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Cutthroat Trout Studies at Virginia Lake, Southeast Alaska

by

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Alaska Department of Fish and G

Division of Sport Fish

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
metric ton	mt
milliliter	ml
millimeter	mm

Weights and measures (English)

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

Spell out acre and ton.

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
hour (spell out for 24-hour clock)	h
minute	min
second	s

Spell out year, month, and week.

Physics and chemistry

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

General

All commonly accepted abbreviations.	e.g., Mr., Mrs., a.m., p.m., etc.
All commonly accepted professional titles.	e.g., Dr., Ph.D., R.N., etc.
and	&
at	@
Compass directions:	
east	E
north	N
south	S
west	W
Copyright	©
Corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
et alii (and other people)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.,
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
number (before a number)	# (e.g., #10)
pounds (after a number)	# (e.g., 10#)
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S. state and District of Columbia abbreviations	use two-letter abbreviations (e.g., AK, DC)

Mathematics, statistics, fisheries

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	C.I.
correlation coefficient	R (multiple)
correlation coefficient	r (simple)
covariance	cov
degree (angular or temperature)	°
degrees of freedom	df
divided by	÷ or / (in equations)
equals	=
expected value	E
fork length	FL
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.
mideye-to-fork	MEF
minute (angular)	'
multiplied by	x
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
standard length	SL
total length	TL
variance	Var

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by

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ABSTRACT

Angler reactions to restrictive harvest regulations for cutthroat trout *Oncorhynchus clarki* at Virginia Lake in Southeast Alaska prompted an examination of the population status for the species from 1995 through 1997. A study to estimate size composition and abundance using a two-event (Petersen/Darroch) closed population (CP) model was conducted in 1995. Sampling was extended in 1996 and 1997 to permit use of a Jolly-Seber (JS) estimator to estimate abundance in 1996. An estimated 6,810 (SE = 256) fish were present in 1995 under the two-event CP model, and 3,620 (SE = 415) were present in 1996 under the JS model. The JS estimate of abundance is biased low because fish were spawning in streams during the 1996 and 1997 sampling events and thus were unavailable for sampling.

Only 1 percent of the cutthroat sampled during the study were larger than the minimum 14-in length limit (> 336 mm fork length) established for harvest in the sport fishery at Virginia Lake.

Key words: Alaska, Virginia Lake, cutthroat trout, abundance, mark-recapture, Petersen, Jolly-Seber.

INTRODUCTION

Virginia Lake, located 11 km east of Wrangell, Alaska has a long history of sport fishing for cutthroat trout *Oncorhynchus clarki*. The lake is accessible via a short floatplane ride from Wrangell or a half-hour boat ride and 15-minute hike along a maintained U. S. Forest Service (USFS) trail. A USFS cabin at the northeast end of the lake is a common destination for anglers spending the night at the lake. From 1989 through 1997, an estimated 58–200 angler-days were fished annually at Virginia Lake to harvest 0–275 cutthroat trout (Appendix A1). Although cutthroat harvests at the lake are relatively low (<1% of the regional harvest), the lake is an important destination for local anglers.

In 1994, the Alaska Board of Fisheries adopted new regional trout regulations (Appendix A2) designating Virginia Lake a "high-use" lake with daily bag and possession limits for cutthroat trout of two fish between 14 and 22 in (356–559 mm) total length and gear restricted to artificial lures only. Prior to the regulation change, anglers were allowed daily bag and possession limits, respectively, of 5 and 10 fish—including only 1 daily and 2 in possession over 16 in (406 mm), and the use of bait was allowed. Since the regulation change, the department has received numerous calls and comments from local anglers indicating that the new regulations are too restrictive and should be relaxed.

In response to the concerns, a study was initiated in 1995 by the Alaska Department of Fish and Game (ADF&G) to assess the cutthroat trout population at Virginia Lake. The objective of this project was to estimate abundance and length distribution of cutthroat trout ≥180 mm fork length (FL). Sampling in 1995 allowed us to estimate abundance using a two-event closed population (CP) model, and sampling in 1996 and 1997 allowed us to estimate abundance in 1996 using an open population model. The two abundance estimates would, we reasoned, provide a robust analysis of population size at Virginia Lake.

STUDY AREA

Virginia Lake is located 11 km east of Wrangell, Alaska on the Southeast Alaska mainland, primarily within the Tongass National Forest (Figure 1). The lake is approximately 3.4 km long by 0.8 km wide, situated at an elevation of 32 m, with a surface area of 257 ha, mean depth of 28 m, and maximum depth of 54 m. Resident fish species include cutthroat trout, kokanee *O. nerka,* Dolly Varden char *Salvelinus malma*, threespine stickleback *Gasterosteus aculeatus*, and cottids (*Cottidae* spp.). Sockeye salmon *O. nerka* and Dolly Varden are the only anadromous species documented in ADF&G records to reach Virginia Lake. The lake outlet is Mill Creek, which empties into the Eastern Passage of Sumner Strait about 1 km downstream from the lake.

Little previous work was conducted on cutthroat trout at Virginia Lake. Jones (1980) noted the lake once had a reputation as a "trophy" cutthroat trout lake, but that some anglers later complained the lake was "fished out." He conducted a multiple-event CP (Schumacher-Eshmeyer) mark-recapture experiment during summer (June–September) and estimated a population of 5,631 cutthroat trout ("primarily") ≥90 mm FL (3.5 in) in the lake (Jones 1980).

In 1988, a fish pass was installed in Mill Creek, which drains into Eastern Passage, as part of a cooperative plan to develop a natural run of sockeye salmon into Virginia Lake (Edmundson et al. 1991). Cooperators included USFS, the Division of Fisheries Rehabilitation, Enhancement, and Development (FRED) of ADF&G, and the Southern Southeast Regional Aquaculture Association (SSRAA). Beginning in April 1989, and continuing in each subsequent spring through 1995, juvenile sockeye fry were released in Virginia Lake. Prior to fish pass installation a natural barrier on lower Mill Creek prevented immigration of anadromous fish, except during times of unusually high water levels (Edmundson et al. 1991). As of spring 1995, sea-run cutthroat trout had not been documented upstream from the natural barrier and fish pass on Mill Creek (M. Haddix, Alaska Department of Fish and Game, Ketchikan, personal communication).

Sport harvests of cutthroat trout in Alaska are estimated annually using a postal survey that samples purchasers of Alaska sport fishing licenses (e.g., Howe et al. 1997). Harvest estimates for Virginia Lake from this survey have been imprecise because of low sampling rates and were not published. Harvest estimates for 1995 and 1996, for example, were 26 and 59 fish. Harvest estimates for Virginia Lake, 1993–1995, were also available from a postal survey of registered users of USFS cabins in Southeast Alaska (Jones 1993, 1994, 1995). Estimates from the USFS cabin survey are minimums because not all anglers use USFS cabins. At Virginia Lake, harvest estimates from the cabin surveys are lower than unpublished (statewide survey) estimates, and thus were not of interest in this study.

METHODS

Mark-recapture experiments were used to estimate the abundance of cutthroat trout ≥180 mm FL in Virginia Lake during early summer 1995 and in early May 1996. Sampling in 1995 occurred during three 9- to 10-day sampling trips, from May 9 to June 26, to estimate abundance with a two-event Petersen/Darroch closed population (CP) model. Sampling was continued over 10 days each summer in 1996 and 1997 (i.e., for a total k = 3 years) to estimate abundance in May 1996 using the Jolly-Seber (JS) model for an open population.

The lake was divided into three sections of roughly equal size (Figure 2) to facilitate sampling, data recording, and evaluation of the experimental assumptions. The three sampling areas were further divided into three sections (nine areas total, not shown) so that daily sampling would proceed systematically from one end of the lake to the other.

During each 9- to 10-day sampling trip, baited traps were systematically moved through the nine sampling areas so that the total amount of gear set was uniformly distributed across all areas of the lake ≤40 m in depth. Immediately prior to each sampling, trap placements were determined by randomly selecting a predetermined number of points on enlarged maps of each sampling area. Traps were set overnight on the lake bottom and depths measured with a fathometer. In addition, hook-and-line (H&L) sampling was conducted by casting or trolling a variety of small lures (spinners, small spoons and other artificial lures) from a boat as it traversed the lake's perimeter.

Baited hoop traps were constructed with four metal hoops and knotless nylon netting, each 1.5 m long and 0.6 m wide with a single 9-cm diameter opening at one end. Salmon eggs disinfected in a 1% Betadine solution for 15 minutes and cured with Borax, along with chunks of herring or canned shrimp (in some traps), were suspended in a perforated bait container within each trap. Salmon eggs were also placed loosely in the traps.

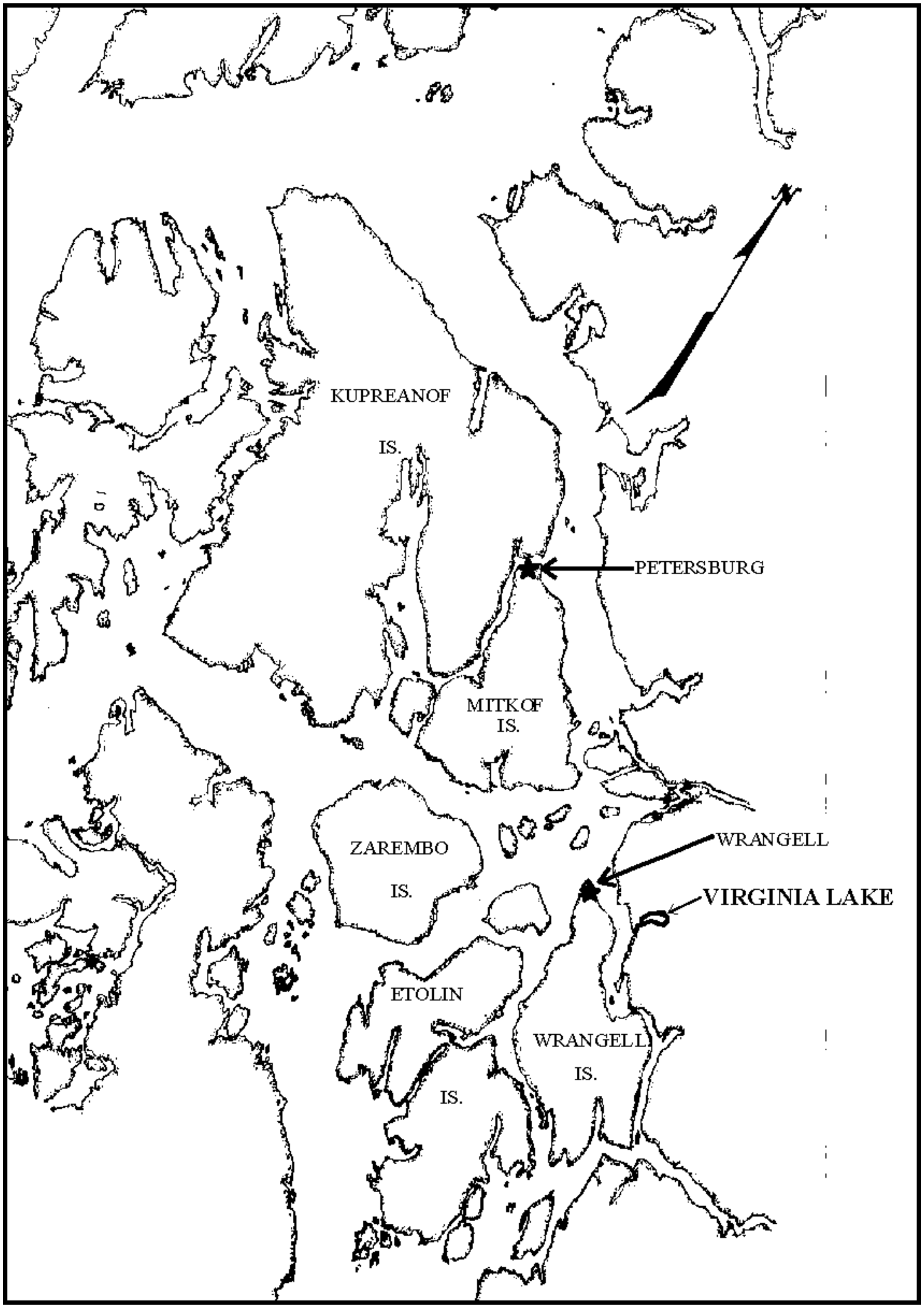


Figure 1.–Petersburg/Wrangell area and location of Virginia Lake in southern Southeast Alaska.

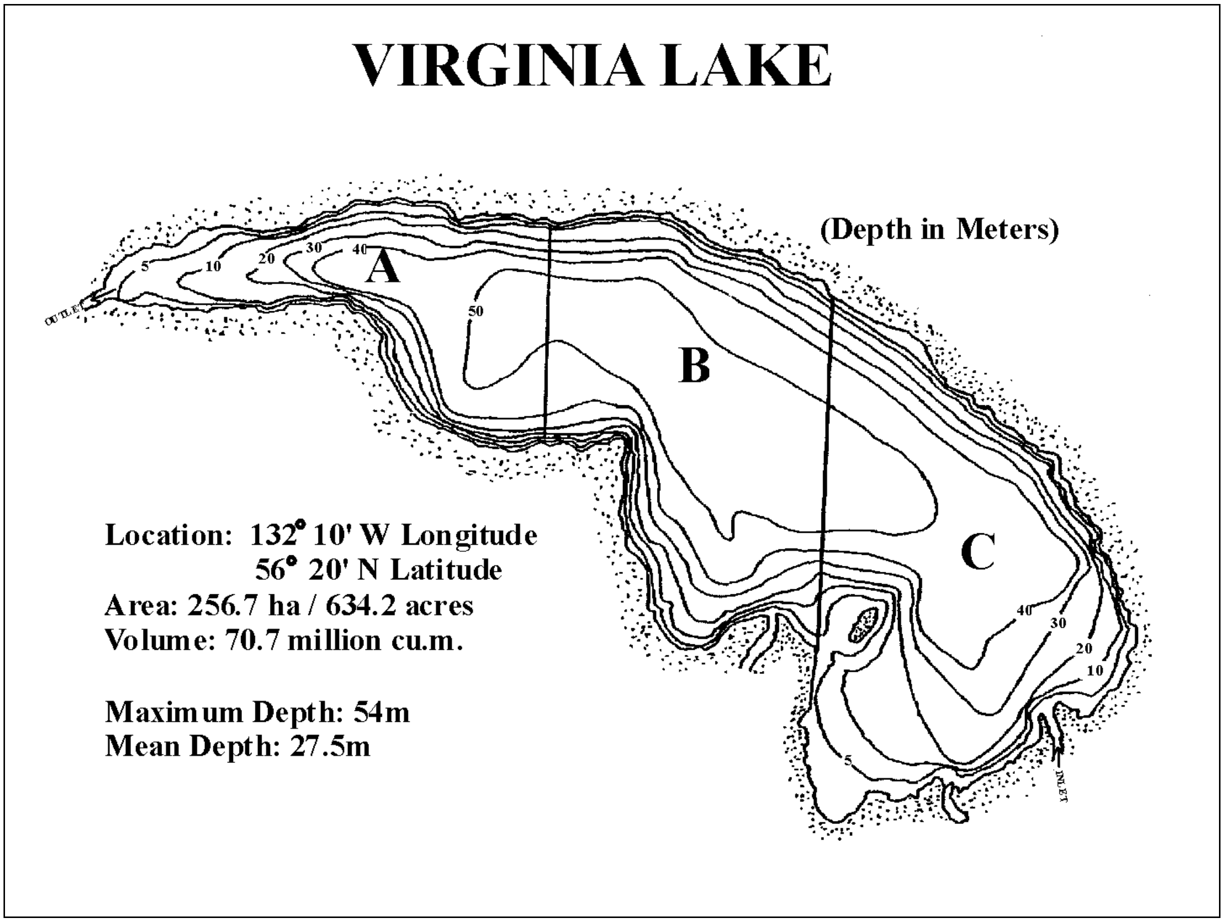


Figure 2.–Study map of Virginia Lake with lake bathymetry and sampling areas shown (T. Zadina, ADF&G).

All cutthroat trout ≥180 mm FL sampled were examined for marks, measured to the nearest mm FL, tagged with a numbered anchor T-bar tag if unmarked (except for fish captured during event 2 in 1995), given a secondary mark to permit estimation of tag loss, and released in the area where captured. Tags were inserted on the left side of the fish immediately below the dorsal fin. Secondary marks were clipped adipose fins in 1995, partial removal of ventral fins in 1996, and a shallow caudal fin clip in 1997. Scales were collected from most fish sampled. Scales were sampled from the caudal peduncle directly above the lateral line. Cutthroat trout <180 mm FL, Dolly Varden, and kokanee captured were only counted

ESTIMATION OF ABUNDANCE IN 1995 UNDER THE CP MODEL

Data for the first (marking) event of the CP model were collected during sampling trips conducted from May 9 to May 22 and from May 23 to June 5, and pooled. Following a 10-day hiatus, a second (recapture) event was conducted between June 16 and June 26. Unmarked fish captured during this later period were not given numbered tags, but were marked by a shallow clip of the upper lobe of the caudal fin to prevent double sampling.

Assumptions to be met for the CP single mark-release experiment are:

1. The population is closed; i.e., recruitment (or immigration) and death (or emigration) do not both occur between sampling events;
2. Every fish has an equal probability of being marked during the first event, *or* every fish has an equal probability of being sampled during the second event, *or* marked and unmarked fish mix completely between events;
3. Marking does not affect the catchability of a fish; and
4. Fish do not lose marks between events, and marks are recognized and reported.

The CP assumption is reasonable, given the relatively short time (10 days) between the two sampling events, but less certain when sampling goals and logistic constraints dictated sampling over a 6-week period. Even though no significant natural mortality or growth recruitment was expected at this time of the year, this assumption cannot be tested in a two-event experiment.

We tested the second assumption with respect to space (lake area), and fish size. The assumption that marked fish were recovered with equal probability in each part of the lake was evaluated with contingency table analysis by testing if, given *some* mixing between areas, marked fish were recaptured with equal probability in each of the three sampling areas during the recovery event. If this hypothesis were accepted ($\alpha = 0.1$) a simple Petersen model would be used to estimate abundance; if not, the stratified estimator (Darroch 1961; Seber 1982, Chapter 11) would be used. Size-selectivity was tested with two Kolmogorov-Smirnov (KS) tests. If size-selective sampling were apparent in the recovery event data, stratification by size group would be evaluated (Appendix A3).

We cannot test for effects of marking on catchability with only two sampling events. Evidence of tag loss and tagging stress was recorded for every fish handled. Because all tagged fish were given a permanent secondary mark (a fin clip), tag loss was measured and could be accounted for in the estimates.

Estimation of Abundance in 1996 under the JS Model

Data for the JS analysis to estimate abundance in 1996 were obtained by pooling sampling data each year. Fish captured several times in a summer were treated as being caught only once. Sampling in 1996 and 1997 occurred from May 1 to May 10.

The assumptions required for accurate estimation under the JS model are as follows (Seber 1982):

1. every fish in the population has the same probability of capture in the *i*th sample;
2. every marked fish has the same probability of surviving from the *i*th to the (i + 1)th sample and being in the population at the time of the (i + 1)th sample;
3. every fish caught in the *i*th sample has the same probability of being returned to the population;
4. marked fish do not lose their marks between sampling events and all marks are reported on recovery; and,
5. all samples are instantaneous (i.e., sampling time is negligible).

A goodness-of-fit (GOF) test (of marked fish seen before versus not seen before *against* seen again versus not seen again) as discussed in Pollock et al. (1990) was used to test the assumptions of homogeneous capture and survival probabilities in 1996. The test is equivalent to the Robson (1969) test for short-term mortality (Pollock et al. 1990).

The condition that the probability of capture is the same for all fish within a sampling event can be waived in an experiment based on the JS model if marked and unmarked fish mix completely between sampling events (Seber 1982). A test for mixing *by mark status* is to compare the recapture/capture (R/C) fractions of fish caught with traps on the lake bottom to those caught near shore with hook-and-line, *using only fish marked with traps in the previous year.* If $(R/C)_{trap} > (R/C)_{H\&L}$, lack of complete mixing is indicated, if $(R/C)_{trap} = (R/C)_{H\&L}$, complete mixing is indicated, and if $(R/C)_{trap} < (R/C)_{H\&L}$,

trap shyness is indicated. A chi-square (2 × 2 contingency table) statistic ($\alpha = 0.1$) was used for the test. Because H&L sampling in 1996 was very limited, comparisons were limited to fish marked by H&L in 1995 or 1995–1996 and then recaptured with both gear types in 1997.

The assumption of equal probabilities of capture is also violated by differential vulnerability to sampling gear (size-selective sampling). A test for size-selective sampling was conducted by comparing an abundance estimate for the entire population of cutthroat trout ≥180 mm FL against the sum of estimates obtained by stratifying the experiment into two size classes. If size-selective sampling was not significant, the sum of the stratified estimates should not be significantly different from the estimate for all fish ≥180 mm FL. We stratified the capture data at 240 mm FL (roughly in half) as this has proven effective in other studies. Adequacy of the stratified data set for large fish was tested using the GOF test noted above. However, the procedure cannot be applied to the smaller size class, because marks applied at time i-1 will more likely have grown out of the analysis than fish marked at time i. Also, the annual survival rate estimate for the small size class is meaningless, because small fish can grow into the larger size class between events.

The assumption that all fish have the same chance of surviving from the ith to the $(i + 1)$th sampling implies the absence of significant age-dependent mortality rates for cutthroat trout ≥180 mm FL (Manly 1970). Little evidence of age-dependent mortality was found for cutthroat trout ≥180 mm FL in Florence Lake (Rosenkranz et al. 1998). An indication of size (or age) dependent mortality in this experiment can be obtained by comparing survival estimates from the larger size class of the length-stratified analysis (described above) to the survival estimates from the unstratified analysis. If the two estimates were similar, the absence of a strong age-dependent mortality schedule at Virginia Lake would be indicated.

Assumption 3 was evaluated by direct examination of the capture histories (mortality status by year) from each event. Double-marking fish with secondary marks addressed assumption 4. Tag loss was calculated for each sampling date/year. Estimates of loss >10% will necessitate special consideration of bias in the estimates.

Assumption 5 seemed reasonable in this experiment, for sampling was confined to 27 days in 1995 (data are limited to event 1), and to 10 days each in 1996 and 1997. Because this was a relatively short period of time in the context of the experiment, we assumed that additions and losses (recruitment and death) to the population during each sampling were insignificant.

Capture histories for the JS analysis were summarized using SAS (SAS 1990), then input to program JOLLY (Brownie et al. 1986) for computation of the GOF statistics and population parameters.

Length Composition

Because sampling gear can be selective for fish of different sizes, the calculation to estimate length composition of the population was conditioned on results from two KS tests (Appendix A3). Because corrections for size-selective sampling were unnecessary, length composition in 20-mm length classes k was estimated:

$$\hat{p}_k = \frac{n_k}{n} \tag{1}$$

$$\text{var}(\hat{p}_k) = \frac{\hat{p}_k(1 - \hat{p}_k)}{n - 1} \tag{2}$$

where n is the number of fish sampled for length, and n_k is the number sampled in length class k.

Catch Per Unit Effort

Mean catch per unit effort (CPUE) by sampling period and gear type was calculated by standard statistical methods. These data are useful for planning and for comparing relative catch rates at different lakes and/or times of the year.

RESULTS

ABUNDANCE IN 1995 UNDER THE CP MODEL

During the first sampling event, 2,632 cutthroat trout between 180 and 408 mm FL were marked and released alive. Of this total, 1,618 were marked in the first 10-day sampling trip and 1,014 were marked in the second 10-day sampling trip. During the second sampling event (the third 10-day trip) 1,316 unique cutthroat trout between 180 and 385 mm FL were examined, and 529 of these had been marked during the first event. Tag loss during the 1995 experiment was estimated at 1% (5 of 529 fish recaptured in the third sampling trip). CPUE for cutthroat trout in traps declined slowly with increasing depth to near 0 fish/trap at 35 m. Sampling appeared to encompass the entire catchable population available to our gear.

The length distributions of cutthroat trout captured during the first event and recaptured during the second event (Figure 3, top panel) were significantly different (KS test, $D_{max} = 0.14$, $P < 0.001$). Size-selective sampling during the second sampling event was also indicated by a contingency table analysis when the numbers marked and recaptured were partitioned into discrete size groups ($\chi^2 = 8.3$, $P = 0.04$, Table 1, Appendix A3). Note that the uniform change in the size distributions (Figure 3, top panel) suggests that growth, rather than size-selective sampling, might be responsible for the observed differences. A comparison of abundance estimates from unstratified and stratified Petersen models was made to determine if size-selectivity was functionally significant. Results of the comparison (Table 2) show size-selective sampling was not functionally significant: $\hat{N} = 6{,}542$ (SE = 196) in the unstratified analysis versus $\hat{N} = 6{,}709$ (SE = 225) in the stratified analysis. Thus, stratified models were not adopted for the analysis.

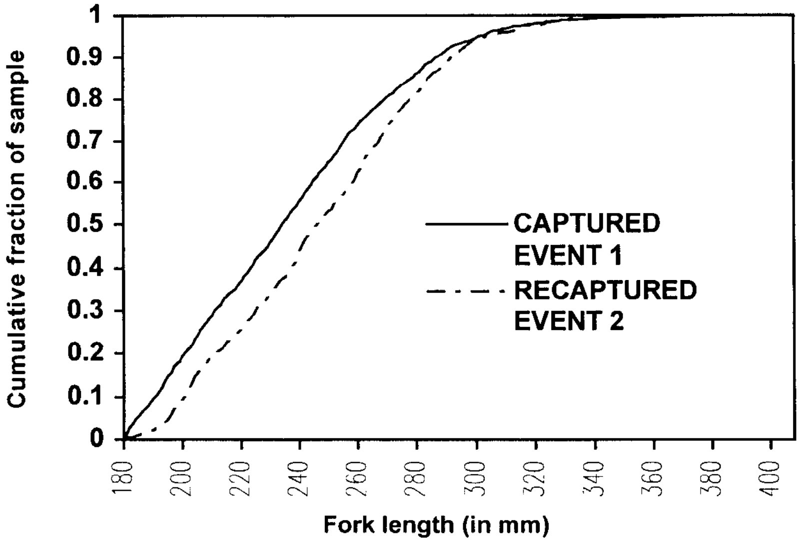
Although some mixing of marked fish into the population was obvious (Table 3), a hypothesis of equal marked fractions was rejected (Table 4; $\chi^2 = 5.9$, $P = 0.052$) showing that mixing was incomplete and capture probabilities were not equal across the lake during the marking event.

The Darroch estimator for partial mixing was used to estimate abundance. An estimated $\hat{N} = 6{,}810$ (SE = 256) cutthroat ≥180 mm FL were present in Virginia Lake during late June 1995. The 95% confidence intervals (CI) for the estimate were (6,308, 7,312) using the approximation CI = $\hat{N} \pm 1.96 \cdot SE(\hat{N})$.

ABUNDANCE IN 1996 UNDER THE JS MODEL

At Virginia Lake in 1996, 1,001 fish between 180 and 352 mm FL were sampled and returned to the population; in 1997, 1,331 fish between 180 and 377 mm FL were sampled and returned to the population. Excluding fish with lost T-bar tags, 176 of the fish sampled in 1996 and 214 of those sampled in 1997 had been marked in prior years. Tag loss was estimated at 7.8% from 1995 to 1996 and at 5.7% overall for fish recovered in 1997, and thus discounted as a significant factor in the analysis.

The estimated abundance of cutthroat trout ≥180 mm FL in Virginia Lake during early May 1996 was 3,620 (SE = 415; Table 5, Appendix A4). Ninety-five percent (95%) confidence intervals (CI) for the estimate are (2,807, 4,433) using the approximation CI = $\hat{N} \pm 1.96 \cdot SE(\hat{N})$. A GOF test for homogeneous capture/survival probabilities reveals no inadequacy ($P = 0.53$; Table 6). Similarly, the estimated survival rates for all fish (0.243) and large fish (0.254) are also similar (Table 5). Contingency table tests for mixing by mark status indicate mixing of marks between 1995 and 1997 ($P = 0.69$; Table 7), and for (pooled) marks placed in 1995–1996 and captured in 1997 ($P = 0.54$; Table 7). Effects of size-selective sampling were not significant, as an estimate of abundance obtained by stratifying the experiment by size groups ($\hat{N} = 3{,}133$, SE = 556, Appendices A5–A6) was not significantly different ($P = 0.48$) from the unstratified estimate. Overall, the experiment assumptions appeared to be met, although experimental power ($1-\beta$) to detect failures of assumptions 1 and 2 is not high. A key to data archived in this analysis is Appendix A7.



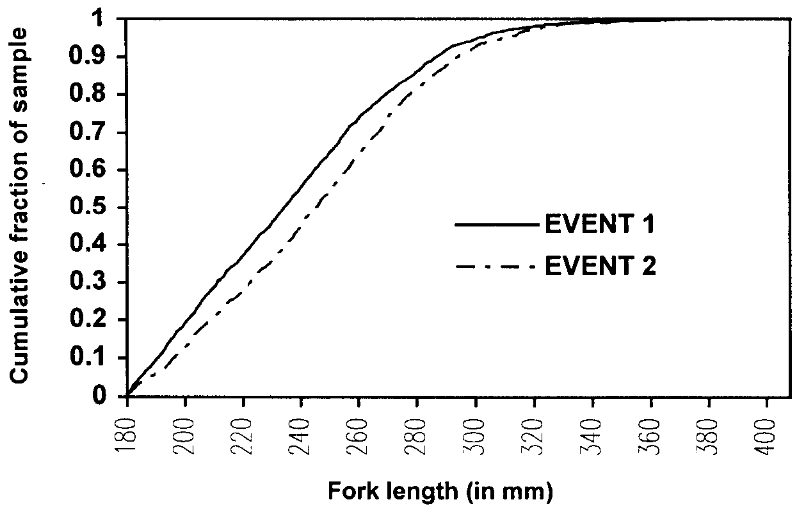


Figure 3.–Cumulative distributions of lengths of cutthroat trout marked in event 1 versus lengths of cutthroat trout recaptured in event 2 (top) and examined during event 2 (bottom), Virginia Lake, 1995.

Length Composition

The length distributions of cutthroat trout captured during the first event and captured during the second event (Figure 3) in 1995 were significantly different (KS test, $D_{max} = 0.11$, $P < 0.001$). Although size-selective sampling was detected during the recovery event (above), the likelihood of selective sampling during the first sampling event in 1995 is indeterminate (Appendix A3). As noted above, growth recruitment and not (functionally significant) sampling selectivity are indicated. We therefore pooled all sampling data from 1995 to estimate length composition of the population.

The estimated length composition of cutthroat trout ≥180 mm FL in Virginia Lake during the

Table 1.–Numbers of marked cutthroat trout recovered by length category, and results of chi-square test to test significant differences during event 2 in 1995.

Length category	Length (mm FL)	Recaptured [a]	Not recaptured [a]	Proportion recovered
I	180–220	167	803	0.17
II	221–260	202	751	0.21
III	261–300	124	419	0.23
IV	>300	27	112	0.19

[a] Excludes fish without lengths recorded at time of marking or recovery.

H_O: $P_I = P_{II} = P_{III} = P_{IV}$ (recapture rates equal for each size class)

Result: $\chi^2 = 8.3$, df = 3, P = 0.04; reject H_O.

early summer of 1995 was mostly (51%) composed of fish <240 mm FL (Table 8). Eighty-four percent (84%) of the population in 1995 was <280 mm FL. Only 40 of the 3,939 cutthroat sampled (1%) were longer than the 14-in minimum size limit (>336 mm FL) established for the sport fishery.

Catch Per Unit Effort

Catch per unit effort of cutthroat trout ≥180 mm FL caught with trap gear (Table 9) ranged from a high of 10.1 fish per trap in 1997 to a low of 7.0 in 1995.

DISCUSSION

A prominent feature of this research was the difference between the JS abundance estimate for 1996 and the CP estimate for 1995. Although these two estimates are not strictly comparable because they pertain to different years, the difference is probably not attributable to natural fluctuation in population size (i.e., differences in annual recruitment and mortality rates). Thus, some undetected failure(s) of the experimental assumptions were likely. Rosenkranz et al. (1998) observed similar differences between CP and JS abundance estimates at Florence Lake. They found that sampling during the spawning

Table 2.–Estimates of abundance (fish ≥180 mm FL) based on stratified and unstratified Petersen models, Virginia Lake, 1995.

Length class	Length (mm FL)	No. marked (n_1)	No. sampled (n_2)	No. marks in n_2 (m_2)	Fraction marked (m_2/n_2)	Est. abundance (N)	Est. SE of abundance (SE[N])
DATA STRATIFIED BY LENGTH [a]							
I	180–220	970	369	132	0.36	2,700	174
II	221–260	953	472	191	0.40	2,349	117
III	261–300	543	376	168	0.45	1,213	57
IV	> 300	139	95	29	0.31	447	59
Sum	≥ 180	2,605	1,312	520	0.40	6,709	225
DATA UNSTRATIFIED BY LENGTH							
All	≥ 180	2,632	1,316	529	0.40	6,542	196

[a] Stratified analysis excludes fish without lengths recorded at time of marking or recovery.

Table 3.–Number of cutthroat trout ≥180 mm FL recovered by tagging and recovery area (m_{ij}), number marked by area (a_i), and number of unmarked captures by area during event 2 (u_j), Virginia Lake, 1995. (Two recaptures from unknown tagging area are excluded.)

Tagging area (m_{ij})	Recovery area (m_{ij})			
	A	B	C	a_i
A	93	21	8	464
B	38	86	59	820
C	25	53	144	1,348
u_j	213	207	367	

Table 4.–Number of marked and unmarked cutthroat trout ≥180 mm FL captured in sampling event 2 by recovery area, Virginia Lake, 1995.

Area	Number with marks	Number without marks	Proportion marked
A	158	213	0.43
B	160	207	0.44
C	211	367	0.37

H_O: $p_A = p_B = p_C$

Result: $\chi^2 = 5.9$, df = 2, P < 0.052; reject H_O.

migration resulted in JS estimates that excluded an unknown portion of the spawning population. Also, estimates based on sampling only a portion of the lake's fishable habitat resulted in biased estimates. These and other explanations, such as a temporary reduction in the catchability of recently captured fish and mortality related to handling and tagging, were considered as possible causes of the discrepant abundance estimates at Virginia Lake.

The possibility that marking temporarily lowered the catchability of marked fish and biased the CP estimate high was easily investigated at Virginia Lake because sampling in 1995 was not highly size-selective (Figure 3, Tables 1 and 2), and the marked fractions did not vary much by area (Table 4). We compared the fraction of fish sampled with marks in the second sampling event of 1995 to the fraction with marks (from the 1995 sampling) during 1996. If marked fish were less catchable just after the hiatus between sampling events in 1995, the marked fraction in 1996 (culled of recruits) should be greater than the marked fraction during the second event of 1995.

Obviously, the fraction of fish sampled in 1996 that were marked in 1995 (Table 10) increased sharply as fish size increased because unmarked (young) fish recruited into the population between sampling events. However, as recruitment into larger size classes waned, the marked fraction in 1995 (Table 2) was estimated. Clearly, results for the larger size classes in 1996 (0.35, 0.42, 0.39; Table 10) are nearly identical to the estimates made during the CP experiment in 1995 (0.40; Table 2). Our ability to catch marked fish was not temporarily lowered in 1995 to the extent needed to explain the discrepancy between abundance estimates.

Table 5.–Jolly-Seber parameter estimates and standard errors. Appendices A4–A6 contain sampling statistics for unstratified JS model (panel A), and the size-stratified JS models (panels B, C).

PANEL A: Cutthroat trout ≥180 mm FL

Year	N	SE(N)	ϕ	SE(ϕ)	p	SE(p)
1995			0.243	0.025		
1996	3620	415			0.275	0.032

PANEL B: Cutthroat trout 180–240 mm FL

Year	N	SE(N)	ϕ	SE(ϕ)	p	SE(p)
1995			0.083	0.016		
1996	1254	240			0.560	0.108

PANEL C: Cutthroat trout >240 mm FL

Year	N	SE(N)	ϕ	SE(ϕ)	p	SE(p)
1995			0.254	0.0614		
1996	1879	502			0.152	0.410

Table 6.–Goodness-of-fit tests for homogeneous capture/survival probabilities by tag group in 1996 (p = probability of capture for each tag group). Results are for the unstratified JS model (panel A), and for large fish in the size stratified JS model (panel B).

PANEL A: 1996—All fish ≥180 mm FL		First captured in 1995	First captured in 1996
Captured in 1996 and recaptured later		23.0	123.0
Expected value		25.7	120.3
Captured in 1996 and not recaptured later		153.0	702.0
Expected value		150.3	704.7
$\chi^2 = 0.39$, df = 1, P = 0.5361	$\hat{p} \rightarrow$	0.13	0.15

PANEL B: 1996—Fish ≥240 mm FL		First captured in 1995	First captured in 1996
Captured in 1996 and recaptured later		2.0	23.0
Expected value		4.0	21.0
Captured in 1996 and not recaptured later		44.0	221.0
Expected value		42.0	223.0
$\chi^2 = 1.27$, df = 1 , P = 0.26	$\hat{p} \rightarrow$	0.043	0.094

Table 7.–Goodness-of-fit tests for complete mixing of fish marked (of all sizes) offshore with traps, by recovery method/location in 1997.

Panel A: marked in 1995		Captured offshore by trap in 1997	Captured onshore by H&L in 1997
Recaptures marked in traps in 1995		214.0	9.0
Expected value		212.9	10.1
Captures not marked in traps in 1995		1068.0	52.0
Expected value		1069.1	50.9
$\chi^2 = 0.16$, 1 df, P = 0.69	$\hat{p} \rightarrow$	0.17	0.15

Panel B: marked in 1995 and 1996		Captured offshore by trap in 1997	Captured onshore by H&L in 1997
Recaptures marked in traps in 1995–96		214.0	12.0
Expected value		215.7	10.3
Captures not marked in traps in 1995–96		1068.0	49.0
Expected value		1066.3	50.7
$\chi^2 = 0.37$, 1 df, P = 0.54	$\hat{p} \rightarrow$	0.17	0.20

Table 8.–Length composition of cutthroat trout ≥180 mm FL sampled in Virginia Lake during 1995 with hook and line and traps.

Fork length (mm)	Count (n_i)	Proportion (p_i)	SE (p_i)
180–199	639	0.1622	0.015
200–219	681	0.1729	0.015
220–239	690	0.1752	0.014
240–259	738	0.1874	0.014
260–279	557	0.1414	0.015
280–299	381	0.0967	0.015
300–319	159	0.0404	0.016
320–339	58	0.0147	0.016
340–359	22	0.0056	0.016
360–379	12	0.003	0.017
380–399	1	0.0003	n/a
400+	1	0.0003	n/a

Significant mortality of marked fish between sampling events in 1995 *might* also cause the CP estimate to be biased high. If such mortality occurred, the recapture rate in 1996–1997 of fish marked in the first event of 1995 and seen again in the second event of 1995 would be greater than the recapture rate of fish marked in the first event of 1995 and not seen in the second event of 1995. Results of this comparison indicate a significant heterogeneity between the two marked groups (P = 0.01, Table 11). Mortality related to natural causes (e.g., spawning) or effects of handling and/or tagging are potential explanations for this heterogeneity. Also, sampling only a portion of the fishable habitat could lead to this result, as some marked fish could "emigrate" to the unfished area and remain uncatchable (Rosenkranz et al. 1998). This latter possibility seems unlikely, because all depths of the lake with significant catch rates were fished, and inlet and outlet areas with cutthroat trout are limited in Virginia Lake. In particular, the outlet stream is only about 1 km in length, and our attempt to capture marked fish in that area during the experiment was largely unsuccessful.

Table 9.– Effort and catch statistics (top panel) and catch per unit effort (CPUE, lower panel) for cutthroat trout (CT) and Dolly Varden (DV) captured in traps (fish/set) and with hook and line (HL, fish/hr) at Virginia Lake 1995–1997.

			Catch					
	Effort		DV		CT <180mm		CT ≥180mm	
Year	No.traps	HL hrs	Trap[a]	HL	Trap[a]	HL	Trap[a]	HL
1995	540	171.5	6,193	1	1,885	15	3,756	200
1996[a]	126	18.0	1,414	0	882	4	998	5
1997	126	18.0	1,397	3	1,605	3	1,267	61

	CPUE					
	DV		CT <180mm		CT ≥180mm	
Year	Trap[a]	HL	Trap[a]	HL	Trap[a]	HL
1995	11.5	0.006	3.5	0.09	7.0	1.17
1996[a]	11.2	0.00	7.0	0.22	7.9	0.28
1997	11.1	0.17	12.7	0.17	10.1	3.39

[a] Traps were generally fished for 18–30 hr/set. HL effort in 1996 was mostly by trolling offshore.

Table 10.–Fraction of fish sampled in 1996 that were marked in 1995, by length class.

Length class	No. marks from 1995 in n_2 (m_2)	No. sampled in 1996 (n_2)	Fraction marked (m_2/n_2)
180–220	25	545	0.05
221–260	108	312	0.35
261–300	47	113	0.42
>300	12	31	0.39

Mortality related to handling and tagging was possible in this experiment, as long as it was confined to 1995 (results of the GOF test in Table 6 pertain to 1996). In contrast, natural mortality of both tagged and untagged fish (e.g., due to spawning) seems less likely because such an effect would not be confined to 1995. Similarly, because sampling at Virginia Lake extended to depths where fish were no longer caught each year, the proposition that spatial sampling was restricted in 1995 seems unlikely. Except for natural mortality of both tagged and untagged fish, each of the potential causes of the observed heterogeneity would lead to a small upward bias in the CP estimate.

Table 11.–Test for homogeneous capture/ survival rates among fish captured in 1995. The contingency table partitions fish marked in event 1 of 1995 according to their status immediately after sampling in event 2. The recovery rate for fish seen in event 2 was significantly higher than for fish not seen in event 2.

	Marked in event 1 (1995)	
	Seen in 2	Not seen in 2
Seen 96–97	64	180
Not seen 96–97	463	1,925
	0.121	0.086

$\chi^2 = 6.4$, df = 1, P = 0.011

Another explanation for the difference between abundance estimates is that a portion of the spawning population was unavailable for sampling during the early (May 1–10) sampling events in 1996 and 1997. The JS estimate of 3,620 fish could then be correct, but for those trout available to the gear in the lake rather than the whole population. Spawning migrations in small streams at Florence Lake do occur during May (Harding 1995; Rosenkranz et al. 1998), so the assumption is reasonable. Spawning probably concluded prior to June 16, when the second sampling event of the 1995 CP experiment began. Provided there was no mortality of trout tagged during the 1995 experiment, the Petersen estimate would be unbiased and relevant to abundance in late June.

The low survival estimate for the period 1995 to 1996 (ϕ = 0.24) provides additional support for the temporary emigration hypothesis: marked fish engaged in spawning in 1996 and 1997 were unavailable for sampling and would appear as "dead" fish in the eyes of the JS model. In comparison, annual survival rates at Florence Lake are much higher (ϕ = 0.42 to 0.54), even though the estimates were believed to be biased low (Rosenkranz et al. 1998).

Changes in the size distributions of fish sampled each year were consistent with the emigration hypothesis. Samples during 1995 showed a shift toward larger fish in late June (Figure 3, lower panel). Also, the size distributions of trout sampled in early May of 1996 and 1997 shifted towards smaller fish, relative to 1995 (Figure 4). The shift to smaller fish in 1996 and 1997 would be expected if a large fraction of mature trout spawned in early May and therefore were not available to the gear.

Other explanations for the low survival estimate at Virginia Lake are possible. Many fish may naturally emigrate from Virginia Lake, for example. A similar, low estimate of survival (ϕ = 0.27) was obtained for fish ≥ 180 mm FL at Lake Eva, a system well known for its

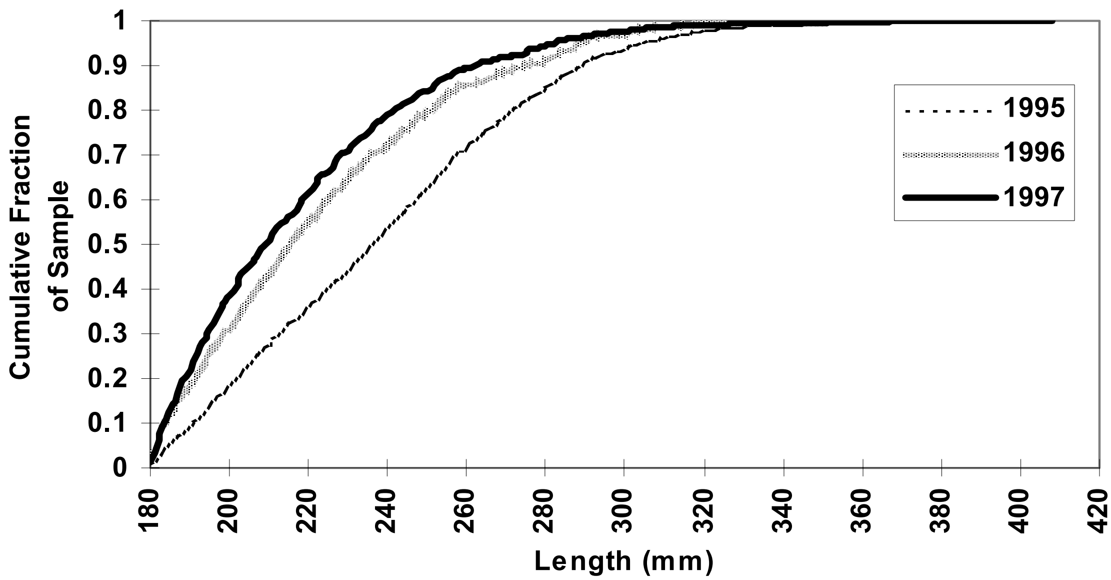


Figure 4.–Cumulative distributions of lengths of cutthroat trout captured at Virginia Lake in traps during 1995, 1996, and 1997.

anadromous cutthroat trout population (Schmidt et al. 1998). We are unaware, however, of a significant anadromous component to the Virginia Lake population. Another possibility is that the resident cutthroat trout did not compete well against the juvenile sockeye salmon released in the lake each spring, but the cutthroat trout in Virginia Lake did not appear thin or highly stressed during our sampling, as they would if this were true.

In summary, the adequacy of the CP and JS experiments is clarified by combining results from each experiment with knowledge of spawning behavior at another lake. Evidence for a temporary reduction in catchability that could lead to the discrepant abundance estimates is lacking. Some heterogeneity was detected among groups of fish tagged over time in 1995. While the cause of the heterogeneity is uncertain, its potential impact is not large. Results in this study indicate slightly higher natural mortality rate for "older" fish, but not nearly enough to produce the magnitude of difference between estimated abundance for 1995 and 1996. Considering that timing of sampling may have affected the estimated "survival" rates, there is little evidence for age-specific differences in mortality rates in this experiment. Sampling during temporary emigrations for spawning in 1996 and 1997 is the most likely explanation of the observed discrepancies. Sampling during the spawning migrations of 1996 and 1997 biased the JS estimate low with respect to the entire population. Some mortality related to handling and tagging may have also occurred in 1995; that would bias both the CP and JS estimates somewhat high if it occurred.

Only 1% of the fish sampled from mid-May to late June 1995 (Table 8) were larger than the minimum legal size (14 in, or about 336 mm FL).

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APPENDIX A

Appendix A1.–Estimated angler effort and cutthroat harvest, Virginia Lake system, 1989-1996. Estimates are unpublished results from the Alaska statewide harvest survey (Al Howe, Alaska Department of Fish and Game, Anchorage, personal communication), and are considered unreliable because of the small number of respondents each year.

Year	Days fished	Cutthroat harvested
1989	157	275
1990	136	161
1991	58	119
1992	62	92
1993	200	67
1994	142	54
1995	130	26
1996	117	59
1997	48	0

Appendix A2.–Harvest regulations for Virginia Lake, 1960–1997.

Years	Daily limit	Additional restrictions	Possession limit
1960-1974	15	3 > 20 in	2 daily bag limits
1975-1979	10	2 > 20 in	2 daily bag limits
1980-1982	4	1 > 16 in	1 daily bag limit
1983-1984	4	1 > 16 in	2 daily bag limit
1985-1993	5	1 > 16 in	2 daily bag limit
1994-1997	2	14-22 in only, bait prohibited year-round	1 daily bag limit

Appendix A3.–Detection of size-selective sampling (from Bernard and Hansen 1992).

Result of Hypothesis Test on Lengths of fish CAPTURED during the First Event and RECAPTURED during the Second Event	Result of Hypothesis Test on Lengths of fish CAPTURED during the First Event and CAPTURED during the Second Event
Case I: **Accept H_o**	**Accept H_o**
There is no size-selectivity during either sampling event.	
Case II: **Accept H_o**	**Reject H_o**
There is no size-selectivity during the second sampling event but there is during the first.	
Case III: **Reject H_o**	**Accept H_o**
There is size-selectivity during both sampling events.	
Case IV: **Reject H_o**	**Reject H_o**
There is size-selectivity during the second sampling event; the status of size-selectivity during the first event is unknown.	

Case I: Calculate one unstratified abundance estimate, and pool lengths, sexes, and ages from both sampling events to improve precision of proportions in estimates of composition.

Case II: Calculate one unstratified abundance estimate, and only use lengths, sexes, and ages from the second sampling event to estimate proportions in compositions.

Case III: Completely stratify both sampling events, and estimate abundance for each stratum. Add abundance estimates across strata to get a single estimate for the population. Pool lengths, ages, and sexes from both sampling events to improve precision of proportions in estimates of composition, and apply formulae to correct for size bias to the pooled data.

Case IV: Completely stratify both sampling events and estimate abundance for each stratum. Add abundance estimates across strata to get a single estimate for the population. Use lengths, ages, and sexes from only the second sampling event to estimate proportions in compositions, and apply formulae to correct for size bias to the data from the second event.

Whenever the results of the hypothesis tests indicate that there has been size-selective sampling (Case III or IV), there is still a chance that the bias in estimates of abundance from this phenomenon is negligible. Produce a second estimate of abundance by not stratifying the data as recommended above. If the two estimates (stratified and unbiased vs. biased and unstratified) are dissimilar, the bias is meaningful, the stratified estimate should be used, and data on compositions should be analyzed as described above for Cases III or IV. However, if the two estimates of abundance are similar, the bias is negligible in the UNSTRATIFIED estimate, and analysis can proceed as if there were no size-selective sampling during the second event (Cases I or II).

Appendix A4.–Summary statistics (above) and capture histories for the unstratified Jolly-Seber model, fish ≥180 mm FL, Virginia Lake.

{PRIVATE }Year	n_I	m_I	R_i	r_I	z_i
1995	2,632	0	2,632	244	0
1996	1,001	176	1,001	146	68
1997	1,331	214	1,331	0	0

Capture history	Frequency
001	1,117
010	702
011	123
100	2,388
101	68
110	153
111	23

Appendix A5.–Summary statistics (above) and capture histories for the stratified Jolly-Seber model, fish 180-240 mm FL, Virginia Lake.

{PRIVATE }Year	n_I	m_i	R_I	r_I	z_i
1995	1,438	0	1,438	73	0
1996	711	67	711	80	6
1997	1,001	86	1,001	0	0

Capture history	Frequency
001	915
010	567
011	77
100	1,365
101	6
110	64
111	3

Appendix A6.–Summary statistics (above) and capture histories for the stratified Jolly-Seber model, fish >240 mm FL, Virginia Lake.

{PRIVATE }Year	n_I	m_i	R_I	r_I	z_i
1995	1,194	0	1,194	69	0
1996	290	46	290	25	23
1997	330	48	330	0	0

Capture history	Frequency
001	282
010	221
011	23
100	1,125
101	23
110	44
111	2

Appendix A7.–Historical data and raw data files used to produce this report.

File Name	Software	Contents
95EVEN12.XLS	Excel	Trap and sport fishing catches, tag numbers, lengths and sample numbers at Virginia Lake in 1995
96VAWL1.XLS	Excel	Trap and sport fishing catches, tag numbers, lengths and sample numbers at Virginia Lake in 1996
97VAWLEF.XLS	Excel	Trap and sport fishing catches, tag numbers, lengths and sample numbers at Virginia Lake in 1997