Fishery Data Series No. 08-47

Abundance and Length Composition of Cutthroat Trout in Turner Lake, Southeast Alaska, 2005, and Summary of 2004 Field Studies in Turner Lake

by

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October 2008

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

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Measures (fisheries)

fork length	FL
mideye to fork	MEF
mideye to tail fork	METF
standard length	SL
total length	TL

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

FISHERY DATA SERIES NO. 08-47

ABUNDANCE AND LENGTH COMPOSITION OF CUTTHROAT TROUT IN TURNER LAKE, SOUTHEAST ALASKA, 2005, AND SUMMARY OF 2004 FIELD STUDIES IN TURNER LAKE

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ABSTRACT

Two-event mark–recapture studies were planned for Turner Lake in 2004 and 2005 to estimate the abundance and length composition of cutthroat trout *Oncorhynchus clarkii*. Fish were captured with hook-and-line gear and large traps, marked with PIT tags and given an adipose finclip as a secondary mark. The second event in 2004 was cancelled due to warm water temperatures and the concern over potential handling mortality. The estimated abundance of cutthroat trout ≥180 mm FL in 2005 was 1,795 fish (SE = 401; 90% CI = 1,292–2,486). Most of the cutthroat trout ≥180 mm FL in Turner Lake were estimated to be ≤299 mm FL ($\hat{p}_{2004}$ = 0.61, SE = 0.03; $\hat{p}_{2005}$ = 0.71, SE = 0.02), while only a small proportion of the population was estimated to be ≥400 mm FL ($\hat{p}_{2004}$ = 0.05, SE = 0.01; $\hat{p}_{2005}$ = 0.03, SE = 0.01). The abundance and length composition estimates are similar to average estimates from studies conducted in 1994–2003. In future mark–recapture projects, we suggest that researchers sample the entire lake simultaneously, as done in 2005, to allow for greater flexibility in the event of warm water temperatures or low recapture rates.

Key words: Turner Lake, cutthroat trout, *Oncorhynchus clarkii*, mark–recapture, length, abundance.

INTRODUCTON

The Alaska Department of Fish and Game (ADF&G) periodically conducts stock assessments of cutthroat trout *Oncorhynchus clarkii* populations in Southeast Alaska (see Bangs and Harding *In press*). While most lakes in Southeast Alaska have a 279 mm TL (11 in) minimum size limit for cutthroat trout (Harding and Jones 2004), Turner Lake is closed to the retention of cutthroat trout in the sport fishery. Turner Lake was the site of cutthroat trout mark–recapture studies from 1994–2003 (see Harding et al. *In prep*). During this period, abundance estimates were stable with no apparent increasing or decreasing trend in abundance. The average annual abundance estimate was 1,902 fish (SD = 352). The estimated number of cutthroat trout caught at Turner Lake between 1992 and 2002 ranged from 312 to 1,152 fish ($\bar{x}$ = 832, SD = 286; Appendix A1; Harding et al. 2005). Harding et al. (*In prep*) estimated the maximum sustainable yield of cutthroat trout during the sample period was 227 fish, or 12% of the population ≥180 mm FL. The goal of this assessment was to obtain estimates of abundance and length composition subsequent to the research conducted by Harding et al. (*In prep*).

OBJECTIVES

The study objectives in 2004 and 2005 were to:

1. Estimate the abundance of cutthroat trout ≥180 mm FL; and,
2. Estimate the length composition of cutthroat trout ≥180 mm FL.

METHODS

STUDY AREA

Turner Lake (Figure 1) is located in the upper Taku Inlet, 26 km east of Juneau. The lake is 14 km long, has a surface elevation just over 22 m, and a surface area of approximately 1,270 ha. The lake is very steep-sided except near the inlet streams and has a maximum depth of 215 m (Schmidt 1979). The lake outlet flows about 1,700 m to the Taku Inlet and is blocked to upstream fish passage by a barrier falls just below the lake. Two U.S. Forest Service recreational cabins are located at the lake, and the primary mode of transportation to the cabin is by float plane. Cutthroat trout and Dolly Varden *Salvelinus malma* are the primary species of fish available to anglers.

SAMPLING DESIGN AND FISH CAPTURE

This study was designed to estimate the abundance and length composition of cutthroat trout in Turner Lake by using mark–recapture methodology. Two events were planned in each of the 2 study years (2004 and 2005), however the second event in 2004 was cancelled due to warm water temperatures. The concern was that the warm water could lead to high levels of handling mortality (see Harding 1999). The sole event in 2004 was conducted between June 10 and June

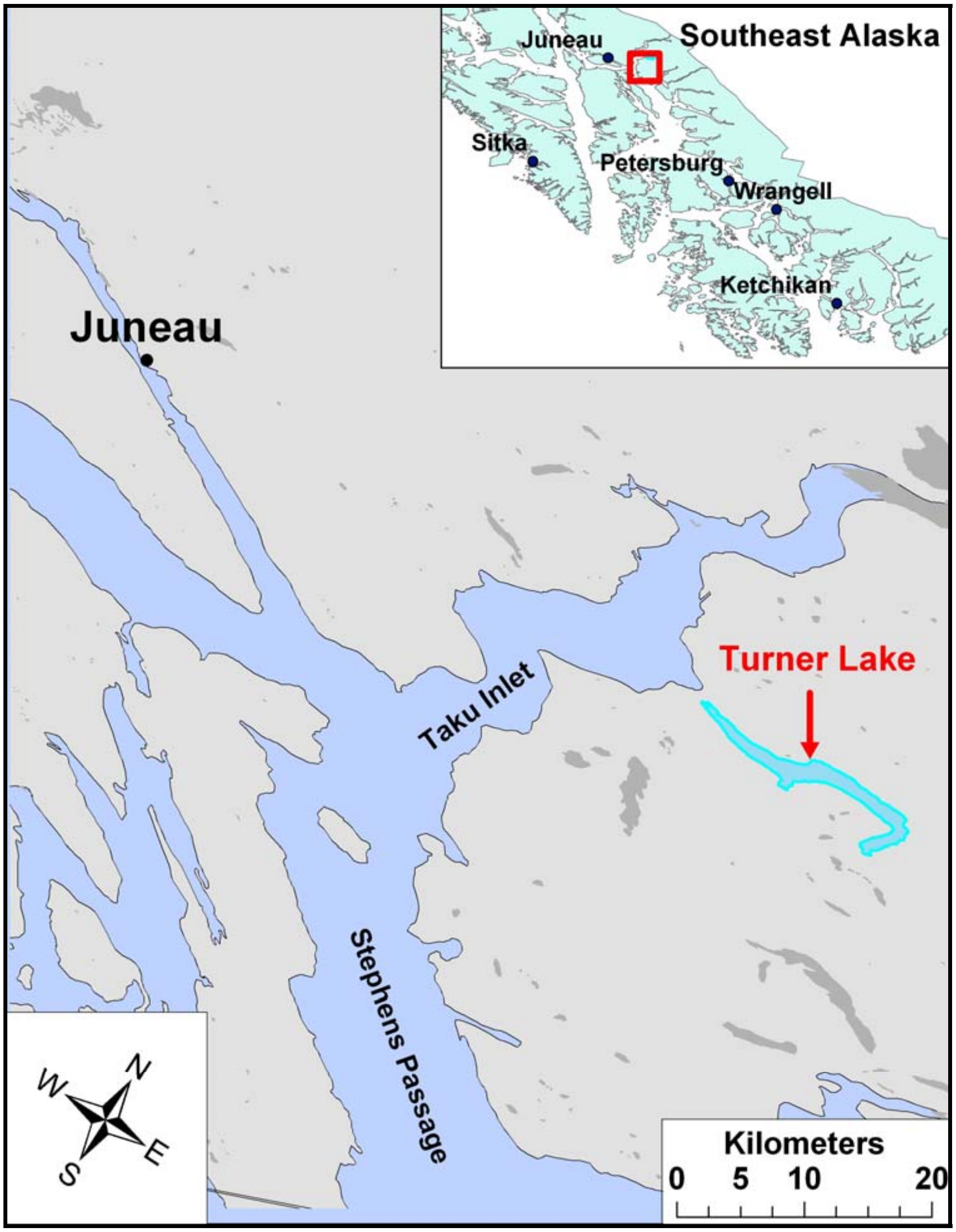

Figure 1.–Location of Turner Lake, near Juneau.

19. Sampling was conducted over 2 events in 2005; the first event (event 1) occurred from June 7 to 16 and the second event (event 2) occurred from June 22 to 30. The rationale for the timing of sampling events was to avoid spawning, which presumably occurred in April, and to avoid the warm water temperatures that are more common in late summer.

Cutthroat trout were captured by employing large traps ("LT", Figure 2 in Rosenkranz et al. 1999) and hook-and-line gear. Bait for the traps consisted of salmon eggs that had been disinfected in a povidone-iodine solution.

The lake was divided into 3 areas to facilitate consistent recording of trap locations and to aid in evaluation of assumptions during data analysis (Figure 2). During each sampling event, a total of 135 overnight trap sets were made across the lake (44 overnight sets in Area A, 35 overnight sets in Area B, and 56 overnight sets in Area C). In 2004, traps were systematically moved around the lake to achieve uniform coverage at depths ≤30 m.

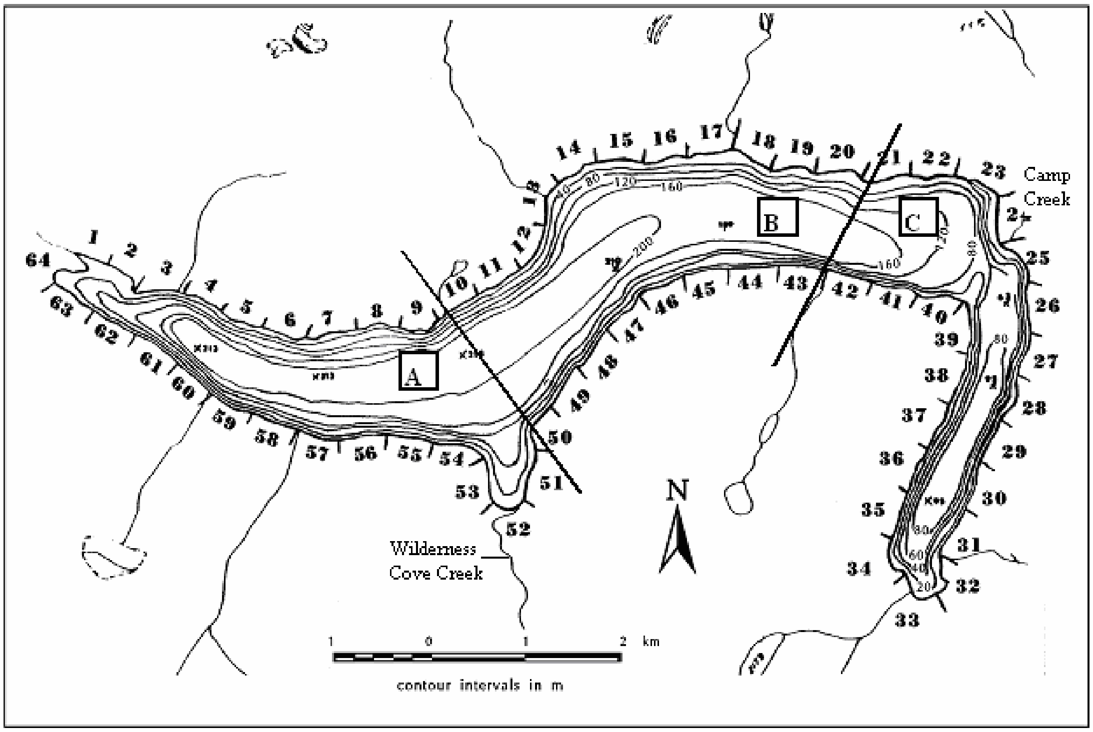

Figure 2.–Location of sampling areas in Turner Lake. The sixty-four shoreline sections were used to ensure uniform hook-and-line fishing effort around the lake margin. The three large lake areas (A, B, C) were used to evaluate study assumptions.

This approach was modified in 2005 such that traps were set in a uniform manner across the lake each day. Thus all areas of the lake (at depths ≤30 m) were sampled simultaneously in 2005, whereas trapping effort was systematically moved around the lake in 2004. Traps were set on the lake bottom and depths were measured with a fathometer or metered buoy line.

Hook-and-line fishing was conducted by casting small spinners in a manner such that all shoreline areas at depths ≤6 m were fished with similar effort. The shoreline was divided into 64 sections of equivalent length (Figure 2) to facilitate uniform hook-and-line fishing effort around the lake. A total of 46.3 hours of hook-and-line sampling effort was expended in 2004; a similar amount of effort (47.8 hours) was expended in the first event of 2005. Hook-and-line effort increased to 62.8 hours in the second event in 2005, however the proportion of effort expended in each shoreline section remained the same.

All cutthroat trout <180 mm FL were counted and released (i.e., not sampled). This minimum size threshold for sampling was selected to be consistent with previous cutthroat trout studies in Southeast Alaska (e.g., Lum and Taylor 2004). All cutthroat trout that were ≥180 mm FL were given an adipose finclip, measured from the tip of the snout to the fork of the tail (to the nearest mm FL), and were given a passive integrated transponder (PIT) tag. The tag was inserted just posterior to the cleithrum into the left side of the fish, at an angle approximately 20 degrees to the mid-line. Entrance wounds caused by tag insertion were sealed with a drop of cyanoacrylate glue. Previously captured fish (as indicated by the presence of a PIT tag or adipose finclip) were measured for length and the PIT tag number was recorded. For each fish captured, the date, time, gear type, lake area (A, B, C), and depth (for LT) were recorded.

The assumptions of the experiment were that:

1) the population was closed (cutthroat trout do not enter the population, via growth or immigration, or leave the population via death or emigration during the experiment);

2) all cutthroat trout had a similar probability of capture in the first or second event, or

marked and unmarked cutthroat trout mixed completely between events;

3) marking of cutthroat trout in the first event did not affect the probability of capture in the second event;

4) cutthroat trout did not lose (or gain) marks between events, and marks were recognized and reported during the second event.

The closure assumption (assumption 1) relied on the relatively short time (6 days) between the 2 sampling events. To evaluate the possibility of handling or tagging mortality (pertinent to assumptions 1, 2, 3), the first 10 fish sampled in each event were held in a LT for observation. After 4 to 6 hours, the status of the fish (e.g., whether they were alive, apparent condition) was ascertained to ensure that handling procedures were not detrimental.

The second assumption was evaluated with tests of consistency for the Petersen estimator (Appendix A2) and with Kolmogorov-Smirnov (K-S) tests for size-selective sampling (Appendix A3). We used the consistency tests to compare capture and recapture rates in each area of the lake. When all 3 of the null hypotheses outlined in Appendix A2 are rejected (α = 0.05), a stratified Peterson estimator (Darroch 1961; and Seber 1982, Chapter 11) is appropriate. Otherwise, when any of the 3 null hypotheses are accepted, a pooled Peterson estimator can be used. We relied on the protocol specified in Appendix A3 for conducting K-S tests to evaluate the potential for size-selective sampling as well as the effects of marking on catchability (assumption 3) and adjusted the analysis (if necessary) accordingly.

Assumption 4 was robust in this experiment, because all fish had a secondary mark (adipose finclip) 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.

DATA ANALYSIS

The abundance of cutthroat trout was estimated by using the Chapman modification of the Petersen estimator (Seber 1982):

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

where:

$\hat{N}$ = the estimated abundance of cutthroat trout ≥180 mm FL;

n_1 = number of cutthroat trout ≥180 mm FL marked in event 1;

n_2 = number of cutthroat trout ≥180 mm FL examined in event 2;

m_2 = number of marked cutthroat trout recaptured in event 2.

The standard error along with a 90% confidence interval about $\hat{N}$ were estimated by using a parametric bootstrap routine in Excel®, whereby I generated random variates (m_2) from the hypergeometric distribution based upon fixed values of n_1, n_2, and $\hat{N}$. For each of the generated m_2 values (B = 5,000 iterations), I used the modified Petersen estimator to generate a potential abundance estimate ($\hat{N}_k$). A 90% confidence interval about the mean was calculated using the 5th and 95th percentiles of the bootstrap distribution (Efron and Tibshirani 1993).

The variance of $\hat{N}$ was calculated by:

$$\text{var}[\hat{N}] = \sum_{k=1}^{B} (\hat{N}_k - \overline{N})^2 / (B - 1) \tag{2}$$

LENGTH COMPOSITION

Size selectivity in sampling was investigated according to the protocols in Appendix A3. The estimated fraction $\hat{p}_a$ of the fish in length group a (20 mm increments) was calculated as:

$$\hat{p}_a = \frac{n_a}{n} \tag{3}$$

where n is the number of fish measured for length and n_a is the number of fish in length group a. The estimated variance for $\hat{p}_a$ is

$$\hat{\text{var}}[\hat{p}_a] = \frac{\hat{p}_a(1 - \hat{p}_a)}{n - 1} \tag{4}$$

The abundance of length group a in the population ($\hat{N}_a$) was estimated by

$$\hat{N}_a = \hat{p}_a \hat{N} \tag{5}$$

where $\hat{N}$ is the estimated abundance of the mark–recapture experiment. From Goodman (1960), the variance of $\hat{N}_a$ is:

$$\hat{\text{var}}[\hat{N}_a] = \hat{\text{var}}(\hat{p}_a)\hat{N}^2 + \hat{\text{var}}(\hat{N})\hat{p}_a^2 - \hat{\text{var}}(\hat{p}_a)\hat{\text{var}}(\hat{N}) \tag{6}$$

RESULTS

2004

The weather in the latter half of June 2004 (when the recapture event was scheduled) was exceptionally warm, with air temperatures in Juneau exceeding record levels for 7 consecutive days. We were unable to accurately measure the surface water temperature but know it was >20° C, which was the maximum reading on our thermometers. After consulting with the project biometrician, we cancelled the second event due to concern over the potentially deleterious effects of handling and capturing fish in warm water (see Harding 1999). Consequently, we were unable to generate an abundance estimate in 2004.

In the sole event of 2004, we captured a total of 242 unique cutthroat trout ≥180 mm.

Length Composition (2004)

Fork lengths of cutthroat trout captured in 2004 ranged from 180 to 546 mm (Table 1). Most of the cutthroat trout ≥180 mm FL in the population were estimated to be ≤299 mm FL ($\hat{p}_{180-299}$ = 0.61, SE = 0.03). A smaller proportion were 300–399 mm FL ($\hat{p}_{300-399}$ = 0.34, SE = 0.03), and very few fish were ≥400 mm FL ($\hat{p}_{400+}$ = 0.05, SE = 0.01; Table 1).

2005

Abundance in 2005 was estimated at 1,795 cutthroat trout ≥180 mm FL (SE = 401; 90% CI = 1,292–2,486; n_1 = 148, n_2 = 216, m_2 = 17). A total of 347 unique cutthroat trout ≥180 mm were captured in this experiment; no tag loss was observed. A length measurement was either not taken or not recorded from 1 cutthroat trout in the second event. This fish was included in the spatial heterogeneity tests and the abundance estimation procedures, but was excluded from the length composition analysis and K-S tests as it could not be assigned to a length group.

Kolmogorov-Smirnov Tests (2005)

Stratification by length was deemed unnecessary as the K-S tests did not indicate any significant differences in length composition between fish captured in the first event and fish recaptured in the second event (D = 0.13, P = 0.95, Figure 3) and between fish captured in the second event versus those recaptured in the second event (D = 0.17, P = 0.71, Figure 4).

Because the number of recaptures was small (i.e., <30), an additional K-S test was conducted whereby the length composition of fish captured in the first event was compared to fish captured in the second event (see Appendix A3) and no

Table 1.–Length composition for cutthroat trout ≥180 mm FL in Turner Lake in 2004. Number sampled (n_a), proportion ($\hat{p}_a$), and standard error (SE) are shown for each 20-mm length class.

Length a, mm FL	n_a	$\hat{p}_a$	SE($\hat{p}_a$)
180–199	25	0.103	0.020
200–219	28	0.116	0.021
220–239	36	0.149	0.023
240–259	20	0.083	0.018
260–279	27	0.112	0.020
280–299	12	0.050	0.014
300–319	23	0.095	0.019
320–339	27	0.112	0.020
340–359	11	0.045	0.013
360–379	13	0.054	0.015
380–399	9	0.037	0.012
400–419	2	0.008	0.006
≥420	9	0.037	0.037
Total	242		

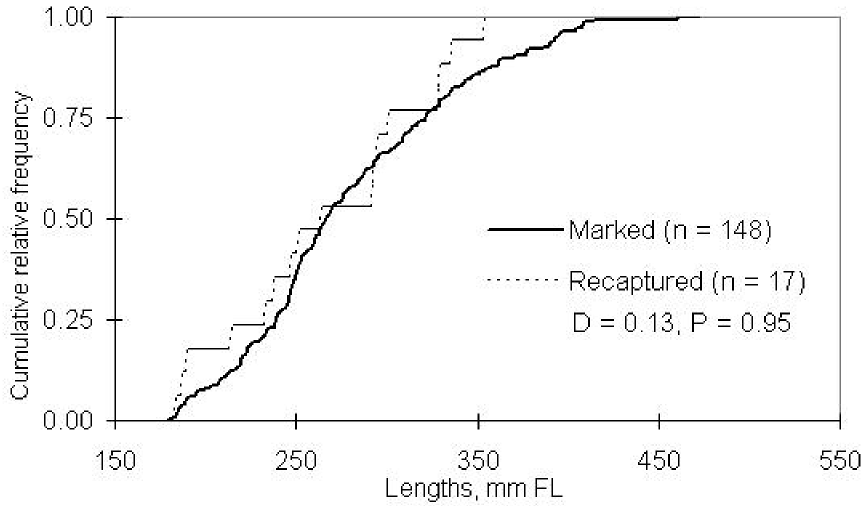

Figure 3.–Cumulative relative frequency of cutthroat trout ≥180 mm FL marked in the first event and recaptured in the second event in 2005.

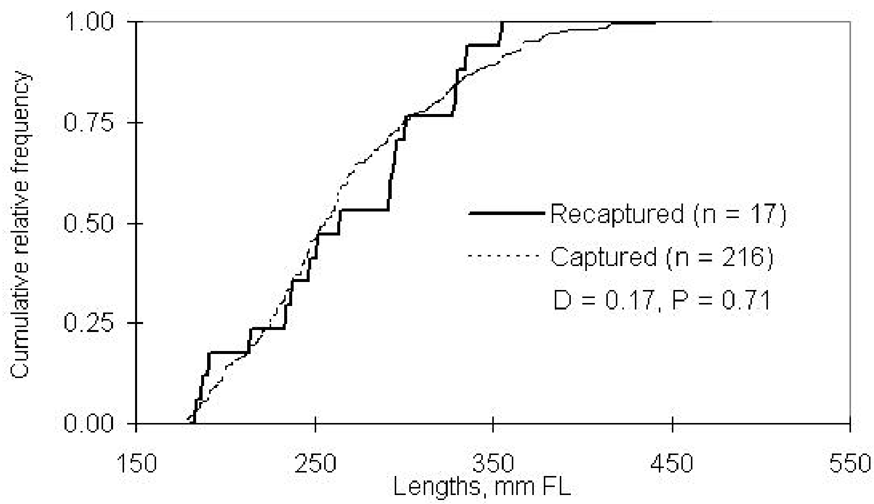

Figure 4.–Cumulative relative frequency of cutthroat trout ≥180 mm FL captured in the second event versus those recaptured in the second event in 2005.

significant difference was detected (D = 0.11, P = 0.18, Figure 5). These results indicated that length composition could be estimated using data from both sampling events (Appendix A3).

Spatial Heterogeneity Tests (2005)

Heterogeneity in capture probabilities due to spatial factors was not considered to be a significant issue in the experiment, as there was no evidence of unequal probability of capture in the first event ($\chi^2 = 0.20$, df = 2, P = 0.91; Table 2; Appendix A2). We were unable to evaluate whether there was an equal probability of capture in the second event or whether mixing was complete because our sample sizes were insufficient for chi-square tests (i.e., the expected frequency was <5 in more than 20% of cells). However, as the modified Petersen model only requires equal probability of capture in the first event *or* second event *or* complete mixing (i.e., only one of these conditions needs to be met), these results indicate that use of this estimator was appropriate.

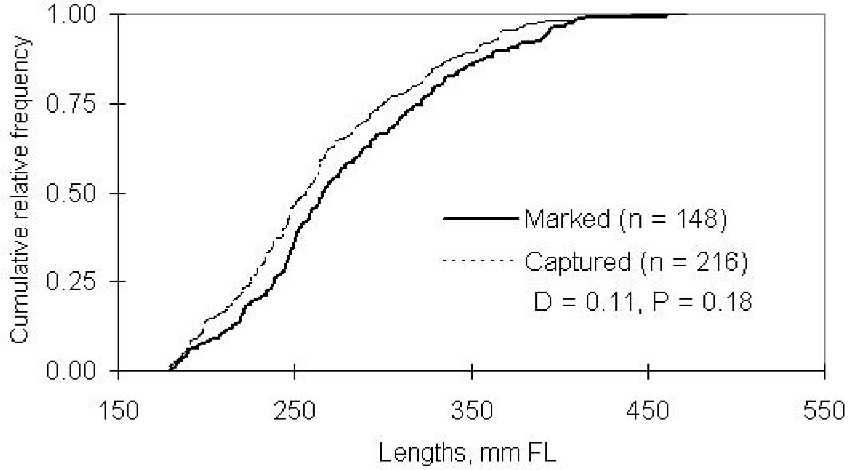

Figure 5.–Cumulative relative frequency of cutthroat trout ≥180 mm FL captured in the first event versus those captured in the second event in 2005.

Length Composition (2005)

Fork lengths of measured cutthroat trout captured in 2005 ranged from 180 to 472 mm (Table 3). Most of the cutthroat trout ≥180 mm FL in the population were estimated to be ≤299 mm FL ($\hat{p}_{180-299}$ = 0.71, SE = 0.02). A smaller proportion were 300 – 399 mm FL ($\hat{p}_{300-399}$ = 0.26, SE = 0.02), and very few fish were ≥400 mm FL ($\hat{p}_{400+}$ = 0.03, SE = 0.01; Table 3).

Table 2.–Summary of cutthroat trout ≥180 mm FL catches in each of the three sampling areas (A, B, C) at Turner Lake, 2005. Summary statistics include the number of fish marked in each area (n_i) in the first event and the number of unmarked fish captured in each area (u_j) in the second event.

		Recovery area		
Marking area	n_i	A	B	C
A	39	3	1	1
B	67	3	3	1
C	42	0	0	5
	u_j	64	42	93

DISCUSSION

Abundance and Length Composition

The 2005 abundance estimate of 1,795 cutthroat trout ≥180mm FL is consistent with abundance estimates from 1994 to 2003, which ranged from 1,539 fish in 2002 to 2,791 fish in 2001 with no apparent increasing or decreasing trend (Harding et al. *In prep*). Length composition estimates from this study (Tables 1 and 3) are also similar to estimates from 1994 to 2003 (Harding et al. *In prep*). As discussed by Harding et al. (*In prep*), Turner Lake was once known for its yield of trophy-size fish (i.e., ≥508 mm or 20 in TL), however we did not catch any fish this size in 2005. Harding et al. (*In prep*) provides additional discussion as to the scarcity of trophy-sized cutthroat trout in Turner Lake; Bangs (2007) describes a similar situation at Patching Lake, where trophy-sized cutthroat trout seem to have largely disappeared.

Sampling Design

After the failure to obtain an abundance estimate in 2004, we slightly modified the sampling design

Table 3.–Length composition and estimated abundance at length for cutthroat trout ≥180 mm FL in Turner Lake in 2005. Number sampled (n_a; events 1 and 2 combined), proportion ($\hat{p}_a$), abundance ($\hat{N}_a$), and standard error (SE) are shown for each 20-mm length class.

Length a, mm FL	n_a	$\hat{p}_a$	SE($\hat{p}_a$)	$\hat{N}_a$	SE($\hat{N}_a$)
180–199	40	0.110	0.016	198	53
200–219	26	0.072	0.014	129	37
220–239	52	0.143	0.018	257	66
240–259	61	0.168	0.020	302	76
260–279	48	0.132	0.018	237	61
280–299	30	0.083	0.014	148	42
300–319	25	0.069	0.013	124	36
320–339	28	0.077	0.014	138	39
340–359	17	0.047	0.011	84	27
360–379	16	0.044	0.011	79	26
380–399	10	0.028	0.009	49	19
400–419	7	0.019	0.007	35	15
≥420	3	0.008	0.005	15	9
Total	363[a]		$\hat{N}$ =	1,795	

[a] 148 (n_1) + 216 (n_2) – 1 fish with no length recorded = 363; includes 17 (m_2) recaptures.

in 2005 to allow for greater flexibility in sampling. Whereas in 2004 we systematically moved the traps around the lake over the course of the event, in 2005 we distributed traps uniformly across the lake (at depths ≤30 m) such that all areas of the lake were sampled simultaneously. This approach is more flexible in the event of warm water temperatures in that the trip could be cut short (say after 5 days) and an abundance estimate could likely be generated, albeit with reduced precision compared to a full event. Similarly this approach is amenable to incremental increases in sampling effort (e.g., additional days of trapping) if catch rates or recapture rates are unsatisfactory. Another advantage of this design is that it is robust to short-term changes in the distribution of fish, which might occur in response to changes in water temperature, food availability, or other unknown factors.

The modified sampling approach, which requires more fuel due to the increased spacing of sampling gear, was facilitated by the purchase of a four-stroke outboard motor, which used approximately 70% less fuel than our older two-stroke motor. This increase in efficiency is significant as all fuel must be flown into camp via a chartered fixed-wing aircraft and is therefore quite expensive.

HANDLING MORTALITY

Although the sport fishing regulations for Turner Lake are conservative (i.e., catch and release only), the potential for significant levels of incidental catch-and-release mortality should not be ignored, particularly when water temperatures are warm (e.g., >16°C). Titus and Vanicek (1988) found that hooking mortality of lure-caught cutthroat trout was <1.5% when water temperatures were between 5.5°C and 15.5°C, but increased to nearly 50% as the water temperature approached 21°C.

The extreme temperatures we observed in 2004 could easily be dismissed as an anomaly, but that would be remiss of the fact that the mean annual temperature in Juneau has increased by about 1.5°C since 1948 (Larsen et al. 2007) and is projected to increase an additional 5.5°C by the end of this century (Kelly et al. 2007). Thus warm water temperatures may be a recurring problem in the coming decades. Therefore, researchers should evaluate ways to minimize mortality as well as sub-lethal effects arising from catch-and-release angling of cutthroat trout in warm water.

POPULATION MONITORING

Although there is currently no monitoring program for cutthroat trout populations in Southeast Alaska, Turner Lake would be a likely candidate for future studies because it is one of the few cutthroat trout populations in Alaska with long-term data (i.e., ≥5 years) on abundance. However, prior to the initiation of future mark–recapture studies on cutthroat trout populations, we recommend that careful consideration be given to regionwide monitoring goals and objectives (see Gibbs 2000 and Steidl 2001). If the monitoring strategy is to evaluate the effectiveness of regionwide regulations, Turner Lake may be a poor choice due to the unique sport fishing regulations (i.e., catch-and-release only).

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APPENDIX A

Appendix A1.–Estimates of sport fishing effort, harvest, and catch of cutthroat trout at Turner Lake, 1992 to 2002. Fishery statistics are from Alaska Department of Fish and Game postal surveys of U. S. Forest Service (USFS) recreational cabins users (Harding et al. 2005).

Fishery Statistic	1992	1993	1994	1995	1999	2002
Hours fished	912	1,373	1,798	1,622	943	511
Days fished	241	379	425	348	199	216
Harvest	24	63	88	57	58	251
Released	288	911	860	754	739	901
Catch (harvest + release)	312	974	948	811	797	1,152

Appendix A2.–Tests of consistency for the Petersen estimator (from Seber 1982, page 438).

Of the following conditions, at least one must be fulfilled to meet assumptions of a Petersen estimator:

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

or,

3. Every fish has an equal probability of being captured and examined during event 2.

To evaluate these three assumptions, the chi-square statistic can be used to examine the following contingency tables as recommended by Seber (1982). At least one null hypothesis needs to be accepted for assumptions of the Petersen model (Bailey 1951, 1952; Chapman 1951) to be valid. If all three tests are rejected, a temporally or geographically stratified estimator (Darroch 1961) should be used to estimate abundance.

I.-Test for complete mixing[a]

	Time/Area Where Recaptured				Not Recaptured
Area/Time Where Marked	1	2	…	t	(n_1-m_2)
1					
2					
…					
s					

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

	Area/Time Where Examined			
	1	2	…	t
Marked (m_2)				
Unmarked (n_2-m_2)				

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

	Area/Time Where Marked			
	1	2	…	s
Recaptured (m_2)				
Not Recaptured (n_1-m_2)				

[a] This tests the hypothesis that movement probabilities (θ) from time or area *i* (*i* = 1, 2, ...s) to section *j* (*j* = 1, 2, t) are the same among sections: H_0: $\theta_{ij} = \theta_j$.

[b] This tests the hypothesis of homogeneity on the columns of the 2-by-t contingency table with respect to the marked to unmarked ratio among time or area designations: H_0: $\Sigma_i a_i \theta_{ij} = kU_j$, where k = total marks released/total unmarked in the population, U_j = total unmarked fish in stratum *j* at the time of sampling, and a_i = number of marked fish released in stratum *i*.

[c] This tests the hypothesis of homogeneity on the columns of this 2-by-s contingency table with respect to recapture probabilities among time or area designations: H_0: $\Sigma_j \theta_{ij} p_j = d$, where p_j is the probability of capturing a fish in section *j* during the second event, and d is a constant.

Appendix A3.–Detection of size- and/or sex-selective sampling during a two-sample mark–recapture experiment and its effects on estimation of population size and population composition.

Size selective sampling: The Kolmogorov-Smirnov two sample test (Conover 1980) is used to detect significant evidence that size selective sampling occurred during the first and/or second sampling events. The second sampling event is evaluated by comparing the length frequency distribution of all fish marked during the first event (M) with that of marked fish recaptured during the second event (R) by using the null test hypothesis of no difference. The first sampling event is evaluated by comparing the length frequency distribution of all fish inspected for marks during the second event (C) with that of R. A third test that compares M and C is then conducted and used to evaluate the results of the first two tests when sample sizes are small. Guidelines for small sample sizes are <30 for R and <100 for M or C.

Sex selective sampling: Contingency table analysis (Chi^2-test) is generally used to detect significant evidence that sex selective sampling occurred during the first and/or second sampling events. The counts of observed males to females are compared between M&R, C&R, and M&C using the null hypothesis that the probability that a sampled fish is male or female is independent of sample. If the proportions by gender are estimated for a sample (usually C), rather than observed for all fish in the sample, contingency table analysis is not appropriate and the proportions of females (or males) are then compared between samples using a two sample test (e.g. Student's t-test).

M vs. R	**C vs. R**	**M vs. C**
Case I:		
Fail to reject H_o	Fail to reject H_o	Fail to reject H_o
There is no size/sex selectivity detected during either sampling event.		
Case II:		
Reject H_o	Fail to reject H_o	Reject H_o
There is no size/sex selectivity detected during the first event but there is during the second event sampling.		
Case III:		
Fail to reject H_o	Reject H_o	Reject H_o
There is no size/sex selectivity detected during the second event but there is during the first event sampling.		
Case IV:		
Reject H_o	Reject H_o	Either result possible
There is size/sex selectivity detected during both the first and second sampling events.		
Evaluation Required:		
Fail to reject H_o	Fail to reject H_o	Reject H_o

Sample sizes and powers of tests must be considered:

A. If sample sizes for M vs. R and C vs. R tests are not small and sample sizes for M vs. C test are very large, the M vs. C test is likely detecting small differences which have little potential to result in bias during estimation. *Case I* is appropriate.

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B. If a) sample sizes for M vs. R are small, b) the M vs. R p-value is not large (~0.20 or less), and c) the C vs. R sample sizes are not small and/or the C vs. R p-value is fairly large (~0.30 or more), the rejection of the null in the M vs. C test was likely the result of size/sex selectivity during the second event which the M vs. R test was not powerful enough to detect. *Case I* may be considered but *Case II* is the recommended, conservative interpretation.

C. If a) sample sizes for C vs. R are small, b) the C vs. R p-value is not large (~0.20 or less), and c) the M vs. R sample sizes are not small and/or the M vs. R p-value is fairly large (~0.30 or more), the rejection of the null in the M vs. C test was likely the result of size/sex selectivity during the first event which the C vs. R test was not powerful enough to detect. *Case I* may be considered but *Case III* is the recommended, conservative interpretation.

D. If a) sample sizes for C vs. R and M vs. R are both small, and b) both the C vs. R and M vs. R p-values are not large (~0.20 or less), the rejection of the null in the M vs. C test may be the result of size/sex selectivity during both events which the C vs. R and M vs. R tests were not powerful enough to detect. *Cases I, II, or III* may be considered but *Case IV* is the recommended, conservative interpretation.

Case I. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated after pooling length, sex, and age data from both sampling events.

Case II. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated using length, sex, and age data from the first sampling event without stratification. If composition is estimated from second event data or after pooling both sampling events, data must first be stratified to eliminate variability in capture probability (detected by the M vs. R test) within strata. Composition parameters are estimated within strata, and abundance for each stratum needs to be estimated using a Petersen-type formula. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance according to the formulae below.

Case III. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated using length, sex, and age data from the second sampling event without stratification. If composition is estimated from first event data or after pooling both sampling events, data must first be stratified to eliminate variability in capture probability (detected by the C vs. R test) within strata. Composition parameters are estimated within strata, and abundance for each stratum needs to be estimated using a Petersen-type formula. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance according to the formulae below.

Case IV. Data must be stratified to eliminate variability in capture probability within strata for at least one or both sampling events. Abundance is calculated using a Petersen-type model for each stratum, and estimates are summed across strata to estimate overall abundance. Composition parameters may be estimated within the strata as determined above, but only using data from sampling events where stratification has eliminated variability in capture probabilities within strata. If data from both sampling events are to be used, further stratification may be necessary to meet the condition of capture homogeneity within strata for both events. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance.

If stratification by sex or length is necessary prior to estimating composition parameters, then overall composition parameters (p_k) are estimated by combining within stratum composition estimates using:

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$$\hat{p}_k = \sum_{i=1}^{j} \frac{\hat{N}_i}{\hat{N}_\Sigma} \hat{p}_{ik} \qquad (1)$$

and,

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

where: j = the number of sex/size strata;
$\hat{p}_{ik}$ = the estimated proportion of fish that were age or size *k* among fish in stratum *i*;
$\hat{N}_i$ = the estimated abundance in stratum *i*; and,
$\hat{N}_\Sigma$ = sum of the $\hat{N}_i$ across strata.

Appendix A4.–Computer files used to estimate the abundance and length composition of cutthroat trout ≥180 mm FL in Turner Lake in 2004 and 2005.

File Name	Description
TURNER05ABUN.XLS	EXCEL spreadsheet with abundance estimates and chi-squared tests for heterogeneity in capture probabilities related to spatial heterogeneity
TURNER05KS.XLS	EXCEL spreadsheet with Kolmogorov-Smirnov size selectivity tests
TURNER2004_2005_LENGTH.XLS	EXCEL spreadsheet with length composition analysis
TURNER2004_2005_DATA.XLS	EXCEL spreadsheet with Turner Lake 2005 raw data, including fish lengths, tag numbers, depths, gear type, and comments