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Dolly Varden and Cutthroat Trout Migrations at Auke Creek in 2001, and Abundance of Cutthroat Trout in Auke Lake, Southeast Alaska

by

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November 2002

Alaska Department of Fish and Game Division of Sport Fish

Symbols and Abbreviations

The following symbols and abbreviations, and others approved for the Système International d'Unités (SI), are used in Division of Sport Fish Fishery Manuscripts, Fishery Data Series Reports, Fishery Management Reports, and Special Publications without definition.

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

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
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	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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TABLE OF CONTENTS

LIST OF TABLES

Table **Page**

LIST OF FIGURES

Figure **Page**

LIST OF APPENDICES

Appendix **Page**

ABSTRACT

The Auke Creek weir near Juneau, Alaska, was operated in 2001 to count migrating sea-run Dolly Varden *Salvelinus malma*, cutthroat trout *Oncorhynchus clarki*, and other species of Pacific salmon *Oncorhynchus*. The number of Dolly Varden emigrants 7,356, was the third lowest in seven years but greater than the 22-year average of 6,428. The number of Dolly Varden immigrants, 4,249, was the second lowest observed since accurate immigration counts for this species began in 1997. Average fork length (FL) of emigrant Dolly Varden was 249 mm (SD = 65 mm). Emigrant and immigrant wild cutthroat trout counts were 337 and 228, respectively. Average fork length of emigrant cutthroat trout was 246 mm (SD = 51 mm). The Jolly-Seber model estimated abundance of cutthroat trout ≥180 mm FL in Auke Lake during 2000 at 479 (SE = 57) during early May and 285 (SE = 29) during late May; these estimates bracket the estimate of 364 (SE = 20) made in 2000 using a Petersen model for a closed population.

Key words: Alaska, Auke Lake, Auke Creek, cutthroat trout, Dolly Varden, sea-run, weir, abundance, length, timing, PIT, VI, tag retention, population estimate, Petersen model, Jolly-Seber model

INTRODUCTION

The Auke Lake system, north of Juneau, Alaska, has native populations of Dolly Varden *Salvelinus malma;* cutthroat trout *Oncorhynchus clarki;* steelhead *O. mykiss;* and pink *O. gorbuscha*, chum *O. keta*, sockeye *O. nerka,* and coho salmon *O. kisutch*. Chinook salmon *O. tshawytscha* have returned to Auke Creek since 1986 as a result of releases of hatchery smolts in Auke Bay near the mouth of Auke Creek. A weir has been operated on Auke Creek, the outlet stream of Auke Lake, since 1962. A permanent structure was constructed in 1980, and in 1997 the weir was modified to enable it to enumerate, in addition to several other species, all immigrant Dolly Varden and cutthroat trout (Table 1). The Auke Creek database on emigrant and immigrant species is the longest and most complete in Southeast Alaska. The Alaska Department of Fish and Game, Division of Sport Fish (ADF&G), the University of Alaska, Fairbanks (UAF), and the National Marine Fisheries Service (NMFS), fund a seasonal biologist to assist with studies at Auke Creek weir, under an interagency cooperative agreement. Fish data collected at the weir are used as indicators of the status of local stocks and help to guide management decisions for the Juneau area. Studies at Auke Creek weir have provided important insights into life history, behavior, age composition, maturity, run timing, and growth of fish present in the Auke Lake system (Neimark 1984a, 1984b; Lum et al. 1998, 1999, 2000, 2001; Taylor and Lum 1999, 2000, 2001, 2002). An annual report for Auke Creek weir summarized the operations and fish counts for 2001 (Taylor and Lum 2002).

DOLLY VARDEN

Dolly Varden have a very complex life history among salmonids (Armstrong and Morrow 1980), and new features are still being learned. Long-term trends in abundance, age structures, growth patterns, and migration timing for Dolly Varden populations in Alaska are largely unknown. Data from the Auke Creek weir will help to close this information gap, and the weir provides managers indicators of Dolly Varden population status around Juneau as urban development in this area continues.

Dolly Varden are important in the local Juneau sport fishery, and Auke Lake provides important overwintering and rearing habitat for local Dolly Varden. Some spawning undoubtedly occurs in the lake system, however, spawner numbers and annual production of smolts remain unknown. Emigrant Dolly Varden at Auke Creek were counted in 1970 and annually since 1980. There were four years in which all, or most, of the emigrant Dolly Varden were fin-marked or tagged when they were captured at Auke Creek weir. Emigrant Dolly Varden were also checked for missing fins and tags, and a subsample of the emigrants were measured to determine inter- and intra-annual changes in size.

Table 1.–Average number of migrant fish of all species counted at Auke Creek, 1980–2001. Hatchery chinook salmon are not allowed to move above Auke Creek weir.

Annual average	Pink salmon	Coho salmon	Sockeye salmon	Chum salmon	Chinook salmon	Dolly Varden	Cutthroat trout	Steelhead
Emigrating	104,916	6,434	16,864	4,161	0	6, 428	263	9[a]
Immigrating	11,481	731	3,473	1,137	219[b]	4,664[a]	273[a]	4[a]

[a] Average of 1997–2001 weir counts, when these species were tallied.

[b] Average of 1987–2001 weir counts; fish are sacrificed at the weir.

CUTTHROAT TROUT

Coastal cutthroat trout have a life history that is characterized by a diversity of expressions within individuals and among populations. There can be both resident and sea-run cutthroat trout in one system. Resident cutthroat trout spend time in a riverine or lacustrine phase before migrating into inlet streams to spawn, never leaving the fresh-water system. Sea-run cutthroat trout typically spend several years in a resident, riverine, or lacustrine phase before migrating to seawater for a period of up to a few months. They return to fresh water to spawn or overwinter, and may repeat this cycle (or a variation) one or more times (Northcote 1997, Trotter 1997). Comprehensive time series of data on the distribution, abundance, age structure, growth, and migration timing for this species are rare, as they are for Dolly Varden. Such data are important to understanding the impact that directed fisheries can have on small populations of cutthroat trout (Behnke 1979, Spense 1990, Wright 1992).

Cutthroat trout are caught in Auke Lake through the ice during the winter and from the beach or boats during the remainder of the year (Table 2). Anecdotal information suggests that the cutthroat trout fishery in Auke Lake was more productive than at present. Strategic planning exercises conducted by ADF&G in 1989 identified improvement of the cutthroat trout fishery in Auke Lake as a goal to help satisfy the demand for sport fisheries along the Juneau roadside (Schwan 1990). The current research program grew from that planning exercise. The result of this effort is the longest and most complete data set across the range of the species.

The first significant trout tagging program at Auke Creek began in 1994. A mark-recapture program to estimate annual spring or summer abundance in the lake began in 1997. Fish tagged in the lake in the spring of 1997 were recovered by anglers in marine waters over the next few summers, suggesting that Juneau roadside fisheries for anadromous cutthroat trout (Table 3) partly depend on stocks that overwinter or reside in Auke Lake.

Trout research at Auke Creek and Auke Lake, particularly the passive integrated transponder (PIT) tagging program started in 1997, has yielded valuable and unique information from an anadromous cutthroat trout system. Growth rates on individual cutthroat trout allow managers to set size-based harvest regulations and describe recruitment into the harvestable size class. Tracking the migration histories of individual fish in and out of the lake allows us to describe use of the lake as rearing area for anadromous fish. Recoveries of tagged fish in local fisheries yield data on saltwater migration patterns and the opportunity to observe the intra- and interannual movements between and within watersheds. As urbanization spreads in the Juneau area, these results will help us to recognize critical habitats and document effects of habitat change.

The purpose of this report is to summarize counts and biological characteristics of Dolly Varden and cutthroat trout at the Auke Creek weir in 2001, as well as results of mark-and-recapture experiments to estimate abundance of cutthroat trout residing in Auke Lake. Our objectives were to:

1. count emigrant Dolly Varden and cutthroat trout at Auke Creek from March 1 through the end of the emigration (usually June 30);
2. estimate the size composition of Dolly Varden and cutthroat trout emigrants;

Table 2.–Estimates of sport fishing effort, total catch, and harvest of cutthroat trout and Dolly Varden in the Auke Creek drainage, 1990–2000. All estimates for Auke Creek drainage were derived from low sample sizes. Unpublished mail survey estimates from Research and Technical Services database, ADF&G, Anchorage.

				Cutthroat trout		Dolly Varden[a]	
Year	Anglers	Trips	Days	Catch	Harvest	Catch	Harvest
1990	34	34	34	17	17	0	0
1991	16	33	23	0	0	0	0
1992	75	87	75	18	0	0	0
1993	50	325	271	391	224	49	0
1994		------------------------- no estimates made in 1994 ------------------------------------					
1995	29	32	29	26	0	0	0
1996	40	397	375	1,104	0	485	0
1997	45	47	47	16	0	54	0
1998	46	100	113	101	17	177	0
1999	33	12	33	9	0	0	0
2000	27	11	27	195	0	0	0

[a] Auke Lake is closed to the harvest of Dolly Varden.

Table 3.–Estimates of sport fishing effort, total catch, and harvest of cutthroat trout and Dolly Varden in the marine areas surrounding Auke Creek, 1990–2000. All estimates for surrounding marine area were derived from low sample sizes. Included in the counts are fishing in Auke Bay by boat along shore, and fishing near the mouth of Auke Creek by boat or by shore. Unpublished mail survey estimates from Research and Technical Services database, ADF&G, Anchorage.

				Cutthroat trout		Dolly Varden	
Year	Anglers	Trips	Days	Catch	Harvest	Catch	Harvest
1990	516	447	571	0	0	103	52
1991	294	343	322	0	0	12	12
1992	623	1359	1494	0	0	8	0
1993	1862	3416	3860	0	0	76	0
1994	2639	5345	7101	0	0	391	103
1995	2273	3471	5225	0	0	109	61
1996	1989	2313	2926	58	11	244	109
1997	1577	2142	2944	28	0	998	197
1998	1735	2088	2797	15	15	150	150
1999	1847	2445	3885	67	29	654	97
2000	2770	3575	5588	45	9	828	108

3. count immigrant Dolly Varden and cutthroat trout at Auke Creek from June 30 through the end of the immigration (usually October 30);
4. measure all tagged cutthroat trout immigrants; and
5. estimate the abundance of cutthroat trout in Auke Lake during spring 2000 using a Jolly-Seber model.

STUDY SITE

The Auke Lake system is a mainland watershed of 1,072 ha located approximately 19 km north of downtown Juneau, Alaska (58°23′, 134°37′), on the Juneau road system. Auke Lake has a surface area of 67 ha and is fed by 5 tributaries. Lake Creek is the largest tributary with a watershed of 648 ha. The greatest depth of Auke Lake is 31 m, and the surface elevation is approximately 19 m. Auke Creek weir is about 400 m downstream from the lake, at the head of tidewater at Auke Bay (Figure 1). The lake shoreline is bordered by forested terrain, which varies from gentle slopes to steepsided banks. The shoreline zone of water consists of areas dominated by emergent vegetation of *Equisetum* spp. and *Nuphar* spp. and other areas characterized by large numbers of submerged and floating conifers anchored to the lakeshore and bottom by their large root wads.

METHODS

EMIGRANT POPULATIONS

The Auke Creek weir was operated from March 1 through June 29 to intercept all emigrant salmonids. During this time, fish could not move upstream through the weir. The weir configuration during spring directed water through 5 inclined traps and vertical aluminum panels covered with 3-mm perforations that were effective at both high and low flows. Fish and water exiting the inclined traps were diverted through an aluminum trough to a fiberglass holding tank downstream from the weir. A separate water source supplied the holding tank to keep the fish alive. Fish were sorted by species, counted, sampled, tagged and released each day. The fish were not anesthetized.

All Dolly Varden were counted and examined for anchor T-bar (Floy) tags and adipose fin marks. Length composition was estimated by using a systematic sampling procedure. Daily, every 10th Dolly Varden captured at the weir was measured to the nearest 5 mm from the tip of snout to fork of tail (FL). Average length of Dolly Varden emigrants sampled at the weir was estimated:

$$\bar{y} = \frac{1}{n}\left(y_1 + y_2 + ... + y_n\right) = \frac{1}{n}\sum_{i=1}^{n} y_i \qquad (1)$$

where $\bar{y}$ is the sample mean or the average of the y-values in the sample, and n is the number sampled for length. The standard error of $\bar{y}$ was estimated as:

$$se(\bar{y}) = \sqrt{\frac{s^2}{n}} = \sqrt{\left(1-\frac{n}{N}\right)\frac{1}{n*(n-1)}\sum_{i=1}^{n}\left(y_i - \bar{y}\right)^2} \qquad (2)$$

where s^2 is the sample variance and N is the weir count. The finite population correction factor (fpc) of 1-n/N is included in s^2 because of the exactly known and relatively high sampling rate.

All cutthroat trout were counted, measured to the nearest millimeter, FL, and examined for anchor T-bar or visual implanted (VI) tags and missing fins. Possible fin marks on cutthroat trout in 2001 included: (1) adipose-clipped fish carrying a PIT tag placed between 1997 and 2001; (2) VI tagged and adipose-clipped fish marked during emigrations from the lake in 1994-1996; (3) left ventral-clipped hatchery fish released in 1994; (4) right ventral-clipped hatchery fish released in 1991; and (5) adipose-clipped hatchery fish released in 1986 and 1987. All cutthroat trout missing the adipose fin were checked with an electronic scanner for a PIT tag (the rate of PIT tag loss has been less than 1%). Each PIT tag has a unique 10 character alphanumeric code or number. Before 2000, PIT tags were inserted under the skin in the dorsal sinus, next to the basal fin rays of the dorsal fin. In 2001, tags were inserted under the skin immediately posterior and parallel to the midpoint of the cleithrum. The tag was inserted in the new location to prevent fishermen from accidentally biting down on the tag or ingesting the tag in situations where the fish was cooked whole and not filleted.

All unmarked spring emigrant cutthroat trout were PIT tagged, adipose finclipped, and given a red photonic dye mark on the anal fin before release. One or two drops of cyanoacrylate (super glue) were used to close the PIT tag wound and prevent tag loss and infection. Newly tagged cutthroat trout were held for 24 hours to check for short-term tag loss.

All cutthroat trout mortalities were measured and sampled for scales and otoliths, and screened for PIT tags, which were removed if present. Scales from cutthroat trout mortalities were taken from the left side of the caudal peduncle immediately above the lateral line (Brown and Bailey 1949, Laakso and Cope 1956). Each fish was wiped with the blunt side of a knife to remove excess mucus before collecting a sample of scales. A sample of 15 to 20 scales from each fish was spread on a microscope slide so that no scales

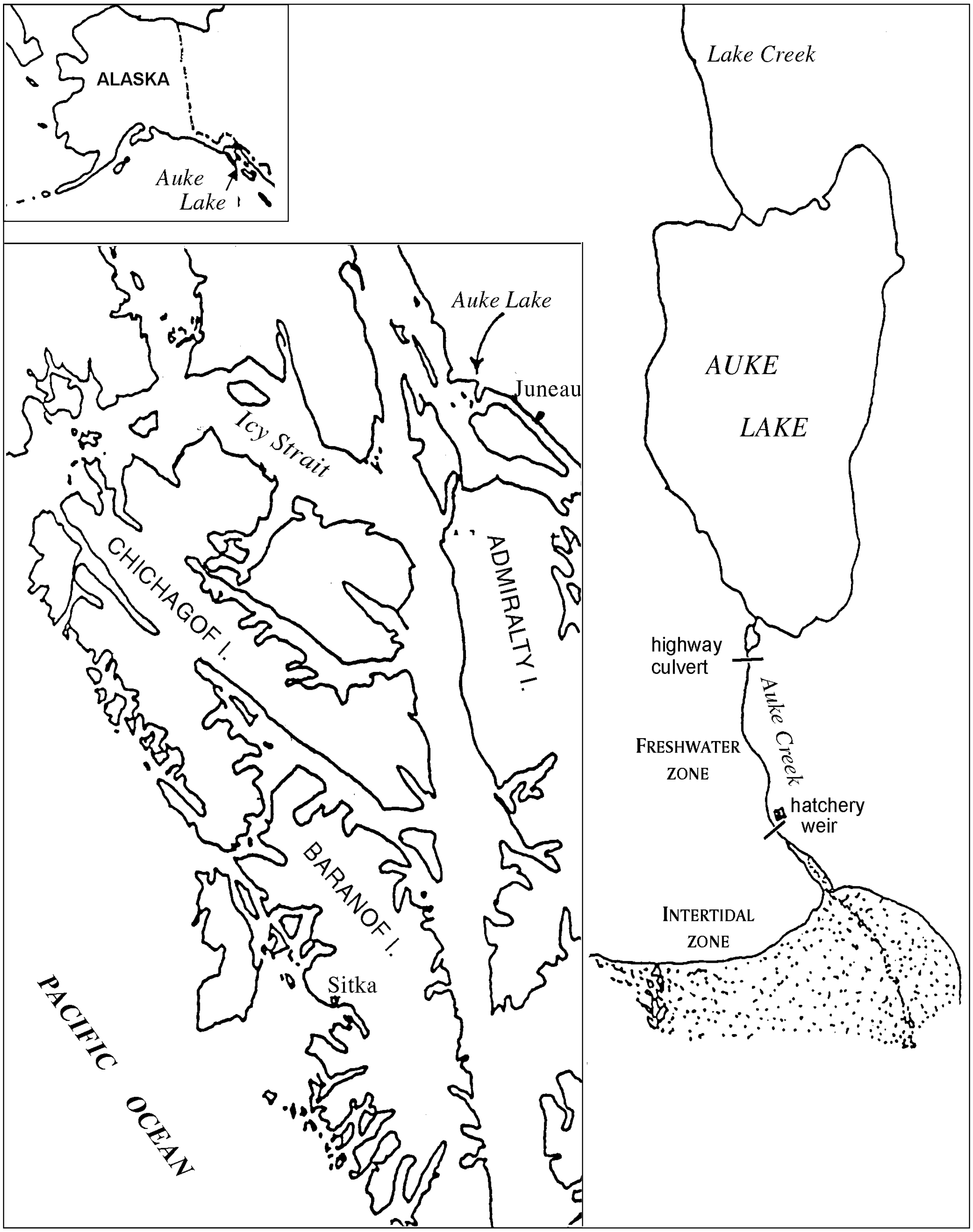

Figure 1.–The Auke Lake system in northern Southeast Alaska and location of the Auke Creek weir.

were overlapping and sandwiched between another slide (Ericksen 1999). The slides were stored in a labeled coin envelope inscribed with the sample number and date.

IMMIGRANT POPULATIONS

The weir was converted to count immigrants on June 29 and operated through October 31. Vertical slotted aluminum panels, 90 × 178 cm, were inserted into the weir structure to divert fish into the adult trap without restricting the water flow. The weir captured all small fish, including Dolly Varden, cutthroat trout, and chinook salmon mini-jacks (0-ocean) as well as adult salmon that moved upstream, while blocking any downstream movements. Aluminum plates, 45 × 90 cm, with 1.5 × 10 cm horizontal slots were placed on the bottom half of the lowest weir panels to prevent passage of small fish. Small fish were captured in two trout traps, 1.5 × 2.4 × 0.8 m high, attached to the upstream side of the weir. Pickets on the trap entrance were spaced 2.5 cm apart to prevent larger salmonids from entering the trout traps. Before 1997, small fish passed through the weir panels and were not counted.

All fall immigrating Dolly Varden and cutthroat trout were counted and released upstream, except that early in the immigration captured cutthroat were kept below the weir to reduce the incidence of injury and death due to low stream flows, high temperatures, and the fish's fragile condition (see Lum et al. 1998 for details). Dolly Varden were examined for adipose finclips and anchor T-bar tags from other studies, and marked fish were measured to the nearest 5 mm FL to enable estimates of growth. Cutthroat trout were measured to the nearest 1 mm FL and examined for marks. Cutthroat missing their adipose fins were checked for dye marks on all fins, and scanned for PIT tag code. Unmarked cutthroat trout were marked with a red dye on the anal fin (blue was used in 2000) but not PIT tagged (ADF&G unpublished data from 1996).

Marine residence varied among individual cutthroat trout and was defined as the number of days between spring emigration and fall immigration at Auke Creek, recognizing of course, that some fish probably did not spend the whole period in salt water. Marine growth (mm and mm/day) of individual fish with a PIT tag was calculated as the increase in fork length during their hiatus from the lake.

Any fish found dead in the creek were measured (nearest mm FL) and sampled for scales, otoliths, and checked for tags. Immigration cutthroat trout mortalities carrying a PIT tag were examined for scarring or encysting, tag placement, and migration of the tag into the body cavity or out through the skin.

CUTTHROAT TROUT IN AUKE LAKE

Abundance, survival, and birth rates of cutthroat trout ≥180 mm FL in Auke Lake during 1998, 1999, and 2000 were estimated using the "full" JS model (Seber 1982), which provides k-2 abundance estimates and k-2 survival rate estimates (k = number of the sampling events). Two JS analyses were made: one with data aggregated by sampling trip to yield an 8-event (by trip) model, and one with data pooled by sampling year to yield a 4-event (by year) model. Fish captured several times during a sampling period were treated as being caught only once. Data for the analysis were collated in SAS (SAS 1990) and an electronic spreadsheet, and input to POPAN (Arnason et al. 1998) to estimate population parameters and obtain capture histories. Parameter estimates were constrained to admissible values in POPAN using the procedures in Schwarz et al. (1993) and Schwarz and Arnason (1996). Goodness of fit (GOF) statistics for the JS model were obtained using program JOLLY (Pollock et al. 1990). JS estimates were also compared to our previous closed population (CP) estimates (Lum et al. 1999, 2000 and 2001).

Three separate sampling trips were made in 1998 between July 8 and August 14 (Lum et al. 1999), two sampling trips were made in 1999 between May 25 and June 16 (Lum et al. 2000), two sampling trips were made in 2000 between May 2 and May 25 (Lum et al. 2001), and one sampling trip was made between April 16 and April 25, 2001. As sampling dates advanced in 2000, and especially in 2001, emigrations were not essentially completed prior to lake sampling. Thus, the current JS analysis does not (as in previous years) exclude marked fish which emigrate after sampling is complete.

Trout residing in Auke Lake were captured with traps baited with chinook salmon eggs, and by casting small spoons, spinners, flies, and other lures. Trap soak-times were typically 22 to 24 hours. Traps were plastic-mesh cylindrical devices 1 m long x 0.5 m diameter, with a funnel entrance at each end (Rosenkranz et al. 1999). Captured trout were inspected for tags or marks and measured for fork length. Fish missing the adipose fin were scanned to determine PIT tag number. Unmarked cutthroat trout ≥180 mm FL were tagged with a uniquely numbered PIT tag, given red dye mark on the right ventral fin, and had their adipose fin excised. Fish caught more than once during the sampling trip were treated similarly (except for tagging) and "recapture" was noted in comments. Trout were handled without using anesthesia and released in the area where they were captured.

The lake was divided into 8 areas to facilitate sampling and accurate recording of locations where cutthroat trout were captured (Figure 2). Data from these areas were then pooled into 3 strata (A, B, C) for testing experimental assumptions. Fishing occurred only in areas ≤15 m deep (Figure 2), because previous work in Auke Lake showed trout were not captured at greater depths during summer (NMFS unpublished data, Juneau, Alaska). Fifteen traps were fished each day, and a fathometer was used to determine depth. Overall fishing effort (number of traps set and hours of hook and line effort) in each area was proportionate to the lake surface area ≤15 m (Table 4). Depth, sampling area, and number of fish caught were recorded by trap set.

Assumptions of the standard (full) JS model (Seber 1982) include:

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 (sampling time is negligible).

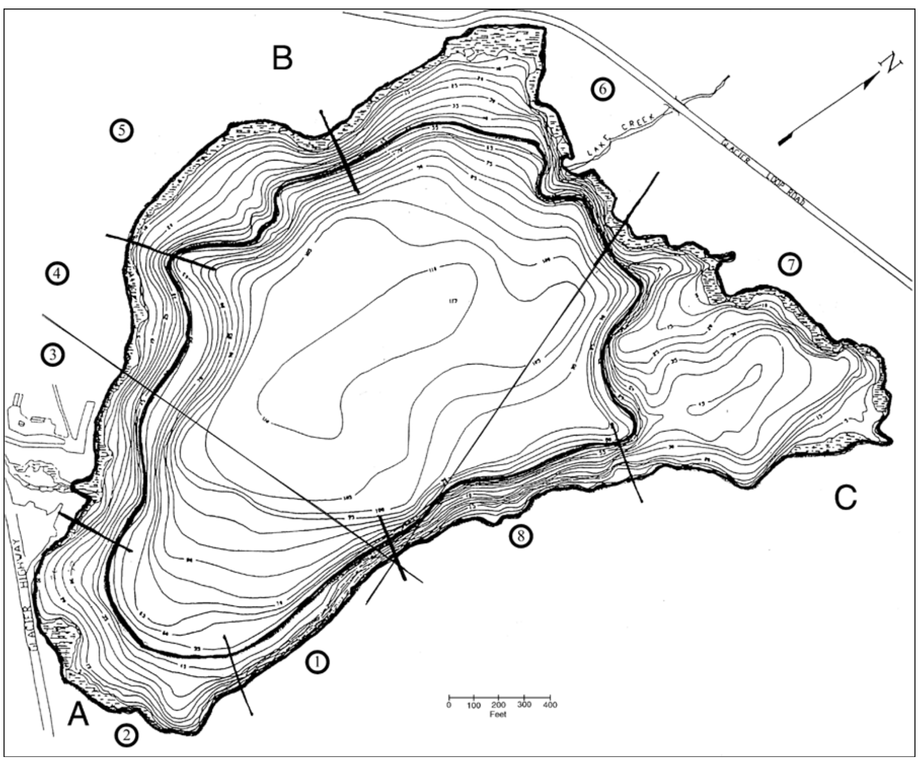

Figure 2.–Bathymetric map of Auke Lake showing location of sampling areas in 2001. The lake area inside the inner bold line was excluded from sampling as depths were >15 m. The two intersecting straight lines indicate the separation between the three strata (A, B, and C) used in analysis.

Table 4.–Distribution of sampling effort in Auke Lake by area in 2001. Sampling effort was uniformly distributed across each of the eight areas (Figure 2) of the lake in direct proportion to the amount of lake surface (<15m depth) present, given a total effort of 135 traps and 20 rod-hours during the 9-day sampling trip.

Area no.	Analysis stratum	Area [a] (km^2)	Prop.[a]	Hook and line effort (hrs)	Trap effort (sets)
1	A	0.5463	0.0459	1:00	6
2	A	2.6098	0.2195	4:23	30
3	A	1.0583	0.0890	1:47	12
4	B	0.8275	0.0696	1:23	9
5	B	1.4691	0.1236	2:28	17
6	B	1.4562	0.1225	2:27	17
7	C	3.1297	0.2632	5:16	36
8	C	0.7932	0.0667	1:20	8
Totals		11.8901	1.0000	20:04	135

[a] Tabulated area and proportions were estimated for 0–15-m depths.

A GOF test (of marked fish seen before versus not seen before, against seen again versus not seen again, Pollock et al. 1990) was used to test for homogeneous capture and survival probabilities by tagged status. The first component of the GOF test is equivalent to the Robson (1969) test for short-term mortality. Pollock et al. (1990: 24) report the second test component to be better at detecting heterogeneous survival probabilities. The sum of the chi-squares from each component forms an omnibus test for violations of the first three assumptions listed above; i.e., equal probability of capture, survival, and return to the population. Because these GOF statistics were highly significant for the annual (pooled data) model, a generalization of the JS model which allows survival rates for newly captured animals and previously captured animals to differ ("Analysis 3" in POPAN, "Model 2 in JOLLY") was considered.

The condition that the probability of capture is the same for all fish within a sampling event can be waived (with respect to sampling location) if marked and unmarked fish mix completely between sampling events (Seber 1982: 211). Such a test was made by comparing the marked fraction (R/C, where R is the number of recaptures and C is the number of captures) of fish caught in strata A, B, and C, using only fish marked in the previous year. If $(R/C)_A = (R/C)_B = (R/C)_C$ complete mixing was indicated; otherwise, incomplete mixing was indicated. A chi-square statistic (from a 3 × 3 contingency table, $\alpha = 0.05$) was used for the test. Since few fish were captured using hook-and-line each year, comparisons based on gear type were not attempted.

The equal probability of capture assumption can also be violated if sampling is size selective. Considerable experience with sampling gear used at Auke Lake shows that our gear is not significantly size selective for fish over 180 mm FL (Lum et al. 1999, 2000).

The assumption that all fish have the same chance of surviving from the i_{th} to the $(i+1)_{th}$ sampling implies the absence of significant age dependent mortality rates for cutthroat trout ≥180 mm FL. Little evidence of age-dependent mortality was found for cutthroat trout ≥180 mm FL in Florence Lake

(Rosenkranz et al. 1999). However, since sea-run cutthroat trout probably spawn in Auke Lake (Lum et al. 2001) and maturing fish probably reside (rear) in the lake prior to their spawning migrations, tagged groups of these fish could experience a different (lower) capture probability in subsequent years than a group of previously tagged resident fish.

Assumption 3 was evaluated by direct examination of the capture histories (mortality status by year) from each event. The number of fish killed or released alive without tags was usually <1% per sampling occasion. Assumption 4 was addressed by double marking trout with different combinations of finclips and photonic dye marks each year and estimating the annual rate of tag loss. Since individual sampling trips span but 9 days, significant violations of assumption 5 were not expected in the 8-event (trip-by-trip) model. However, a large emigration through the weir during a trip, or between 2 trips within a year would contribute to a violation of this assumption. Also, estimates of significant "birth" and/or "mortality" rates between sample periods within a year from the detailed (8-trip) model would suggest assumption 5 was violated for an annual (4-trip) model.

The fraction p_a of cutthroat trout in 20-mm size increments in Auke Lake was estimated:

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

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

where n is the number of fish measured for length, n_a is the subset of n that belong to length group a, and a fpc is again included because of the high sampling rate and availability of an abundance estimate N from the mark-recapture experiment. The estimated abundance of length group a in the population is

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

$$\mathrm{var}\left[\hat{N}_a\right] = \mathrm{var}(\hat{p}_a)\hat{N}^2 + \mathrm{var}(\hat{N})\hat{p}_a^2 + \mathrm{var}(\hat{p}_a)\,\mathrm{var}(\hat{N}) \qquad (6)$$

where the variance equation for two independent variables is from Goodman (1960).

RESULTS

MIGRANT DOLLY VARDEN

Emigrant and immigrant Dolly Varden populations were counted at Auke Creek in 2001. A total of 7,356 Dolly Varden emigrated in 2001. The emigration, which declined between 1995 and 2000, was above the 22-year average of 6,428 (Table 5, Figure 3). The first Dolly Varden was captured March 9 and the last June 27 (Appendix A1, Figure 4). The midpoint of the emigration was May 12, and the average midpoint date of the emigration, 1980–2001, was May 9, range April 30 to May 24. Average fork length of emigrant Dolly Varden in 2001 was 249 mm (SD = 65), range 40 to 570 mm (n = 778). The weekly average length of Dolly Varden declined during the migration; i.e., larger fish emigrated earlier (Figure 5). The Dolly Varden immigration of 4,249 fish began on June 29 when the upstream trap was installed, and the last fish was captured October 31 when the weir was removed (Figure 4, Appendix A2). This was the second lowest count since upstream migration of Dolly Varden was first monitored in 1997. Immigration counts for 1997–2000 were 5,705, 4,993, 4,709, and 3,665 Dolly Varden. Major peaks in immigration occurred intermittently in July and September, following heavy rainfall.

Table 5.–Annual counts of spring emigration, wild Dolly Varden and cutthroat trout at Auke Creek, 1980–2001 (hatchery-produced or lake-stocked cutthroat trout not included in this table)**.**

Year	Dolly Varden	Midpoint of emigration	Cutthroat trout	Midpoint of emigration
1980	3,110	13-May	85	18-May
1981	6,461	5-May	157	14-May
1982	4,136	24-May	157	31-May
1983	3,718	7-May	149	15-May
1984	4,512	8-May	198	14-May
1985	3,052	14-May	112	21-May
1986	4,358	13-May	99	24-May
1987	6,443	6-May	250	17-May
1988	6,770	30-Apr	294	9-May
1989	7,230	8-May	259	18-May
1990	6,425	5-May	417	11-May
1991	5,579	17-May	237	20-May
1992	6,839	4-May	219	16-May
1993	5,074	8-May	174	14-May
1994	7,600	4-May	422	13-May
1995	11,732	9-May	412	13-May
1996	11,323	4-May	462	7-May
1997	10,506	7-May	418	12-May
1998	7,532	1-May	336	11-May
1999	6,393	14-May	341	16-May
2000	5,254	6-May	249	13-May
2001	7,356	12-May	337	20-May
Mean	6,428	9-May	263	16-May

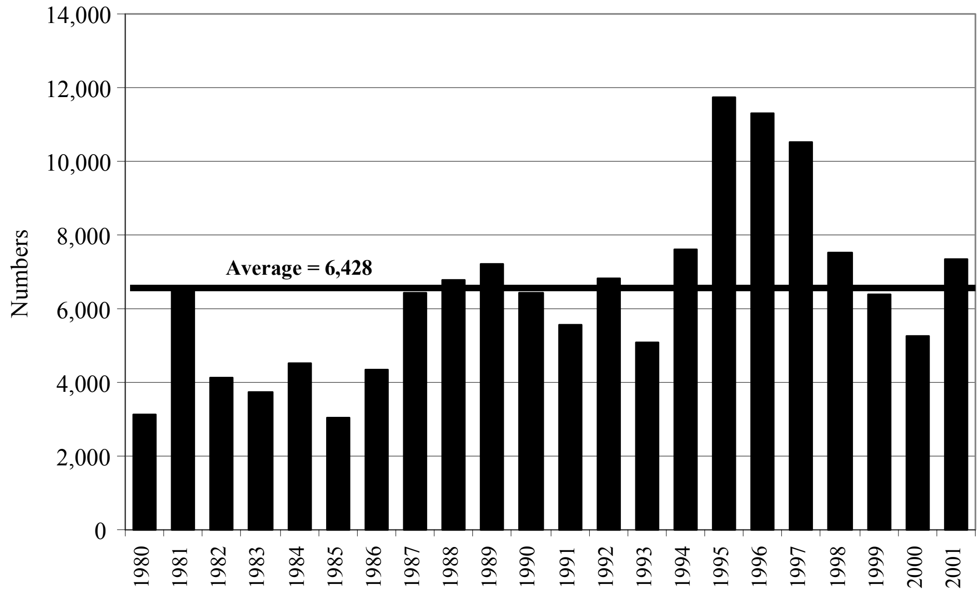

Figure 3.–Annual spring emigration of Dolly Varden at Auke Creek, 1980–2001.

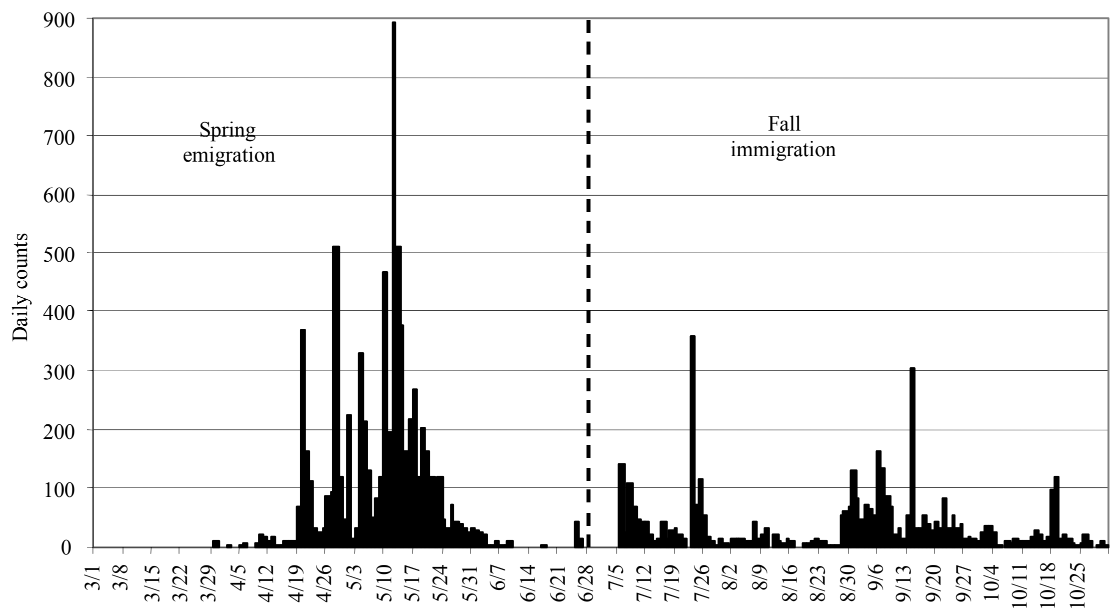

Figure 4.–The 2001 spring emigration and fall immigration of Dolly Varden at Auke Creek. Spring emigration started March 9 and ended June 29. Fall immigration started July 6 and ended October 31 at which time the upstream weir was removed. Vertical dashed line delineates when the weir was converted to count fall immigrants, June 29.

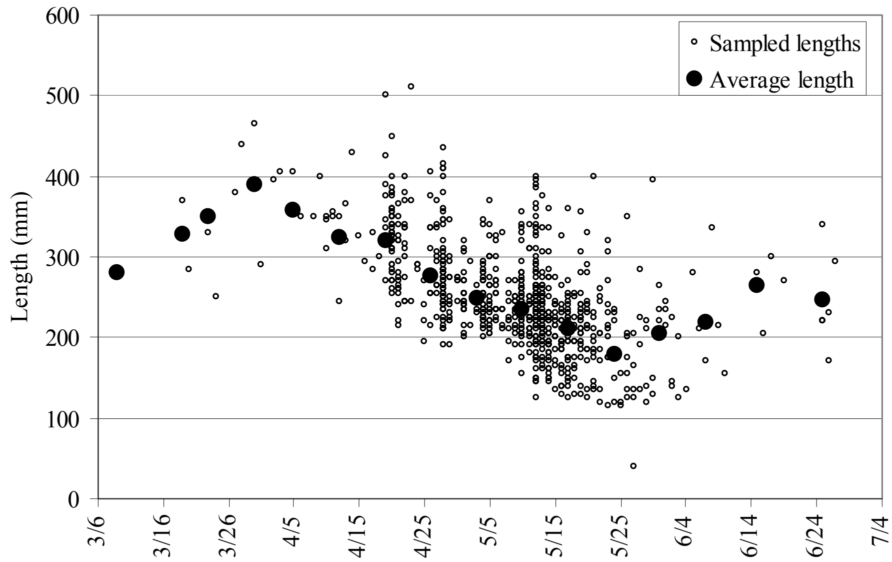

Figure 5.–Dolly Varden lengths (mm) over time during the spring emigration at Auke Creek, 2001. Average lengths for each migration week are overlaid upon sampled length data.

EMIGRANT CUTTHROAT TROUT

A total of 337 cutthroat trout emigrated during 2001. The emigration count for wild fish had been declining since a high value of 462 in 1996. The 2001 count of 337 was above the 22-year average of 263 wild fish (Table 5, Figure 6). The first emigrant was captured March 20, and the last June 29, after which the weir was converted to an upstream migrant trap and no additional emigration was allowed (Figure 7, Appendix A1). The midpoint of emigration was May 20, and the average median date of emigration is May 16 (1980–2001); range May 7 to May 31 (Table 5). Water temperatures during the emigration during 2001 ranged between 3.8° and 17.8°C.

Of the 337 emigrant cutthroat trout during 2001, 143 were missing their adipose fin, and 194 were not marked or tagged. All fish missing an adipose fin in 2001 had a PIT tag (tag retention was 100%). The marked fish included 76 wild fish tagged before 2000, and 68 fish tagged in Auke Lake during the lake abundance project in spring 2001. Average fork length for emigrant sea-run cutthroat trout was 246 mm (SD = 51 mm) and ranged from 136 to 408 mm. The weekly average length of all emigrants declined over time (Figure 8). Of the 337 emigrant cutthroat trout 12% (42) fish were males, 15% (49) were females, and 73% (246) showed no obvious signs of gender. Twenty-one percent of the emigrants were obviously ripe, 11% (38/337) attributed to ripe males, and 10% (32/337) attributed to ripe females. Ripeness of maturing fish started to decline after May 14 and the last ripe fish was seen on May 20. "Ripeness" or "ripe" was defined as being ready to spawn, and "obviously ripe" was defined as fish that easily extruded gametes or dripped gametes.

IMMIGRANT CUTTHROAT TROUT

A total of 228 cutthroat trout immigrated and were examined for marks and PIT tags in fall 2001. We started recording fall immigrant cutthroat trout in 1997, with subsequent counts being 467, 361, 205, and 105, respectively. No cutthroat trout migrated upstream in August, 167 did in September, and 61 in October 2001. As noted in the methods, some cutthroat trout were not ready to remain in fresh water when captured at the weir early in the immigration, and they were placed back downstream. Run timing data are biased, but we do not know how to avoid this, given that releasing the fish too early above the weir results in high mortality.

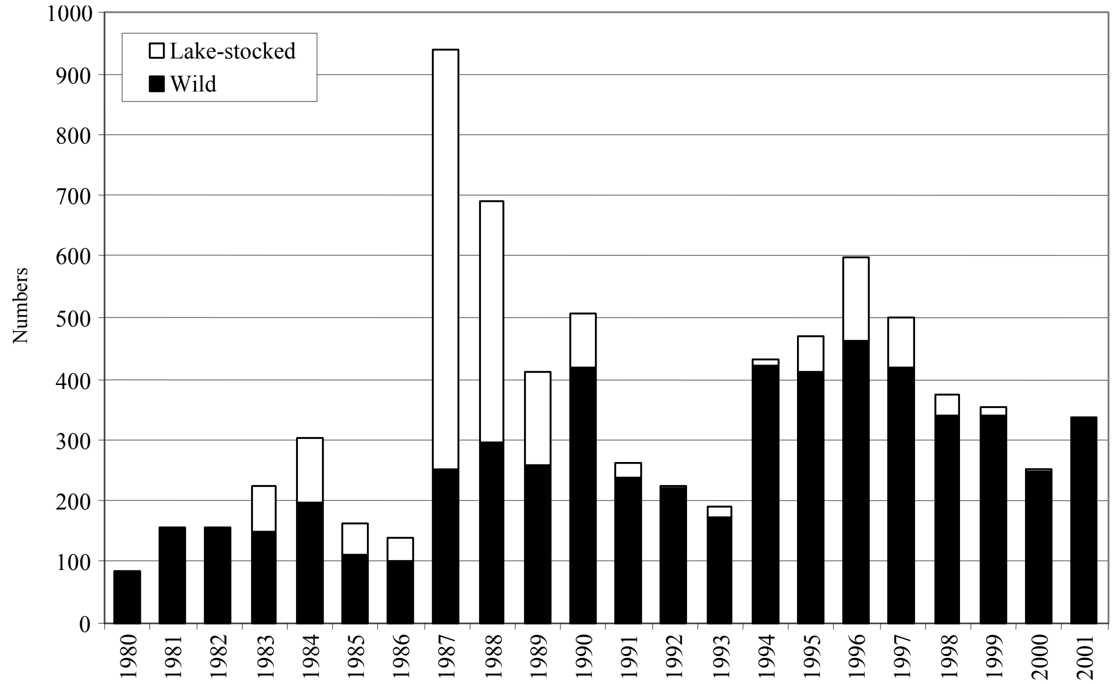

Figure 6.–Annual spring emigration for cutthroat trout at Auke Creek, 1980–2001. Hatchery cutthroat trout were stocked in Auke Lake in 1983 (1,286 right ventral marked and 4,078 left ventral marked fish); 1986 (3,489 adipose marked fish); 1987 (1,1719 adipose marked fish); 1991 (2,465 right ventral marked fish); and 1994 (3,098 left and right ventral marked fish).

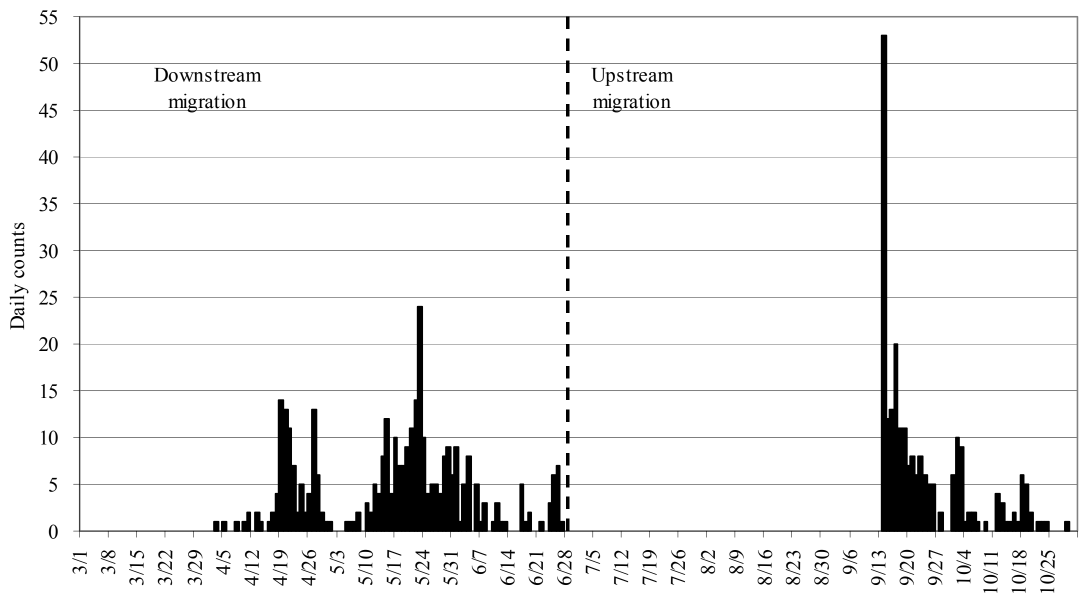

Figure 7.–The cutthroat trout spring emigration and fall immigration at Auke Creek, 2001. Spring emigration started April 3 and ended June 27. Fall immigration started September 14 and ended October 31. The vertical dashed line delineates when the weir was converted to count fall immigrants, June 29.

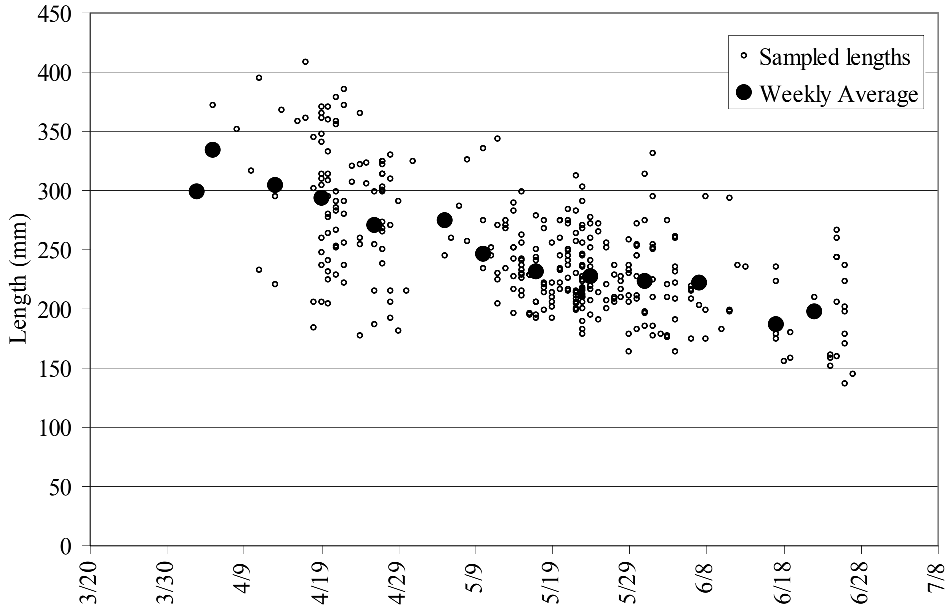

Figure 8.–Cutthroat trout lengths (mm) over time during the spring emigration at Auke Creek, 2001. Average lengths for each migration week are overlaid upon sampled length data.

During spring 2001, we switched to a red dye-mark on the anal fin on all spring emigrants leaving Auke Creek because of the higher retention of the red dye-mark in previous years (Lum et al. 2001). PIT tag retention on immigrant cutthroat trout in 2001 was 99.5% (227/228). A total of 93 of fall immigrant cutthroat trout had been dye-marked during the 2001 spring emigration, and 9 had a dye-mark from previous years as proven by the PIT tag number. Thirty-eight percent (38%) of cutthroat trout marked in spring 2001 (35 of 93) retained the red anal fin dye-mark, and 6 of the 9 (67%) previously marked retained the red anal fin dye-mark.

Immigrant cutthroat trout averaged 258 mm FL (SD = 57 mm), ranging from 160 to 403 mm. Average lengths of immigrating cutthroat trout did not vary greatly over time (Figure 9). The length frequency distribution for both fall and spring migrants is skewed towards shorter lengths, with the fall migrant distribution being slightly bimodal (Figure 10).

Growth rate tends to decrease as the size of the fish gets larger. Marine residence and growth of cutthroat trout was determined for fish with PIT tags that emigrated and immigrated at Auke Creek in 2001. PIT-tagged cutthroat trout that returned to Auke Creek in the summer and fall 2001 had an average hiatus of 131 days (SE = 2, range 81–185 days) from Auke Lake, compared to 126 days in 1998, 133 days 1999, and 149 days in 2000. The data did not show a relationship between emigration time and the immigration (return) time for cutthroat trout leaving Auke Creek, and there was not a strong relationship between size at emigration and the duration of marine residence. Average growth during the hiatus was 60 mm (SE = 2 mm) and ranged from 9 to 112 mm (Figure 11). The average growth rate during the hiatus was 0.474 mm/day (SE = 0.019), almost average for the previous four years (0.48, 0.49, 0.45, and 0.30 mm/day observed, respectively, in 1997–2000) (Lum et al. 2001).

CUTTHROAT TROUT IN AUKE LAKE

We captured a total of 299 cutthroat trout in 2001 in Auke Lake, 293 of which were caught in large traps and 6 by hook and line. Although 252 cutthroat trout were ≥180 mm FL, the largest numbers of fish (73) were in the 201–220 mm FL size class (Table 6, Figure 12).

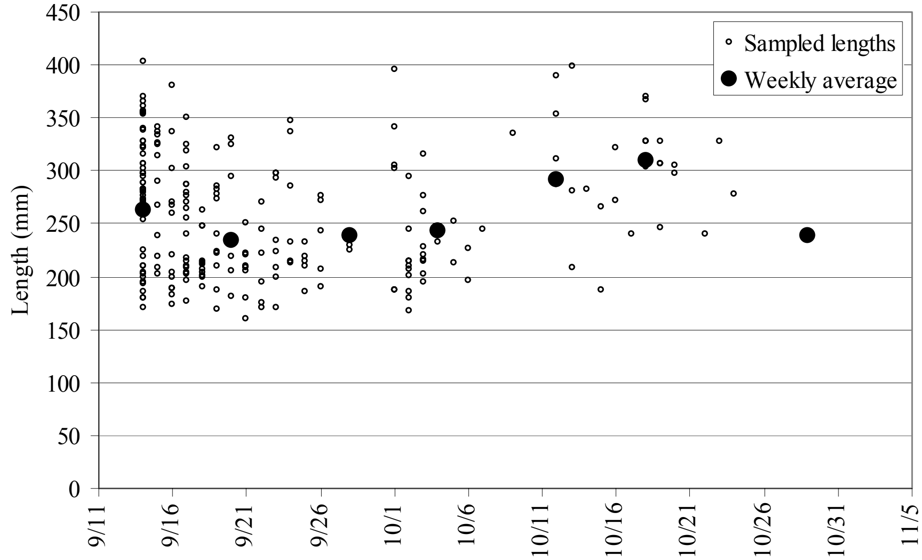

Figure 9.–Cutthroat trout lengths (mm) over time during the fall immigration at Auke Creek, 2001. Average lengths for each migration week are overlaid upon sampled length data.

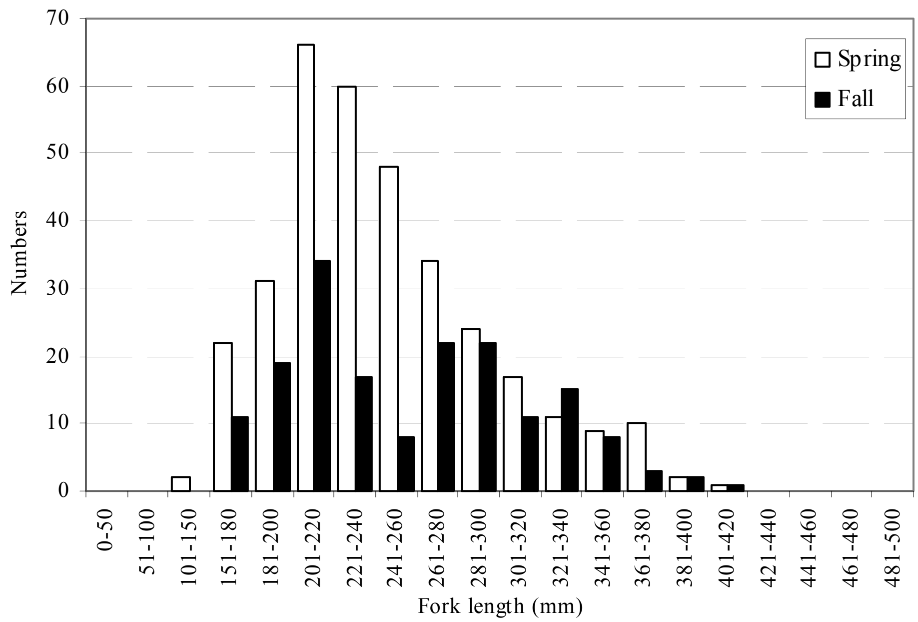

Figure 10.–Length frequency distributions of cutthroat trout captured at Auke Creek weir, spring emigration and fall immigration, 2001.

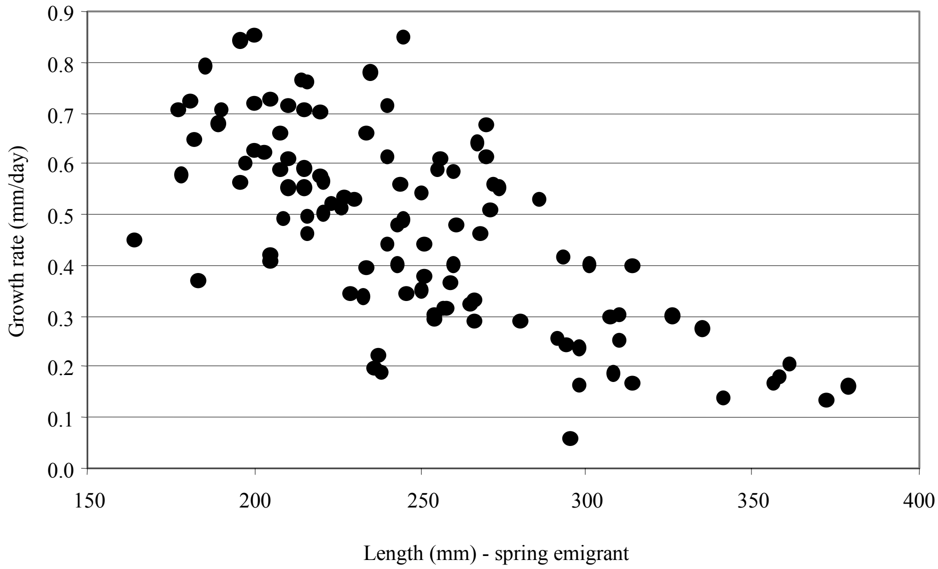

Figure 11.–Cutthroat trout growth (mm/day) during time between spring emigration and fall immigration plotted against their size at the time of spring emigration and tagging, Auke Creek, 2001.

Table 6.–Sampling effort (hours), cutthroat trout catch, and catch per unit effort (CPUE, fish per hr) in Auke Lake during sampling event April 16–25, 2001, by sampling gear and fish length-class.

Gear type	Effort (hr)	≥180 mm		≤180 mm		Combined	
		Catch	CPUE	Catch	CPUE	Catch	CPUE
Hook and line	20	6	0.300	0	0.000	6	0.300
Large traps	3,240	246	0.076	47	0.015	293	0.090
All gear		252		47		299	

During 2001, we captured and released 192 unmarked cutthroat trout between 180 and 315 mm FL and 42 fish tagged in 2000 or 1999. Eighteen (18) fish were captured more than once in 2001 and were thus "redundant" within this sampling event. Four (sea-run) fish tagged at the weir before 2001 and 51 other newly tagged fish captured during the 2001 sampling (in May and June) later emigrated by the weir. Tag loss in 2001 was insignificant (0 fish). Summary statistics and capture histories for the annual and trip-by-trip JS models are shown in Appendices A3 and A4.

Marked fish were homogeneously mixed into the unmarked population between sample years 1999 and 2000 (χ^2 = 3.15, P = 0.207), and between sample years 2000 and 2001 (χ^2 = 3.20, P = 0.202, Table 7). This result was not unexpected, as Auke Lake is relatively small.

In contrast, the component 1 GOF test for homogeneous capture/survival probabilities by tag group (Robson's test for short-term mortality) suggests the JS model does not fit the annual data well (p = 0.0004, Table 8), but it does fit the trip-by-trip data (p = 0.471). Details of the component 1 GOF test for annual data (Table 9) reveals that, in contrast to a "typical" (undesired) pattern when tagging and/or handling leads to a short-term *reduction* in mortality, the probability of later recapturing fish first captured (and tagged) in a given year was *three to five times higher* than for recapturing previously marked fish also captured in that year.

The second GOF test (component 2) for homogeneous capture/survival probabilities was less useful because key capture histories were absent in the annual data (due to the small sample size in 1998), and sample sizes are very low for nearly every test (Tables 8 and 9).

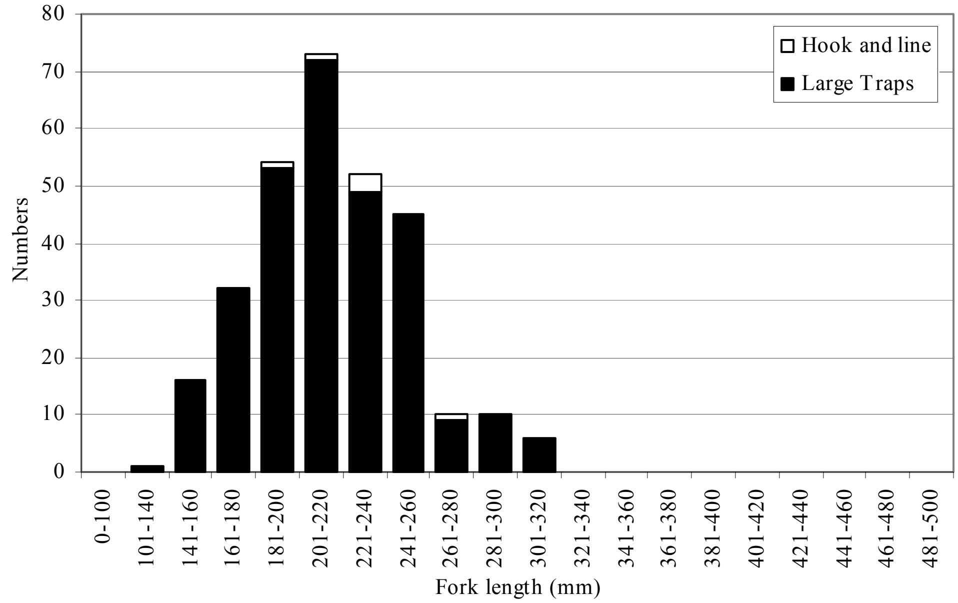

Figure 12.–Length frequency of cutthroat trout captured at Auke Lake by gear type, 2001.

Table 7.–Number of cutthroat trout marked, captured, and recaptured by stratum between sampling years 1998–2001, and chi-square test for mixing between years. Stratum A = study areas 1, 2, 3; stratum B = study areas 4, 5, 6; stratum C = study areas 7 and 8.

PANEL A: Marking in 1999, sampling in 2000

Stratum fish was marked	Total fish marked	Number recaptured, by stratum A	B	C	Total (all strata)	Number unseen	Proportion recaptured
A	165	24	12	7	43	122	0.26
B	102	6	10	7	23	79	0.23
C	85	4	9	11	24	61	0.28
Total	352	34	31	25	90	262	0.26
Unmarked fish caught		57	72	73	202		
Total caught in recapture event		91	103	98	292		
Marked fraction		0.37	0.30	0.26	0.31		

χ^2 = 3.15, 2 df, P = 0.207, *Accept H_o: marked fraction is constant across recovery strata*

PANEL B: Marking in 2000, sampling in 2001

Stratum fish was marked	Total fish marked	Numbers recaptured, by stratum A	B	C	Total (all strata)	Number unseen	Proportion recaptured
A	91	0	3	3	6	85	0.07
B	103	1	9	7	17	86	0.17
C	98	1	2	11	14	84	0.14
Total	292	2	14	21	37	255	0.13
Unmarked fish caught		32	59	105	196		
Total caught in recapture event		34	73	126	233		
Marked fraction		0.06	0.19	0.17	0.16		

χ^2 = 3.20, 2 df, P = 0.202, *Accept H_o: marked fraction is constant across recovery strata*

Table 8.–Summary of goodness-of-fit tests for homogeneous capture/survival probabilities by tag group. Asterisks denote tests which contained a cell with an expected value of less than 2. Overall chi-squares are the sum of the individual test statistics.

		Component 1		Component 2	
Year	Period	Test statistic	P-value	Test statistic	P-value
Annual model					
1999		3.719	0.0538		
2000		11.814	0.0006	0.272	0.873*
Overall statistics:		15.539	0.0004	0.272	0.873*
Trip-by-trip model					
1998	2	3.197	0.074		
"	3	0.130	0.719*	2.484	0.289*
1999	4	0.566	0.452	2.182	0.336*
"	5	0.001	1.000	3.746	0.154*
2000	6	0.0001	1.000	10.621	0.005
"	7	1.696	0.193	2.377	0.305*
Overall statistics:		5.590	0.471	21.409	0.030

The significant heterogeneity by tag group in the annual data suggests a generalization of the JS model having different survival rates for newly-captured and previously-captured fish might be useful (Brownie and Robson 1983). Such an analysis (model "2" in JOLLY and "model 3" in POPAN) is effective when a one-period *reduction* in survival due to tagging is present. However, we discounted this approach because a) the absence of key capture histories (noted above) meant we could not verify a statistical gain (GOF) by using the generalized JS model, b) abundance estimates from such an analysis ($\hat{N}_{1999}$=808, $\hat{N}_{2000}$=583) were significantly higher than trip-by-trip JS and other in-season Peterson estimates (discussed below), and c) it is unclear whether the generalized analysis is appropriate when previously tagged fish are recaptured at *lower rates* than newly marked fish.

Estimates of abundance, survival, and recruitment of cutthroat trout ≥180 mm FL in Auke Lake using the annual and trip-by-trip models are summarized in Table 10. Estimates using the

Table 9.–Breakdown of statistics for homogeneous capture/survival probabilities by tag group for the annual JS experiment (p = probability of capture for each group). Results of component-1 tests for 1999 and 2000 indicate heterogeneity by tag group; lack of recoveries from 1998 essentially invalidates the component-2 test.

Component 1 test for 1999		First captured in 1998	First captured in 1999
Captured in 1999 and recaptured in 2000		2.00	92.00
Captured in 1999 and not recaptured in 2000		20.00	238.00
χ^2 = 3.7195, 1 df, P = 0.0538	$\hat{p} \rightarrow$	0.091	0.279

Component 1 test for 2000		First captured in 1999	First captured in 2000
Captured in 2000 and recaptured in 2001		3.00	35.00
Captured in 2000 and not recaptured in 2001		91.00	163.00
χ^2 = 11.814, 1 df, P = 0.0006	$\hat{p} \rightarrow$	0.032	0.177

Component 2 test for 2000		Captured in 1998, not in 1999	Captured in 1998 and 1999	First captured in 1999
Captured in 2000		4.00	2.00	88.00
Captured in 2001, not in 2000		0.00	0.00	4.00
χ^2 = 0.272, 2 df, P = 0.873	$\hat{p} \rightarrow$	n.a.	n.a.	0.04

Table 10.–Jolly Seber estimates of abundance (N), survival (ϕ), and births (B) of cutthroat trout ≥180 mm FL at Auke Lake, 1998–2001.

Year	$\hat{N}$	SE($\hat{N}$)	$\hat{\phi}$	SE($\hat{\phi}$)	$\hat{B}$	SE($\hat{B}$)
Annual model						
1998			0.414	0.090		
1999	566	121	0.338	0.048	191	68
2000	383	50				
2001						
Trip-by-trip model [a]						
1998 (1)			1.000 [b]	– [c]		
1998 (2)	243	57	1.000 [b]	– [c]	0 [b]	– [c]
1998 (3)	243	57	0.376	0.064	402	36
1999 (1)	494	30	0.877	0.075	0 [b]	– [c]
1999 (2)	433	43	0.385	0.040	232	22
2000 (1)	399	26	0.735	0.085	0 [b]	– [c]
2000 (2)	293	35				
2001 (1)						

[a] Estimates constrained to admissible values (Schwarz and Arnason 1996).

[b] Constrained value.

[c] SE for constrained value not available.

annual model are suspect for the reasons noted above. Also, some mortality between trips in early 1999 and 2000 violates the instantaneous sampling assumption if data are pooled. Estimates from the trip-by-trip model result from constraining the first (i.e., trip 1 to trip 2) survival and first and last recruitments to admissible values. Abundance decreases by trip in 2000, as it should, because the annual emigration was occurring during sampling. Reported annual harvests at Auke Lake are <20 fish from 1998 through 2000 (Table 2), so estimates of survival are essentially estimates of natural rates.

Length data collected during both events during 2000 were used to estimate the length composition of cutthroat trout ≥180 mm FL (Table 11). Cutthroat trout caught in the lake averaged 208 mm (SD = 47 mm) and ranged from 102 to 347 mm. Length frequency distributions of cutthroat trout captured during the first and second sampling events were not significantly different (d_{max} = 0.108, P = 0.217; Lum et al. 2001). Almost 50% of the population in 2000, using the average trip-by-trip abundance estimate (346) was ≤220 mm FL. By regulation, harvest of cutthroat trout in Auke Lake is restricted to fish ≥356 mm FL (14 inches TL), so very few of the cutthroat trout in Auke Lake during May exceeded the 14-inch minimum size limit.

Table 11.–Length composition of cutthroat trout ≥180 mm FL, Auke Lake, 2001. Number sampled (n_k), proportion (p_k), abundance (N_k), and standard error (SE) are shown for each 20-mm length class.

Length k, mm FL	n_k	P_k	SE(p_k)
180–200	88	0.327	0.019
201–220	45	0.167	0.015
221–240	21	0.078	0.011
241–260	37	0.138	0.014
261–280	34	0.126	0.013
281–300	30	0.112	0.013
301–320	10	0.037	0.008
321–340	3	0.011	0.004
341–360	1	0.004	0.002
Total	269		

A total of 38 PIT tagged cutthroat trout immigrated into Auke Lake in the fall of 2000 (Lum et al. 2001); 28 of those fish emigrated from the lake in 2001, leaving 10 that either chose to remain in Auke Lake or died during the winter. None of these 10 fish were caught in the lake in 2001. Thus, an estimate of overwinter survival of PIT tagged fish remaining alive in the lake in 2001 was not made. We estimate that overwinter survival of the 38 immigrants was 74%, assuming the 10 fish that stayed in the lake died. For the three previous years, overwinter survival for PIT tagged fall immigrants was 67%, 58%, and 60% (Lum et al. 1999, 2000, 2001).

The average overwinter survival of PIT tagged sea-run migrants at Auke Creek, 1997–2000, was 65% and was significantly greater than survivals in other studies. These survival rates are significantly greater than the JS "overwinter" survival rate for all Auke Lake fish in this study (38%, SE = 6%, and 39% SE = 4%, estimated for 1998 and 1999, respectively) or similar lake-bound populations in Neck Lake (51%, SE = 6%, Harding et al. 1999) or Florence Lake (40–52%, SE = 2-3%, Rosenkranz et al. 1999). This difference is in part due to presence of immature anadromous fish that leave the lake at some point (deflating the annual survival statistic). In fact, a JS analysis of the capture history data for 1998–2001 (described above), which excludes all fish ever observed at the weir, yields an annual survival estimate of 0.51 (SE = 0.065), similar to that found in other studies in Southeast Alaska. We note that overwinter survival rates also do not include the spawning and spawning migration period when mortality may be substantial.

During our 2000 lake and weir studies, we examined 97 cutthroat trout PIT tagged in Auke Lake in 1999 and found that 77% (75) of these fish retained their photonic dye secondary marks. We also examined 11 fish tagged and marked in 1998 and 7 of these had retained their mark for a retention of 64% for the second year. In 1999 we estimated an 87% retention rate for marks placed in 1998 (Lum et al. 1999). During our 2001 lake and weir studies, we examined 34 cutthroat trout PIT tagged in Auke Lake in 2000 and found that 79% (27) of these fish retained their red photonic secondary dye mark. This shows that our dye marks are not dependable for long-term (more than several month) experiments. List of archived computer files for the Auke Creek weir and Auke Lake trout studies is shown in Appendix A5.

DISCUSSION

The JS abundance estimates by trip during 1999 ($\hat{N}$ = 494 SE = 30, and $\hat{N}$ = 433 SE = 43) are very similar to our 1999 CP model estimate of 464 (SE = 23; Lum et al. 2000) and the JS estimates by trip during 2000 ($\hat{N}$ = 399 SE= 26, $\hat{N}$ = 293 SE = 35) are similar to our 2000 CP model estimate of 364 (SE = 20, Lum et al. 2001). We do not know the cause of the heterogeneous capture/survival probabilities seen in the (annual JS) analysis where sampling data from trips within a year are pooled. But, it does appear that such an analysis should be avoided at Auke Lake, at least when samplings within a year occur during a period of flux in the population (i.e., before the spring emigration is completed).

Classic examples of high heterogeneity by marked group occur when newly tagged animals experience a *lower* probability of survival and capture than do previously tagged animals, and the cause is associated with a temporary (one-period) effect of handling or tagging on survival (Pollock et al. 1990, Harding 1995, Rosenkranz et al. 1999). In our case, fish that were newly tagged fish in 2000 exhibited a *higher* probability of survival and capture than previously marked (especially in 1998) fish. The observed effect could be related to the relatively greater age and/or size of the previously marked fish. The older fish in our example may also simply have succumbed to natural causes, or they may have been alive but unavailable to sampling in 2001. The later possibility could occur, for example, if sampling in 2001 occurred when older-aged fish were less likely to be captured because they were spawning. Although other studies in Alaska suggest cutthroat trout can live 15 years (Harding 1995, Erikson 1999), tagging results at Auke Lake show that fish are seldom recaptured more than a few years after initial capture. This finding is in part, at least, an artifact of the anadromous component of the Auke Lake system. Also, perhaps the average characteristics (e.g., age, maturity, eventual anadromy, sex) of the fish captured and tagged varied by sampling trip within years (1998–2000). Significant differences in the probability of capturing fish over time within a year could thus lead to heterogeneity of the pooled samples across years.

Another source of heterogeneity (and the low number of marked fish in 1998 that led to the small expected values- or complete absence of- certain captures histories, Tables 8 and 9) may be linked to the high water temperatures (18° to 20°C to a depth of 2 to 3 meters) seen in July and August 1998. The relatively late sampling dates and high water temperature that year may be associated with low catch rates because some groups of fish avoided our baited traps or had other sources of food during this time, such as aquatic insects and eggs from other spawning salmonids that immigrated through the weir in July and August. These cutthroat trout may then have been fully available to our gear after 1998.

In completing the current analysis, an error was found in how data were handled to estimate abundance and survival for 1999 for a previous report (Lum et al. 2001). A new analysis results in estimates ($\hat{N}_{1999}$ = 552, SE = 117; $\hat{\phi}_{98-99}$ = 0.413, SE = 0.089, $\hat{\phi}$ is the estimated overwinter survival), that are only very slightly higher than those reported earlier, both of which also agree closely with current estimates (Table 10).

The completion of the 2000 field season brought to a close a three-year study to estimate abundance of resident cutthroat trout in Auke Lake. In 2001, sampling effort was reduced to half, but tagging and monitoring continued in the lake. Some insight about the life histories of cutthroat trout using Auke Lake is apparent from capture histories tabulated since PIT tagging began at the weir in 1997 and in the lake in 1998. In general, the summertime population of cutthroat trout in Auke Lake consists of fish that are truly resident (potamodromous), and fish that are actually migratory (diadromous and anadromous) at some point in their life. Prevalence of fish in the latter group was especially interesting to us. Eighteen (18) of 121 (15%) PIT tagged fish handled during lake sampling in 1998 (and which did not pass the weir at any time in 1998) eventually emigrated from the lake; 15 (83%) of the 18 fish left in 1999, and 3 (17%) left in 2000. In 1999, 16 of 364 (4%) of the PIT tagged fish handled in the lake emigrated during spring 2000 (11 fish, 69%) and 2001 (5 fish, 31%). Thus, a 2-year average of 9% of the summer "residents" survived to exhibit sea-run behavior. Of the 18 eventual emigrants from the 1998 lake sampling, 5 (28%) returned to the lake during the fall immigration within the same year that they left. Only 1 of the 16 (6%) eventual emigrants from the 1999 lake sampling returned to the lake during the following fall 2001 immigration. In 2001, 62 of 259 (24%) PIT tagged fish handled in Auke Lake left through the weir after the lake study and prior to changing the weir to receive immigrants. Of the 62 emigrants, 31 (50%) returned to the lake during the fall immigration within the same year that they left.

It is very difficult to distinguish sea-run from resident cutthroat trout in a lake that is accessible to upstream migrants. For example, some sea-run fish appear to become temporary lake residents and some apparent "residents" mature and emigrate. A small number of (presumably sea-run) fall immigrants elect to not participate in the next spring emigration, and remain in Auke Lake. Over three years (1998–2000), we estimate an average of 8% (annual estimates were 6%, 13%, and 4%, Lum et al. 1999, 2000) of the PIT tagged immigrants that lived through the spring emigration and lake sampling events, remained in the lake. A total of 11 such PIT tagged fish have been captured in Auke Lake from 1998 through 2000. The majority (10 of 11, or 91%) of these fish were not seen leaving the lake again, and most (9 of the 11) were not captured in the lake in a subsequent year, suggesting they died in the lake. Two of these 10 fish were captured in the lake in 2 successive years, while the other 8 were never seen again. These anadromous recruits to the summer population in the lake could be spawning in the lake, or electing to forgo their annual emigration (and perhaps spawning). The one (of the 11) tagged fish that did leave the lake again first passed the weir in both directions in 1997, remained in the lake during 1998 and 1999, and then passed the weir in both directions in 2000.

Inference about life history from this sample of 11 fish requires some qualification. First, the Auke

Creek weir is not operated during winter. Generally, from November 1 through March 1 there can be unmonitored fish passage past the weir site. Also, some of the 8 PIT tagged fish that were never seen again were captured in the lake in May of 1999 or 2000, prior to the conclusion of the spring emigration. It is possible that some of these fish did not "elect" to stay in the lake, but died en-route to the sea (or weir) after capture in the lake possibly due to handling mortality. Handling mortality should be very low because lake temperatures during this period are low, and little stress is typically placed on previously captured and tagged fish. It is also possible that a few fish tried to emigrate after the weir was converted to an upstream trap about June 30 (see Figure 7) but could not do so because the weir blocked downstream migration and they subsequently reentered and lake and died. We have not yet devised a viable method to allow upstream migration while the weir is operated to count emigrants and vice versa.

CONCLUSIONS AND RECOMMENDATIONS

The Dolly Varden and cutthroat trout assessments in Auke Lake/Creek provide a rare time series of abundance, survival, growth, migration timing, and other life history information for these species. The data for cutthroat trout is the longest and most complete series of its kind in existence and should be continued. The continuity of the dataset will become increasingly important as urban development continues in the Juneau area. Tagging of emigrant cutthroat trout at Auke Creek provides particularly valuable information and should be continued. Tagging trout and char migrants at Auke Creek also meshes well with other local trout/salmon projects where the tagged fish may be sampled. Information on salt- and freshwater migrations and habitat preferences are important because these species utilize other watersheds for spawning and juvenile rearing. While anecdotal in nature, the pre-1960 population of cutthroat trout in Auke Lake may have been substantially larger than it is now, and the recent pattern of declining numbers of emigrants and immigrants at Auke Creek may be of concern if it continues.

Sampling the lake in late May and early June improved catch rates but presented significant problems because the spawning and smolt emigration was incomplete. Sampling prior to spawning (e.g., April) would avoid this problem, but it is difficult to predict when ice-out will occur, and if it will be possible after ice-out to complete sampling without running into the spawning season (when some fish become unavailable to sampling) or the annual emigration. Thus, the best time to sample Auke Lake appears to be after the emigration is complete, and while water temperatures remain low. This window of opportunity will vary from year to year and require adapting schedules to actual spring conditions. A continued evaluation of photonic dye marks, with a focus on extending their visibility over time is also recommended.

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APPENDIX A

Appendix A1.–Daily counts of spring emigrant salmonids at Auke Creek, 2001.

Daily counts								
	Water temp	Pink salmon fry	Coho salmon smolts	Sockeye salmon smolts	Chum salmon fry	Dolly Varden	Cut-throat trout	Steel-head
March 1	1.6	0	0	0	0	0	0	0
2	1.7	65	0	0	53	0	0	0
3	1.7	79	0	0	92	0	0	0
4	1.7	59	0	0	114	0	0	0
5	1.7	76	0	0	140	0	0	0
6	1.7	47	0	0	117	0	0	0
7	1.8	107	0	0	148	0	0	0
8	1.9	44	0	0	184	0	0	0
9	2.0	98	0	0	330	1	0	0
10	1.9	99	0	0	346	0	0	0
11	2.0	64	0	0	381	0	0	0
12	2.1	121	0	0	200	0	0	0
13	2.2	132	0	0	317	0	0	0
14	2.2	77	0	0	248	0	0	0
15	2.4	164	0	0	478	0	0	0
16	2.4	237	0	0	633	0	0	0
17	2.5	222	0	0	669	0	0	0
18	2.5	271	0	0	668	0	0	0
19	2.4	289	0	0	614	1	0	0
20	2.2	238	0	0	491	1	0	0
21	2.4	270	0	0	564	0	0	0
22	2.5	437	0	0	721	0	0	0
23	2.6	307	0	0	710	1	0	0
24	2.9	506	0	0	681	1	0	0
25	3.1	765	0	0	805	0	0	0
26	3.1	1285	0	0	909	0	0	0
27	3.1	781	0	0	465	1	0	0
28	3.1	1238	0	0	674	1	0	0
29	3.3	1763	0	0	655	0	0	0
30	3.3	1547	0	0	629	7	0	0
31	3.5	948	0	0	465	1	0	0
April 1	4.1	1477	0	0	522	0	0	0
2	4.2	1975	0	0	649	2	0	0
3	4.7	1429	0	0	597	1	1	0
4	3.9	2681	0	0	1549	0	0	0
5	4.0	2257	0	0	570	4	1	0
6	4.0	2561	0	0	574	6	0	0
7	4.1	1920	0	0	456	0	0	0
8	4.0	2174	0	0	499	1	1	0
9	4.2	2690	0	0	1453	5	0	0
10	4.2	2042	0	0	417	23	1	0
11	4.4	1557	0	0	363	16	2	0
12	4.6	1886	0	0	282	11	0	0
13	4.6	3789	0	0	374	17	2	0
14	4.9	1513	0	0	251	3	1	0
15	5.0	2653	0	0	216	4	0	0
16	5.1	2539	0	0	201	9	1	0
17	5.8	2199	0	0	256	12	2	0
18	5.8	2311	0	0	156	8	4	0
19	5.7	2872	0	0	150	69	14	0
20	6.2	1920	0	0	79	372	13	0
April 21	6.6	1792	0	0	64	161	11	0
22	7.2	1421	0	0	44	112	7	0
23	6.8	459	0	0	24	29	2	0
24	6.8	285	0	0	9	24	5	0

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Appendix A1.–Page 2 of 3.

Daily counts								
	Water temp	Pink salmon fry	Coho salmon smolts	Sockeye salmon smolts	Chum salmon fry	Dolly Varden	Cut-throat trout	Steel-head
April 25	6.9	474	0	0	22	32	2	0
26	7.1	113	0	0	5	86	4	0
27	7.0	88	0	0	6	94	13	0
28	7.0	32	0	1	3	511	6	0
29	6.9	26	2	0	2	121	2	0
30	6.9	15	1	2	2	47	1	0
May 1	7.3	8	2	3	5	224	1	0
2	6.8	1	1	0	1	13	0	0
3	6.7	2	0	2	0	33	0	0
4	6.6	0	9	3	2	329	0	0
5	6.6	3	14	8	2	212	1	0
6	6.8	1	12	5	3	132	1	0
7	6.9	0	14	4	1	48	1	0
8	6.7	2	21	10	3	82	2	0
9	6.7	1	18	5	2	118	0	0
10	6.8	0	36	7	0	468	3	0
11	7.3	0	30	8	2	195	2	0
12	7.6	0	57	17	0	893	5	0
13	7.8	0	85	10	0	509	4	0
14	8.2	0	127	21	0	376	8	0
15	7.8	0	271	25	0	160	12	0
16	8.2	0	245	52	0	215	4	0
17	8.6	0	363	57	0	267	10	1
18	9.2	0	269	81	0	119	7	0
19	9.6	0	420	278	0	203	7	1
20	9.6	0	289	274	0	160	9	1
21	10.1	0	289	262	0	118	11	0
22	9.9	0	302	638	0	83	14	0
23	9.4	0	572	964	0	117	24	1
24	9.4	0	497	1099	1	46	10	1
25	9.3	0	356	2708	0	30	4	0
26	10.3	0	245	2656	0	70	5	0
27	11.8	0	158	2032	0	45	5	1
28	12.2	0	167	2640	1	37	4	0
29	12.3	0	202	1363	2	32	8	0
30	12.0	0	116	1049	3	25	9	0
31	12.2	0	132	1100	3	34	6	0
June 1	12.0	0	88	1013	6	26	9	0
2	12.7	0	71	730	1	25	1	0
3	12.7	0	60	305	2	23	5	0
4	12.2	0	46	394	4	3	8	1
5	12.5	0	36	225	4	2	0	0
6	12.4	0	40	286	1	10	5	0
7	12.6	0	19	201	2	4	1	0
8	13.3	0	12	216	5	4	3	0
9	14.1	0	12	154	2	8	0	0
10	13.4	0	6	102	4	1	1	0
11	13.6	0	5	71	4	0	3	0
12	13.6	0	1	82	0	0	1	0
13	13.5	0	3	44	0	0	1	0
14	13.9	0	5	31	2	0	0	0
15	14.7	0	6	73	1	1	0	0
16	15.3	0	2	26	0	1	0	0
17	15.5	0	3	14	0	2	5	0
18	15.8	0	0	21	0	0	1	0

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Appendix A1.–Page 3 of 3.

Daily counts								
	Water temp	Pink salmon fry	Coho salmon smolts	Sockeye salmon smolts	Chum salmon fry	Dolly Varden	Cut-throat trout	Steel-head
June 19	16.2	0	0	9	0	1	2	0
20	16.3	0	0	9	0	0	0	0
21	16.2	0	2	11	0	0	0	0
22	16.1	0	0	5	1	0	1	0
23	15.9	0	0	5	0	0	0	0
24	16.1	0	0	1	0	0	3	0
25	16.5	0	0	11	2	41	6	0
26	16.7	0	3	2	3	15	7	1
27	17.7	0	0	0	0	1	1	0
28	17.6	0	0	2	1	0	0	0
29	17.0	0	0	1	0	0	0	0
Totals		61,504	5,742	21,428	23,372	7,356	337	8

Appendix A2.–Daily counts of fall immigrant salmonids at Auke Creek weir, 2001. Counts do not include sockeye or coho jacks (0-ocean; <400 mm MEF), or chinook mini-jacks (0-ocean).

	Daily counts								
	Water temp	Sockeye salmon adults	Pink salmon adults	Chum salmon adults	Coho salmon adults	Chinook salmon adults	Dolly Varden	Cut-throat trout	Steel-head
June 27	17.7	68	0	0	0	0	0	0	0
28	17.6	0	0	0	0	0	0	0	0
29	17.0	0	0	0	0	0	0	0	0
30	17.3	0	0	0	0	0	0	0	0
July 1	17.6	0	0	0	0	0	0	0	0
2	17.6	0	0	0	0	0	0	0	0
3	17.6	0	0	0	0	0	0	0	0
4	17.1	0	0	0	0	0	0	0	0
5	16.3	0	0	0	0	0	0	0	0
6	15.4	184	0	0	0	0	142	0	0
7	14.6	11	0	0	0	0	24	0	0
8	13.6	90	0	0	0	0	109	0	0
9	13.6	400	0	0	0	0	68	0	0
10	13.9	250	0	1	0	0	47	0	0
11	13.9	323	0	2	0	0	40	0	0
12	13.8	642	0	1	0	0	40	0	0
13	13.9	86	0	2	0	0	21	0	0
14	14.0	128	0	2	0	0	7	0	0
15	14.5	107	0	4	0	0	13	0	0
16	15.2	233	0	6	0	1	43	0	0
17	15.7	88	3	5	0	0	14	0	0
18	15.6	30	0	4	0	0	28	0	0
19	15.8	3	1	3	0	0	29	0	0
20	17.0	6	0	3	0	0	20	0	0
21	18.1	0	0	1	0	0	15	0	0
22	18.3	0	0	0	0	0	0	0	0
23	16.5	508	4	25	0	1	357	0	0
24	16.3	91	4	12	0	0	71	0	0
25	15.2	68	11	16	0	0	115	0	0
26	14.5	128	22	16	0	1	52	0	0
27	14.5	59	41	13	0	0	17	0	0
28	14.4	16	20	7	0	2	10	0	0
29	14.5	20	40	18	0	0	3	0	0
30	14.7	10	21	20	0	3	15	0	0
31	14.5	2	34	25	0	3	5	0	0
Aug. 1	14.8	3	4	23	0	5	3	0	0
2	15.6	4	25	35	0	0	14	0	0
3	16.3	3	10	38	0	2	14	0	0
4	16.3	3	13	48	0	0	14	0	0
5	16.4	5	21	48	0	0	12	0	0
6	16.5	6	12	37	0	2	8	0	0
7	16.7	5	12	33	0	0	42	0	0
8	16.4	2	7	18	0	6	13	0	0
9	16.1	5	8	22	0	3	21	0	0
10	16.3	5	12	19	0	0	29	0	0
11	16.8	0	17	19	0	2	1	0	0
12	16.8	0	36	10	0	0	23	0	0

-continued-

	Daily counts								
	Water temp	Sockeye salmon adults	Pink salmon adults	Chum salmon adults	Coho salmon adults	Chinook salmon adults	Dolly Varden	Cut-throat trout	Steel-head
Aug. 13	17.4	0	23	20	0	0	7	0	0
14	18.0	0	16	6	0	0	6	0	0
15	18.3	1	32	1	0	0	15	0	0
16	18.1	0	30	1	0	0	9	0	0
17	18.0	0	27	0	0	0	0	0	0
18	16.9	0	33	0	0	0	0	0	0
19	16.7	0	59	0	0	0	6	0	0
20	16.7	0	183	0	0	0	6	0	0
21	16.7	24	375	5	0	0	8	0	0
22	16.8	2	207	1	0	0	16	0	0
23	16.1	1	100	0	0	2	8	0	0
24	15.8	2	117	0	0	0	12	0	0
25	15.3	0	115	0	0	1	2	0	0
26	15.2	0	137	0	0	0	3	0	0
27	14.9	26	1,298	2	0	2	3	0	0
28	14.8	123	1,074	4	0	17	52	0	0
29	14.8	15	633	5	0	26	59	0	0
30	14.4	19	809	2	0	18	68	0	0
31	14.2	13	641	2	0	100	127	0	0
Sept. 1	13.8	14	301	3	0	6	81	0	0
2	13.2	16	268	0	0	3	47	0	0
3	13.1	40	276	0	0	2	71	0	0
4	13.0	11	172	0	0	1	65	0	0
5	12.7	22	133	0	0	6	51	0	0
6	12.4	14	339	0	0	6	165	0	0
7	12.3	9	171	0	0	3	134	0	0
8	12.1	7	110	0	0	0	88	0	0
9	12.1	4	66	0	0	0	69	0	0
10	12.5	1	42	0	0	0	21	0	0
11	12.4	1	20	0	0	0	32	0	0
12	12.2	0	15	0	0	0	13	0	0
13	11.5	2	35	0	0	0	54	0	0
14	11.6	1	38	0	190	0	304	53	0
15	11.8	2	12	0	22	0	32	12	0
16	12.0	0	11	0	39	0	32	13	0
17	12.0	0	14	0	53	0	55	20	0
18	11.8	0	6	0	44	0	37	11	0
19	11.8	0	4	0	43	0	28	11	0
20	11.5	0	3	0	16	0	43	7	0
21	11.3	0	0	0	56	0	33	8	0
22	11.3	0	0	0	16	0	82	6	0
23	11.1	0	0	0	16	0	31	8	0
24	10.8	1	0	0	51	0	51	6	2
25	10.7	0	0	0	33	0	30	5	0
26	10.5	0	0	0	8	0	37	5	0
27	10.5	0	0	0	9	0	14	0	0
28	10.3	0	0	0	14	0	17	2	0
29	10.1	0	0	0	11	0	13	0	1

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Appendix A2.– Page 3 of 3.

		Daily counts							
	Water temp	Sockeye salmon adults	Pink salmon adults	Chum salmon adults	Coho salmon adults	Chinook salmon adults	Dolly Varden	Cut-throat trout	Steel-head
Sept. 30	10.0	0	0	0	14	0	11	0	0
Oct. 1	9.9	0	0	0	37	0	24	6	0
2	9.8	0	0	0	61	0	35	10	0
3	9.9	0	0	0	30	0	35	9	0
4	10.0	0	0	0	24	0	25	1	1
5	10.2	0	0	0	13	0	3	2	1
6	10.2	0	0	0	5	0	0	2	1
7	9.9	0	0	0	1	0	12	1	0
8	9.8	0	0	0	4	0	6	0	0
9	9.6	0	0	0	5	0	15	1	1
10	9.3	0	0	0	4	0	9	0	1
11	9.2	0	0	0	3	0	9	0	0
12	8.9	0	0	0	10	0	12	4	0
13	8.6	0	0	0	9	0	16	3	0
14	8.5	0	0	0	0	0	26	1	1
15	8.3	0	0	0	2	0	21	1	1
16	8.2	0	0	0	2	0	8	2	0
17	8.0	0	0	0	3	0	17	1	0
18	7.7	0	0	0	4	0	98	6	0
19	7.6	0	0	0	5	0	116	5	1
20	7.5	0	0	0	1	0	15	2	0
21	7.3	0	0	0	3	0	19	0	0
22	7.1	0	0	0	1	0	15	1	0
23	7.0	0	0	0	0	0	6	1	0
24	6.8	0	0	0	1	0	4	1	0
25	6.6	0	0	0	1	0	5	0	0
26	6.3	0	0	0	1	0	23	0	0
27	6.0	0	0	0	0	0	9	0	0
28	6.0	0	0	0	0	0	1	0	0
29	6.0	0	0	0	0	0	3	1	0
30	6.2	0	0	0	0	0	11	0	0
31	6.0	0	0	0	0	0	4	0	0
Total		3,963	8,323	588	865	224	4,249	228	11

Appendix A3.–Summary statistics for Jolly-Seber models, Auke Lake, 1998–2001.

Year	n_i	m_i	R_i	r_i	z_i
Annual model					
1998	89	0	89	26	0
1999	352	22	352	94	4
2000	292	94	292	38	4
2001	234	42	234	0	0
Trip-by-trip model					
1998 (1)	41	0	41	17	0
1998 (2)	42	5	42	18	12
1998 (3)	19	8	19	4	22
1999 (1)	192	13	192	122	13
1999 (2)	265	114	265	77	21
2000 (1)	182	51	182	100	47
2000 (2)	205	138	205	33	9
2001 (1)	234	42	234	0	0

n_i = number of fish caught, marked, and released in sample i.

m_i = number of marked fish caught in sample i.

R_i = number returned to the population alive with marks from sample i.

r_i = number caught in sample i which are recaptured later.

z_i = number not caught in sample i which were previously captured and are recaptured later.

Appendix A4.–Capture histories for Jolly-Seber models, Auke Lake, 1998–2001

Capture history[a]	Frequency	Capture history[a]	Frequency	Capture history[a]	Frequency
Annual model					
1110	2				
1100	20				
1010	4				
1000	63				
0111	3				
0110	85				
0101	4				
0100	238				
0011	35				
0010	163				
0001	192				
Trip-by-trip model					
11100000	2	01001000	2	00010000	64
11010000	1	01000100	1	00001111	3
11001000	1	01000010	2	00001110	10
11000000	1	01000000	23	00001100	8
10101000	2	00110000	1	00001010	21
10100000	2	00101000	1	00001001	2
10011000	2	00100000	9	00001000	107
10010010	1	00011110	14	00000111	16
10010000	1	00011100	10	00000110	51
10001000	3	00011010	8	00000101	5
10000010	1	00011001	1	00000100	59
10000000	24	00011000	67	00000011	14
01100000	2	00010110	1	00000010	53
01011000	3	00010100	4	00000001	192
01010010	1	00010010	9		
01010000	3	00010001	1		

[a] A "0" signifies not captured during that particular sampling event, and a "1" signifies a capture; i.e., a capture history of 1,1,1,0 represents a group of fish that were captured during the 1st, 2nd, and 3rd sampling events and not captured during the 4th event. The sampling events correspond to trips within years in which sampling occurred, in this case: 1998(1), 1998(2), 1998(3), 1999(1), 1999(2), 2000(1), 2000(2), and 2001(1).

Appendix A5.–List of computer data files archived from this study.

Data file	Description
Cut01.xls	Excel file of length information for emigrant and immigrant cutthroat trout, Auke Creek weir, 2001
Down2001.xls	Excel file of the counts of emigrant salmonids at Auke Creek weir, 2001
DV2001.xls	Excel file of the lengths of marked and unmarked Dolly Varden emigrating at Auke Creek weir, 2001
Grwct01.xls	Excel file of recovered tagged cutthroat trout with lengths and growth information for the 2001 field season
Lake01-1.xls	Excel file of cutthroat trout PIT tagging information for the abundance study in Auke Lake, 2001
Pit01.xls	Excel file of PIT tagging information from spring tagging and fall recoveries of cutthroat trout at Auke Creek weir, 2001
Up2001.xls	Excel file of the counts of immigrant salmonids at Auke Creek weir, 2001