 anglers sampling each section. There was less effort for BFTs because they were considered experimental, and only a small number were available for this study. Based on section area, up to 24 trap days for BHTs, 6 trap days for BFTs, and 14 hours and 51 minutes of hook and line sampling occurred per section (Table 1).

Traps were set on the lake bottom at depths ≤40 m overnight, and depths were determined with a fathometer. In a previous study, CPUE declined as depth increased to almost 0 fish/trap at 35 m (Harding, Chadwick, and Freeman 1999). Setting traps to ≤40 m ensured all cutthroat trout in the lake had an equal probability of encountering gear. H&L was uniformly distributed along the shoreline of each section. All traps fished 1 of the 9 sections for 1 overnight period before being moved to a new area in a randomly selected order. During the recapture event the geographic order in which traps were set across the lake was similar to the previous trip. This ensured a relatively constant hiatus between sampling events by area of the lake. Traps were pulled in the morning, ~24 hours after being set and moved to a new section. Once traps were set, H&L sampling occurred within the same section.

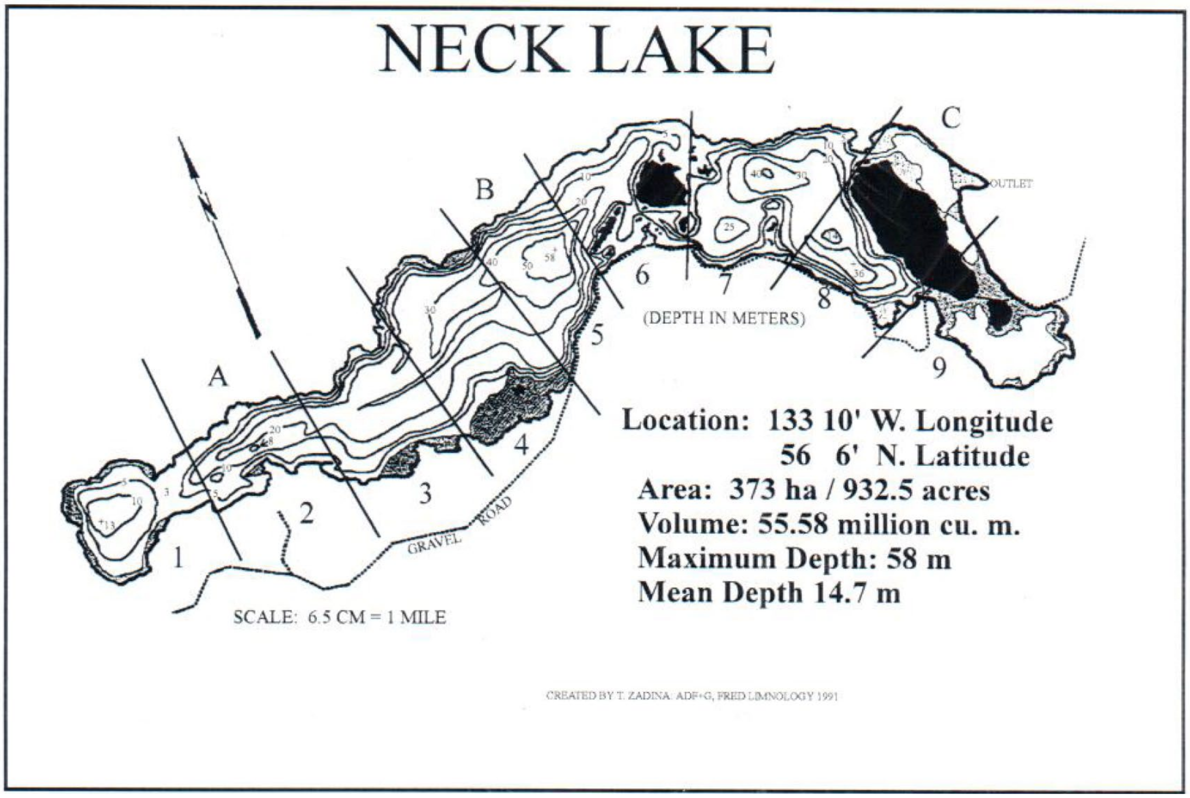

Figure 2.–Bathymetric map of Neck Lake study site on Prince of Wales Island in Southeast Alaska, with sampling area and section divisions.

Note: Area A is divided into sections 1–3, area B into sections 4–6, and area C into sections 7–9.

Table 1.–Distribution of effort for sampling gear for cutthroat trout per area in Neck Lake during 2018.

Section	Area (km^2)	Prop	H&L hours per event	BHT days per event	BFT days per event
Section 1	3.18	0.099	8:06	13	3
Section 2	2.73	0.085	6:45	11	3
Section 3	3.98	0.124	9:54	16	4
Section 4	5.94	0.185	14:51	24	6
Section 5	2.32	0.072	5:51	9	3
Section 6	3.50	0.109	9:00	14	4
Section 7	4.87	0.152	12:09	20	5
Section 8	3.87	0.120	9:54	16	4
Section 9	1.73	0.054	4:30	7	2
Totals	32.12	1.000	81:00	130	34

Note: Baited hoop trap = BHT, baited funnel trap = BFT, Hook and line = H&L.

Note: Tabulated area (Area km^2) and proportions (Prop) are estimates for 0 to 40 m.

Note: H&L hours per event is the cumulative effort of 3 anglers.

DATA COLLECTION

Abundance and Length Composition

During the marking and recapture events, cutthroat trout ≥180 mm FL were examined for marks, measured from tip of the snout to the fork of the tail (nearest mm FL), tagged (if untagged) with a uniquely numbered T-bar anchor tag, and given a secondary mark. Tags were inserted on the left side of the fish below the dorsal fin. Secondary marks were a clipped adipose fin during the first event and a clipped tip of the left pectoral fin during the second event to control for tag loss. All fish ≥180 mm FL captured were allowed to recover and then released in the area of capture. Length, tag number (or presence of a secondary mark), gear type, trap number, and depth of set for tagged and newly captured (untagged) fish were recorded by date and species. Mortality status and select comments (old or new tag or other scars, physical condition, etc.) were recorded. Catch and the number of gear units (trap-days, etc.) for each gear type were recorded for each sampling day. Cutthroat trout <180 mm FL and other species captured were counted and released unmarked. All data collected were recorded on custom field data sheets and entered electronically in the Craig ADF&G office.

After thorough inspection of the data to ensure obvious errors were removed, an R script[1] was used to check for errors in the Soldotna ADF&G Division of Sport Fish office. The program checked for acceptable dates, species, gear type, location in the lake, mortality status, lengths, and correct (acceptable) tag numbers on newly marked and recaptured fish. Also, paired lengths of marked and recaptured fish were compared for obvious recording and data entry errors, then rechecked for accuracy by comparing individual computer line entries to the original field data form entries.

Archiving

A final, edited copy of the data, along with a data map, was electronically sent to Division of Sport Fish Research and Technical Services (RTS) for archiving. The data map included a description of all electronic files contained in the data archive, all data fields, and details of where hard copies of any associated data are to be archived, if not in RTS. The data archive will include all R scripts and R input data files, Excel workbooks (presently in Excel 2010), and any other data summaries. Data fields for the tagging file included (for each fish) lake, area location and depth, gear, species, date, time, fork length, tag number, adipose clip and all other secondary marks, sex, ASL form number, mortality, and comments. The original hard copies and electronic files of all tagging and recovery forms and scales were logged and stored in the Craig ADF&G SF office.

DATA ANALYSIS

Abundance Estimate

Assumptions

The assumptions necessary for accurate estimation of abundance with a 2-event closed population model are as follows:

1) the population was closed; i.e., recruitment (or immigration) and death (or emigration) did not occur between sampling events;

[1] R Core Team (2017). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

2) every fish had an equal probability of being marked during the marking event, *or* every fish had an equal probability of being sampled during the recapture event, *or* marked and unmarked fish mixed completely between events;
3) marking did not affect the catchability of a fish; and
4) fish did not lose marks between events, *and* marks were recognized in the recovery sample and reported.

The closure assumption (assumption 1) was addressed by the sample design given the natural barrier on Neck Creek, the relatively short time (30 days) between the 2 sampling events, sampling dates that allowed tributary spawning fish to return to the study area, and our expectation that significant natural mortality would not occur during the growing season. Growth recruitment was tested by comparing the size of fish at marking and at recapture.

The probability of capture/mixing assumption (assumption 2) had a good chance of being satisfied geographically because sampling effort was distributed in proportion to available habitat throughout the lake during each event and because ~30 days passed between events. Contingency table tests of equal recovery rates for fish marked during the marking event in each stratum and equal marked fractions during the recapture event in each stratum (Arnason et al. 1996) were used to verify this assumption using the 3 lake areas as geographic strata. Significant results on both tests would indicate geographic stratification was necessary for an unbiased estimate of abundance. The probability of capture assumptions (assumption 2) with respect to size-selective sampling were evaluated with Kolmogorov–Smirnov (KS) tests.

We could not test for effects of marking on catchability (assumption 3) due to having only 2 sampling events. However, Harding, Laker, and Marshall (1999) provided some evidence that capture with baited hoop traps and tagging does not lead to a significant short-term trap avoidance reaction.

Assumption 4 should be robust in this experiment, because all fish were double-marked and technicians were instructed to rigorously examine all captured fish for marks. Evidence of tag loss or tagging stress was recorded for every fish handled. Because all tagged fish were given a permanent secondary mark (a fin clip), tag loss could be estimated.

Estimation

In a 2-event mark–recapture experiment the number of recaptures during the recapture event (m_2) follows a hypergeometric distribution:

$$m_2 \sim \frac{\binom{n_1}{m_2}\binom{N-n_1}{n_2-m_2}}{\binom{N}{n_2}} \qquad (1)$$

where n_1 is the number of fish ≥180 mm FL marked and released during the marking event, n_2 is the number of fish that were ≥180 mm FL during the marking event and inspected during the recapture event, and N is the size of the population. Generally, n_1 and n_2 are considered fixed but under growth recruitment n_2 is not observed because some fish that were smaller than 180 mm FL during the marking event may have grown to larger than 180 mm FL during the recapture event. Instead, we observed n_2^*, the number of fish that were ≥180 mm FL during the recapture event and inspected during the recapture event. A model was developed to estimate the number of fish that would have been included in the recapture event sample in the absence of growth. The model was based on estimating the distribution of growth increments occurring between events:

$$\delta_i \sim \text{Normal}(\mu, \sigma^2) \tag{2}$$

where δ_i are the differences in the length of tagged fish between the marking and recapture events (i = 1 to 138). The parameter estimates of μ and σ^2 were used during Monte Carlo simulation to predict length differences δ_j^* (j = 1 to 994), one for each fish captured during the recapture event. An estimate of n_2 (the number of fish captured during the recapture event that were ≥180 mm FL during the marking event) is:

$$n_2 = \sum_{1}^{994} \text{I}\left(\widehat{fl}_{j,1} \geq 180\right) \tag{3}$$

$$\widehat{fl}_{j,1} = fl_{j,2} - \delta_j^*$$

where $I()$ is an indicator function that equals 1 when a condition is true and 0 when a condition is false, $\widehat{fl}_{j,1}$ is the estimated length during the marking event of the fish examined during the recapture event, and $fl_{j,2}$ is the observed length during the recapture event.

This model was run in JAGS through R. We ran 4 chains for 25,000 iterations with a 500-iteration burn-in. Every 5th iteration was retained for the posterior. Initial values were randomly sampled from each parameter's support. Model parameters all converged, with Rhat <<1.1 and effective sample sizes of 1,000 or greater.

Length Composition

The sample for length composition was obtained from all lengths collected from newly captured fish during the marking event. Length composition was calculated in 20 mm FL increments using standard statistical techniques. Wilson confidence intervals were used for proportional composition estimates. The length composition procedure was repeated relative to the 11-inch (273 mm) legal size limit to show the proportion of the population that was available to harvest and the average size of the harvestable population.

Rapid Population Assessment

We estimated the proportion of the population available to harvest using 1- to 8-day datasets created from all possible combinations of sampled days when traps were checked during the marking event (9 total days). These estimates are plotted relative to the 2018 confidence interval to show potential variability associated with estimating the population available to harvest with a reduced assessment. During 2018, sampling effort with traps and H&L was restricted to a single section during each day. We also used 2018 CPUE estimates for each gear type to calculate expected sample sizes and the resulting accuracy of a mark–recapture abundance estimate that could be expected with different gear combinations using the techniques of Robson and Regier (1964).

RESULTS

ABUNDANCE ESTIMATION

During the marking event a total of 1,175 cutthroat trout captures occurred, of which 849 were unique cutthroat trout between 180 and 400 mm FL that were marked and released. During the recapture event a total of 1,014 cutthroat trout captures occurred, of which 839 unique cutthroat trout between 180 and 425 mm FL were examined. The total number of recaptures during the recapture event was 137 fish and no tag loss was detected.

Because of the natural barrier to migration on Neck Creek and no fish observed spawning in tributaries during either sampling event, the population was assumed to satisfy the closure assumption with respect to immigration and emigration. During the 1996–1998 study, growth recruitment and mortality were assumed to be negligible, mainly due to the relatively short time (8 days) between the 2 sampling events and the expectation that significant natural mortality would not occur over the summer. Because our sampling events were further apart temporally, we investigated the possibility of growth recruitment by looking at growth increments between marking and recapture for recaptured cutthroat trout (Figure 3). Both positive and negative growth increments were measured because the differences could include measurement errors during both events. The distribution of growth increments was centered on positive values (mean = 5 mm), and a 95% confidence interval for the mean (4.1 mm – 5.9 mm) did not include zero. There was no linear relationship between the growth increment and the measured length during the marking event. We interpret this as evidence of growth between marking and recapture that violates the closure assumption because some fish that were <180 mm FL during the marking event could have been ≥180 mm FL during the recapture event.

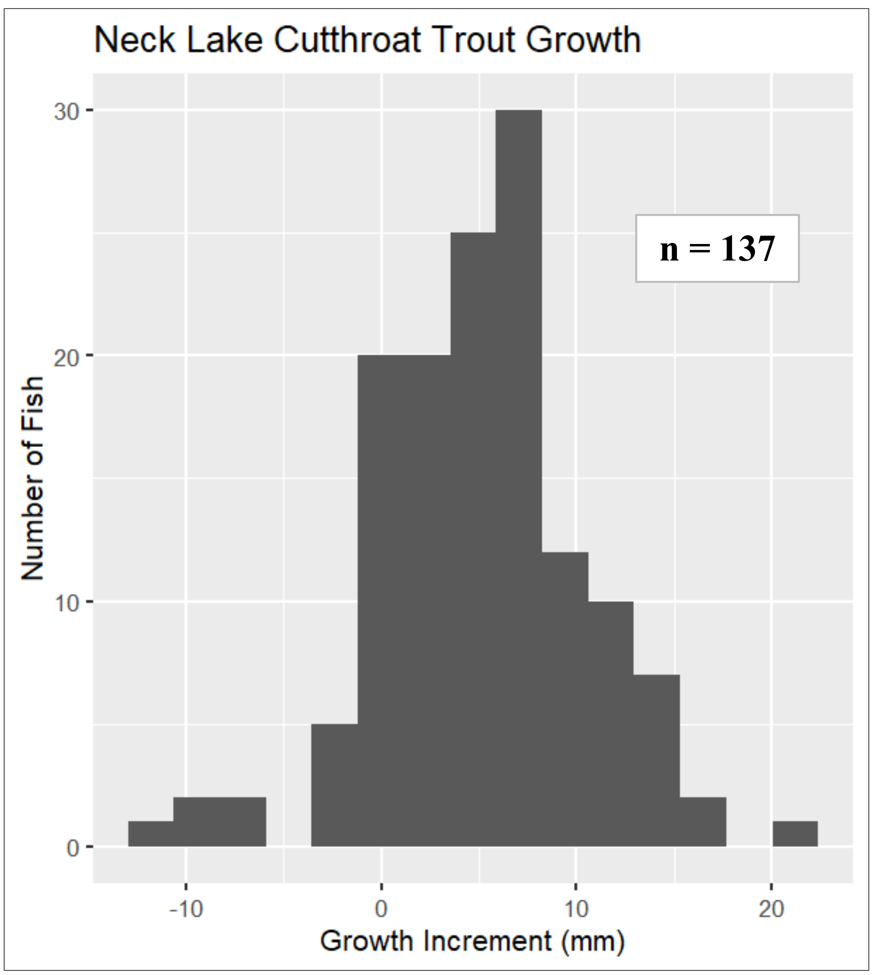

Figure 3.–Observed cutthroat trout growth increments in numbers of fish in Neck Lake during 2018.

Catch of cutthroat trout ≥180 mm FL declined with increasing depth during the marking event with most fish caught at depths less than 3.1 m (Figure 4). During the recapture event most fish were caught at depths between 3.2 and 6.1 m (Figure 4). Catch of cutthroat trout during both events was largest in the first 6.1 m of depth, moderate between 6.2 and 15.2 m of depth, and zero for all sets below 15.3 m. Because gear set at depth greater than 15.3 m captured no fish, we believe sampling encompassed the entire catchable population.

Three geographic areas were used to test equal probability of capture assumptions (Figure 2). Marked fractions were similar among recovery areas (P = 0.11, Table 2, top panel) and recovery rates were similar among marking areas (P = 0.50, Table 2, bottom panel). Incomplete mixing of marked fish occurred among sampling areas (Table 3). These results justify pooling geographical strata when estimating abundance. Test results for marked fractions would be affected by growth recruitment, whereas the recovery rate and mixing tests would be unaffected.

Three empirical cumulative density functions were compared to test for size selectivity in both the marking and recapture sampling events (Figure 5). The length distribution of cutthroat trout sampled during the recapture event was not significantly different (KS test C vs. R; Dmax = 0.09; P = 0.25; Figure 5, top panel; Appendix B) from the length distribution of recaptured cutthroat trout, indicating the marking event was not size-selective. The length distribution of cutthroat trout sampled during the marking event was significantly different (KS test M vs. R; Dmax = 0.13; P = 0.045; Figure 5, middle panel) from the length distribution of recaptured cutthroat trout, indicating the recapture event was size-selective. Finally, a comparison of the length distribution of fish sampled during the marking and recapture events was significantly different (KS test M vs. C; Dmax = 0.13; $P \sim 0.00$; Figure 5, bottom panel) and that the recapture sample was skewed toward longer fish. Although these results are consistent with growth between the 2 events, the difference between the 2 empirical density functions suggests there may have been some selectivity toward larger fish in recapture event beyond the observed growth increments.

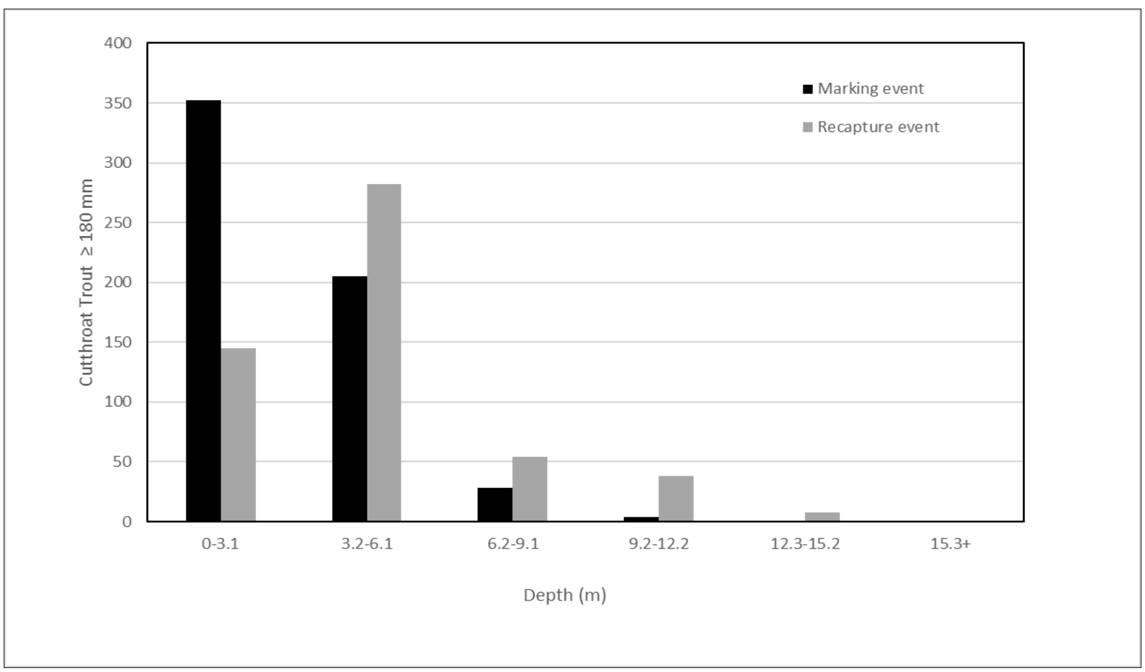

Figure 4.–Catch of cutthroat trout ≥180 mm FL captured in traps during marking and recapture events by depth in Neck Lake during 2018.

Table 2.–Results of chi-square consistency tests for use of pooled Peterson model to estimate abundance of cutthroat trout in Neck Lake during 2018.

Recapture area	Number marked	Number unmarked	Fraction marked
A	44	182	0.19
B	61	297	0.17
C	32	223	0.13

$X^2 = 4.4$, df = 2, P = 0.11; accept H_o

Marking area	Marks recaptured	Marks not recaptured	Fraction recovered
A	44	212	0.17
B	55	266	0.17
C	38	234	0.14

$X^2 = 1.3$, df = 2, P = 0.50; accept H_o

Note: Test for equal marked fractions in recapture event by recapture area (upper panel) and test for equal recovery rates for marked in the marking event by marking area (lower panel).

Table 3.–Number of cutthroat trout ≥180 mm FL recaptured by marking and recapture area in Neck Lake during 2018.

Tagging area	Recapture area			Not recaptured
	A	B	C	
A	32	13	1	212
B	10	38	7	266
C	2	12	24	234

$X^2 = 83.6$, df = 6, P = 0; reject H_o

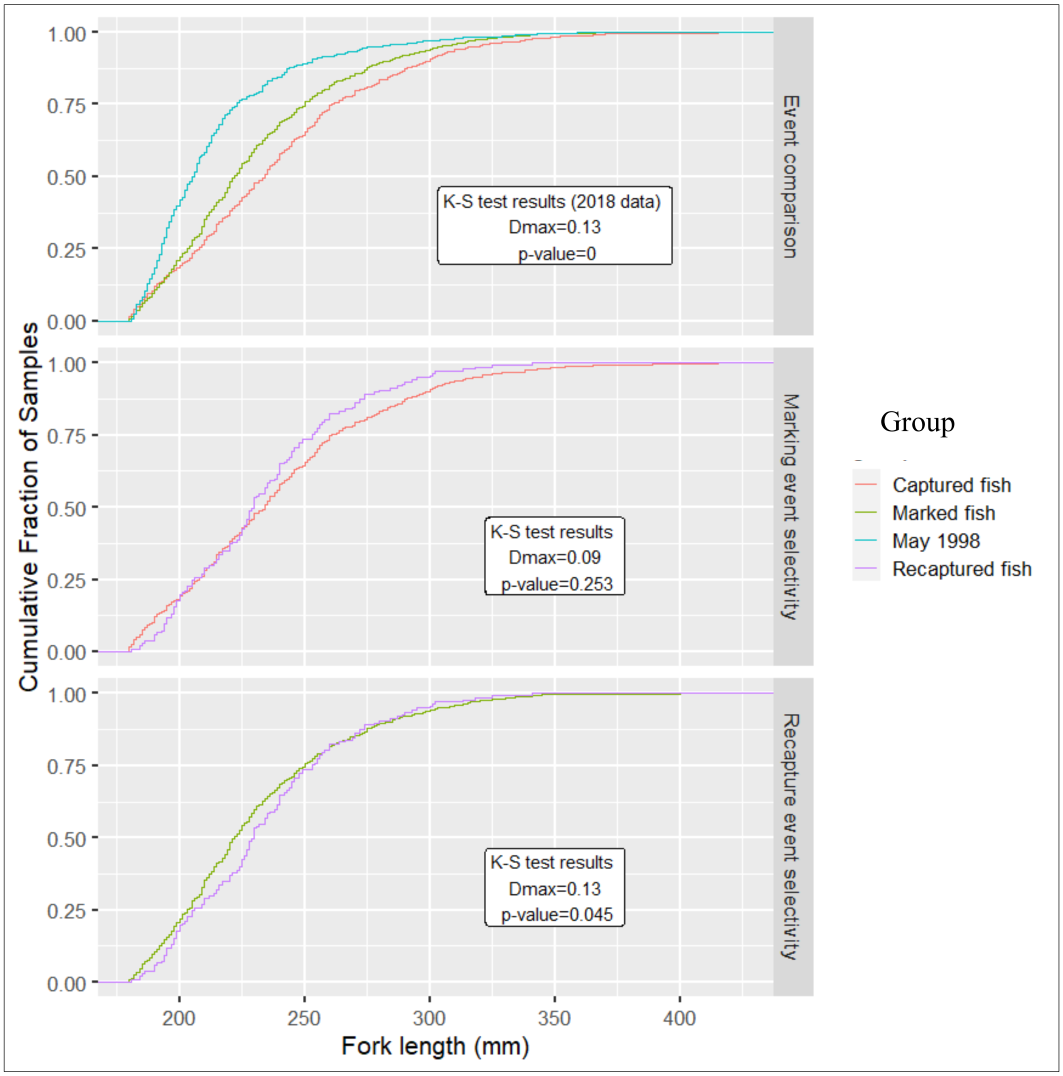

Figure 5.–Length distributions of cutthroat trout ≥180 mm FL from marking and recapture events from Neck Lake during 2018.

Based on the test results presented above we estimated the abundance of Neck Lake cutthroat trout after accounting for growth between marking and recapture. The estimated number of cutthroat trout examined during the recapture event that were ≥180 mm FL *during the marking event* was 791 fish (95% CI 779–804), suggesting 48 of the 839 cutthroat trout that were ≥180 mm FL when examined during the recapture event only reached 180 mm FL after the marking event. The estimated abundance of cutthroat trout ≥180 mm FL in Neck Lake during the marking event is 4,959 fish (SE = 361, 95% CI 4,325–5,726). This estimate can be compared to naïve abundance (5,173, SE = 367) estimated with a Chapman estimator [$N = (n_1+1)(n_2+1)/(m_2+1)–1$] to consider the effect of ignoring growth recruitment.

LENGTH COMPOSITION

The mean lengths of cutthroat trout ≥180 mm FL newly captured during the marking event and recapture event were 230 (SE = 1.3) and 239 (SE = 1.5) mm FL, whereas recaptured cutthroat trout were on average 5 mm longer when they were recaptured compared to when they were marked. In addition, there was some evidence that the recapture event selected for larger fish (Figure 5, middle panel). Therefore, only length data collected during the marking event were used to estimate length composition.

During May of 2018, approximately 69% of cutthroat trout ≥180 mm FL were ≤240 mm FL with the largest number of fish between 201 and 220 mm FL (Table 4). Fourteen percent of the cutthroat trout sampled during the marking event were longer than the 11-inch TL minimum size limit or 273 mm FL minimum size limit[2] established for the sport fishery (Table 5). Length compositions of unique fish ≥180 mm FL captured during both events in 2018 indicated larger fish than 1998 (Figure 5, bottom panel).

Gear Comparison

Catch of cutthroat trout ≥180 mm FL and <180 mm FL varied by gear type due to greater effort for BHTs than BFTs (Table 6). CPUE for BHTs and BFTs of cutthroat trout ≥180 mm FL were 2.9 and 5.4 fish per 24-hour set (Table 6). BHTs were set at greater depths than BFTs, lowering the CPUE of BHTs. The deepest a BFT was set during both events was 6 m. The CPUE of BHTs set 6 m or less increased to 3.5 cutthroat trout ≥180 mm FL per set. CPUE for H&L was 3.8 cutthroat trout ≥180 mm FL per angler-hour (Table 6). Across all samples of fish ≥180 mm FL, mean FL was 219 (SE = 1.6) for BFTs, 229 (SE = 1.4) for BHTs, and 250 (SE = 1.7) for H&L.

The length composition of cutthroat trout varied temporally and by gear type (Figure 6 and 7). Kolmogorov–Smirnov tests of the distribution of lengths captured in each gear type indicate BFTs and BHTs captured similarly sized fish (D = 0.069, p = 0.34) during the marking event and that both BFTs (D = 0.550, p ~ 0.0) and BHTs (D = 0.540, p ~ 0.0) captured smaller fish than H&L sampling (Figure 7). During the recapture event the size distribution of fish captured in BFTs was smaller than those captured in BHTs (D = 0.20, p ~ 0) and the size distribution of fish captured in BHTs was smaller than fish sampled by H&L (D = 0.120, p = 0.01l; Figure 7). Even during the recapture event the intermediate-sized fish captured in BHTs were also commonly encountered by the other gear types (Figure 7).

[2] TL = 1.023(FL) developed by Carlander (1969).

Table 4.–Length composition and estimated abundance by 20 mm FL length class for cutthroat trout ≥180 mm FL in Neck Lake during 2018.

Length	Sample size	Proportion	SE	95% CI (proportion)	Abundance	SE
180 – 200	187	0.221	0.013	0.194 – 0.249	1,092	181
201 – 220	224	0.264	0.014	0.235 – 0.295	1,308	197
221 – 240	173	0.204	0.013	0.178 – 0.232	1,011	174
241 – 260	108	0.127	0.010	0.106 – 0.151	631	139
261 – 280	69	0.081	0.009	0.065 – 0.102	403	111
281 – 300	39	0.046	0.007	0.034 – 0.062	228	84
301 – 320	28	0.033	0.006	0.022 – 0.047	164	71
321 – 340	13	0.015	0.004	0.009 – 0.026	76	49
341 – 360	6	0.007	0.003	0.003 – 0.015	35	33
361 – 380	1	0.001	0.000	0.000 – 0.007	6	14
381 – 400	1	0.001	0.000	0.000 – 0.007	6	14
Total	849	1			4,959	361

Table 5.–Composition and estimated abundance for cutthroat trout ≥180 mm FL relative to the legal size limit in Neck Lake during 2018.

Length	Sample Size	Proportion	SE	95% CI (Proportion)	Abundance	SE
180 – 273	773	0.863	0.011	0.839 – 0.885	4,281	340
274 – 400	116	0.137	0.011	0.115 – 0.161	678	144
Total	849	1.000			4,959	361

Note: Legal size limit is 11 inches TL (279 mm) or ≥10.75 FL (273 mm).

Table 6.–Effort and catch of cutthroat trout (top panel) and catch per unit effort (lower panel) by gear type at Neck Lake during 2018.

	Effort			Catch					
				> 180 mm FL			< 180 mm FL		
Event	BHT	BFT	H&L	BHT	BFT	H&L	BHT	BFT	H&L
Marking	130	33	80	375	214	310	182	79	15
Recapture	129	34	89	377	150	337	63	52	35
Combined	259	67	169	752	364	647	245	131	50

	CPUE					
	> 180 mm FL			< 180 mm FL		
Event	BHT	BFT	H&L	BHT	BFT	H&L
Marking	2.9	6.5	4.3	1.4	2.4	0.2
Recapture	2.9	4.4	3.8	0.5	1.5	0.4
Combined	2.9	5.4	3.8	1.0	2.0	0.3

Note: Baited hoop trap = BHT, baited funnel trap = BFT, hook and line = H&L.

Note: BHT and BFT unit of effort is 24 h set and H&L unit of effort is angler-hour.

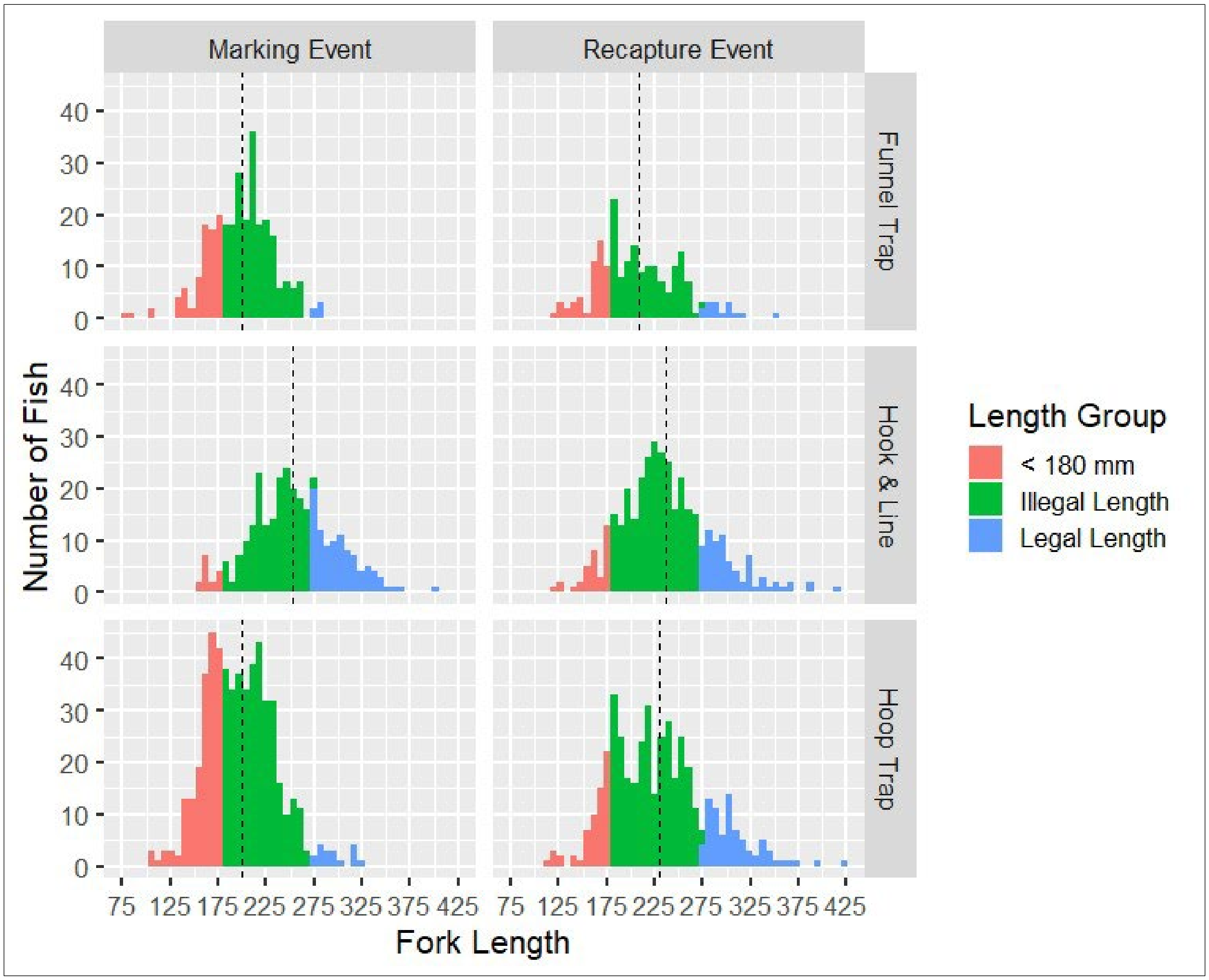

Figure 6.–Length distributions of cutthroat trout (mm FL) per event by gear type in Neck Lake during 2018.

Note: Mean length is marked by the vertical hash mark line; legal length is 11 inches TL or 273 mm FL, and illegal length is <11 inches TL or 273 mm FL.

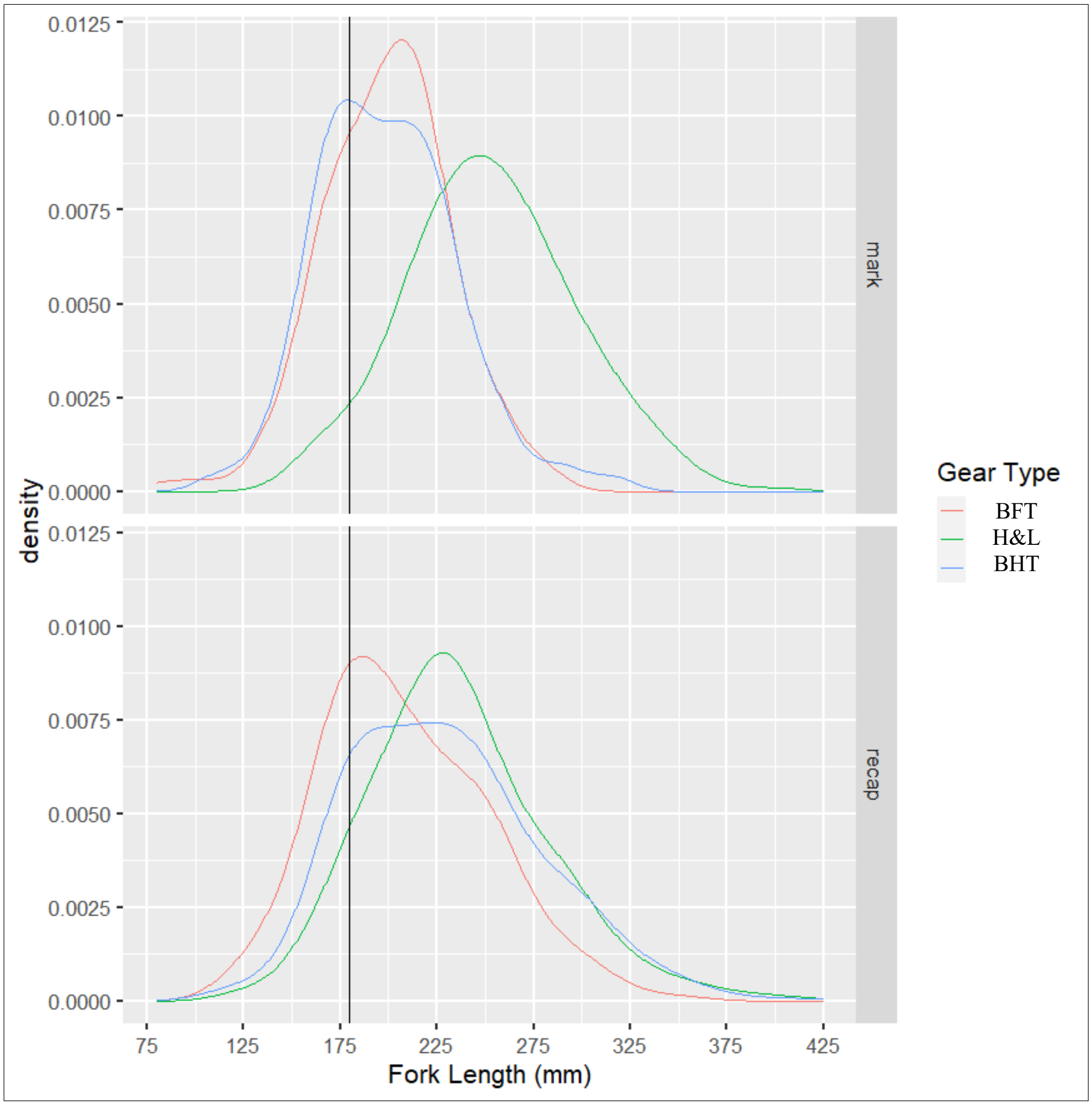

Figure 7.–Length composition in mm of cutthroat trout by gear type and sampling event in Neck Lake during 2018.

Note: Baited hoop trap = BHT, baited funnel trap = BFT, hook and line = H&L.

Other species captured during the study included coho salmon smolt, Dolly Varden, kokanee, sculpin, and stickleback. Coho salmon smolt were caught in all gear types; however, the number captured was only recorded for the traps because very few were caught with H&L. A total of 1,625 coho salmon smolt were captured and the majority were caught during the marking event (1,412) as smolt released from net pens in early May that emigrated from the lake (Table 7). A total of 1,325 Dolly Varden were captured during both events with all but one caught in traps (Table 7). The majority of Dolly Varden were caught in traps set at depths between 6 and 15 m (Figure 8). A total of 47 kokanee were captured with the majority caught in BHTs (Table 7). A total of 323 sculpin and 1 threespine stickleback were captured in traps.

Table 7.–Effort and catch of Dolly Varden, coho salmon smolt and kokanee captured by gear type and by event at Neck Lake during 2018.

	Effort			Catch								
				Dolly Varden			Coho salmon smolt			Kokanee		
Event	BHT	BFT	H&L	BHT	BFT	H&L	BHT	BFT	H&L	BHT	BFT	H&L
Marking	130	33	80	557	293	1	1,107	305	ND	3	0	0
Recapture	129	34	89	669	21	0	121	92	ND	38	1	5
Combined	259	67	169	1,226	314	1	1,228	397	ND	41	1	5

Note: Baited hoop trap = BHT, baited funnel trap = BFT, hook and line = H&L. BHT and BFT unit of effort is 24-hour set, and H&L unit of effort is angler-hour.

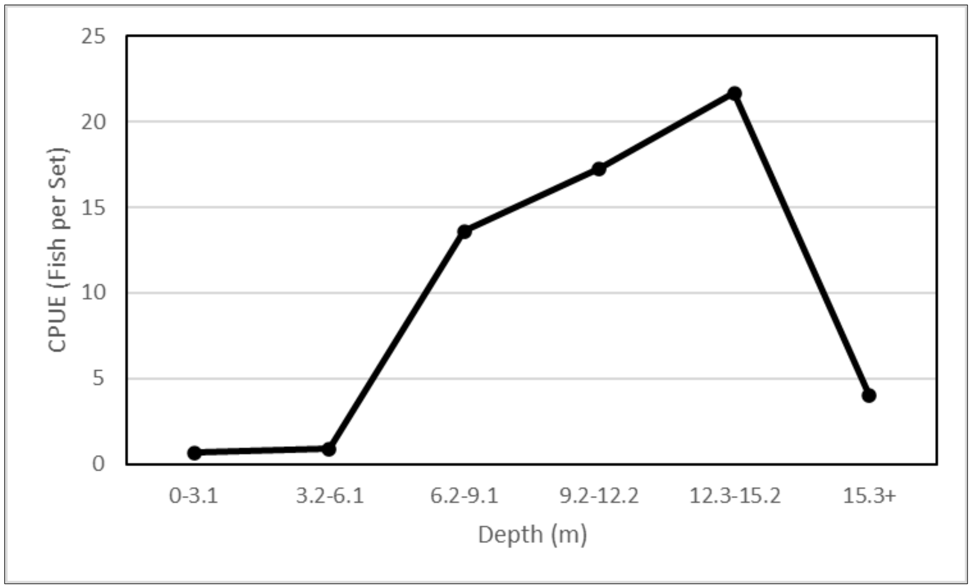

Figure 8.–Dolly Varden CPUE by depth in Neck Lake during 2018.

Rapid Stock Assessment Evaluation

Data generated from all possible 1- to 8-day combinations of days sampled during the marking event were used to calculate the proportion of the cutthroat trout population that was available for harvest (Figure 9). Even when estimates were based on small, geographically concentrated datasets (e.g., 1 day per section samples), the point estimate varied over a narrow range (80–94%), although the point estimate was often (7 of 9 estimates) outside of the 95% CI from the full dataset. When 4-day sample combinations were used the range of point estimates narrowed (82–91%) and fewer point estimates were outside of the 95% CI from the full dataset (26 of 126 estimates).

During 2018 hoop traps were used more often than funnel traps (~4 hoop traps per single funnel trap), although funnel traps captured more fish per unit of effort. Catch rates for the 2018 study suggest mark–recapture abundance estimates of similar accuracy could be produced in fewer days if the ratio of hoop traps to funnel traps were reversed, or if funnel traps were used exclusively (Table 8).

Table 8.–Expected sample sizes and accuracy (RP) of the resulting mark–recapture abundance estimate with various gear type configurations and sampling days for cutthroat trout in Neck Lake during 2018.

	4 BHT per BFT		4 BFT per BHT		BFT Only	
Days	*n*	RP	*n*	RP	*n*	RP
3	588	0.59	764	0.39	822	0.35
4	784	0.38	1,018	0.26	1,096	0.24
5	979	0.28	1,273	0.20	1,371	0.18
6	1,175	0.22	1,527	0.16	1,645	0.14
7	13,710	0.18	1,782	0.13	1,919	0.12
8	1,567	0.15	2,036	0.11	2,193	0.10

Note: BHT = baited hoop trap and BFT = baited funnel trap; *n* is the number sampled and RP = relative precision.

Note: The use of 4 BHT per BFT was the 2018 configuration.

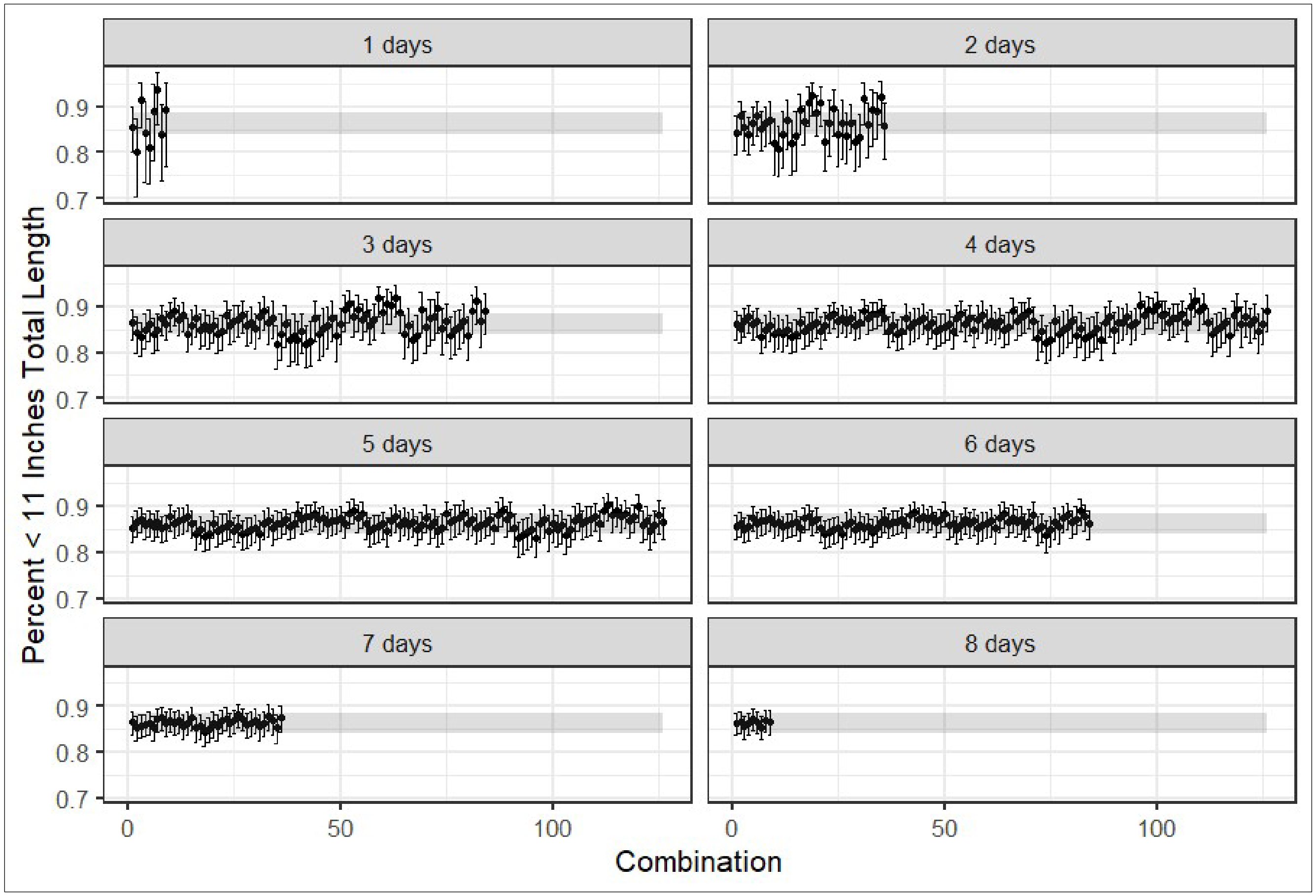

Figure 9.–Percent of cutthroat trout below the legal size limit and 95% CI for every possible combination of days sampled during the marking event in Neck Lake during 2018.

Note: The shaded area shows the 95% CI from the full dataset.

Note: Legal size limit (TL) is 11 inches (279 mm) or 10.75 inches FL (273 mm).

DISCUSSION

ABUNDANCE AND LENGTH ESTIMATES

The sampling design for this study was very similar to that of 1998, except for an additional gear type and more time between marking (May) and recapture (July) events. The longer hiatus of 4 weeks between events during the 2018 study did allow for growth between events, as indicated by a larger mean length of marked fish captured during the recapture event. Growth was not detected during the 1998 study with 8 days between events (Harding, Chadwick, and Freeman 1999). The majority of annual growth for salmonids occurs during the summer months and a large food source of coho salmon smolt was available during the marking event. Growth between marking and recapture events has been documented in rainbow trout mark–recapture studies. Growth of 9.5 mm was documented during a 6-week hiatus between sampling events on the Gulkana River and the marking event occurred when a large food source of eggs from spawning salmon was available (Schwanke and Taras 2009).

It had been 20 years since coho salmon rearing commenced and the cutthroat trout population in Neck Lake was last examined. Sampling goals required to estimate abundance and length composition for desired precision criteria were exceeded in both studies with only minor differences in sampling design indicating that the studies are comparable. The 2018 study suggests that coho salmon rearing in Neck Lake has a positive effect on the cutthroat trout population as indicated by a larger population of larger fish. The mean length of unique cutthroat trout ≥180 mm FL was larger in May 2018 (230 mm, SE = 1.3) than May 1998 (219 mm, SE = 0.9). Length compositions of fish captured in 2018 and 1998 also indicated larger fish in 2018 (Figure 5). In addition to a larger size of fish, the abundance of cutthroat trout ≥180 mm FL estimated in late May 2018 was 1,808 fish greater than estimated in late May 1998.

The shift to a larger population and larger fish may be a result of 20 years of coho salmon rearing in Neck Lake. Coho salmon fry are raised in net pens for much of the year, and commercial feed that filters through the net pens may provide supplemental food for cutthroat trout. Feed and fish waste from freshwater net pen aquaculture operations can have diverse effects on lakes including increased primary productivity, changes in algal community composition, and bottom-up enhancement of fisheries (out et al. 2017). In addition, coho salmon smolt are a food source for cutthroat trout when released into the lake each May. Approximately 1.7 million coho salmon smolt are released in the lake each May, and it was common for captured cutthroat trout to have coho salmon smolt in their stomachs, as indicated by coho salmon smolt tails protruding from their throats.

The estimated length composition of cutthroat trout ≥180 mm FL in Neck Lake during May indicates that 14% of fish were available for harvest with the 11-inch TL or 273 mm FL minimum size limit. In 1998, approximately 7% of fish exceeded the 11-inch size limit. The 11-inch minimum size limit is based on length at maturity data for Southeast Alaska cutthroat trout stocks and ensures that most cutthroat trout in a population can spawn at least once before being subjected to harvest (Harding 2013).

CATCH AND GEAR ANALYSIS

Catch of cutthroat trout in 2018 was higher at greater depths during the recapture event than the marking event (Figure 4). During the marking event in May the highest catch for traps occurred at depths less than 3.1 m. In contrast, the highest catch during the recapture event in July took place at depths between 3.4 and 9 m (Figure 4). During the recapture event cutthroat trout were observed milling around and in traps in less than 3 m of water during the day they were set, but these traps had a lower catch than in May (Figure 4). This suggests that fish were exiting traps during the 24-hour set time. Surface water temperatures averaged 12.4°C during the marking event in May and 19.1°C during the recapture event in July, and shallow sets during July may have been in water too warm for cutthroat trout to tolerate for long periods of time. Although catch did not significantly differ between events, previous studies have shown that the catch of baited traps declines as summer progresses (Harding et al. 2009).

The CPUE of BFTs was higher than BHTs, even when fished at similar depths. The main differences between the design of the traps are that BFTs have tunnel openings on both ends and smaller openings. The 2 entrances for BFTs may account for the higher CPUE. The smaller trap openings on BFTs suggest they might capture smaller fish than BHTs, although support for that hypothesis by our data is mixed. During the marking event the size distribution of fish caught in BFTs and BHTs was similar, although BHTs did capture larger fish during the recapture event. The largest fish captured in a BFT was 350 mm FL, compared to 425 mm FL for a BHT (Figure 7). The difference in size of fish captured could be attributed to a 2.6 cm smaller opening for BFTs, which likely excludes larger fish.

The use of 3 gear types allowed for the capture of a broad size range of fish. The mean size of cutthroat trout ≥180 mm FL captured with H&L was ~20 mm larger than BHTs. The ability to sample the larger fish in a population provided population data that may be missed if only traps that select for smaller fish are used to sample a lake. Field observations from this study highlighted issues with H&L sampling, mainly a difference in angler proficiency. H&L sampling during this study consisted of 2 boats with 1 to 2 anglers per boat sampling in the same section. CPUE varied greatly between the boats. During the recapture event CPUE for each boat was 6.28 and 2.22 cutthroat trout ≥180 mm FL per hour. This difference was due to angler proficiency and highlights the importance of having proficient anglers when incorporating H&L into population studies.

A comparison of CPUE between the traps and H&L was difficult due to duration of trap sets (~24 hours). It has been common practice in previous cutthroat trout studies in SEAK to set traps overnight with ~24-hour soak times. However, if traps were checked more often, such as multiple times per day, CPUE could be estimated by the hour instead of set, allowing for comparable estimates of CPUE between traps and H&L. If traps were checked and reset more frequently throughout a sample day, it is possible that more fish may be caught. Fish would be less likely to exit traps during a shorter set duration and resetting the trap should negate effects of fish that had not yet encountered the trap before it was checked.

RAPID STOCK ASSESSMENT

An important metric of stock status with respect to fisheries management is the percentage of fish protected from harvest. This proportion was well estimated in 2018 (0.863, 95% CI 0.839–0.885) but could also be well estimated with much smaller sample sizes. Binomial sampling theory predicts a sample of 188 (about 2 days for Neck Lake in 2018) would be sufficient to estimate this proportion to within ~7% in the worst-case scenario[3]. On larger lakes it may be logistically difficult to obtain a spatially representative sample on very short trips, although this difficulty is reflected

[3] With respect to estimating precision, the worst-case scenario occurs when the proportion equals 50%.

in Figure 9, where the 2-day subsamples represent a hypothetical project and sampling occurred in less than half of the sampling areas used in 2018. A single hypothetical trip of 4 days subsampled from 2018 Neck Lake data would obtain more than enough samples and allow for sampling effort to be well distributed with respect to available fish habitat. Figure 9 contains many spatially non-representative samples due to the 2018 sampling design (one section fished per day for traps), and a spatially representative sample could be drawn in less time under a new sampling design. These findings are likely applicable to many cutthroat trout populations in SEAK. Neck Lake is a comparatively large lake with large variability in fish size, so sampling smaller lakes with populations of uniform size fish should also be well estimated. The results of the reduced dataset analysis indicate that a rapid assessment strategy that focuses on legal length percentage or length composition estimates may provide useful information for assessing cutthroat trout populations and their management.

Catch per trap set was extremely variable, with ranges of 0 to 31 cutthroat trout ≥180 mm FL caught in 24-hour sets. Many factors contribute to this variability including general set location, set duration, depth, water temperature, bait scent dispersion, trap orientation, density of fish in the general area, and movement of fish in and out of traps. Although CPUE has been used as an index of abundance in situations where populations were monitored with identical methods for several successive years, the concept is poorly suited for a rapid assessment strategy.

If estimates of abundance were desired, 2 sampling trips would be required, although the length of each trip could be reduced. The easiest way to conduct mark–recapture experiments in less time would be to increase the CPUE of the sampling program. Results from Neck Lake suggest this objective could be achievable. In 2018, we achieved ~15% relative precision with two 9-day sampling trips and because ~4 hoop traps were used for every one funnel trap. Because the CPUE for funnel traps was higher we estimated a similar precision could have been achieved in only 6 days had we exclusively used funnel traps (Table 8). A rapid assessment strategy may also require managers to accept reduced precision to be efficient. Our results suggest ~25% relative precision would have been achievable with 4 days of sampling effort per event if funnel traps were exclusively used.

Using multiple gear types in a mark–recapture study offers insurance against biased sampling, but 2018 results suggest hoop traps may be expendable. Both funnel and hoop traps captured smaller fish than hook and line gear with hoop trap catches similar in size to funnel traps during the marking event and intermediate sizes captured with funnel traps and hook and line gear during the recapture event (Figure 7).

Another way to increase CPUE of the sampling program may involve checking traps multiple times per day so that captured fish do not have time to escape before sampling. An examination of trap retention over time and estimation of an optimal soak time for BFTs and BHTs could provide information regarding more effective set durations.

Although days of sampling effort is a convenient metric to compare studies of Neck Lake cutthroat trout, we need to account for lake area when comparing sampling programs among lakes. Neck Lake is 32 square kilometers and in 2018 we deployed 164 trap-days of effort per sampling event, or ~5.1 trap-days per square kilometer. If 73 trap-days were deployed in 4 sampling days, sampling density would be reduced to 2.3 trap-days per square kilometer and further efficiencies might be possible. In 2018, the number of traps deployed per day ranged from 9 to 30, based on the surface area of the lake section sampled. The calculations above assume an average deployment of 18 traps per day, although a rapid assessment project would likely benefit by maximizing the number of traps deployed each day.

Based on this initial study, the authors suggest that a rapid assessment study would entail an intensive sampling strategy of checking traps at set intervals throughout the day with H&L sampling between checks. The patterns of larger CPUE of BFTs, with similar size distribution of the catch, relative to BHTs should also be verified in projects. This strategy should result in a large enough sample size to estimate length composition. If an abundance estimate is desired, 2 trips would be required with expected precision dictated by trip length and CPUE of the sampling program.

ACKNOWLEGEMENTS

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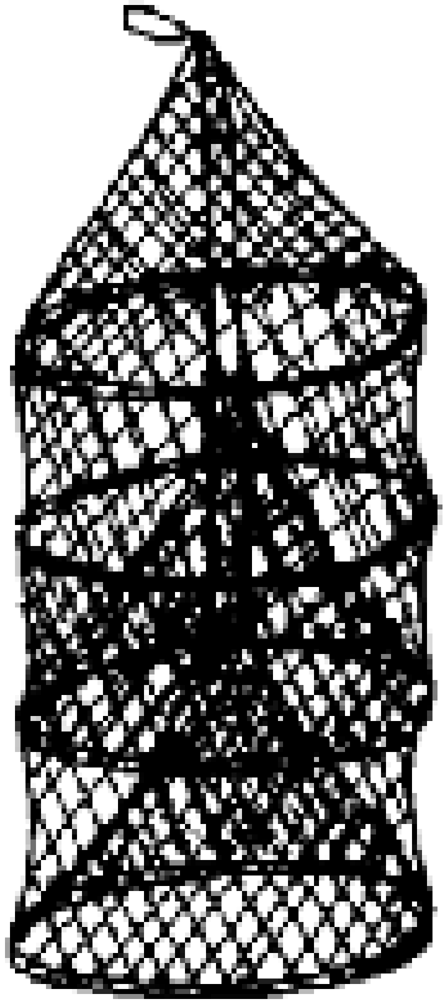
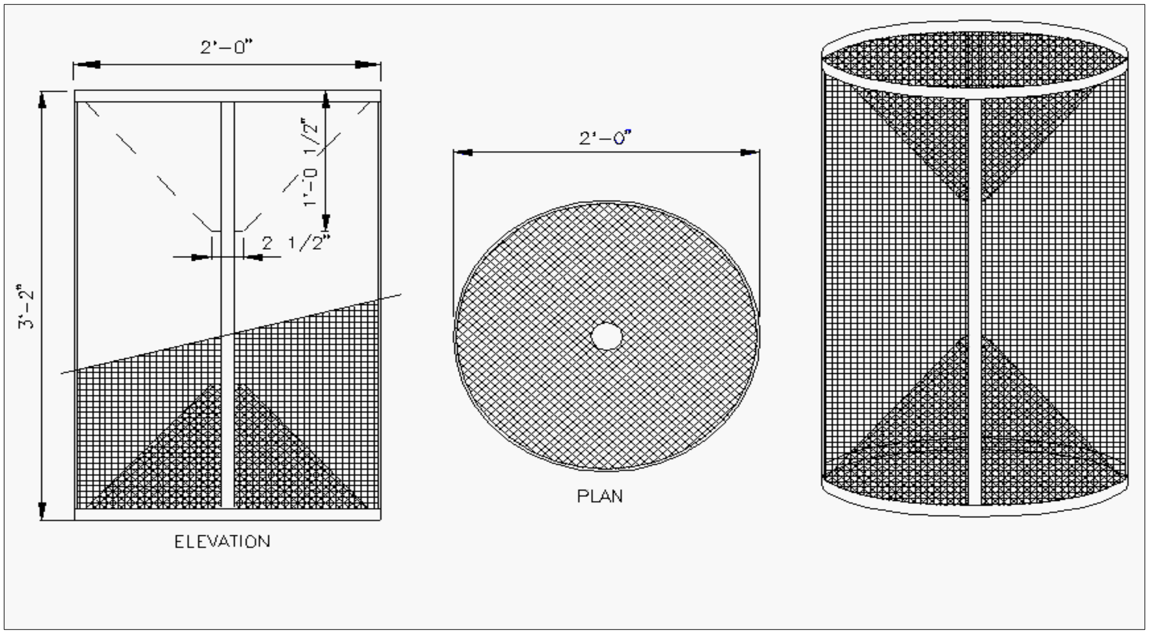
APPENDIX A: PROJECT GEAR TYPES

Appendix A1.–Baited hoop trap design (BHT).



Appendix A2.–Large baited funnel trap design (BFT).



APPENDIX B: PROJECT BIOMETRICS

Appendix B1.–Detection and mitigation of selective sampling during a 2-event mark–recapture experiment.

Size- and sex-selective sampling may cause bias in 2-event mark–recapture estimates of abundance and size and sex composition. Kolmogorov–Smirnov (KS) 2-sample tests are used to detect size-selective sampling and contingency table analyses (Chi-square tests of independence) are used to detect evidence of sex-selective sampling.

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

DEFINITIONS

M = Lengths or sex of fish marked in the first event
C = Lengths or sex of fish inspected for marks in the second event
R = Lengths or sex of fish marked in the first event and recaptured in the second event

SIZE-SELECTIVE SAMPLING: KS TESTS

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

KS Test 1 C vs R Used to detect size selectivity during the marking event.
H_o: Length distributions of populations associated with C and R are equal

KS Test 2 M vs R Used to detect size selectivity during the recapture event.
H_o: Length distributions of populations associated with M and R are equal

KS Test 3 M vs C Used to corroborate the results of the first two tests.
H_o: Length distributions of populations associated with M and C are equal

SEX-SELECTIVE SAMPLING: CHI-SQUARE TESTS

Three contingency table analyses (χ^2-tests on 2x2 tables) are used to test for sex-selective sampling.

χ^2 Test 1 C vs R Used to detect sex selectivity during the marking event.
H_o: Sex is independent of the C - R classification

χ^2 Test 2 M vs R Used to detect sex selectivity during the recapture event.
H_o: Sex is independent of the M - R classification

χ^2 Test 3 M vs C Used to corroborate the results of the first two tests.
H_o: Sex is independent of the M - C classification

The following table presents possible results of selectivity testing, their interpretation, and prescribed action.

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

COMPOSITION ESTIMATION FOR STRATIFIED ESTIMATES

An estimate of the proportion of the population in the kth size or sex category for stratified data with I strata is calculated as follows:

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

with variance estimated as

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

where

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

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

$\hat{N}$ = estimated total abundance

$$= \sum_{i=I}^{I} \hat{N}_i \tag{3}$$

APPENDIX C: ARCHIVED DATA

Appendix C1.–Archived data files used for analysis of this project.

File Name	Description
Neck 2018 AWL Data.xlsx	Excel spreadsheet with cutthroat AWL, catch, and Dolly Varden data for Neck Lake in 2018.
1998 Neck AWL Data.xlsx	Excel spreadsheet with cutthroat AWL, catch, and Dolly Varden data for Neck Lake from 1998.
Neck CPUE Data 2018.xlsx	Excel spreadsheet with trap CPUE data for Neck Lake in 2018.
NeckCTanalysis.Rproj	R code used in the estimate of abundance, length composition, and an examination of simplified long-term monitoring techniques for Neck Lake cutthroat trout.