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Tumakof Lake (Redfish Bay) Subsistence Sockeye Salmon Project: 2002–2004 Final Report

by

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February 2008

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

Symbols and Abbreviations

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Measures (fisheries)

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

Mathematics, statistics

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

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ABSTRACT

From 2002 to 2004, we estimated sockeye escapement into Tumakof Lake by counting through a weir and using mark-recapture methods to verify the sockeye weir counts. We also estimated the number of sockeye salmon (*Oncorhynchus nerka*) harvested in the subsistence and sport fisheries at the head of Redfish Bay, and we collected baseline information on the freshwater habitat of sockeye juveniles (2002 and 2003 only). In all three years (2002–2004), the weir count was lower than the mark-recapture estimate by 18 to 29%, presumably because fish passed through the weir undetected. Using mark-recapture methods, we estimated an escapement into Tumakof Lake of 49,000 sockeye salmon in 2004, a decline from the escapement of 58,000 fish in 2003, but an increase from the escapement of 34,000 fish in 2002. In 2004, sport and subsistence fishers harvested 1,200 sockeye salmon. Similar to 2002 and 2003, the 2004 harvest was only 2% of the total number of sockeye adults returning to the marine terminal area of Redfish Bay. Therefore, the current level of subsistence and sport harvests in Redfish Bay do not appear to be high enough to appreciably limit future sockeye recruitment in Tumakof Lake. In 2002 and 2003, we observed very low levels of *Daphnia longiremis*, the preferred zooplankton prey of sockeye fry, which suggests that the predation pressure was high from sockeye fry and other planktivores. Consequently, we believe this system may be approaching carrying capacity due to food limitations.

Key words: Sockeye salmon, *Oncorhynchus nerka*, subsistence harvest, sport harvest, weir, Tumakof Lake, Redfish Bay, Sitka, escapement, mark-recapture, zooplankton

INTRODUCTION

The Redfish Bay/Tumakof Lake system, located near Sitka (Figure 1), produces salmon runs used by subsistence, sport, and commercial fishermen. Members of the Tlingit Kiks.ádi clan were the traditional caretakers of Redfish Bay and had smokehouses in the area (Goldschmidt et al. 1998). Subsistence harvests have been recorded on ADF&G permits in Redfish Bay continuously from 1985 to 2005 with harvests ranging from 100 fish in 1986 to 1,111 fish in 1994 (Appendix A). We estimated the sport fish harvest to be 50 sockeye salmon (*Oncorhynchus nerka*) in 2002 and 300 in 2003, at the head of Redfish Bay. In both 2002 and 2003, the subsistence and sport harvests were just 2% of the total number of sockeye salmon return to the bay. The sockeye harvest by the commercial seine fishery was highly variable in Redfish Bay (Subdistrict 113-13) from 1960 to 2004 (Appendix B). The highest commercial catch recorded was 23,000 sockeye salmon in 1968 followed by 18,000 fish in 2000. Less than 1,000 sockeye salmon were harvested in nine years during this period, and no sockeye salmon were harvested in 17 of the 45 years for which we have harvest information.

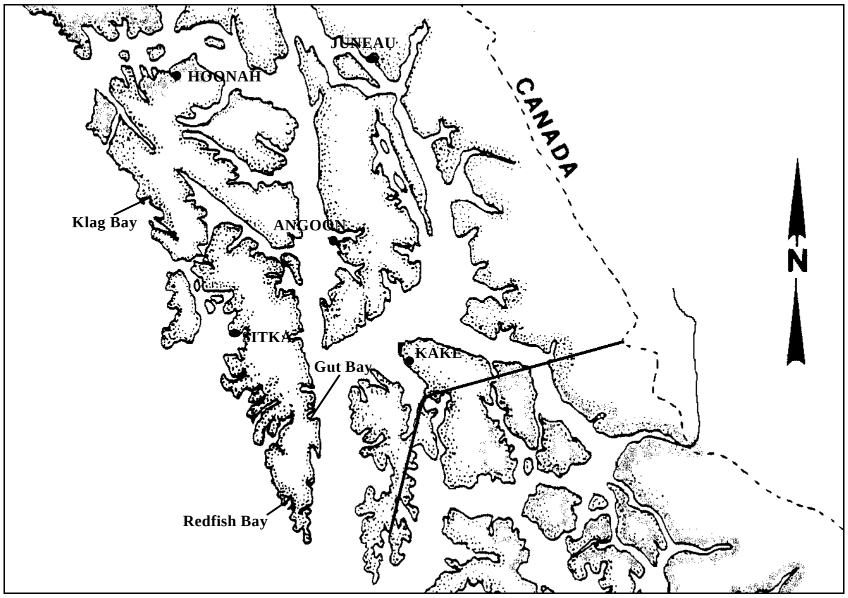

Figure 1.–The location of Redfish Bay in relation to Sitka on Baranof Island, Alaska.

Escapement estimates indicate that sockeye returns to Tumakof Lake are variable. The larger escapements of 58,000 fish in 2003 (Stahl et al. 2008) and 66,000 fish in 1966 are approximately double the 2002 escapement of 34,000 fish (Lorrigan et al. 2003), and four times higher than the escapement count in 1955 of 14,176 fish (Hilsinger 1955). These comparisons are limited by the fact that the older escapement estimates were based solely on weir counts, without any assessment of accuracy through mark-recapture or other methods. The weir counts must be considered minimal escapement estimates, given the difficulty of obtaining an accurate weir count in this system.

Unlike many other sockeye runs in Southeast Alaska which are harvested in multiple, mixed-stock commercial fisheries, Tumakof Lake sockeye salmon are primarily harvested within Redfish Bay, where they are the only run of sockeye salmon present. Outside of Redfish Bay, very few sockeye salmon are harvested off the outer coast of Baranof Island south of Sitka (Appendix B). As a result, the total annual sockeye run size can be estimated by summing commercial, subsistence, and sport harvests in Redfish Bay plus the escapement into Tumakof Lake.

In 2002, the stock assessment study of sockeye salmon in Tumakof Lake was initiated by the Sitka Tribe of Alaska, largely in response to an illegal harvest of 8,100 sockeye salmon inside the regulatory markers at the head of Redfish Bay in 2000. At that time, very little was known about the size of the Tumakof Lake sockeye run, making it difficult to evaluate the impact of this illegal harvest to future sockeye recruitment into the lake. The primary objectives of this three-year project were to estimate sockeye escapement into Tumakof Lake, including age, sex, and length composition, and to estimate subsistence and sport harvests in Redfish Bay with on-site surveys. A weir with a mark-recapture study was used to estimate escapement. Information on sockeye rearing habitat in Tumakof Lake, including estimates of zooplankton biomass and physical characteristics of the lake, was collected in 2002–2003. In this report, we summarize information collected during 2004, the final year of our study, and compare the results for all three years of our study, 2002–2004.

OBJECTIVES

1. Count sockeye salmon and other fish species into Tumakof Lake by use of a weir.
2. Estimate sockeye escapement with a mark-recapture study on the spawning grounds so that the coefficient of variation is less than 10%.
3. Estimate the age, sex, and length composition of the sockeye escapement so that the coefficient of variation is 10% or less for the two major age classes.
4. Estimate subsistence and sport harvests of sockeye salmon from Redfish Bay by on-site surveys so that the estimated coefficient of variation is less than 15%.

METHODS

STUDY SITE

Tumakof Lake (ADF&G stream no. 113-13-003; lat 56°22.387'N, long 134°51.409'W) is the southern most sockeye lake on Baranof Island (Figure 1), approximately 120 km from the community of Sitka. Redfish Bay, the location of the subsistence and sport fisheries, is approximately 500 m from the outlet of Tumakof Lake. The total watershed area is approximately 1,062 ha. Tumakof is a dimictic lake at an elevation of about 9 m, with a maximum depth of 99 m and an average depth of 51 m (Figure 2). Tumakof Lake is steep-sided with numerous cascades falling from the hillside, but no well-defined inlet streams. In addition to sockeye salmon, this lake supports small runs of coho (*O. kisutch*), pink (*O. gorbuscha)*, and chum salmon (*O. keta*), and Dolly Varden (*Salvelinus malma*). Sockeye and coho salmon have little difficulty negotiating the short outlet stream and cascades, but pink and chum have not been observed above the second falls. No inlet streams flow into the lake; instead, sockeye spawning habitat consists of large cobbles and boulders on the lake's northern beaches. Spawners congregate in beach areas associated with cascades.

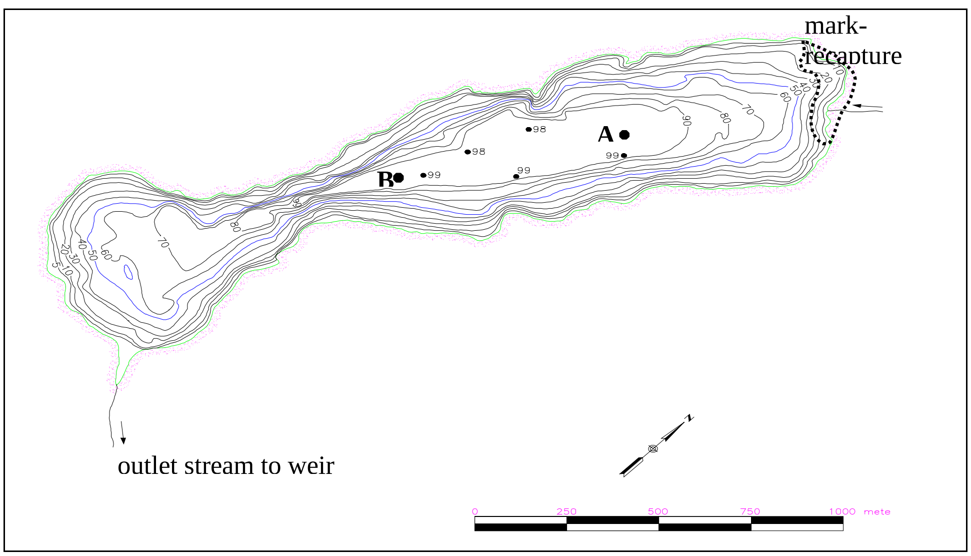

Figure 2.–Tumakof Lake bathymetric map with locations of the 2002–2003 limnological sampling Stations (A and B).

Sockeye Escapement Estimate

Weir Counts

We counted salmon daily by species through an aluminum picket weir on the outlet stream of Tumakof Lake, which was operated from 5 July to 10 October. The location and dimensions of the weir were described by Lorrigan et al. (2003). The accuracy of sockeye counts was verified by a mark-recapture study, using the weir as a marking platform.

Mark-Recapture Study

To test the integrity of the weir and provide an independent estimate of sockeye escapement into Tumakof Lake, we estimated escapement using a closed, stratified, two-sample mark-recapture model (Arnason et al. 1996). The first sample, or marking phase of the study, was conducted at the weir. The crew marked 18% of the fish passed through the weir using an adipose clip as the primary mark. Four secondary marks were also applied to stratify the marked fish into four distinct time periods within the season. The type of fin clip and the dates the clips were applied in 2004 were: left auxiliary process clip from 7 July to 28 August; left pelvic fin clip from 29 August to 9 September; right pelvic fin clip from 10 September to 18 September; partial dorsal fin clip from 19 September to 9 October. Fish were marked and released above the weir as quickly as possible to minimize handling time.

The second sample, or the recovery phase of the mark-recapture study, was conducted after the end of weir operation, to record the number of marked and unmarked sockeye salmon observed on the spawning grounds. In Tumakof Lake, only the beach spawning area at the northern end of the lake (Figure 2) was suitable for sampling fish using seine gear. Because this also appeared to be the primary spawning area of the lake, we conducted all secondary sampling in this beach spawning area. Three sampling events were conducted in 2004, on 7 October, 16 October, and 5 November. The crew made as many seine sets as possible in a day. All captured fish were examined for marks during secondary sampling and then marked with an opercular punch to prevent duplicate sampling in future trips (sampling without replacement).

Data Analysis

The two-sample Petersen method is a simple model for estimating total escapement based on the total number of fish marked as they move into the spawning grounds (first sample), the total number of fish subsequently sampled for marks (second sample), and the number of marks recovered in the second sample (Seber 1982, p.59; Pollock et al. 1990). Stratified mark-recapture models extend the two-sample Petersen method over two or more sampling occasions or events in both the marking (first) and mark-recovery (second) samples. Stratified models are widely used for estimating escapement of salmonids as they migrate into the spawning grounds (Arnason et al. 1996). Spawning migrations may last for a month or more, during which there can be substantial variation in biological parameters such as daily immigration or mortality rates. A fundamental assumption of the Petersen and related mark-recapture models is that capture probabilities for individual animals are equal (Pollock et al. 1990). The natural variation typical of salmon escapements presents many possibilities for individual capture probabilities to vary, but if the assumptions of equal probability of capture required by the Petersen model are met, then a simplified model can be used. Briefly stated, the three assumptions of equal probability of capture are: 1) all fish have an equal probability of capture in the first sample (marking), 2) all fish have an equal probability of capture in the second sample (mark-recovery), and 3) fish mix completely between the first and second sample. Generally, if one or more of these assumptions is met, data from all marking and all mark-recovery samples can be pooled, thereby providing the most precise estimate. However, if none of the assumptions are met, the pooled estimate can be badly biased (Arnason et al. 1996).

We used the Stratified Population Analysis System (SPAS) software to aid in analyzing and interpreting mark-recapture results (Arnason et al. 1996; for details, refer to http://www.cs.umanitoba.ca/~popan/). SPAS calculates Darroch and "pooled Petersen" estimates and provides two goodness-of-fit tests to compare observed and expected capture probabilities in the marking (first) and mark-recovery (second) samples (Arnason et al. 1996). The test of the assumption of complete mixing is incorporated into the test for equal probability of capture in the second sample. We considered a goodness-of-fit test with a p-value ≤ 0.05 to be statistically significant—providing evidence that the necessary assumptions were not met. However, under the guidance of Arnason et al. (1996), if at least one goodness-of-fit test was not significant, we could consider the pooled Petersen estimate as valid. In addition, if SPAS failed to converge on a solution for the Darroch estimate, if the Darroch estimate was very different from the pooled estimate, or if both goodness-of-fit tests failed, then we searched for a partial pooling scheme that closely fit actual sampling conditions. We followed the guidelines and suggestions in Arnason et al. (1996) to help decide between the pooled Petersen and Darroch estimates.

We used the following alternative method to estimate the 95% confidence interval for the number of fish in the escapement, N. The confidence interval estimate provided in the SPAS output is based on an assumption that N is normally distributed. However, normal confidence intervals for N are often badly biased and have poor coverage probability, especially with small sample sizes. Following the usual Petersen method for estimating escapement, we let K denote the number of fish marked in a random sample of a population of size N. We let C denote the number of fish examined for marks in the second sample (recovery phase), and let R denote the number of fish in the second sample with a mark. Then the pooled Petersen estimate of the number of fish in the entire population, $\hat{N}$, is given by $\hat{N} = \frac{(K+1)(C+1)}{(R+1)} - 1$. In this equation, R is the random variable, and C and K are assumed to be constants. In mark-recapture sampling, R follows a hypergeometric distribution by definition, which can be approximated with the Poisson distribution (Thompson 1992). Simplifying the Petersen mark-recapture equation, we have $\frac{1}{\hat{N}} \approx \frac{R}{C\,K}$. In the Poisson approximation for R, the mean and variance are the same, so

$\text{var}(\frac{1}{\hat{N}}) \approx \frac{R}{(C\,K)^2}$, $\text{SE}(\frac{1}{\hat{N}}) = \frac{\sqrt{R}}{C\,K}$, and the coefficient of variation (CV) is $\text{CV}(\frac{1}{\hat{N}}) = \frac{SE(1/\hat{N})}{1/\hat{N}} \cdot 100$.

With moderate or large numbers of mark-recoveries, which will generally be the case if the pooled Petersen estimate meets the criteria outlined above, the distribution for R could be approximated with the normal distribution. Therefore we could assume $\frac{1}{\hat{N}}$ is approximately normally distributed, and we generated 95% confidence intervals for $\frac{1}{N}$ as,

$$\frac{1}{\hat{N}} \pm 1.96 \cdot \mathrm{SE}(\frac{1}{\hat{N}}).$$

Finally, 95% confidence intervals for *N* were generated by inverting the confidence intervals for $\frac{1}{N}$.

SOCKEYE ESCAPEMENT AGE, SEX, AND LENGTH COMPOSITION

We sampled 700 sockeye salmon for scales, length, and sex at the Tumakof Lake weir to describe the age and size structure of the population, by sex. Age and length data were paired from each sample. Three scales were taken from the preferred area of each fish (INPFC 1963) and prepared for analysis (Clutter and Whitesel 1956). Scale samples were analyzed at the ADF&G Age Laboratory in Douglas Alaska. Age classes were designated by the European aging system where freshwater and saltwater years are separated by a period. For example, a fish designated age 2.3 spent two years in freshwater after hatching and 3 years in saltwater, and had a total age of six years (Koo 1962). We measured the length of each fish from mid eye to tail fork to the nearest millimeter (mm). The proportion of each age-sex group was estimated along with its associated standard error, using standard statistical techniques assuming a binominal distribution, described in common references, such as Thompson (1992).

HARVEST ESTIMATE

The sampling unit for subsistence fishing was a boat-party, that is, any number of people fishing from a single boat, and all participating boat-parties could be accurately counted. All boat-parties were interviewed after they completed fishing. The sampling unit for sport fishing was an individual fisher with a fishing rod, and again, all fishers could be accurately counted and were interviewed at the conclusion of fishing. We conducted interviews during daylight hours and to determine gear type used, effort (net or rod hours), and harvest by species. We summed the sockeye harvest across all gear types and days for each type of fishery to obtain the total number of sockeye salmon harvested in Redfish Bay by fishery. The on-site subsistence sockeye harvest estimate was compared to the total subsistence harvest reported on ADF&G subsistence permits in 2004. Commercial harvest information was obtained from the ADF&G Division of Commercial Fisheries database, which compiles data from fish tickets submitted by fishing boats and processors.

RESULTS

SOCKEYE ESCAPEMENT ESTIMATE

Weir Counts

A total of 40,302 sockeye salmon were counted through the Tumakof weir between 5 July and 10 October 2004. During this period, 8,413 pink, 30 chum, and 1,186 coho salmon, and 132 Dolly Varden char were also counted through the weir. Peak sockeye counts on 5–6 September and 13 September coincided with rising water levels of the outlet stream to Tumakof Lake

(Figure 3; Appendix C). The water level in the outlet stream remained high from 13 September through the weir closure on 10 October, and pickets were removed from the weir due to high water between 21 and 24 September. A total of 2,824 sockeye salmon washed up dead against the weir in high water between 26 September and 6 October; most of these were assumed to be unspawned fish killed by being forced against the weir during the flooding. When the weir was removed on 10 October, very few fish were observed downstream from the weir and the estuary.

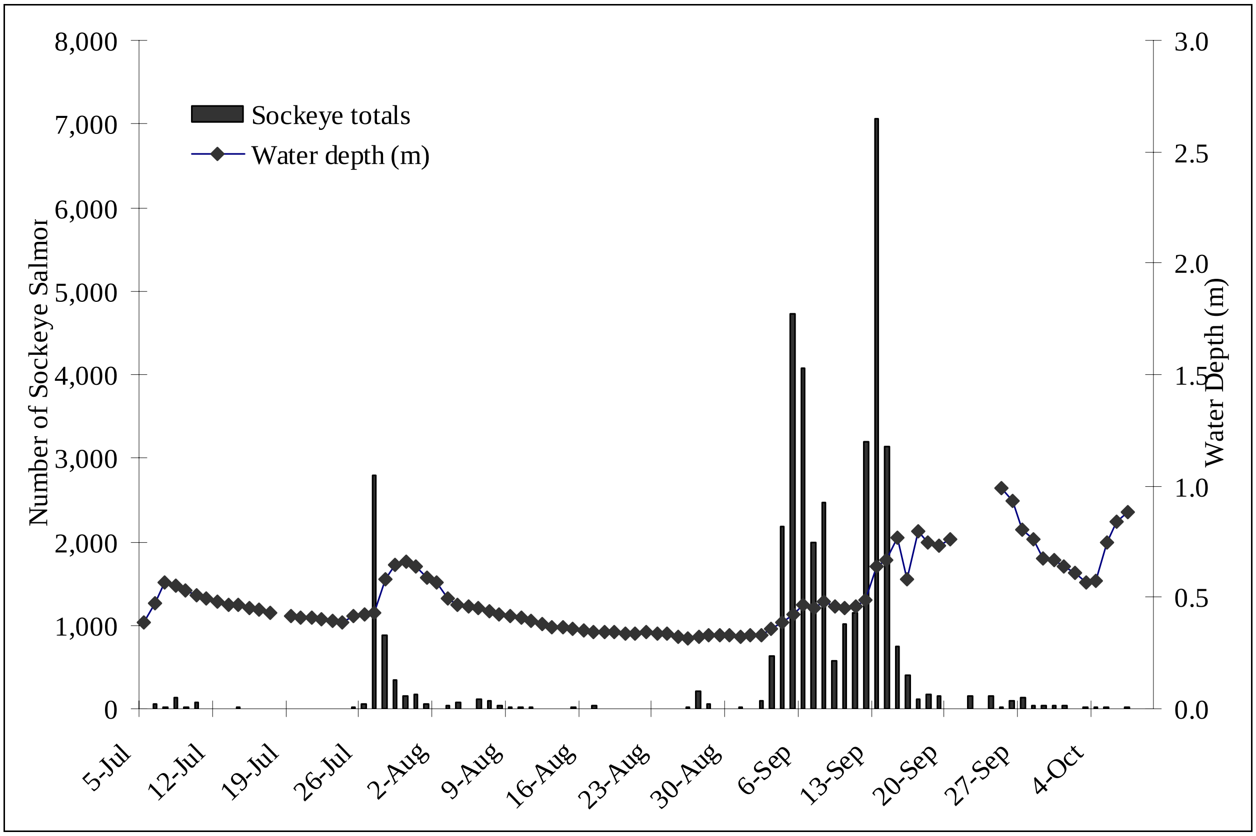

Figure 3.–Daily weir counts of sockeye salmon in comparison with water depth in Tumakof Lake's outlet stream in 2004.

Mark-Recapture Estimate

Because it was difficult to predict the size and timing of the sockeye run into Tumakof Lake, the number of secondary marks applied with each fin clip type varied widely. The left pelvic fin clip was applied to twice as many fish (*n*=2,505) as the left auxiliary process clip (*n*=1,252). The right pelvic fin clip was applied to 3,039 fish, and the dorsal fin clip was applied to only 274 sockeye salmon at the end of the season. We pooled marks from the first two periods and the last two periods to more evenly distribute the secondary marks into two larger groups (Table 1).

Table 1.–Number of sockeye salmon marked at the weir for each marking period, and number of recoveries of marked fish by recapture event and marking stratum in Tumakof Lake in 2004. The number of fish passed through the weir during each marking period is included for comparison. The four original marking strata were collapsed into two strata, shown below, due to low recoveries of marked fish from each stratum. Recapture sampling on the spawning grounds occurred on 7 October (recapture event 1), 16 October (recapture event 2), and 5–November (recapture event 3).

Marking at weir					Marks recaptured on spawning grounds				
Marking stratum	**Dates**	**Sockeye count**	**Number marked**	**Percent marked**	**Event 1**	**Event 2**	**Event 3**	**Total recaptures**	**Percent of marks recovered**
1	7 Jul–9 Sep	21,800	3,757	17%	38	42	37	117	3%
2	10 Sep–9 Oct	18,502	3,313	18%	6	9	25	41	1%
Total marked and recaptured		40,302	7,070	18%	44	51	62	158	
				Total sampled	275	378	449	1,102	
Percent of fish in recapture samples with marks					16%	13%	14%	14%	

Recapture sampling occurred on 7 October, 16 October, and 5 November in the beach spawning area on the north side of Tumakof Lake. Although the crew marked 17–18% of the sockeye salmon that were counted through the weir, marked fish comprised only 14% of the fish sampled on the spawning grounds (Table 1). Similar percentages of marked fish, between 13 and 16%, were observed in each of the three sampling events. The percentage of secondary marks recaptured on the spawning grounds declined from 3% of first stratum marks to 1% of second stratum marks (Table 1).

The pooled Petersen estimate was 49,000 (CV=8%) sockeye salmon, and the 95 % confidence interval was 42,000–58,000 sockeye salmon. Goodness-of-fit tests, performed to determine appropriateness of pooling strata, resulted in no indication of violation of the assumption of equal proportions (p = 0.64). However, the tests indicated a violation of the assumption of complete mixing or equal probability of capture in the second event (i.e. fish marked in the first stratum had a different probability of recovery than fish marked in second stratum; $p \leq 0.005$). Because one of the goodness-of-fit tests passed ($p > 0.05$), we accepted the pooled Petersen mark-recapture estimate (Arnason et al. 1996). After subtracting the 2,800 unspawned sockeye salmon found dead on the weir, we estimated a spawning escapement of approximately 46,200 sockeye salmon in Tumakof Lake in 2004.

SOCKEYE ESCAPEMENT AGE, SEX, AND LENGTH COMPOSITION

Age-5 sockeye salmon (age-1.3 and -2.2 fish) comprised an estimated 57% of the fish that were sampled, and age-6 sockeye salmon comprised over 20% of the escapement. The returning adult sockeye salmon were about evenly split, among those sampled, between those with one year and those with two years of freshwater growth. However, when the proportions in each age class were weighted by weekly escapement, the estimated escapement of fish with one freshwater year increased to an overall 62.9% in the age-1.1, -1.2, and -1.3 classes (Table 2). Because over two-thirds of the total escapement passed during just two weeks in September, the age distribution in those two weeks (5–18 September) had more influence on the weighted age distribution for the season. In particular, age-1.2 fish increased to 44% of the escapement during the week of 12

September, while the relative percentages age-2.2 and -2.3 fish dropped off sharply in that week (Table 3). The largest fish, on average, were those that spent three years in the ocean, returning at age 1.3 and 2.3 (Table 4).

Table 2.–Age composition of sockeye salmon in Tumakof lake escapement by sex, brood year, and age class, sampled 7 July–19 September, 2004. Std. error represents the standard error of the estimated percentage in each age class. The percent for each age class was weighted by the weekly weir count. The escapement estimate per age class for the entire season was calculated using the weighted percent per age class and the escapement estimate (49,000 fish).

Brood year	**2001**	**2000**	**1999**	**2000**	**1999**	**1998**	
Age	**1.1**	**1.2**	**1.3**	**2.1**	**2.2**	**2.3**	**Total aged**
Male							
Sample size	8	81	114	13	118	76	410
Percent of total	1.3%	12.8%	18.0%	2.1%	18.7%	12.0%	64.9%
Standard error	0.4%	1.3%	1.5%	0.6%	1.6%	1.3%	1.9%
Female							
Sample size	-	36	78	-	53	55	222
Percent of total		5.7%	12.3%		8.4%	8.7%	35.1%
Standard error		0.9%	1.3%		1.1%	1.1%	1.9%
All Fish							
Sample size	8	117	192	13	171	131	632
Percent of total	1.3%	18.5%	30.4%	2.1%	27.1%	20.7%	100%
Standard error	0.4%	1.5%	1.8%	0.6%	1.8%	1.6%	-
Weighted percent	2.0%	27.4%	33.5%	2.1%	22.9%	12.0%	100%
Escapement estimate	924	12,659	15,477	970	10,580	5,544	46,200

Table 3.–The percent of each age class by week from 4 July to 25 September in Tumakof Lake in 2004. The percents are based on the total number of samples taken weekly. Although fish were passed through the weir after 25 September, scale samples were not taken.

Week beginning	**1.1**	**1.2**	**1.3**	**2.1**	**2.2**	**2.3**	**Weir counts**
4-Jul	0%	15%	10%	5%	46%	23%	223
11-Jul	0%	20%	40%	0%	20%	20%	106
25-Jul	1%	18%	40%	1%	17%	23%	4,262
1-Aug	0%	4%	15%	7%	15%	59%	483
8-Aug	0%	5%	21%	16%	11%	47%	182
15-Aug	4%	11%	15%	0%	41%	30%	50
29-Aug	0%	31%	19%	0%	33%	16%	810
5-Sep	1%	14%	35%	2%	32%	16%	17,045
12-Sep	3%	44%	33%	3%	14%	3%	15,812
19-Sep	11%	44%	0%	0%	44%	0%	636

Table 4.–Mean fork length (mm) of sockeye salmon in Tumakof Lake escapement by brood year, sex, and age class, sampled 7 July–19 September, 2004. Std. error represents the standard error of the length estimate in each age class.

Brood year	**2001**	**2000**	**1999**	**2000**	**1999**	**1998**
Age	**1.1**	**1.2**	**1.3**	**2.1**	**2.2**	**2.3**
Male						
Sample size	8	81	114	13	118	76
Mean length (mm)	389	531	585	368	534	584
Standard error	7.1	2.6	2.6	8.0	2.6	3.7
Female						
Sample size	-	36	78	-	53	55
Mean length (mm)		524	574		534	581
Standard error		3.9	2.7		3.2	2.6
All Fish						
Sample size	8	117	192	13	171	131
Mean length (mm)	389	529	581	368	534	583
Standard error	7.1	2.2	1.7	5.8	1.8	1.7

HARVEST ESTIMATE

In 2004, subsistence and sport fishers interviewed during the on-site surveys reported harvesting 625 and 585 sockeye salmon, respectively, in Redfish Bay. The crew counted and interviewed all participating subsistence boat-parties and sport anglers, so these harvest totals were considered to be a complete harvest census. In comparison, a total of 550 sockeye salmon were reported harvested on 22 subsistence permits in Redfish Bay (ADF&G Division of Commercial Fisheries database 2005; Appendix A). No anglers reported sockeye salmon harvested in the bay on the 2004 statewide sport fish survey (Robert Chadwick, ADF&G Sport Fish biologist, personal communication 2006). The commercial harvest of sockeye salmon inside Redfish Bay was just 70 fish; outside of but adjacent to the bay, 692 sockeye salmon were harvested (ADF&G Division of Commercial Fisheries database 2005; Appendix B). The sum of harvests in all three fisheries, subsistence, sport, and commercial, totaled 1,972 sockeye salmon.

The 2004 subsistence estimate was similar to the 2003 estimate (600 fish) and about half the 2002 estimate (1,300 fish). The sport fish harvest increased over the three years of our study; the 2004 harvest (600 fish) was double the estimate for 2003 (300 fish) and 12 times higher than the 2002 estimate (50 fish). However, the assignment of the sockeye salmon harvest in Redfish Bay to two respective fisheries may not be accurate, because some subsistence fishers may have used sport fishing gear but reported their sockeye harvest on their subsistence permits (Dave Gordon and Bob Chadwick, ADF&G Sitka Area Management Biologists for Commercial Fisheries and Sport Fish Divisions, personal communication 2006). Although rod and reel gear is not a legal gear for subsistence fishing in Redfish Bay, it is legal at nearby Redoubt Lake, which is also in the Sitka management area. Some subsistence fishers may have erroneously applied these permit conditions at Redfish Bay and reported fish harvested with rod and reel on their subsistence permits, while the technicians conducting the survey recorded these catches as sport harvest.

DISCUSSION

We achieved the primary objectives of our three-year study, to estimate the sockeye escapement into Tumakof Lake and to estimate the subsistence and sport harvests in Redfish Bay. The 2002 sockeye escapement estimate was at the lower end of the range of historic estimates, however the 2003 and 2004 escapement estimates were at the upper end of this range (Table 5). Nevertheless, the three years' estimates were consistent, with only about a two-fold difference between the highest and lowest confidence interval bounds. The historic weir counts in 1955 and 1966 were somewhat below and above, respectively, than the more recent range of escapements. However, the earlier measures were based only upon weir counts without mark-recapture or other independent validation. Undercounts seem especially likely in this system, which is susceptible to rapid increases in stream level, with consequent flooding or damage to weirs.

Table 5.–Historic and recent sockeye salmon counts through the Tumakof Lake weir and sockeye mark-recapture escapement estimates for 2002 through 2004.

Year	Weir count	Mark-recapture estimate	95% confidence interval
1955	14,200	-	-
1966	66,000	-	-
2002	24,128	34,000	28,000–43,000
2003	42,241	58,000	51,000–67,000
2004	40,302	49,000	43,000–58,000

For example, we know the sockeye count in 2004 underestimated true escapement, because some sockeye salmon that had not yet ascended to the lake were able to pass freely through or around the weir when flooding occurred late in the season. The water level remained high until weir operation ended in October, providing numerous opportunities for fish to pass undetected. Observations of these problems at the weir were confirmed by lower than expected proportions of marked fish in samples taken on the spawning grounds.

The discrepancy in recapture probabilities of fish marked in different strata provides further evidence that not all fish were counted at the weir. Even though the crew consistently marked 17–18% of fish passed through the weir, a higher proportion of the fish marked in the first stratum were recaptured compared to the second (Table 1). The decline in recapture rates for the last marking strata probably correspond with flooding events at the weir; fish that passed through the weir undetected during the flood, diluted the proportion of marked fish recaptured on the spawning grounds. However, the lower percent of marked fish on the spawning grounds from the second marking stratum could also indicate that fish entering the lake in the latter half of the season may not have moved on to the spawning grounds by the last sampling event on 9 November.

Although observations and mark-recapture results confirmed some undercounting of fish passing the weir, we also recognize the possibility that mark-recapture estimates could be biased high. Violations of several basic assumptions in combination can lead to seriously inflated estimates (Arnason et al. 1996). Recapture sampling effort was probably inadequate in all three years of this study to completely ensure against such a multiplier effect.

We recommend weir operation on Tumakof Lake be extended to mid-October, or long enough that late running sockeye salmon are counted and proportionately marked the same as the earlier fish. For example, when the weir was removed in mid-September in 2002 and 2003 schools of sockeye salmon were still observed in the stream below the weir site (Lorrigan et al. 2003). In 2004, the weir was operated for three additional weeks, until 10 October, and the crew counted 1,000 sockeye salmon during that later period. We also recommend more effort be focused on mark-recapture sampling on the spawning grounds. In order to meet equal capture probability assumptions, sampling must span the entire spawning period, with at least four to five sampling events throughout the fall starting at the beginning of September and continuing into November. However, practical problems associated with late season weir and mark-recapture operations include more hazardous travel conditions for crews, and greater likelihood and frequency of flooding and damage to the weir.

Because both the weir and the mark-recapture sampling had problems, we suggest other methods to estimate escapement be explored if this project is funded in the future. Perhaps, an underwater camera at the weir, or a resistance-board weir, could help solve the problem of salmon passing through the weir undetected. In addition, we recommend using individual numbered tags to allow more sensible marking stratification schemes. Numbered tags also make it possible to track individual fish so that we could estimate the timing of the sockeye spawners moving from the weir to the spawning grounds.

In all three years, sport and subsistence users harvested only 2–4% of the total sockeye returns. Harvests at this level probably have little effect on the Tumakof Lake sockeye population at the run sizes estimated in 2002–2004. Because exploitation is light, it may not be necessary to continue annual on-site surveys to estimate escapement or subsistence and sport harvests. The comparison of on-site surveys with user-reported harvests on the subsistence permits did not reveal any consistent trend in the way subsistence users report their catch. However, sport harvest data are not always available for Redfish Bay. Nevertheless, if on-site surveys are not continued, the reported harvest totals from the subsistence permits may be adequate, particularly when in-season monitoring is not necessary, as has been the case in recent years. An increase in participation in the subsistence fishery by only a few individuals, however, may have a considerable effect. Fishers often use large boats and are capable of catching large numbers of fish in a short period. Therefore, any available information on subsistence and sport harvest, including totals from returned subsistence permits and sport fish mail surveys, should be reviewed annually for changes or increases which may warrant further monitoring of harvest.

It is also difficult to draw conclusions about factors that may be limiting sockeye production in Tumakof Lake, with only two years of zooplankton and lake habitat information. We only have one set of paired data, the 2002 sockeye escapement estimate and the zooplankton biomass and densities in 2003. An accurate estimate of the number of sockeye fry produced per spawner, over several years to account for variation in over-wintering conditions, would provide some indication as to whether sockeye production in the lake is limited by spawning area. However, the large number of floating and submerged logs in the lake make fry sampling with hydroacoustic and trawl gear nearly impossible. A comparison of zooplankton biomass, by species, over several years in Tumakof Lake and other lakes in Southeast Alaska gives us a glimpse into the ability of this lake to support sockeye fry (Mills and Schiavone 1982). Zooplankton biomass estimates in Tumakof Lake were high in 2002 and 2003 compared to other Southeast Alaska lakes, but the biomass and mean size of *Daphnia*, a preferred prey for sockeye fry, were below average. This situation could be a result of intense grazing pressure upon the

Daphnia population by a predator population that is near carrying capacity (Table 6; Koenings and Burkett 1987; Mazumder and Edmundson 2002).

Another bit of evidence lies in the proportion of sockeye salmon with more than one year of freshwater growth we have observed in the Tumakof Lake escapements. In a typical Southeast Alaskan sockeye system, most sockeye fry attain sufficient growth to leave the lake after one year (Koenings and Burkett 1987). However, in two years out of three in our study, more than half the sockeye salmon returning to Tumakof Lake had two or more years of freshwater growth. In fact, substantial percentages of sockeye salmon with three years of freshwater growth were sampled in the 2002 and 2003 escapements, a rare occurrence in Southeast Alaska. Although prey limitation is an obvious suspect, other factors can also limit sockeye fry growth in a lake, such as temperature (Edmundson and Mazumder 2001) and competition from other planktivores (Walters and Juanes 1993).

Table 6.–Zooplankton biomass and *Daphnia* biomass and average size in 2002 and 2003 for 13 small lakes in Southeast Alaska.

2002				2003			
Lake	Zooplankton biomass (mg per m^2)	Daphnia biomass (mg per m^2)	Daphnia avg. size (mm)	Lake	Zooplankton biomass (mg per m^2)	Daphnia biomass (mg per m^2)	Daphnia avg. size (mm)
Klawock	499	16	0.9	Kutlaku	618	84	0.51
Tumakof	496	2	0.65	Tumakof	500	0	0.66
Luck	316	18	0.77	Klawock	431	37	0.97
Klag	222	5	0.97	Salmon Bay	351	32	0.93
Salmon Bay	205	19	0.75	Klag	316	7	0.68
Kutlaku	131	35	0.51	Luck	201	6	0.73
Thoms	119	7	0.57	Thoms	163	7	0.55
Hetta	49	7	0.67	Hetta	45	2	0.68
Falls	41	1	0.69	Falls	29	1	0.66
Average	231	12	0.72	Average	295	20	0.71
Median	214	10	0.71	Median	305	7	0.68

In conclusion, three years of escapement and harvest information on Tumakof Lake sockeye salmon have shown that the combined subsistence, sport, and commercial harvests in Redfish Bay were low compared to the observed escapement sizes. Consequently, we believe these fisheries pose no risk to the sustainability of sockeye salmon in this lake system at the current harvest levels. Although the illegal fishing activity in 2000, yielded a catch of 8,000 (44% of the commercial harvest), it is unlikely to effect future returns, as the level is well below sustainable harvest levels for a stock of this magnitude. The low *Daphnia* biomass observed in 2002 and 2003 suggests that larger escapements may not translate into greater overall fry production, especially in years of low zooplankton production.

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APPENDICES

Appendix A.–Sockeye salmon harvest at the head of Redfish Bay (Subdistrict 113-13) reported on subsistence permits issued for 1985–2004 (ADF&G Division of Commercial Fisheries database; accessed February 2005).

Year	Permits	Sockeye	Sockeye per permit
1985	7	128	18
1986	4	100	25
1987	5	222	44
1988	4	186	47
1989	7	260	37
1990	10	515	52
1991	5	250	50
1992	11	532	48
1993	10	397	40
1994	22	1,111	51
1995	13	483	37
1996	13	618	48
1997	26	1,016	39
1998	25	915	37
1999	26	659	25
2000	13	281	22
2001	22	478	22
2002	21	1,101	52
2003	19	784	41
2004	15	548	37
2005	7	223	32

Appendix B.–Commercial sockeye harvest in Redfish Bay (Subdistrict 113-13) and the two adjacent subdistricts on the outer coast of Baranof Island (Subdistricts 113-11 and 113-21) from 1960 to 2004 (ADF&G Division of Commercial Fisheries database; accessed February 2005).

Year	Redfish Bay	Outer coast of Baranof Island, South of Redfish Bay	Outer coast of Baranof Island, North of Redfish Bay
1960	4,369	0	0
1961	0	0	0
1962	0	0	0
1963	0	0	0
1964	0	0	0
1965	7	5,050	1,181
1966	9,775	0	0
1967	926	0	0
1968	23,217	0	0
1969	0	0	0
1970	2,433	9,060	0
1971	0	0	0
1972	3,366	3,196	0
1973	2,599	2,280	0
1974	10,203	1,766	0
1975	0	0	0
1976	0	13,058	0
1977	7,495	0	0
1978	2,413	7,753	0
1979	0	1,417	722
1980	90	6,277	2,974
1981	3,015	0	0
1982	3,003	0	0
1983	728	0	0
1984	3,857	0	0
1985	0	0	0
1986	1,897	0	0
1987	1,821	0	0
1988	885	0	0
1989	2,558	0	0
1990	0	798	0
1991	695	0	0
1992	173	0	0
1993	2,410	354	0
1994	0	0	0
1995	0	0	0
1996	7,569	0	0
1997	0	0	0
1998	0	0	0
1999	4,298	0	0
2000[a]	17,867	0	0
2001	0	32	390
2002	0	7	11
2003	693	30	41
2003	41	30	0
2004	70	162	530

[a] The 8,000 illegal sockeye salmon harvested in 2000 are included in this harvest total.

Appendix C.–The 2004 Tumakof Lake weir counts by species and sockeye salmon marking schedule, and daily water temperature and depth of Tumakof Lake's outlet stream.

Date	Water depth (m)	Water temp (°C)	Mark given	Number marked	Sockeye jacks (<400 mm)	Number ASL samples	Sockeye daily counts	Sockeye cum. counts	Daily % marked	Cum. total marked	Cum. % marked	Coho counts	Pink counts	Chum counts
5-Jul	0.39	17												
6-Jul	0.48	14												
7-Jul	0.57	15	AD LA	21		10	51	51	41%	21	41%			
8-Jul	0.55	15	AD LA	0		0	19	70	0%	21	30%			
9-Jul	0.53	15	AD LA	10		10	125	195	8%	31	16%			
10-Jul	0.51	15	AD LA	23		10	28	223	82%	54	24%			
11-Jul	0.49	15	AD LA	0		0	74	297	0%	54	18%			
12-Jul	0.48	15	AD LA	6		6	7	304	86%	60	20%			
13-Jul	0.47	17	AD LA	4		4	5	309	80%	64	21%			
14-Jul	0.46	16	AD LA	0		0	0	309		64	21%			
15-Jul	0.45	17.5	AD LA	14		14	14	323	100%	78	24%			
16-Jul	0.44	18	AD LA	6		6	6	329	100%	84	26%			
17-Jul	0.43	17.5	AD LA	0		0	0	329		84	26%			
18-Jul			AD LA	0		0	0	329		84	26%			
19-Jul	0.41	17	AD LA	0		0	0	329		84	26%			
20-Jul	0.41	17	AD LA	0		0	0	329		84	26%			
21-Jul	0.41	17	AD LA	0		0	0	329		84	26%			
22-Jul	0.40	17	AD LA	0		0	0	329		84	26%			
23-Jul	0.40	18	AD LA	0		0	0	329		84	26%			
24-Jul	0.39	18	AD LA	0		0	0	329		84	26%			
25-Jul	0.41	17	AD LA	0		0	0	329		84	26%			
26-Jul	0.42	16	AD LA	19		19	26	355	73%	103	29%			
27-Jul	0.43	18	AD LA	57		21	57	412	100%	160	39%			
28-Jul	0.58	18	AD LA	527		40	2,789	3201	19%	687	21%			
29-Jul	0.65	17	AD LA	149		40	879	4080	17%	836	20%			
30-Jul	0.66	18	AD LA	39		20	352	4432	11%	875	20%			
31-Jul	0.64	18	AD LA	43	3	30	159	4591	27%	918	20%	1		

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Date	Water depth (m)	Water temp (°C)	Mark given	Number marked	Number ASL samples	Sockeye daily counts	Sockeye cum. counts	Cum. total marked	Cum. % marked	Coho counts	Pink counts	Chum counts
1-Aug	0.59	20	AD LA	0	26	0	174	4,765	0%	918	19%	
2-Aug	0.57	18	AD LA	60	5	0	65	4,830	92%	978	20%	
3-Aug	0.49	18	AD LA	0	0	0	0	4,830		978	20%	
4-Aug	0.47	17	AD LA	13	2	10	39	4,869	33%	991	20%	
5-Aug	0.46	17	AD LA	30	3	10	73	4,942	41%	1,021	21%	
6-Aug	0.45	17	AD LA	8	0	9	4,951	1,029	21%	1	1	0
7-Aug	0.44	17	AD LA	118	20	123	5,074	1,147	23%	0	0	0
8-Aug	0.42	17	AD LA	62	20	100	5,174	1,209	23%	0	0	0
9-Aug	0.41	17	AD LA	0	0	39	5,213	1,209	23%	0	0	0
10-Aug	0.41	18	AD LA	0	0	18	5,231	1,209	23%	0	0	0
11-Aug	0.39	18	AD LA	0	0	14	5,245	1,209	23%	0	0	0
12-Aug	0.38	18	AD LA	11	0	11	5,256	1,220	23%	0	0	0
13-Aug	0.37	18.5	AD LA	0	0	0	5,256	1,220	23%	0	0	0
14-Aug	0.36	19	AD LA	0	0	0	5,256	1,220	23%	0	0	0
15-Aug	0.36	20	AD LA	0	0	0	5,256	1,220	23%	0	0	0
16-Aug	0.35	18	AD LA	11	10	11	5,267	1,231	23%	0	0	0
17-Aug	0.35	20	AD LA	0	0	0	5,267	1,231	23%	0	0	0
18-Aug	0.34	20	AD LA	21	20	37	5,304	1,252	24%	3	3	0
19-Aug	0.34	20	AD LA	0	0	2	5,306	1,252	24%	0	0	0
20-Aug	0.34	18	AD LA	0	0	0	5,306	1,252	24%	0	0	0
21-Aug	0.34	19	AD LA	0	0	0	5,306	1,252	24%	0	0	0
22-Aug	0.34	19	AD LA	0	0	0	5,306	1,252	24%	0	0	0
23-Aug	0.34	19	AD LA	0	0	0	5,306	1,252	24%	0	0	0
24-Aug	0.34	19	AD LA	0	0	0	5,306	1,252	24%	0	0	0
25-Aug	0.32	18	AD LA	0	0	0	5,306	1,252	24%	0	0	0
26-Aug	0.32	18	AD LA	0	0	0	5,306	1,252	24%	0	0	0
27-Aug	0.32	18	AD LA	0	0	13	5,319	1,252	24%	1	12	0
28-Aug	0.33	18	AD LA	0	0	212	5,531	1,252	23%	3	42	0
29-Aug	0.33	18	AD LV	0	0	58	5,589	1,252	22%	5	306	0

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Date	Water depth (m)	Water temp (°C)	Mark given	Number marked	Number ASL samples	Sockeye daily counts	Sockeye cum. counts	Cum. total marked	Cum. % marked	Coho counts	Pink counts	Chum counts
30-Aug	0.33	18	AD LV	0	0	7	5,596	1,252	22%	0	180	0
31-Aug	0.33	18	AD LV	0	0	4	5,600	1,252	22%	0	44	0
1-Sep	0.33	18	AD LV	0	0	12	5,612	1,252	22%	1	83	0
2-Sep	0.33	18	AD LV	6	6	9	5,621	1,258	22%	0	142	0
3-Sep	0.36	18	AD LV	30	30	93	5,714	1,288	23%	9	68	0
4-Sep	0.38	16	AD LV	44	40	627	6,341	1,332	21%	20	297	0
5-Sep	0.43	16	AD LV	271	140	2,187	8,528	1,603	19%	43	320	0
6-Sep	0.46	16	AD LV	666	40	4,729	13,257	2,269	17%	44	370	0
7-Sep	0.45	16	AD LV	514	40	4,081	17,338	2,783	16%	41	300	0
8-Sep	0.48	15	AD LV	375	30	1,993	19,331	3,158	16%	42	153	0
9-Sep	0.46	14	AD LV	599	1	2,469	21,800	3,757	17%	27	228	0
10-Sep	0.45	14	AD RV	207	10	578	22,378	3,964	18%	8	96	0
11-Sep	0.46	14	AD RV	120	10	1,008	23,386	4,084	17%	14	843	0
12-Sep	0.49	14	AD RV	201	10	1,156	24,542	4,285	17%	138	1,938	0
13-Sep	0.64	14	AD RV	379	0	3,187	27,729	4,664	17%	97	340	0
14-Sep	0.66	14	AD RV	431	0	7,070	34,799	5,095	15%	236	1,025	0
15-Sep	0.77	12	AD RV	770	10	3,147	37,946	5,865	15%	47	566	2
16-Sep	0.58	14	AD RV	520	10	737	38,683	6,385	17%	47	599	2
17-Sep	0.80	13	AD RV	296	0	397	39,080	6,681	17%	8	158	2
18-Sep	0.75	14	AD RV	115	10	118	39,198	6,796	17%	0	58	4
19-Sep	0.73	13	AD D	146	10	172	39,370	6,942	18%	4	93	3
20-Sep	0.76	15	AD D	128	0	154	39,524	7,070	18%	50	114	0
21-Aug	0.34	19	AD LA	0	0	0	5,306	1,252	24%	0	0	0
22-Aug	0.34	19	AD LA	0	0	0	5,306	1,252	24%	0	0	0
23-Sep	-	-	-	0	0	156	39,680	7,070	18%	14	11	0
24-Sep	-	-	-	0	0	0	39,680	7,070	18%	0	0	0
25-Sep	0.99	13	AD D	0	0	154	39,834	7,070	18%	1	0	0
26-Sep	0.93	12	AD D	0	0	16	39,850	7,070	18%	12	0	1
27-Sep	0.80	12	AD D	0	0	92	39,942	7,070	18%	34	7	2

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Appendix C.–Page 4 of 4.

Date	Water depth (m)	Water temp (°C)	Mark given	Number marked	Number ASL samples	Sockeye daily counts	Sockeye cum. counts	Cum. total marked	Cum. % marked	Coho counts	Pink counts	Chum counts
28-Sep	0.76	12.5	AD D	0	0	131	40,073	7,070	18%	24	6	1
29-Sep	0.68	11	AD D	0	0	39	40,112	7,070	18%	27	2	2
30-Sep	0.67	10.5	AD D	0	0	44	40,156	7,070	18%	24	4	2
1-Oct	0.64	11.5	AD D	0	0	40	40,196	7070	18%	13	0	0
2-Oct	0.61	11.5	AD D	0	0	31	40,227	7,070	18%	8	0	2
3-Oct	0.56	12	AD D	0	0	6	40,233	7,070	18%	16	1	2
4-Oct	0.57	11.5	AD D	0	0	13	40,246	7,070	18%	13	0	4
5-Oct	0.75	12	AD D	0	0	14	40,260	7,070	18%	47	0	1
6-Oct	0.84	11.5	AD D	0	0	17	40,277	7,070	18%	18	0	0
7-Oct	0.88	11.5	AD D	0	0	2	40,279	7,070	18%	1	0	0
8-Oct	-	11	AD D	0	0	19	40,298	7,070	18%	25	1	0
9-Oct	-	-	AD D	0	0	4	40,302	7,070	18%	19	0	0