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Abundance of Cutthroat Trout in Auke Lake, Southeast Alaska, in 2004

by

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and

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May 2006

Alaska Department of Fish and Game

Divisions of Sport Fish and Commercial Fisheries

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Measures (fisheries)

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

Mathematics, statistics

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

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ABSTRACT

The estimated abundance of cutthroat trout ≥180 mm in Auke Lake, located near Juneau, Alaska, was 535 (SE = 84) in spring 2004; this estimate falls between the estimates made in previous years. Estimated overwinter survival was 0.435 (SE = 0.069) and recruitment was 345 (SE = 61) fish. Average fork length of cutthroat trout sampled was 241 mm (SD = 2) and had a standard deviation of 40.

Key words: Southeast Alaska, Auke Lake, Auke Creek, cutthroat trout, sea-run, abundance, length, timing, passive integrated transponder (PIT), tag retention, population estimate, Jolly-Seber model, overwinter survival.

INTRODUCTION

The Auke Lake system, north of Juneau, Alaska, has native populations of Dolly Varden *Salvelinus malma;* cutthroat *Oncorhynchus clarkii* and steelhead trout *O. mykiss;* and pink *O. gorbuscha*, chum *O. keta*, sockeye *O. nerka*, and coho salmon *O. kisutch*. There is only a small number of overwintering juvenile steelhead, but no spawning population in Auke Lake. A weir has been operated on Auke Creek, the outlet stream of Auke Lake, since 1962. A permanent structure was constructed in 1980 and additional modifications were made in 1997 to capture all immigrant Dolly Varden and cutthroat trout. Studies at Auke Lake, in conjunction with the studies completed at the 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 (Lum et al. 1998, 1999, 2000, 2001, 2002; Lum and Taylor 2004, 2006, and *In prep*; Neimark 1984a, 1984b; Taylor and Lum, 1999, 2000, 2001, 2002, 2003, 2004 2005, Unpublished). An annual report for Auke Creek weir summarized the operations and fish counts for 2005 (Taylor 2006 Unpublished).

Coastal cutthroat trout have a life history that is characterized by a diversity of expressions within individuals and among populations. There can be resident and sea-run cutthroat trout in the same system. Resident cutthroat trout spend time in a riverine or lacustrine phase before migrating into inlet streams to spawn, never leaving the freshwater 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 freshwater 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. 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 1). 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, and the result of this effort is the longest and most complete data set across the range of species.

The first significant trout tagging program at Auke Creek began in 1994 when fish leaving Auke Lake were captured and visual implant (VI) tagged at the weir. This was followed with the implementation of passive integrated transponder (PIT) tagging at the weir in 1997. Anglers in marine waters recovered fish tagged leaving Auke Lake in spring 1997 over the next few summers, suggesting that Juneau roadside fisheries for anadromous cutthroat trout (Table 2) partly depend on stocks that overwinter or reside in Auke Lake. After a pilot study in 1997, a mark-recapture program to estimate annual spring or summer abundance in Auke Lake began in 1998.

Table 1.–Estimates of sport fishing effort, total catch, and harvest of cutthroat trout in the Auke Creek drainage, 1990–2004. Estimates of catch and harvest were derived from small numbers of mail survey responses and are thus imprecise (Statewide Harvest Survey database, Alaska Department of Fish and Game, Division of Sport Fish, Research and Technical Services, Anchorage).

					Cutthroat Trout	
Year	**Anglers**	**Trips**	**Days**	**Responses**	**Catch**	**Harvest**
1990	34	34	34	2	17	17
1991	16	33	23	1	0	0
1992	75	87	75	4	18	0
1993	50	325	271	4	391	224
1994	[a]	[a]	[a]	[a]	[a]	[a]
1995	29	32	29	1	26	0
1996	40	397	375	3	1,104	0
1997	45	47	47	2	16	0
1998	46	100	113	4	101	17
1999	33	12	33	1	9	0
2000	54	22	54	2	195	0
2001	86	307	353	5	807	24
2002	135	788	1,071	8	1,735	38
2003	17	25	25	1	0	0
2004	83	14	83	1	0	0

[a] No estimates were made in 1994

Table 2.–Estimates of sport fishing effort, total catch, and harvest of cutthroat trout and Dolly Varden in the marine areas surrounding Auke Creek, 1990–2004. Included in the counts are boat and shore fishing in Auke Bay and boat and shore fishing near the mouth of Auke Creek. Estimates of catch and harvest derived from smaller numbers of survey responses are increasingly imprecise (Statewide Harvest Survey database, Alaska Department of fish and Game, Division of Sport Fish, Research and Technical Services, Anchorage).

					Cutthroat Trout	
Year	**Anglers**	**Trips**	**Days**	**Responses**	**Catch**	**Harvest**
1990	516	447	571	16	0	0
1991	294	343	322	13	0	0
1992	623	1,359	1,494	29	0	0
1993	1,862	3,416	3,860	99	0	0
1994	2,639	5,345	7,101	118	0	0
1995	2,273	3,471	5,225	97	0	0
1996	1,989	2,313	2,926	91	58	11
1997	1,577	2,142	2,944	66	28	0
1998	1,735	2,088	2,797	74	15	15
1999	1,847	2,445	3,885	81	67	29
2000	2,770	3,575	5,588	130	45	9
2001	2,429	3,916	4,841	115	12	0
2002	1,672	2,036	2,927	84	7	7
2003	2,122	2,037	3,419	75	127	37
2004	1,707	2,081	3,406	64	21	0

Trout research at Auke Creek and Auke Lake, particularly the PIT-tagging program, 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 allow us to describe use of the lake as a rearing area for anadromous cutthroat trout. Recoveries of tagged fish in local fisheries yield data on saltwater migration patterns and provide the opportunity to observe the intra- and inter-annual 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.

OBJECTIVES

The purpose of this report is to summarize the estimates for abundance and overwinter mortality of cutthroat trout residing in Auke Lake during spring 2004 using a multi-event 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 on the Juneau road system. Auke Lake has a surface area of 67 ha and is fed by five tributaries. Lake Creek is the largest tributary with a watershed of 648 ha. The maximum 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 shoreline of Auke Lake is bordered by forested terrain, which varies from gentle slopes to steep-sided banks. The shoreline zone of water consists of areas dominated by emergent vegetation of *Equisetum spp.* and *Nuphar spp*. and other areas are characterized by large numbers of submerged and floating conifers anchored to the lakeshore and bottom by large root wads. At least 50% of the shoreline has been urbanized by residential development, along with portions of the streambanks along inlet streams.

METHODS

Sampling to estimate abundance, survival, and birth rates of cutthroat trout ≥180 mm FL in Auke Lake using the "full" Jolly-Seber (JS) model (Seber 1982) was conducted annually from 1998 to 2004. The JS analysis was made with data pooled by sampling year to yield a 7-event model having k-2 abundance estimates and k-2 survival rate estimates (k = number of sampling events). Fish captured several times during a sampling year were treated as being caught only once. Data for the analysis were collated in Statistical Analysis Software (SAS 1990) and an electronic spreadsheet, and analyzed with POPAN (Arnason et al. 1998) to estimate population parameters and obtain capture histories. Program JOLLY (Pollock et al. 1990) was used to obtain goodness-of-fit (GOF) statistics for the JS model.

In 1998, sampling was conducted by three separate trips made in July and August (Lum et al. 1999). In subsequent years, two trips were made in 1999 between May and June (Lum et al. 2000), two trips were made in 2000 in May (Lum et al. 2001), one trip was made in 2001 in April (Lum et al. 2002), and one trip was made in June in 2002 (Lum and Taylor 2004), 2003 (Lum and Taylor. 2006), and 2004 (Lum and Taylor *In prep*). As sampling dates became earlier in 1999, and especially in 2001, emigrations of anadromous trout were not completed before the start of lake sampling. In 2002 through 2005, sampling was scheduled during June to follow the anadromous emigration and precede summer conditions characterized by water temperatures dangerous to fish captured and tagged in the study (Table 3).

Table 3.–Summary of the dates of Auke Lake sampling, 1998–2005.

Year	Trip	Sampling dates
1998	1	July 8 to 17
	2	July 22 to 31
	3	August 5 to 14
1999	1	May 22 to June 2
	2	June 7 to 16
2000	1	May 2 to 11
	2	May 16 to 25
2001	1	April 16 to 25
2002	1	June 4 to 13
2003	1	June 4 to 13
2004	1	June 7 to 16
2005	1	May 31 to June 9

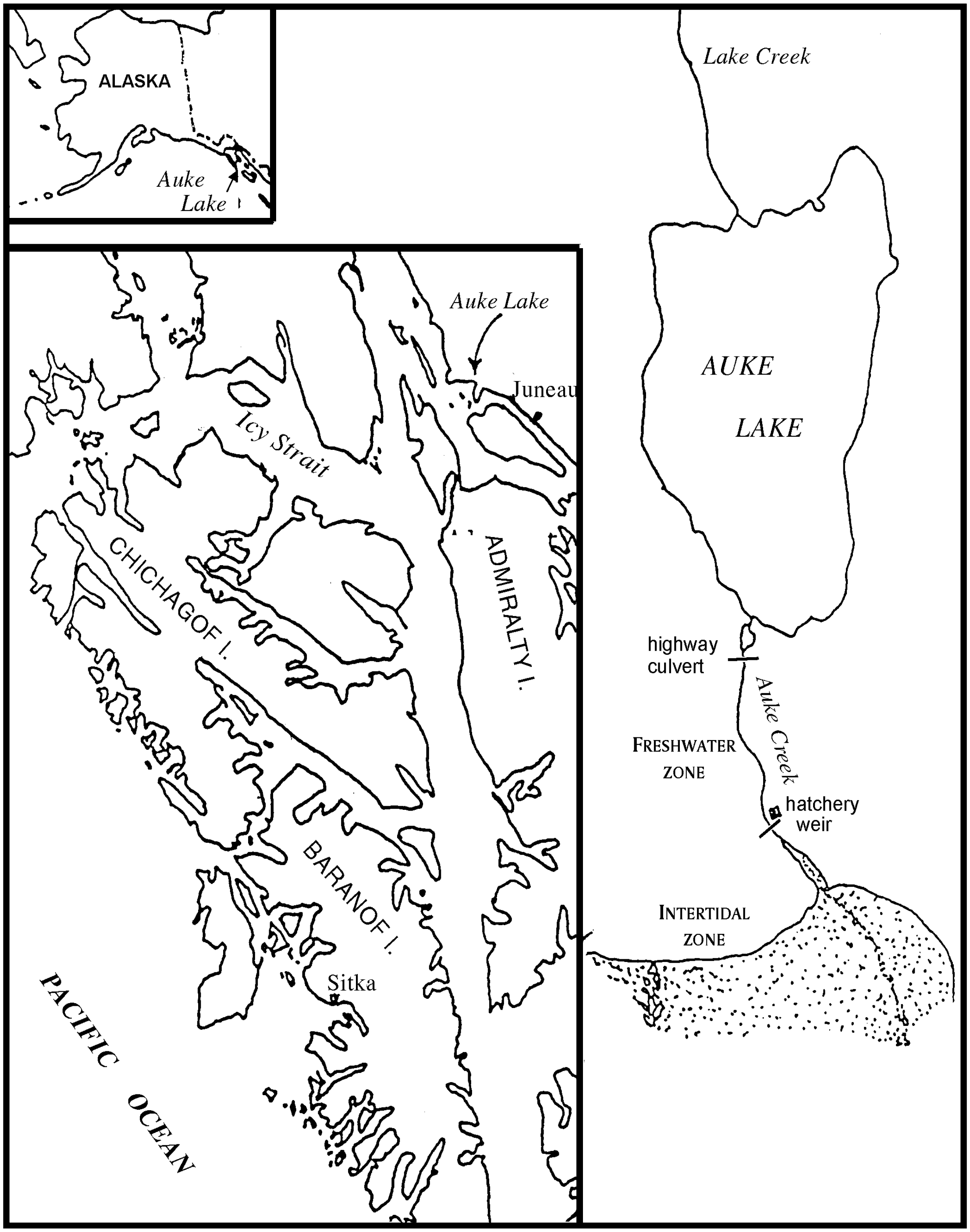

Figure 1.–The Auke Lake system in northern Southeast Alaska and location of the Auke Creek weir.

Cutthroat trout were captured using two types of traps baited with Chinook salmon eggs. Fifteen traps were plastic-mesh cylindrical devices 1 m long x 0.5 m diameter with a funnel entrance at each end and were referred to as "large traps" (Rosenkranz et al. 1999). Because of limited gear resources, one trap was a nylon-mesh, cylindrical hoop trap 2 m long x 0.5 m diameter. When fishing, the rings of the hoop trap were attached to 12 mm x 2 m metal conduit to hold the trap in the cylindrical shape. There was a funnel entrance at one end of the hoop trap, and the opposite end, where fish would be trapped, was closed with twine and large binder clamps. Trap soak-times were typically 22 to 24 hours. The use of hook-and-line fishing with small spoons, spinners, and other lures was discontinued after 2002 because of extremely low catch rates. Capture rates of large traps and hoop trap were tested to determine whether catches could be pooled (Chi-square = 0.806, and P = 0.369, df = 1, Lum and Taylor 2004).

Captured trout were inspected for tags or marks and measured to the nearest mm FL. Fish missing their adipose fin were scanned to determine PIT tag number. Unmarked cutthroat trout ≥180 mm FL were tagged with a uniquely numbered PIT tag, given a red dye mark on the left ventral fin, and had their adipose fin excised. Fish caught more than once during the sampling year 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 eight areas to facilitate sampling and accurate recording of locations where cutthroat trout were captured (Figure 2). Data from these areas were then pooled into three strata (A, B, C) for testing experimental assumptions. Trapping was conducted only in areas ≤15 m deep because previous work in Auke Lake showed trout were not captured at greater depths during the summer (Lum and Taylor 2004). All traps were fished each day and a fathometer was used to determine depth. Overall fishing effort (number of traps set) in each area was proportional to the lake surface area where depth was ≤15 m (Table 4). The depth, sampling area, and number of fish caught were recorded by trap set.

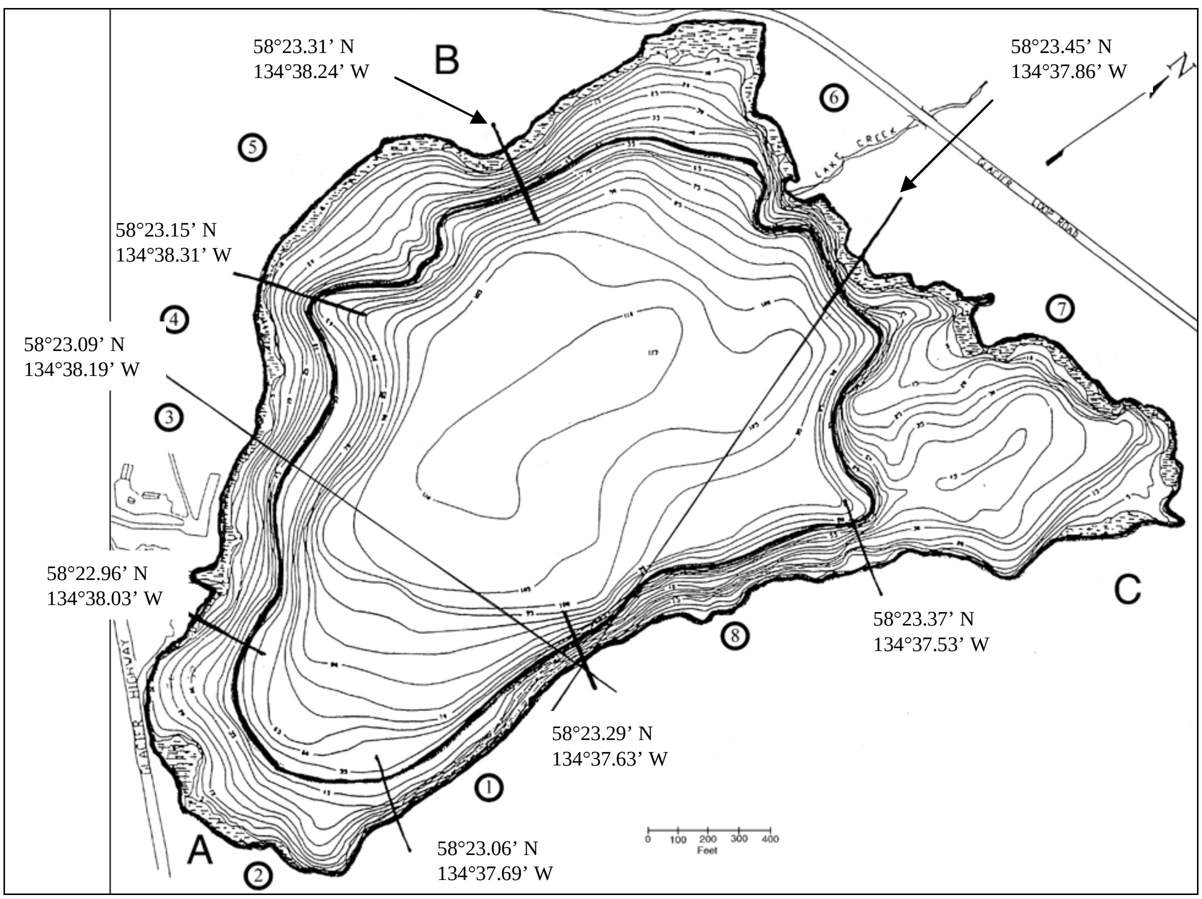

Figure 2.–Bathymetric map of Auke Lake showing location of sampling areas in 2005. The lake area inside the inner bold line denotes depths >15 m that are excluded from sampling. The two intersecting straight lines indicate the separation between the three strata (A, B, and C) used in analysis

Table 4.–Distribution of sampling effort in Auke Lake by area in 2005. 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 goal of deploying 144 traps over the 9-day sampling trip.

Area No.	Analysis stratum	Area (km^2)	Proportion [a]	No. of traps set each day	Total trap effort (sets)
1	A	0.5463	0.0459	1	9
2	A	2.6098	0.2195	3–4	29
3	A	1.0583	0.0890	2	18
4	B	0.8275	0.0696	1	9
5	B	1.4691	0.1236	2	18
6	B	1.4562	0.1225	2	18
7	C	3.1297	0.2632	4	36
8	C	0.7932	0.0667	1	9
Totals		11.8901	1.0000	16–17	146

[a] Tabulated area and proportions are estimates for 0-15 m depths

.

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;
5. All samples are instantaneous (sampling time is negligible).

A two-component GOF test (Pollock et al. 1990) was used to evaluate the assumptions of homogeneous capture and survival probabilities. The first component of the GOF test is equivalent to the Robson (1969) test for short-term mortality, but the second test component is better at detecting heterogeneous survival probabilities (Pollock et al. 1990). 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. If these GOF statistics were significant, 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. Heterogeneity by capture history (via the GOF test detailed above) has been observed in previous JS analyses at Auke Lake; fish caught for the first time in sample *i* have been *more* likely to be recaptured than fish tagged in previous years (Lum and Taylor 2004).

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). Complete mixing was evaluated by comparing the marked fractions (R/C, where R is the number of recaptures and C is the number of captures irrespective of gear) of fish caught in strata A, B and C, using fish that were marked the previous year. If (R/C)A = (R/C)B = (R/C)C, complete mixing was indicated; otherwise, mixing was incomplete. A chi-square statistic (from a 2 x 3 contingency table, $\alpha = 0.05$) was used for the test. Complete mixing has been observed ($P > 0.05$) between all successive sample years since 1999 (Lum and Taylor *In prep*).

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 ≥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 or size dependent mortality rates for cutthroat trout ≥180 mm FL. We do not have an experimental design to test for this, but note that age-dependent mortality could occur in our population (Lum and Taylor *In prep*).

Assumption 3 was evaluated by direct examination of the capture histories (mortality status by year) from each event. Historically, the number of fish killed or released alive without tags has been very low (<1%). Assumption 4 was addressed by double marking trout with different combinations of fin clips and photonic dye marks each year and estimating the annual rate of tag loss. Because individual sampling trips spanned but 9 days, significant violations of assumption 5 were not expected. However, a large emigration or mortality during sampling would contribute to violation of this assumption.

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

$$\hat{p}_k = \frac{n_k}{n} \quad (1)$$

and the variance of $\hat{p}_k$ was estimated:

$$\hat{\mathrm{var}}\left(\hat{p}_k\right) = (1 - \frac{n}{\hat{N}})\frac{\hat{p}_k(1-\hat{p}_k)}{n-1} \quad (2)$$

where n is the number of fish measured for length and n_k is the subset of n that belong to length group k. A finite population correction (FPC) was included in the variance equation because of the high sampling rate and availability of an abundance estimate $\hat{N}$ from the mark-recapture experiment. The standard error of p_k was estimated:

$$S\hat{E}(\hat{p}_k) = \sqrt{\hat{\mathrm{var}}(\hat{p}_k)} \quad (3)$$

The abundance of cutthroat trout by size increment N_k was estimated:

$$\hat{N}_k = \hat{p}_k\left(\hat{N}\right) \quad (4)$$

The variance of $\hat{N}_k$ was estimated:

$$\hat{\mathrm{var}}(\hat{N}_k) = \hat{N}^2\left(\mathrm{var}(\hat{p}_k)\right) + \hat{p}_k^2\left(\hat{\mathrm{var}}\left(\hat{N}\right)\right) - \left(\hat{\mathrm{var}}(\hat{N})\right)\left(\mathrm{var}(\hat{p}_k)\right) \quad (5)$$

The standard error of N_k was estimated:

$$S\hat{E}(\hat{N}_k) = \sqrt{\hat{\mathrm{var}}(\hat{N}_k)} \quad (6)$$

RESULTS

A total of 195 cutthroat trout between 123 and 335 mm FL were captured from May 31 to June 9, 2005 using large minnow traps and a hoop trap (Table 5). The catch per unit of effort (CPUE) in early June was 0.06 fish per hour (Table 5). Of the total, three groups of cutthroat trout were not included for the purpose of calculating the abundance estimate for 2004:

1) 45 fish < 180 mm FL; 2) 15 fish captured more than once during the 2005 survey, and therefore, considered "redundant" within this sampling event; and 3) one fish that was not tagged because of poor condition. The resulting total was 134 unique cutthroat trout ≥180 mm FL. Of these, 79 fish had been tagged in previous years and 55 fish had not been previously captured and marked. Three fish, or 3.8% (3 of the 79 previously marked fish) had lost their tag. Capture histories and summary statistics for sampling fish ≥180 mm FL since 1998 were compiled for the JS analyses (Appendix A1; Table 6).

Marked and unmarked fish mixed completely ($P > 0.05$) between all successive sample years 1999–2004 (Lum and Taylor *In prep*) and 2004–2005 (Appendix A2). Mixing was expected across years because Auke Lake is relatively small. The component-1, component-2, and overall GOF tests for homogeneous capture/survival probabilities (Table 7; Appendix A3) suggested the JS model does not fit the data well ($P < 0.05$). Inspection of the test results (Table 7) shows that half (i.e., 3 of 6) of the component-1 GOF statistics were significant ($P < 0.05$). A summary of the capture probabilities from the component-1 GOF test (Robson's test for short-term mortality, Appendix A4) reveals that the probability of recapturing fish in the year that it was tagged was nearly twice that for recapturing fish tagged in previous years. The component-2 GOF tests are less telling (as but 2 of 5 tests are significant at $P < 0.05$) although these are less powerful tests due to small sample size (Appendix A3).

The poor GOF tests suggest use of the generalized JS model, which estimates separate survival rates for newly captured and previously

Table 5.–Sampling effort (hours), cutthroat trout catch, and catch per unit effort (CPUE, fish per hour) by sampling gear and fish length-class in Auke Lake in 2005. All captures of a fish are included in the catch.

			≥180 mm		<180 mm		Combined	
Sampling dates	**Gear type**	**Efforts (hours)**	**Catch**	**CPUE**	**Catch**	**CPUE**	**Catch**	**CPUE**
May 31–June 9	Large traps (15)	3,240	148	0.046	42	0.013	190	0.059
	Hoop traps (1)	216	2	0.009	3	0.014	5	0.023
	All gear	3,456	150	0.043	45	0.013	195	0.056

Table 6.–Summary statistics for Jolly-Seber models, Auke Lake, 1998–2005.

Year	n_i	m_i	R_i	r_i	z_i
1998	89	0	89	26	0
1999	352	22	352	96	4
2000	292	94	292	51	6
2001	233	41	233	46	16
2002	259	58	259	100	4
2003	370	99	370	97	5
2004	290	91	290	40	11
2005	134	51	134	0	0

n_i = number of fish captured in sample *i*.

m_i = number of marked fish caught in sample *i*.

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

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

z_i = number of fish caught before and after sample *i* , but not caught in sample *i*.

Table 7.–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	Test statistic	P-value	Test statistic	P-value
1999	3.911	0.048		
2000	4.483	0.034	0.407	0.816*
2001	1.789	0.181	11.246	0.004*
2002	10.126	0.001	0.397	0.820*
2003	1.750	0.186	4.183	0.124*
2004	0.324	0.569	7.323	0.026*
Overall by component	22.38	0.001	23.56	0.009*
Overall:	45.94	< 0.001		

captured fish (Brownie and Robson 1983, named "Model 2" in JOLLY and "Analysis 3" in POPAN). Neither thefull or generalized model "fit" the data well (P=0.001 for the full JS model and P=0.063 for the generalized "Model 2"). Because the generalized model uses a subset of the available capture histories, precision of those estimates was much lower than the precision of the estimates from the full JS model (Table 8). The 1999 estimate (for example) from the generalized model (808, SE=428) looks larger than the estimates from the full JS (561, SE=118) or Petersen (464, SE=23; Lum et al. 2001) models, but the difference(s) between the estimates from the different models are not statistically significant (P>0.4). The similarity between the estimates from each model is likely the result of high capture rates (35% to 86%). Therefore, the more precise full JS model estimates in Table 8 are preferable, and while there was significant heterogeneity in capture/survival rates by group, the source of the heterogeneity and appropriate corrective procedures (if any) are unknown. Estimated 2004 harvests at Auke Lake and the surrounding marine area (0 fish each, Table 1) remain low, although the estimates for Auke Lake are very poor (imprecise) due to the very low sampling rate (one angler).

Cutthroat trout ≥180 mm FL sampled in Auke Lake in 2004 averaged 241 mm FL (SE = 2, range 180 to 333 mm FL, Figure 3) and had a standard deviation of 40. Using the annual abundance estimate (535), 52.4% of the population in 2004 was ≤240 mm FL (Table 9). By regulation, harvest of cutthroat trout in Auke Lake is restricted to fish ≥356 mm FL (14 inches TL) and no cutthroat trout in Auke Lake during June were estimated to be of harvestable size. Comparing across eight years of sampling, the average size of fish ≥180 mm sampled in 2005 was slightly larger than in previous years. For those fish <180 mm, fish sampled in 2005 were on average consistent with previous years.

Table 8.–Estimates of abundance ($\hat{N}$), survival ($\hat{\phi}$), and births ($\hat{B}$) of cutthroat trout ≥180 mm FL at Auke Lake, 1998–2004. Estimates from POPAN Model 3 (right panel) are simply shown for comparison to the preferred estimates from full JS model.

	Full JS Model						Generalized Model (Model 3 POPAN)					
Year	$\hat{N}$	$SE(\hat{N})$	$\hat{\phi}$	$SE(\hat{\phi})$	$\hat{B}$	$SE(\hat{B})$	$\hat{N}$	$SE(\hat{N})$	$\hat{\phi}$	$SE(\hat{\phi})$	$\hat{B}$	$SE(\hat{B})$
1998	-	-	0.411	0.088	-	-	-	-	0.592	-	-	-
1999	561	118	0.349	0.045	199	48	808	428	0.381	0.103	142	372
2000	394	44	0.370	0.071	526	120	450	83	0.445	0.170	652	258
2001	672	139	0.218	0.031	154	30	852	321	0.221	0.064	147	68
2002	301	22	0.438	0.042	306	26	336	45	0.439	0.056	304	41
2003	438	31	0.435	0.069	345	61	452	41	0.447	0.093	353	80
2004	535	84	-	-	-	-	555	113	-	-	-	-

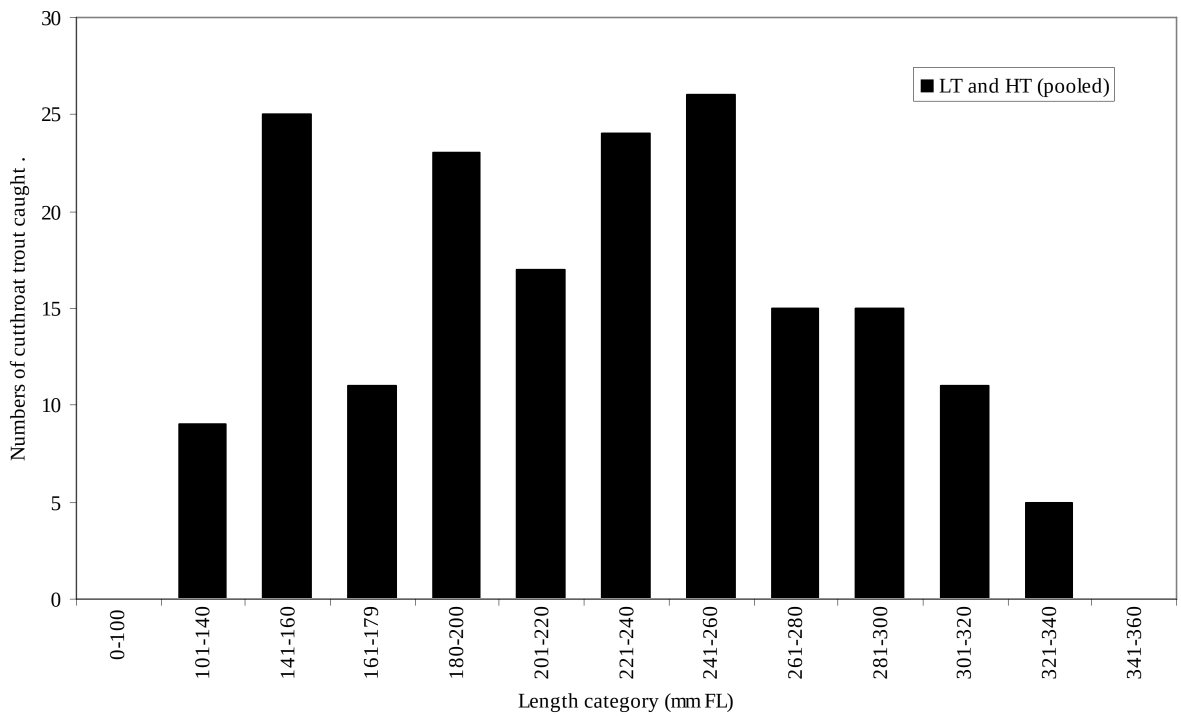

Figure 3.–Fork lengths of cutthroat trout captured in Auke Lake by gear type in 2005. Fish captured more than once are not plotted, and no hook and line fishing was conducted in 2005. These proportions will be expanded to estimate abundance ($\hat{N}_{2005}$) by size in the next annual report when an estimate for 2005 can be calculated. LT = Large traps, and HT = Hoop traps.

Table 9.–Length composition and estimated abundance at length for cutthroat trout ≥180 mm FL in Auke Lake in 2004. Number sampled (nk), proportion ($\hat{p}_k$), abundance ($\hat{N}_k$), and standard error (SE) are shown for each 20-mm length class. Fish captured more than once were not used to calculate proportions (Lum and Taylor *In prep*).

Length k, mm FL	n_k	$\hat{p}_k$	SE($\hat{p}_k$)	$\hat{N}_k$	SE($\hat{N}_k$)
180–200	55	0.190	0.016	101.5	17.9
201–220	52	0.179	0.015	95.9	17.1
221–240	45	0.155	0.014	83.0	15.1
241–260	44	0.152	0.014	81.2	14.8
261–280	36	0.124	0.013	66.4	12.5
281–300	35	0.121	0.013	64.6	12.2
301–320	16	0.055	0.009	29.5	6.7
321–340	5	0.017	0.005	9.2	3.1
341–360	2	0.007	0.003	3.7	1.8
Total	90		$\hat{N}$ =	535	

A total of 25 PIT-tagged cutthroat trout immigrated into Auke Lake in fall 2004 (Lum and Taylor *In prep*). Seventeen of those fish emigrated from the lake in spring 2005, leaving eight that either remained in Auke Lake or died over the winter. None of the remaining eight fish were caught while sampling in Auke Lake in 2005, suggesting the overwinter (2004–2005) survival estimate of these PIT-tagged fish was 68% (=17/25). Estimates for overwinter survival for PIT-tagged sea-run migrants in Auke Lake (1998–2005) average 62% (Table 10). These overwinter survival estimates are higher than our annual survival rate estimates because the later include all other sources of spring and summer mortality, such as that due to spawning (Table 10).

The data from this study has been electronically archived by ADF&G, Research and Technical Services in Anchorage, Alaska (Appendix A5).

DISCUSSION AND RECOMMENDATIONS

The cutthroat trout assessments in Auke Lake, with those at the Auke Creek weir, provide a rare time series of abundance, survival, growth, migration timing, and other life history information for both resident and anadromous species using Auke Lake. The continuity of these data sets and the duration for which they are collected will become increasingly important as urban development continues in the Juneau area.

Survival estimates generated from this work are either annual survival estimates provided by a Jolly Seber model or overwinter survival estimates obtained from a comparison of tagged fall immigrants to tagged emigrants seen the following spring. The occurrence of an alternative life history or overwinter strategy would only have a minor effect on the overwinter estimate because previous tagging years have shown that only a small number of fish stay in Auke Lake for more than one year. Fish that remain in Auke Lake or in other systems for any length of time will appear as mortalities unless caught in the multi-year study that allows for alternative capture histories when estimating annual survival, which is updated each year. The more complex life history issue is the percentage of fish in the spring that return in the same year they were tagged. From unpublished data in 1997 and 1998 when PIT tagging was in its infancy at the Auke Creek weir, preliminary estimates suggests that around 30 to 40% of the tagged fish return in the fall to Auke Creek in the same year they were tagged. The accounting of weir emigrants provides a conservative estimate of marine survival within the same year, but would not truly give an accurate accounting without multi-year monitoring.

Annual survival estimates for two similar lake-bound populations in Southeast Alaska (Neck Lake - 51%, SE = 6%, Harding et al. 1999; two estimates for Florence Lake – 40%, SE = 2% and

52%, SE=3%; Rosenkranz et al. 1999) are higher than our estimate of about 37% for Auke Lake (Table 10). This difference may be the result of immature anadromous fish in Auke Lake that emigrate and do not return. In fact, a JS analysis of the capture history data for 1998–2001 (Lum and Taylor 2004), which excludes all fish observed at the weir, yields an annual survival estimate of 0.51 (SE = 0.065), similar to that found in these other studies in Southeast Alaska.

Tagging of the resident sea-run trout in Auke Lake has complimented other local projects where tagged migrants are sampled, and movement between systems can be determined. An example of this is the recent work at Jordan Creek, and Duck Creek (Lum and Glynn *In prep*), and at Dredge Creek (*Unpublished data*). This similarly occurs in Auke Lake where PIT-tagging occurs on a "resident" fish only for the fish to be recorded leaving Auke Lake through the Auke Creek weir two years later. A few (<5%) cutthroat trout PIT-tagged leaving Auke Lake immigrate into these systems, overwinter for up to two years, and then emigrate in the spring. Additional studies of this sort, supported by the emigrant tagging at Auke Creek, would help us better determine the importance of these migratory populations to the Juneau roadside fisheries. The resident tagging in the lake helps provide a snapshot to the various life history strategies utilized by cutthroat trout in an anadromous system that just so happens to support a resident population.

Table 10.–Estimated survival rates for cutthroat trout in Auke Lake, 1997–2005.

Year	Overwinter Survival[a]	Annual Survival[b]
1997–1998	67%	-
1998–1999	58%	41%
1999–2000	60%	35%
2000–2001	74%	37%
2001–2002	48%	22%
2002–2003	65%	44%
2003–2004	52%	44%
2004–2005	68%	-
average	62%	37%

[a] Estimates for PIT tagged fall immigrants (Lum et al. 1999, 2000; 2001; 2002; Lum and Taylor 2004, 2006 and *In prep).*

[b] Estimates from the JS model (Table 9).

The timing of the lake sampling in 2002, 2003, 2004 and again in 2005 (in early June) appears to be near ideal because the emigration is complete, water temperatures remain low, and fish catches in the traps are relatively good. This window of opportunity probably varies from year to year and may require minor changes to maintain the target sampling conditions. Warmer water temperatures have been experienced in late June for the last few years, so sampling in 2005 was conducted in early June. Because of the problems with capture and survival heterogeneity, it may be worthwhile to revisit the use of the two-event sampling scheme within a year. With high sampling rates in Auke Lake, these analyses should be robust. Converting to a two-event sampling scheme would no doubt mean shifting the sampling dates earlier to avoid warmer conditions in the later part of June, while still avoiding the spring emigration from the lake.

Auke Lake is home to both resident and sea-run cutthroat trout. There are indications that some sea-run trout spawn in Auke Lake (Lum et al. 2001) in the spring after overwintering in Auke Lake. This suggests that heterogeneity in capture and survival probabilities based on life history (resident and anadromous) trajectories is possible in this experiment. Indeed, heterogeneity based on capture history has been observed in all previous JS analyses at Auke Lake (fish caught for the first time in year *i* have been *more* likely to be recaptured in year *i* than fish tagged in previous years). The presence of anadromous trout and perhaps age dependent mortality are thought to be the likely reasons for this heterogeneity (Lum and Taylor 2004). The heterogeneity imparts some bias to our estimates. Assuming, for illustration, that estimates from generalized (in POPAN) JS models for 2000–2003 are unbiased, our JS estimates for this period (Table 8) would be biased low by about 10% (or 3% in 2002). Survival estimates should suffer less from the heterogeneity (Pollock et al. 1990); they may be biased low by 3% using the comparison above (or about -1% in 2001). Although there is no confidence in applying the generalized JS model to these data, one apparent conclusion from the generalized model is that fish first captured *prior* to the most recent sampling event "survive" at a lower (almost one-half) rate than newly captured fish. The relatively poor "survival" of the older capture group may result from permanent emigration of smolt, and age dependant mortality. A key piece of information lacking from this study is a maturity schedule (age-at-maturity or size-at-maturity) and aging analysis for fish in the Auke Lake. Age analysis could possibly be obtained from a multi-year analysis of the PIT tagging information with an estimate of the age at first capture. Also, genetic studies could be implemented to look at the differences between resident and anadromous fish.

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APPENDIX A

Appendix A1.–Capture histories for the Auke Lake Jolly-Seber model, 1998–2005.

Capture history[a]	Frequency	Capture history[a]	Frequency	Capture history[a]	Frequency
00000001	83	00001111	2	01010000	4
00000010	170	00010000	151	01100000	78
00000011	29	00010011	1	01100100	1
00000100	195	00010100	2	01101000	5
00000101	5	00011000	28	01101110	1
00000110	63	00011100	10	01110000	1
00000111	8	00100000	157	01111000	2
00001000	113	00101000	7	10000000	63
00001001	2	00110000	31	10100000	4
00001010	2	00111000	2	11000000	20
00001100	64	00111100	1	11100000	2
00001101	4	01000000	236		
00001110	14	01001000	2		

[a] A "0" signifies not captured during that particular sampling event while 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 years: 1998, 1999, 2000, etc.

Appendix A2.–Number of cutthroat trout marked in 2004 and recaptured in 2005 by stratum, and chi-square test for mixing between years.

		Numbers recaptured in 2005 by stratum					
Stratum fish was marked	Total fish marked in 2004	A[a]	B[b]	C[c]	Total (all strata)	Number not seen	Proportion recaptured
A	84	5	5	2	12	72	0.14
B	102	5	7	5	17	85	0.17
C	104	4	2	5	11	93	0.11
Total	290	14	14	12	40	250	0.14
Unmarked fish caught		33	25	38	96		
Total caught in recapture event		47	38	49	134		
Marked fraction		0.30	0.37	0.24	0.30		

X^2 = 1.50, 2 df, P = 0.47, *Accept H_o: marked fraction is constant across recovery strata*

[a] Study areas 1, 2, and 3.

[b] Study areas 4, 5, and 6.

[c] Study areas 7 and 8.

Appendix A3.–Breakdown of statistics for homogeneous capture/survival probabilities by tag group for the Jolly-Seber experiment at Auke Lake. $\hat{p} \rightarrow$ is the probability of capture for each group.

Component 1 test for 1999		First captured in 1998	First captured in 1999
Captured in 1999 and recaptured in 2000		2.00	94.00
Captured in 1999 and not recaptured in 2000		20.00	236.00
χ^2 = 3.911, 1 df, P = 0.048	$\hat{p} \rightarrow$	0.091	0.285

Component 1 test for 2000		First captured in 1999	First captured in 2000
Captured in 2000 and recaptured in 2001		10.00	41.00
Captured in 2000 and not recaptured in 2001		84.00	157.00
χ^2 = 4.483, 1 df, P = 0.034	$\hat{p} \rightarrow$	0.106	0.207

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	6.00
χ^2 = 0.407, 2 df, P = 0.816	$\hat{p} \rightarrow$	1.00	1.00	0.936

Component 1 test for 2001		First captured in 2000	First captured in 2001
Captured in 2001 and recaptured in 2002		5.00	41.00
Captured in 2001 and not recaptured in 2002		36.00	151.00
χ^2 = 1.789, 1 df, P = 0.181	$\hat{p} \rightarrow$	0.122	0.214

Component 2 test for 2001		Captured in 1999, not in 2000	Captured in 1999 and 2000	First captured in 2000
Captured in 2001		4.00	3.00	34.00
Captured in 2002, not in 2001		2.00	7.00	7.00
χ^2 = 11.246, 2 df, P = 0.004	$\hat{p} \rightarrow$	0.667	0.300	0.829

Component 1 test for 2002		First captured in 2001	First captured in 2002
Captured in 2002 and recaptured in 2003		12.00	88.00
Captured in 2002 and not recaptured in 2003		46.00	113.00
χ^2 = 10.126, 1 df, P = 0.001	$\hat{p} \rightarrow$	0.207	0.438

Component 2 test for 2002		Captured in 2000, not in 2001	Captured in 2000 and 2001	First captured in 2001
Captured in 2002		15.00	5.00	38.00
Captured in 2003, not in 2002		1.00	0.00	3.00
χ^2 = 0.397, 2 df, P = 0.820	$\hat{p} \rightarrow$	0.938	1.00	0.927

-continued-

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Component 1 test for 2003		First captured in 2002	First captured in 2003
Captured in 2003 and recaptured in 2004		21.00	76.00
Captured in 2003 and not recaptured in 2004		78.00	195.00
χ^2 = 1.75, 1 df, P = 0.186	$\hat{p} \rightarrow$	0.212	0.280

Component 2 test for 2003	Captured in 2001, not in 2002	Captured in 2001 and 2002	First captured in 2002
Captured in 2003	3.00	12.00	84.00
Captured in 2004, not in 2003	1.00	0.00	4.00
χ^2 = 4.183, 2 df, P = 0.124			
$\hat{p} \rightarrow$	0.75	1.00	0.955

Component 1 test for 2004		First captured in 2003	First captured in 2004
Captured in 2004 and recaptured in 2005		11.00	29.00
Captured in 2004 and not recaptured in 2005		80.00	170.00
χ^2 = 0.324, 1 df, P = 0.569	$\hat{p} \rightarrow$	0.121	0.146

Component 2 test for 2004	Captured in 2001, not in 2002	Captured in 2001 and 2002	First captured in 2002
Captured in 2004	3.00	17.00	71.00
Captured in 2005, not in 2004	2.00	4.00	5.00
χ^2 = 7.323, 2 df, P = 0.026			
$\hat{p} \rightarrow$	0.60	0.810	0.934

Appendix A4.–Summary of capture probabilities by tag group and sampling year for the Jolly-Seber experiment at Auke Lake. See Appendix A3 for details leading to these statistics.

	Component 1		**Component 2**		
Year (trips)	First captured before sample *i*	First captured in sample *i*	Captured in *i*-2, not in *i*-1	Captured in *i*-2 and *i*-1	First captured in *i*-1
1998 (1-3)	-	-	-	-	-
1999 (1,2)	0.091	0.285	-	-	-
2000 (1,2)	0.106	0.207	1.000	1.000	0.936
2001	0.122	0.214	0.667	0.300	0.829
2002	0.207	0.438	0.938	1.000	0.927
2003	0.212	0.280	0.750	1.000	0.955
2004	0.121	0.146	0.600	0.810	0.934
2005	-	-	-	-	-
Mean	0.143	0.262	0.791	0.822	0.916

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

Data File	**Description**
Lake 2005.xls	Excel file of cutthroat trout PIT tagging information for the abundance study in Auke Lake, 2005.