Fishery Data Series No. 16-41

Abundance and Length Composition of Cutthroat Trout in Florence Lake, Southeast Alaska, 2002

by

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and

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October 2016

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

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Mathematics, statistics

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

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October 2016

This investigation partially financed by the Federal Aid in Sport fish Restoration Act (16 U.S.C.777-777K) under Project F-10-17, Job No. R-1-1.

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This document should be cited as follows:
Bangs, P. D., and D. C. Love. 2016. Abundance and length composition of cutthroat trout in Florence Lake, Southeast Alaska, 2002. Alaska Department of Fish and Game, Fishery Data Series No. 16-41, Anchorage.

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ABSTRACT

A two-event mark–recapture study was conducted during 2002 at Florence Lake in Southeast Alaska to estimate the abundance and length composition of coastal cutthroat trout *Oncorhynchus clarki clarki*. Fish were captured with hook and line gear and hoop traps, marked with t-bar anchor tags, and given a dye mark as a secondary mark. The pooled Petersen estimate of abundance of cutthroat trout ≥180 mm fork length (FL) was 13,515 fish (SE = 1,010; 95% CI = 11,534 – 15,495). Most of the cutthroat trout ≥180 mm FL were estimated to be ≤300 mm FL ($\hat{p}_{180-300}$ = 0.987, SE = 0.054). A much smaller proportion were 301–360 mm FL ($\hat{p}_{301-360}$ = 0.02, SE = 0.006), and very few fish were ≥360 mm FL ($\hat{p}_{360+}$ = 0.005, SE = 0.002). Although the Petersen estimate was biased, abundance estimates and length composition of large and small fish were relatively similar to estimates from 1994 and 2003.

Key words: Florence Lake, Southeast Alaska, coastal cutthroat trout, Oncorhynchus clarki clarki, mark–recapture, length composition, abundance

INTRODUCTON

Florence Lake, located on the west side of Admiralty Island, supports one of the largest known populations of coastal cutthroat trout *Oncorhynchus clarki clarki* in Southeast Alaska (Bangs and Harding 2008). Prior to extensive clearcut logging in the Florence Lake watershed in the early 1990s, the lake was one of the most popular cutthroat trout fisheries in Southeast Alaska (Jones et al. 1992). Angler effort has since declined substantially (Appendix A1). Based upon the declining angler effort at Florence Lake since the watershed was clearcut, as well as the high density of cutthroat trout, the Alaska Board of Fisheries (BOF) adopted less restrictive sport fishing regulations (5 AAC 47.023) for the lake in 1994 (Harding and Jones 2004). At the time, the BOF had reduced daily harvest limits for many cutthroat trout populations in Southeast Alaska and Florence Lake was identified as one of the populations where additional harvest opportunities could be maintained. The revised regulations are the least restrictive cutthroat trout regulations in Southeast Alaska (5 fish daily bag limit, 10 fish possession limit, no minimum size limit for fish, bait is allowed year round).

The Alaska Department of Fish and Game (ADF&G), Division of Sport Fish (DSF) conducted annual mark–recapture experiments in Florence Lake between 1991 and 1994 to estimate the abundance and length composition of cutthroat trout (Rosenkranz et al. 1999). Results from these studies were used to make initial recommendations about sampling cutthroat trout at Florence and other resident fish bearing lakes in Southeast Alaska. The objectives of this study were to estimate the abundance and length composition of cutthroat trout in Florence Lake in 2002.

OBJECTIVES

The study objectives in 2002 were to:

1. estimate the abundance of cutthroat trout ≥180 mm fork length (FL); and
2. estimate the length composition of cutthroat trout ≥180 mm FL.

METHODS

STUDY AREA

Florence Lake lies approximately 50 km southwest of Juneau, on the west side of Admiralty Island (Figure 1) at longitude 134.630 and latitude 57.805 (Decimal Degrees; NAD83, State Plane, FIPS 5001). The 431-hectare lake is narrow (<1 km wide) and about 7.2 km long, with a maximum depth of approximately 27 m. The lake outlet flows about 2 km into Chatham Strait and passes over a barrier falls about 400 m upstream of tidewater, which blocks the lake to anadromous fish passage. A U.S. Forest Service recreational cabin is located at the east end of the lake, and the primary mode of transportation to the cabin is by float plane. Coastal 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 coastal cutthroat trout in Florence Lake by using a two-event mark–recapture experiment. The first event (the marking event) occurred between April 30 and May 9, 2002. The second event (the recapture event) occurred between June 4 and June 12, 2002. Cutthroat trout were captured by deploying hoop traps (HT, Figure 2 in Rosenkranz et al. 1999) baited with salmon eggs that had been disinfected in a povidone-iodine solution. The lake was divided into 3 areas (Figure 2) to facilitate consistent recording of trap locations and to aid in evaluation of assumptions during data analysis. During the first sampling event, a total of 107 overnight trap sets were made across the lake (26 overnight sets in Area A, 55 overnight sets in Area B, and 26 overnight sets in Area C). During the second sampling event, a total of 108 overnight trap sets were made across the lake (26 sets in Area A, 56 sets in Area B, and 26 sets in Area C). Traps were set on the lake bottom and depths were measured to the nearest m with a fathometer or metered buoy line. Hook and line (HL) sampling gear was also employed during the second event. This entailed casting small spinners in a manner such that all shoreline areas at depths ≤6 m were fished with similar effort. A total of 10 hours HL sampling effort was expended (2 hours in Area A, 6 hours in Area B, and 2 hours in Area C).

All cutthroat trout <180 mm FL that were captured were counted and released, but not sampled or included in the mark–recapture experiment. This minimum size threshold for sampling was selected to be consistent with previous cutthroat trout studies in Southeast Alaska (e.g., Rosenkranz et al. 1999). All cutthroat trout ≥180 mm FL were given a red anal fin dye mark, measured to the nearest mm FL, and given a uniquely numbered t-bar anchor tag (Hallprint Pty Ltd., Victor Harbor, South Australia[1]). Previously captured fish (as indicated by the presence of a t-bar tag or dye mark) were measured for length and the t-bar anchor tag number was recorded. For each fish ≥180 mm FL captured, the date, time, gear type, lake area (A, B, C), and depth (for HT) were recorded.

[1] This and subsequent product names are included for a complete description of the process and do not constitute product endorsement.

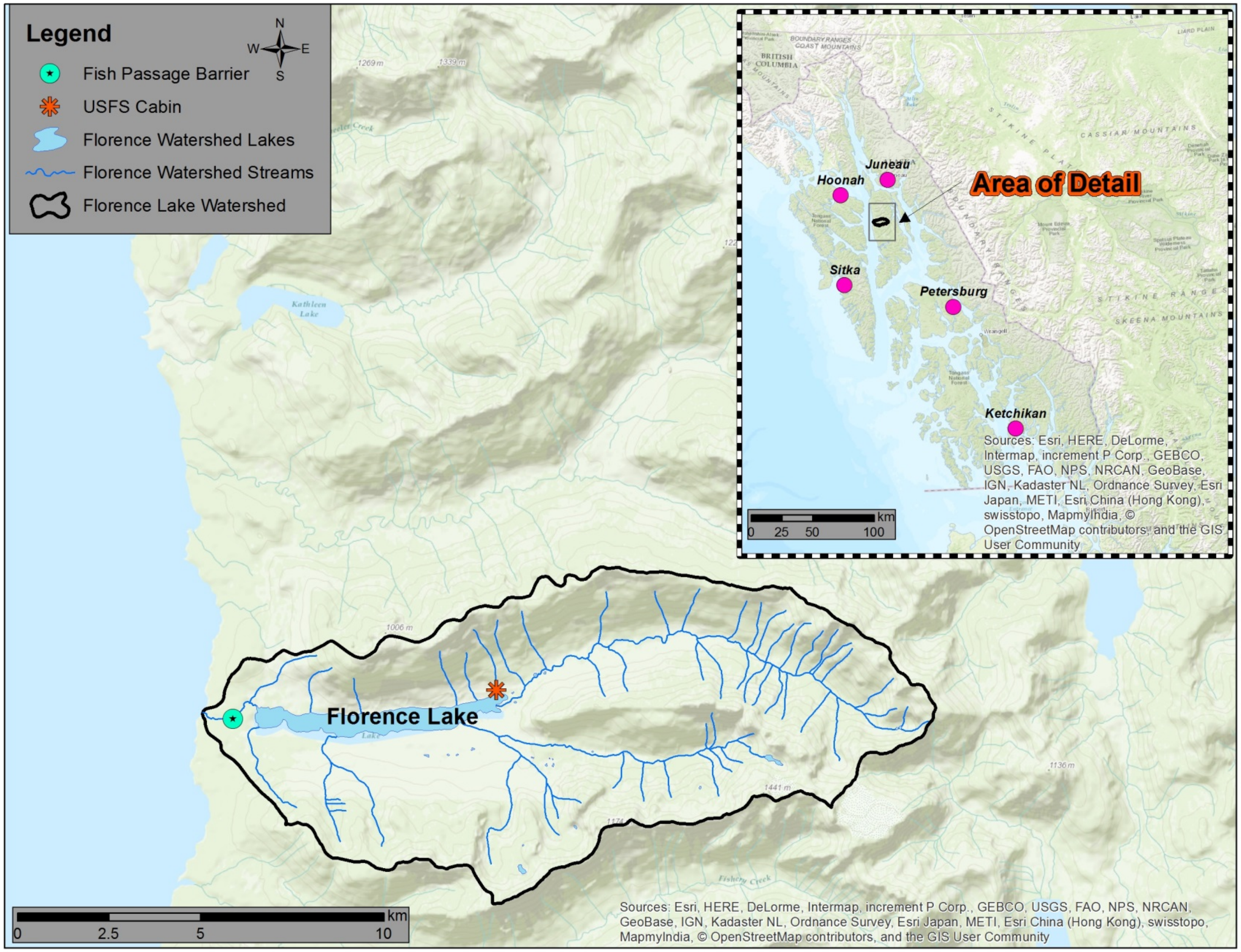

Figure 1.–Location of Florence Lake and surrounding watershed on Admiralty Island in Southeast Alaska.

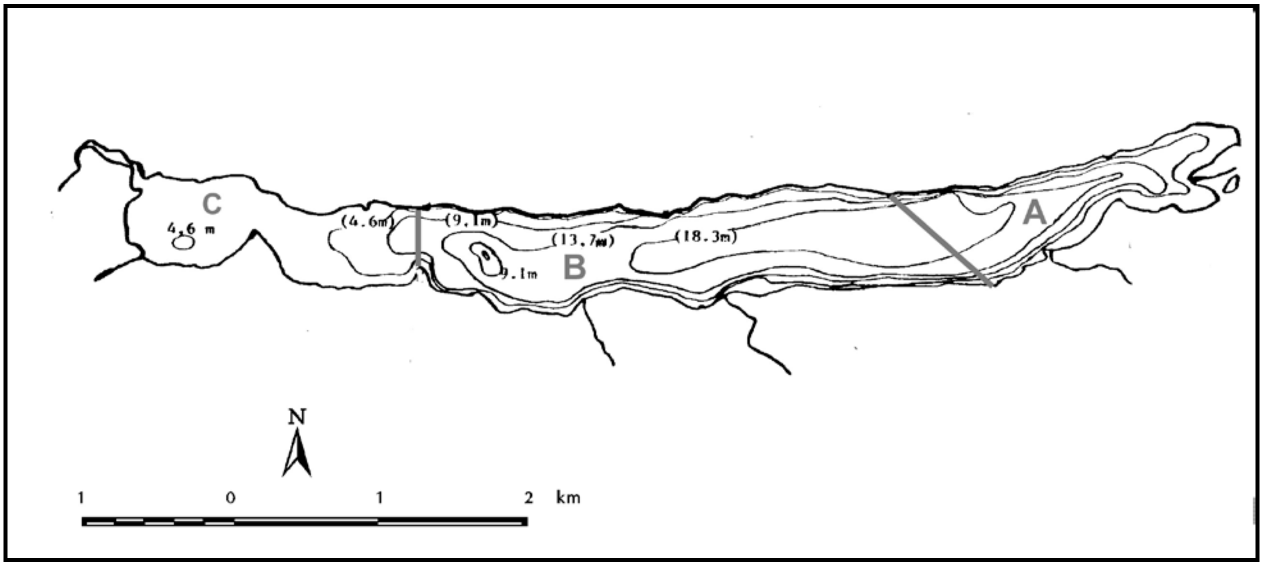

Figure 2.–Location of sampling areas in Florence Lake, 2002. The three large lake areas (A, B, C) were used to evaluate study assumptions.

DATA ANALYSIS

Chapman's (1951) modification of the Petersen model (Seber 1982) was used for estimating the abundance of cutthroat trout ≥180 mm FL. Assumptions of the two-event mark–recapture experiment were as follows:

1) the population was closed (cutthroat trout do not enter the population via immigration or growth recruitment [i.e., from <180 mm FL to ≥180 mm FL], or leave the population via death or emigration, between sampling events);
2) all marked and unmarked cutthroat trout mixed completely between sampling events, *or* every fish had an equal probability of being marked during the first event, *or* every fish had an equal probability of being sampled during the second event;
3) marking of cutthroat trout in the first event did not affect the probability of capture in the second event; and
4) cutthroat trout did not lose (or gain) marks between events, and marks were recognized and reported during the second event.

Fulfillment of the closure assumption (assumption 1) relied on the relatively short time (34 days) between the start of the first sampling event and the start of the second. The second assumption was evaluated with tests of consistency for the Petersen estimator (Appendix B1) and with Kolmogorov-Smirnov (K-S) tests for size-selective sampling (Appendix B2). Contingency tables used to evaluate the chi-square statistic were used to compare capture and recapture rates in each area of the lake. When all three of the null hypotheses outlined in Appendix B1 were rejected ($\alpha = 0.05$), the partially stratified estimator described by Darroch (1961) was considered appropriate (Seber 1982). Otherwise, when any of the three null hypotheses were accepted, a Peterson estimator was used. The protocol specified in Appendix B2 provided guidance for conducting K-S tests to evaluate the potential for size-selective sampling (differences in probability of capture for different sized fish). 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 overnight in a HT for observation. The status of these fish (e.g., whether they were alive, apparent condition) was evaluated to determine if handling procedures were detrimental. Assumption 4 was robust in this experiment because all fish had a secondary mark (red anal fin dye mark) and technicians were instructed to thoroughly examine all captured fish for marks.

The Chapman modification of the Petersen model is:

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

where $\hat{N}$ is the estimated abundance, n_1 is the number marked in the first event, n_2 is the number examined in the second event, and m_2 is the number recaptured in the second event.

The standard error and a 90% confidence interval about $\hat{N}$ were estimated by using a parametric bootstrap routine in Excel, whereby random variates (m_2) were generated from a 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), equation (1) was used 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:

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

LENGTH COMPOSITION

Size selectivity in sampling was investigated according to the protocols in Appendix B2. The estimated fraction $\hat{p}_a$ of the fish in length group a (20 mm increments) was calculated as:

$$\hat{p}_a = \frac{n_a}{n} \qquad (3)$$

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

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

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

$$\hat{N}_a = \hat{p}_a \hat{N} \qquad (5)$$

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

$$\begin{aligned} \hat{\text{var}}[\hat{N}_a] = {} & \hat{\text{var}}(\hat{p}_a)\hat{N}^2 + \\ & \hat{\text{var}}(\hat{N})\hat{p}_a^2 - \hat{\text{var}}(\hat{p}_a)\hat{\text{var}}(\hat{N}) \end{aligned} \qquad (6)$$

RESULTS

CATCH SUMMARY

Capture data in both events and across all 3 sampling areas are summarized in Table 1. A total of 1,344 cutthroat trout ≥180 mm FL were marked during the first event sampling in Florence Lake in 2002. A total of 1,436 trout were captured in the second event, of which 142 had been marked during the first event. In total, 2,638 unique cutthroat trout ≥180 mm were captured in the mark-recapture experiment. No tag loss was observed between marking events based on secondary marks on recaptured fish. Of the total sampled, there were 4 mortalities during event 2, which were examined and included in the abundance estimation and tests of consistency for the Petersen estimator. Measurements taken from these four fish were also included in the length composition analysis and the K-S tests. There were 3 mortalities during the first marking event that were not tagged; therefore, they were not included in the abundance estimation procedures, length composition analysis, or K-S tests. All fish held overnight to evaluate potential handling effects appeared healthy and were released. A length measurement was either not taken or not recorded for one 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 because it could not be assigned to a length group.

Table 1.–Summary catches of coastal cutthroat trout ≥180 mm FL in each of the three sampling areas (A, B, C) at Florence Lake, 2002.

		Marked			
	Total fish marked	but not recaptured	Number of marked fish recaptured by area of capture		
Area fish was marked	(n_i)	(a_i)	A	B	C
A	624	572	24	19	9
B	562	485	13	42	22
C	158	145	0	2	11
Total marked fish recaptured			37	63	42
Total unmarked fish caught (u_j)			205	370	719

Note: Summary statistics include the number of fish marked in each area (n_i) in the first event and the number of marked fish that were not recaptured in each area (a_j) in the second event.

Estimation of abundance under the Petersen Model

The use of the Chapman modification of the Petersen model required, among other assumptions, that at least one of the three conditions described above (Data Analysis, assumption 2) be satisfied. No significant evidence of size-selective sampling was detected for the first and second sampling events, based on results of K-S tests. The length compositions of cutthroat trout marked in the first event and subsequently recaptured in the second event were not significantly different (D = 0.084, P = 0.310, Figure 3). Further, the length compositions of all fish captured and recaptured during the second event were not significantly different (D = 0.067, P = 0.578, Figure 4). A third test that compared all marked fish (n_1 = 1,344) in the first event to the total captured in the second event (n_2 = 1,436) was rejected, but because samples sizes were large this test probably detected small differences that had little potential to bias a pooled Petersen estimator (Appendix B2).

Although some mixing between sampling areas did occur between sampling events, the null hypothesis of complete mixing between areas was rejected (χ^2 = 34.90, df = 2, P < 0.001; see "complete mixing test" in Appendix B1), and evidence of unequal probabilities of capture in the first event was found (χ^2 = 35.01, df = 2, P < 0.001; see the "equal proportions test" in Appendix B1). The null hypothesis of no difference in the marked fractions among the recovery areas (second event probability of capture) was also rejected (χ^2 = 10.05, df = 2, 0.001< P < 0.01; see the pooled version of the "complete mixing test" in Appendix B1). Because capture probabilities by area appeared to be heterogeneous (Table 1) and incomplete mixing among the areas and between sampling events appeared to be a source of bias in evaluating assumptions for the modified Petersen estimator, the model described by Darroch (1961) was prescribed to provide a minimally biased estimate of abundance.

Attempts to fit a Darroch model to the data collected in this experiment were not successful. The estimate provided by the Chapman modified Petersen model was biased, and most likely biased low because of heterogeneity in probability of capture by area occurring during both sampling events. The pooled Petersen estimate was 13,515 cutthroat trout ≥180 mm FL (SE = 1010; 95% CI = 11,534 – 15,495; n_1 = 1,344, n_2 = 1,436, m_2 = 142).

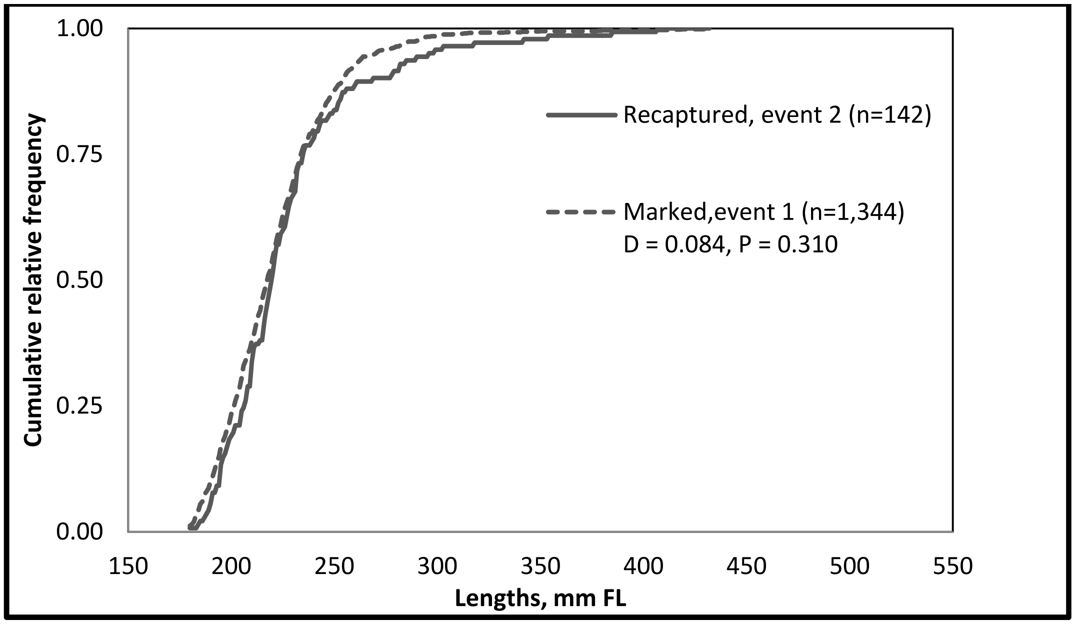

Figure 3.–Cumulative relative frequency of coastal cutthroat trout ≥180 mm FL marked in the first event and recaptured in the second event at Florence Lake in 2002.

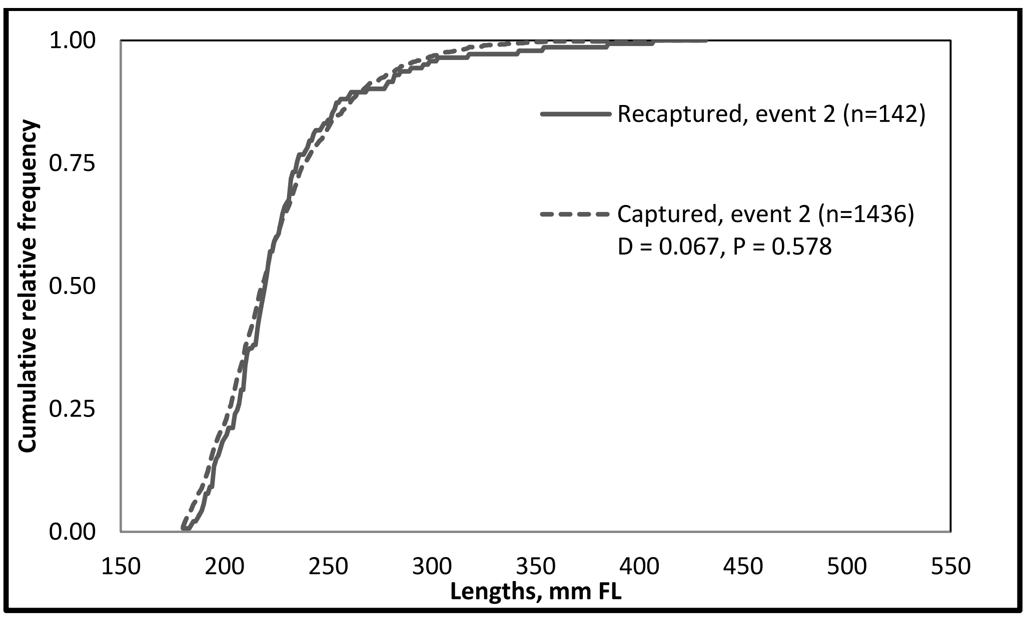

Figure 4.–Cumulative relative frequency of coastal cutthroat trout ≥180 mm FL captured in the second event versus those recaptured in the second event at Florence Lake in 2002.

LENGTH COMPOSITION

Fork lengths of measured cutthroat trout captured in 2002 ranged from 180 to 464 mm. Most of the cutthroat trout ≥180 mm FL were estimated to be ≤300 mm FL ($\hat{p}_{180-300}$ = 0.987, SE = 0.054). A much smaller proportion were 301–360 mm FL ($\hat{p}_{301-360}$ = 0.02, SE = 0.006), and very few fish were ≥360 mm FL ($\hat{p}_{360+}$ = 0.005, SE = 0.002). More fish in the 180–280 mm FL size range (Table 2) were sampled during event 1 (93.2%) compared to event 2 (87.5%), and more fish >300 mm FL were sampled during event 2 (6.8%) compared to event 1 (3.6%). However, length frequency distributions for fish 280 mm FL and smaller for both sampling events were not significantly different based on KS tests (D = 0.035, P = 0.357).

Table 2.–Frequency by length category and cumulative proportion for event 1 (all fish marked) and event 2 (all fish captured) for cutthroat trout ≥180 mm FL in Florence Lake in 2002.

	Event 1		Event 2	
Length category (mm FL)	Frequency	Cumulative proportion	Frequency	Cumulative proportion
180–200	16	0.012	15	0.010
201–220	311	0.243	316	0.231
221–240	427	0.561	450	0.544
241–260	334	0.810	318	0.765
261–280	164	0.932	161	0.878
281–300	44	0.964	82	0.935
301–320	31	0.987	49	0.969
321–340	6	0.992	25	0.986
341–360	2	0.993	11	0.994
>360	9	1.000	9	1.000
Total	1,344		1,436	

DISCUSSION

ABUNDANCE

Catch rates did not appear to be significantly different between sampling events. Harding et al. (1999) provides some evidence that capture with HT and tagging does not lead to significant short-term trap avoidance; therefore, capture using HT was assumed to be similar between mark and recapture events. Fish marked in 2002 that were held overnight did not appear to experience handling or tagging-related mortality. Based on secondary marks on recaptured fish, tag loss was not observed. Foster (2003) measured the smallest mature male in Florence Lake at 174 mm FL and the smallest mature female at 208 mm FL. All fish larger than these sizes could be considered capable of spawning and may have immigrated or emigrated into or out of the lake population during the sampling period. Use of the "spawning season straddle" strategy (Rosenkranz et al. 1999) was intended to minimize problems with the "closure" assumption, because all fish were expected to be available during both sampling events; however, K-S tests indicated that there was no difference in the size composition of fish sampled during the two sampling events in Florence Lake in 2002 (Figure 3). Unequal probability of capture in different areas of the lake was evident based on incomplete mixing and spatial heterogeneity of recaptures, indicating that the Chapman modification of the Petersen model provided a biased estimate. Although the Darroch model would be appropriate in order to minimize bias, an admissible estimate was not obtained, leaving the biased Petersen estimate. Other studies (Rosenkranz et al. 1999; Bangs 2009) have successfully generated abundance estimates without any known or detectable bias; readers are therefore advised to refer to these studies for more reliable information on the abundance of cutthroat trout at Florence Lake.

LENGTH COMPOSITION

Length composition estimates for 1991 through 1993 for Florence Lake were not reported by Rosenkranz et al. (1999). Length composition estimates from this study ($\hat{p}_{180-300}$ = 0.96, Table 2) were similar to the estimates from 1994($\hat{p}_{180-300}$ = 0.99; Harding 1995) and 2003 ($\hat{p}_{180-299}$ = 0.97; Bangs 2009). For the same reasons described above, readers are advised to refer to Bangs (2009) for more reliable and more recent (although quite dated) information on length composition of cutthroat trout at Florence Lake.

POPULATION MONITORING

In general, the Florence Lake coastal cutthroat trout population appears to be relatively stable, exhibiting minimal fluctuations in abundance. Some level of continued study may be warranted because extensive timber harvest in the riparian zone of the lake may have long-term effects on habitat and trout population abundance. Careful consideration would need to be given to sampling design in any future mark–recapture studies to ensure that population model assumptions are met. Gibbs (2000) and Steidl (2001) provide helpful recommendations for designing monitoring programs.

Table 3.–Length composition and estimated abundance-at-length for coastal cutthroat trout ≥180 mm FL in Florence Lake in 2002.

Length *a* (mm FL)	n_a	$\hat{p}_a$	SE($\hat{p}_a$)	$\hat{N}_a$	SE($\hat{N}_a$)
180–200	16	0.012	0.003	161	42
201–220	311	0.231	0.012	3127	281
221–240	427	0.318	0.013	4294	364
241–260	334	0.249	0.012	3359	297
261–280	164	0.122	0.009	1649	172
281–300	44	0.033	0.005	442	73
301–320	31	0.023	0.004	312	60
321–340	6	0.004	0.002	60	25
341–360	2	0.001	0.001	20	14
>360	9	0.007	0.002	91	31
Total	1,344		$\hat{N}$ =	13,515	

Note: Number sampled (n_a ; first event only), proportion ($\hat{p}_a$), abundance ($\hat{N}_a$), and standard error (SE) are shown for each 20 mm length class.

ACKNOWLEDGEMENTS

Ken and Karen Koolmo conducted the fieldwork at Florence Lake. Bob Marshall provided advice for the study design. Daniel Reed provided biometric review. Roger Harding and John Der Hovanisian provided critical review. Jeff Nichols and Kyra Sherwood prepared the final manuscript for publication. Funding for this project was provided by the U.S. Fish and Wildlife Service through the Federal Aid in Sport Fish Restoration Act (16 U.S.C. 777-777K) under Project F-10-17, Job No. R-1-1.

REFERENCES CITED

Bailey, N. T. J. 1951. On estimating the size of mobile populations from capture-recapture data. Biometrika 38: 293–306.

Bailey, N. T. J. 1952. Improvements in the interpretation of recapture data. Journal of Animal Ecology 21:120–127.

Bangs, P. D. 2009. Abundance and length composition of cutthroat trout in Florence Lake, Southeast Alaska, 2003. Alaska Department of Fish and Game, Fishery Data Series No. 09-06, Anchorage.

Bangs, P. D., and R. D. Harding. 2008. The status and management of coastal cutthroat trout in Alaska. Pages 37–44 [*In*] P. J. Connolly, T. H. Williams, and R. E. Gresswell, editors. Proceedings of the 2005 coastal cutthroat trout symposium: status, management, biology, and conservation. Oregon Chapter, American Fisheries Society, Portland.

Chapman, D. G. 1951. Some properties of the hypergeometric distribution with applications to zoological censuses. University of California Publications in Statistics 1:131–160.

Conover, W. J. 1980. Practical nonparametric statistics, second edition. John Wiley and Sons, New York.

Darroch, J. N. 1961. The two-sample capture-recapture census when tagging and sampling are stratified. Biometrika 48:241–260.

Efron, B., and R. J. Tibshirani. 1993. First Edition. An introduction to the bootstrap. Chapman and Hall, New York, NY

Foster, M. B. 2003. Maturity, fecundity, growth, and sustained yield of coastal cutthroat trout at Florence Lake, Southeast Alaska. M.S. thesis, University of Alaska, Fairbanks.

Gibbs, J. P. 2000. Monitoring populations. Pages 213–252 [*In*] L. Boitani and T. K. Fuller, editors. Research techniques in animal ecology: controversies and consequences. Columbia University Press, New York.

Goodman, L. A. 1960. On the exact variance of products. Journal of the American Statistical Association 55:708–713.

Harding, R. 1995. Abundance and length composition of cutthroat trout in Florence, Turner, and Young Lakes, Southeast Alaska, 1994. Alaska Department of Fish and Game, Fishery Data Series No. 95-43, Anchorage.

Harding, R. D. 1999. Evaluation of short-term handling and tagging mortality of cutthroat trout at Florence Lake, Southeast Alaska, 1998. Alaska Department of Fish and Game, Fisheries Data Series No. 99-24, Anchorage.

Harding, R. D., 2012. Survey of anglers using Southeast Alaska recreational cabins during 2009. Alaska Department of Fish and Game, Fishery Data Series No. 12-81, Anchorage.

Harding , R. D., and C. L. Coyle. 2011 Southeast Alaska steelhead, trout, and Dolly Varden management. Alaska Department of Fish and Game, Fishery Data Series No. 11-17, Anchorage, Alaska, USA.

Harding, R., and J. D. Jones. 1993. Cutthroat trout studies at Florence Lake, Southeast Alaska, 1992. Alaska Department of Fish and Game, Fishery Data Series No. 93-44, Anchorage, Alaska, USA.

Harding, R., and J. D. Jones. 1994. Abundance of cutthroat trout in Florence Lake, Alaska, 1993. Alaska Department of Fish and Game, Fishery Data Series No. 94-35, Anchorage, AK.

Harding, R.D., and J.D. Jones. 2004. The development and evaluation of conservative trout regulations in Southeast Alaska based on length at maturity. Pages 231–239 [*In*] Moore, S. E., R. F. Carline, and J. Dillon, editors. Wild Trout VIII symposium proceedings. Yellowstone National Park, Wyoming.

Harding, R. D., M. Laker, and R.P. Marshall. Freeman. 1999. Abundance and length, trap avoidance, and short-term spatial movement of cutthroat trout at McKinney Lake, Southeast Alaska, 1996. Alaska Department of Fish and Game, Fishery Data Series No. 99-20, Anchorage.

Harding, R. D., K. A. Kondzela, and R. S. Mullen. 2005. Southeast Alaska recreational cabin survey, 2002. Alaska Department of Fish and Game, Fishery Data Series No. 05-11, Anchorage.

REFERENCES CITED (Continued)

Harding, R. D., K. A. Kondzela, and R. P. Marshall. 2009. Survey of anglers using Southeast Alaska recreational cabins during 2006. Alaska Department of Fish and Game, Fishery Data Series No. 09-60, Anchorage.

Jones, J. D., A. E. Bingham, and R. Harding. 1989. Cutthroat trout studies: Turner/Florence lakes, Alaska, during 1988. Alaska Department of Fish and Game, Fishery Data Series No. 111, Juneau, Alaska, USA.

Jones, J.D., R. Harding, and A. E. Bingham. 1990. Cutthroat trout studies: Turner/Florence lakes, Alaska, during 1989. Alaska Department of Fish and Game, Fishery Data Series No. 90-24, Anchorage, Alaska, USA.

Jones, J. D. and R. Harding. 1991. Cutthroat trout studies: Turner/Florence lakes, Alaska, during 1990. Alaska Department of Fish and Game, Fishery Data Series No. 91-53, Anchorage, Alaska.

Jones, J. D., R. P. Marshall, and R. Harding. 1992. Cutthroat trout studies at Florence and Hasselborg lakes, Southeast Alaska, 1991. Alaska Department of Fish and Game, Fishery Data Series No. 92-43, Anchorage, Alaska, USA.

Jones, J. D. 1993. Southeast Alaska recreational cabin survey,1992. Alaska Department of Fish and Game, Fishery Data Series No. 93-53, Anchorage.

Jones, J. D. 1994. Harvest surveys at U.S. Forest Service public use cabins in Southeast Alaska, 1993. Alaska Department of Fish and Game, Fishery Data Series No. 94-39, Anchorage.

Jones, J. D. 1995. Southeast Alaska recreational cabin survey, 1994. Alaska Department of Fish and Game, Fishery Data Series No. 95-32, Anchorage.

Jones, J. D., and K. Kondzela. 2001. Southeast Alaska Recreational Cabin Survey, 1999. Alaska Department of Fish and Game, Fishery Data Series No. 01-9, Anchorage.

Rosenkranz, G., R., P. Marshall, R. D. Harding, and D. R. Bernard. 1999. Estimating natural mortality and abundance of potamodromous lake dwelling cutthroat trout at Florence Lake, Alaska. Alaska Department of Fish and Game, Fishery Manuscript No. 99-1, Anchorage.

Seber, G. A. F. 1982. On the estimation of animal abundance and related parameters, second edition. Griffin and Company, Ltd. London.

Steidl, R. J. 2001. Practical and statistical considerations for designing population monitoring programs. Pages 284–288 [*In*] R. Field, R. J. Warren, H. Okama, and P. R. Sievert, editors. Wildlife, land and people: priorities for the 21st century. Proceedings of the Second International Wildlife Management Congress. The Wildlife Society, Bethesda, MD.

APPENDIX A

Appendix A1.–Estimates of sport fishing effort, harvest, and catch of cutthroat trout at Florence Lake, 1992 to 2009.

Fishery Statistic	1992	1993	1994	1999	2002	2006	2009
Hours fished	332	423	803	101	126	35	--[a]
Days fished	59	94	232	75	54	11	--[a]
Harvest	175	197	326	88	77	9	0
Released	844	1,990	1,082	317	405	97	41
Catch (harvest + release)	1,019	2,187	1,465	405	481	106	41

Note: Fishery statistics are from Alaska Department of Fish and Game postal surveys of U. S. Forest Service (USFS) recreational cabins users (Jones 1993–1995; Jones and Kondzela 2001; Harding et al. 2005; Harding et al. 2009; Harding and Coyle 2011; Harding 2012).

[a] Information about angler effort (days and hours fished) is not available for 2009 because these questions were eliminated in the simplified cabin survey in order to minimize missing data that occurred in previous surveys.

APPENDIX B

Appendix B1.–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 the first event;

   or

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

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.–"Complete mixing test"[a]

	Time/Area Where Recaptured				Not Recaptured
Area/Time Where Marked	1	2	…	t	$(n_1\text{-}m_2)$
1					
2					
…					
S					

II.–"Equal Proportions test"[b]

	Area/Time Where Examined			
	1	2	…	t
Marked (m_2)				
Unmarked $(n_2\text{-}m_2)$				

III.–Pooled version of "Complete mixing test"[c]

	Area/Time Where Marked			
	1	2	…	s
Recaptured (m_2)				
Not Recaptured $(n_1\text{-}m_2)$				

[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: $\theta_{ij} = \theta_j$ (test for homogeneity of the rows of the s by (t+1) table.

[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. Accepting H_0: is consistent with an equal probability of capture during the first event.

[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 B2.–Detection of size- 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 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), 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, comparing M and C, is 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 of second sampling events. The counts of observed males to females are compared between M&R, C&R, and M&C as described above, using the null hypothesis that the probability that a sampled fish is male or female is independent of sample. When the proportions by gender are estimated for a sample (usually C), rather an observed for all fish in the sample, contingency table analysis is not appropriate and the proportions of females (or males) are 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	Reject H_o

There is size/sex selectivity detected during both the first and second sampling events.

Case V

Fail to reject H_o	Fail to reject H_o	Reject H_o

Sample sizes and powers of tests must be considered in Case V:

A. If sample sizes for M vs. R and C vs. R tests are not small and sample sizes for M vs. C test are very large, the M vs. C test is likely detecting small differences that have little potential to result in bias during estimation. *Proceed as for Case 1*.

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. May proceed as for *Case I* 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. May proceed as for *Case I* 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. May proceed as for *Cases I, II, or III* 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 then estimated within strata, and weighted by stratified Petersen abundances, to yield overall composition estimates (see 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 then estimated within strata, and weighted by stratified Petersen abundances, to yield overall composition estimates (see formulae below)

Case IV. 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, an overall composition parameters (p_k) is estimated by combining within stratum composition estimates using:

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

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

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;

$\hat{N}_\Sigma$ = $\sum_{i=1}^{j} \hat{N}_i$

APPENDIX C

Appendix C1.–Computer files used to estimate the abundance and length composition of cutthroat trout ≥180 mm FL in Florence Lake in 2002.

File Name	Description
Flor_02_Abun.xlsx	Excel 2007 spreadsheet with abundance estimates and chi-squared tests for heterogeneity in capture probabilities related to spatial heterogeneity
Flor_02_KStests.xls	Excel 2003 spreadsheet with Kolmogorov-Smirnov size selectivity tests
Flor_02_Length.xlsx	Excel 2007 spreadsheet with length composition analysis
Flor_02_Data.xlsx	Excel 2007 spreadsheet with Florence Lake 2002 raw data, including fish lengths, tag numbers, depths, gear type, and comments