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Hetta Lake Subsistence Sockeye Salmon Project: 2008 Annual Report

by

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and

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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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The Division of Sport Fish Fishery Data Series was established in 1987 for the publication of technically oriented results for a single project or group of closely related projects. Since 2004, the Division of Commercial Fisheries has also used the Fishery Data Series. Fishery Data Series reports are intended for fishery and other technical professionals. Fishery Data Series reports are available through the Alaska State Library and on the Internet: http://www.sf.adfg.state.ak.us/statewide/divreports/html/intersearch.cfm This publication has undergone editorial and peer review.

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TABLE OF CONTENTS

Page

LIST OF TABLES

Table **Page**

LIST OF FIGURES

Figure **Page**

LIST OF APPENDICES

Appendix **Page**

ABSTRACT

The sockeye salmon (*Oncorhynchus nerka*) run returning to Hetta Lake on Prince of Wales Island plays a central role in culturally based subsistence practices of current Hydaburg residents. This same, once abundant resource, provided for the original Haida settlements in the area starting in the late 1700s and Tlingit settlements before that, and also supplied several early commercial salmon canneries from the late 1800s through the 1950s. In more recent years, Hydaburg residents became increasingly concerned about low harvests and a possible decline in the Hetta Lake sockeye run. The Hydaburg Cooperative Association partnered with the Alaska Department of Fish and Game to begin a new stock assessment program in 2001. A subsistence harvest survey and sockeye salmon escapement count were once again completed in 2008, the eighth year of this program. Lake temperature, light profiles, and zooplankton populations were also measured, and hydroacoustic and trawl surveys were conducted to estimate small fish populations in the lake. The harvest survey documented a total harvest of 3,585 sockeye salmon from Hetta Cove, mainly during July through mid-August. The escapement count was 4,883 sockeye salmon passing the Hetta Creek weir from June through late September. While the subsistence sockeye harvest was about the same as in 2007, the escapement was down sharply from the previous 2 years. The combined return (subsistence harvest plus escapement) was substantially below the recent 4 -year average. The estimated seasonal mean zooplankton biomass was only 10 $mg{\cdot}m^{-2}$, well below the low levels observed in previous seasons. The estimated sockeye fry population of about 383,000 fish showed a dramatic increase from numbers in 2005 and 2006, when the Hetta Lake fish assemblage was dominated by threespine sticklebacks (*Gasterosteus aculeatus*).

Key words: sockeye salmon, *Onchorynchus nerka*, subsistence, Hetta Lake, Hydaburg, Prince of Wales Island, Southeast Alaska, escapement, mark-recapture, harvest census, zooplankton, fry, stickleback, hydroacoustic

INTRODUCTION

The Hetta Lake sockeye salmon (*Oncorhynchus nerka*) run is one of the most important subsistence resources accessed by residents of the village of Hydaburg on south Prince of Wales Island. Hetta Lake sockeye salmon played a central role in the history of this village, as well as former Haida and Tlingit settlements which pre-dated the modern village (Langdon 1977; Betts et al., ADF&G Div. of Subsistence, *unpublished report*). In the late 1960s, the U.S. Fish and Wildlife Service operated a weir on the Hetta Lake outlet stream. Where observations at the start of the commercial fishing era suggested a run of 100,000 to 200,000 sockeye salmon returning to Hetta Lake (Moser 1899), only some 15,000 to 24,000 sockeye salmon were counted through the 1960s weir. When ADF&G operated a weir on the Hetta Lake outlet stream for one year in 1982, the count had dropped even farther, to about 5,000 fish (Conitz 2008).

Hydaburg residents, with generations of experience in fishing on the Hetta Lake sockeye run, increasingly expressed their concerns about depletion of the stock. In 2001, ADF&G and the Hydaburg Cooperative Association began a new cooperative sockeye stock assessment project at Hetta Lake, which has continued annual operations through 2009. During the first few years of study, spawning population estimates were attempted using mark-recapture experiments in the lake and stream spawning areas. Difficulties in sampling fish in the lake spawning areas, especially late in the protracted fall spawning period, raised questions about the reliability and completeness of these estimates. Mark-recapture estimates from the stream spawning area were more reliable and bracketed the entire spawning period for that area; these estimates were combined with regular observations (visual counts and some mark-recapture sampling) in the lake spawning areas. The best available spawning population estimates produced in this manner did suggest that the stock had reached a very low level (McEwen et al. 2002; Lewis and Cartwright 2004; Cartwright et al. 2005; Conitz et al. 2007). A weir was installed on the lake outlet stream in 2005 in order to improve reliability of our spawning population estimates, and that year's weir count of just 3,300 sockeye salmon confirmed our suspicion of low spawner numbers (Host et al. 2008). The following 2 years, however, saw much improved escapement counts: 17,930 sockeye salmon in 2006 and 12,860 sockeye salmon in 2007 (Conitz 2008; Blikshteyn and Conitz 2009).

The subsistence harvest of sockeye salmon has been monitored in conjunction with escapement since 2001, primarily by a Hydaburg biologist and elder who has personally interviewed everyone returning to the Hydaburg dock or known to have participated in fishing. Not surprisingly, the size of the harvest shows a relationship with the size of the escapement into Hetta Lake. For example, both 2004 and 2005 were low escapement years, and only 630 and 350 sockeye salmon were harvested in the marine terminal area subsistence fishery. In 2006, when a much higher number of sockeye salmon was counted at the weir, the subsistence harvest reached almost 10,000 fish. Subsistence fishermen and users in Hydaburg employ a range of cultural adaptations to respond to variable salmon returns (Betts et al., ADF&G Div. of Subsistence, *unpublished report*). In some years when the Hetta sockeye runs are low, Hydaburg fishermen shift their efforts to other streams in the area, such as Eek, Klakas, and Hunter Bay, but recently low sockeye runs have been widespread in the area. Furthermore, fish from Hetta Lake origin are usually the largest component in Hydaburg's total subsistence sockeye harvest, which at the very low stock sizes recently observed may not adequately meet subsistence needs.

The Hetta Lake sockeye stock assessment project has also included assessments of small fish and zooplankton populations in the lake in order to evaluate the relationship of these factors with the dynamics of the sockeye population. Small pelagic fish surveys, using trawl and hydroacoustic sampling gear, have been conducted every year except 2007, including a successful survey in 2008. Zooplankton have been sampled in Hetta Lake every year to evaluate the quality and quantity of the forage base available for rearing sockeye fry.

The primary objectives in the Hetta Lake study in 2008 were, as in previous years, to obtain reliable estimates of sockeye escapement and subsistence harvest. The weir on the Hetta Lake outlet stream was operated again for a fourth consecutive season, and a harvest survey was conducted in Hydaburg and on the fishing grounds for an eighth consecutive season. A mark-recapture study was conducted in conjunction with the weir operation in an effort to validate the weir count, and sockeye salmon were also sampled at the weir for age, sex, and length composition. Zooplankton sampling was conducted monthly from mid-May through mid-September, and hydroacoustic and trawl sampling to estimate the sockeye fry population was completed in September.

OBJECTIVES

1. Survey all subsistence fishermen on the fishing grounds or after they return to Hydaburg, to determine the total sockeye harvest in the terminal areas of Hetta Lake and other sockeye streams in the Hydaburg area.

2. Count sockeye salmon escapement into Hetta Lake at the weir, throughout as much of the spawning migration period as is feasible.

3. Estimate the escapement of sockeye salmon into Hetta Lake using mark-recapture methods so that the estimated coefficient of variation would be less than 10%.

4. Estimate the age, length, and sex composition of the Hetta Lake sockeye salmon escapement.

5. Estimate the abundance and density of sockeye salmon fry and other pelagic fish species in Hetta Lake, such that the coefficient of variation would be less than 15%.

6. Measure water column temperature and record light profiles in Hetta Lake during the sampling season. Estimate zooplankton species composition, size, density, and biomass.

METHODS

STUDY SITE

Hetta Lake (ADF&G stream no. 103-25-047; 55°10.17'N 132°34.03'W) is located on the southwestern side of Prince of Wales Island, at an elevation of 9.4 m (Figure 1). This dimictic oligotrophic lake has organically stained water, a surface area of 207 ha, and mean and maximum depths of 48.0 m and 92.0 m (Figure 2). The volume of the lake is 99.4 million m^3, and water residence time was estimated to be about 12.6 months. The Hetta Lake watershed is a 24 km^2 area of steep slopes covered with spruce, cedar, and hemlock forest, much of which was logged in the 1950s. The lake has one main tributary stream, Hetta Creek which enters the lake on the northeastern side, and numerous small mountainside drainages, of which Old Hatchery Creek on the south side and Camp Creek on the north side are the largest. The lake outlet is on the west end, and the 600 m long outlet stream drains into Hetta Cove. Sockeye salmon spawn in Hetta Creek, and along many shoreline areas including the gravel beaches at the east end of the lake and the area around the mouth of Old Hatchery Creek on the southern side of the lake. In addition to sockeye salmon, other fish species present in Hetta Lake include pink (*O. gorbusha*), chum (*O. keta*), and coho (*O. kisutch*) salmon, cutthroat (*O. clarki*) and steelhead (*O. mykiss*) trout, Dolly Varden char (*Salvelinus malma*), threespine stickleback (*Gasterosteus aculeatus*), and sculpins (*Cottus* sp.).

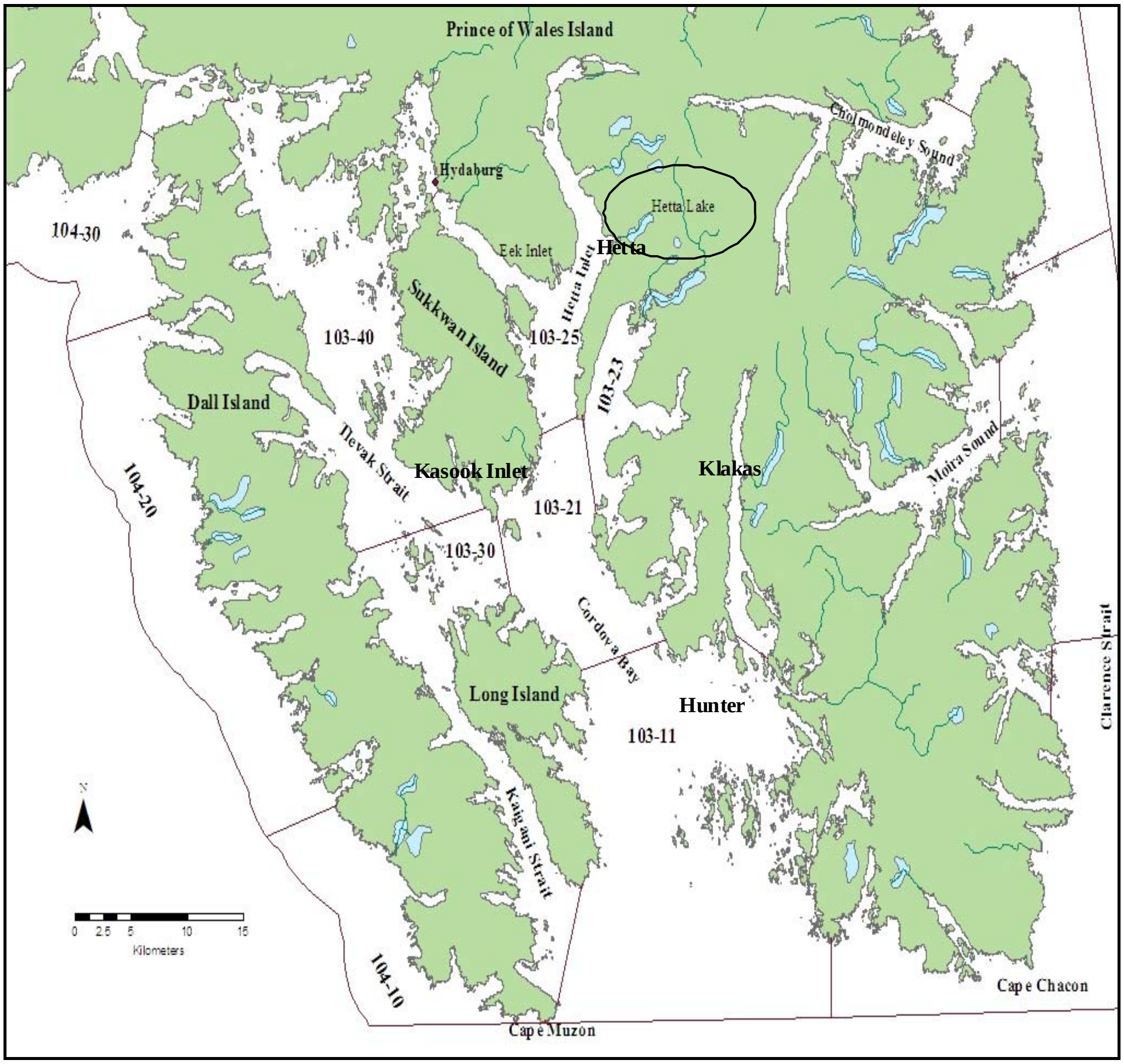

Figure 1.–The geographic location of Hetta Lake and subsistence fishing areas of Hetta Cove, Klakas Inlet, Hunter Bay, Kasook Inlet, and Eek Inlet shown in relationship to Hydaburg on southeast Prince of Wales Island. Commercial salmon fishing subdistricts are also shown.

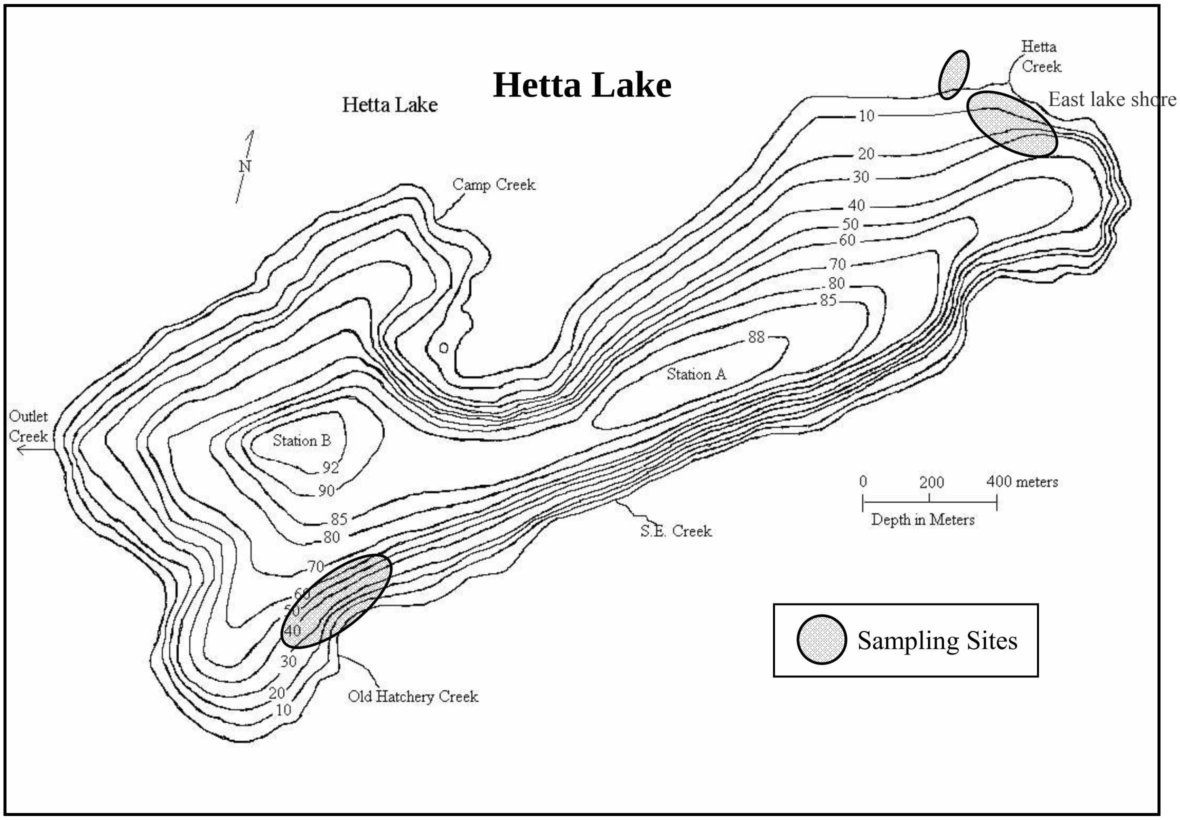

Figure 2.–Hetta Lake bathymetric map with locations of inlet and outlet streams, mark-recapture and visual counts sampling sites (Hetta Creek, east lake shore, and Old Hatchery Creek), and limnological sampling stations (A and B).

SUBSISTENCE HARVEST

To determine subsistence salmon harvest, all subsistence fishermen from Hydaburg were interviewed by a project biologist or technician after a fishing trip, either on the fishing grounds or in the harbor at Hydaburg. All fishing areas in the Hydaburg area were included in the survey: Hetta Cove, Eek Inlet, Hunter Bay, Klakas Inlet, and Kasook Inlet (see Figure 1). The standard interview form included date and area fished, number of fish harvested by species, time and duration of fishing, and fishing gear used. Every party that fished and returned to Hydaburg was interviewed in 2008, so the responses comprised a complete census of subsistence harvest and effort. Individual harvests in each area were summed for season totals, by species.

SOCKEYE ESCAPEMENT ESTIMATE

Weir Count

The aluminum bipod and picket weir was located on the outlet creek at Hetta Lake. It was 17 m wide with pickets spaced 4.5 cm apart at center. Fish passed through an opening in the weir into a 2.5-m by 1.25-m rectangular trap box constructed of aluminum channel and pickets. A field crew from the Hydaburg Cooperative Association operated the weir from 30 May to 23 September 2008. All fish captured at the weir were enumerated by species and released upstream of the weir. A subsample of the sockeye salmon escapement was sampled for age (using scale samples), sex, and length, and marked with fin clips for the mark-recapture study.

Visual Surveys

Crew members visually counted sockeye spawners around the mouth of Hetta Creek and around the lake shoreline, targeting all the main spawning areas. The surveys were conducted by boat on 26 August, 5 and 16 September, 8 October, and 4 November 2008. The main purpose of the surveys was to define spawn timing in the various important spawning sites, including the extent of late season spawning. Due to logistics, weather, and crew misunderstanding, no foot surveys were conducted in Hetta Creek in 2008.

Mark-Recapture Estimate

In addition to the weir count, sockeye salmon escapement into Hetta Lake was estimated using a closed, stratified, 2-sample mark-recapture model (Arnason et al. 1996). The first sample, or marking phase of the study, consisted of fish marked at the weir at a constant marking rate of 30% of the daily number of sockeye salmon passed through the weir. An adipose fin clip was used as the primary mark. A secondary mark was also used, divided into 4 temporal marking strata differentiated by fin clips: 30 May–12 June (dorsal), 13 June–5 August (left axillary), 6–25 August (left pelvic), and 26 August–24 September (right pelvic). The second sample, or the recovery phase of the mark-recapture study, consisted of fish captured and examined for marks on the spawning grounds, beginning toward the end of the weir operation period and continuing into October. Sampling was conducted in all accessible spawning areas, including Hetta Creek, during 4 sampling events on 26 August, 5 and 16 September, and 8 October. Fish captured in these 4 strata were marked with distinct opercular punches to prevent duplicate sampling and thus ensure sampling without replacement.

The 2-sample Petersen model provides a simple method for estimating population size, based on the number of animals marked in the first sample, the number of animals subsequently sampled for marks in the 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 both the first (marking) and second (mark-recovery) samples temporally over 2 or more sampling events, and are widely used for estimating escapement of salmonids as they migrate into their spawning streams (Arnason et al. 1996). A fundamental assumption of the Petersen and related mark-recapture models is that capture probabilities for individual animals are equal (Pollock et al. 1990). Briefly stated, the assumptions of equal capture probability 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. In stratified sampling, if one or more of these assumptions is met, the marking and recovery strata can generally 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).

The Stratified Population Analysis System (SPAS) software was used for analysis (Arnason et al. 1996; for details, refer to http://www.cs.umanitoba.ca/~popan/). To test for consistency of capture probabilities in the marking and recapture strata, 2 chi-square tests are provided with this software. A test for equal capture probability in the first sample compares observed and expected numbers of marked and unmarked fish in each recapture stratum. A test for equal capture probability in the second sample, or equivalently, complete mixing, compares observed and expected numbers of those fish marked in the initial (marking) strata which were recaptured or not recaptured. These tests are labeled "equal proportions" and "complete mixing," respectively. A test statistic with *p*-value ≤ 0.05 was considered to be "significant." Neither test statistic or only one test statistic being significant indicated that all marking and all recapture strata could be pooled without too great a risk of bias and the simple Petersen ("pooled-Petersen") estimator could be used. On the other hand, if both test statistics were signficant, a higher risk of bias in the pooled Petersen estimator was indicated. In this case, the stratified Darroch estimator was used if it could be calculated. If the SPAS program was unable to converge to a solution for the Darroch estimator, the guidelines and suggestions in Arnason et al. (1996) were used to search for a partial pooling scheme that would lead to a valid estimate. The data were also examined for any obvious deficiencies or discrepancies in sample sizes and recapture numbers, and events during the season were considered, such as flooding or missed sampling dates, that may have led to inconsistencies.

If a valid mark-recapture estimate was generated, the 95% confidence interval bounds were used to judge the accuracy of the weir count. If the weir count fell within the 95% confidence interval bounds, it was considered accurate. If the weir count was below the lower 95% confidence interval bound, we considered the possibility that the weir count was inaccurate and some fish escaped through undetected. In that case, the mark-recapture estimate, if unbiased, could be more accurate. A weir count above the 95% confidence interval bounds could only indicate the mark-recapture estimate was inaccurate, because the weir count, if free of counting errors, would always represent a minimum number of fish in the lake. If a valid mark-recapture estimate could not be generated, the weir count was accepted as the best estimate, of at least minimum escapement.

SOCKEYE ESCAPEMENT AGE AND LENGTH COMPOSITION

Sockeye salmon were sampled roughly in proportion to weekly escapement at the weir for scales, length measurement, and sex identification (Table 1). Scale samples were paired with sex and length data from each sample. Three scales were taken from the preferred area of each fish (INPFC 1963) and prepared for analysis as described by Clutter and Whitesel (1956). Scale samples were analyzed at the ADF&G Salmon Age Laboratory in Douglas, Alaska. Age classes were designated by the European aging system where freshwater years are counted after hatching and emergence from the gravel, and freshwater and saltwater years are separated by a period. The total age includes the time from fertilization to hatching and emergence. For example, a fish of age 2.3 spent 2 years in freshwater after hatching and 3 years in saltwater, and was 6 years old when it returned to the lake to spawn (Koo 1962). The length of each fish was measured from mid eye to tail fork to the nearest millimeter (mm). The proportion in 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).

SOCKEYE FRY POPULATION ASSESSMENT

Hydroacoustic and mid-water trawl sampling methods were used to estimate abundance and age-size distributions of sockeye fry and other small pelagic fish in Hetta Lake in 2008. To control year-to-year variation in our estimates, the acoustic survey in 2008 was once again conducted along the same 14 transects that were randomly chosen in 2002 (2 from each of 7 sampling sections of the lake) as permanent transects for this lake (Lewis and Cartwright 2004).

Table 1.–Approximate weekly sampling schedule for sockeye salmon at the Hetta Lake weir in 2008.

Statistical week	Date	Fish to sample
24	8–4 Jun	10
25	15–21 Jun	10
26	16–28 Jun	10
27	29 Jun–5 Jul	10
28	6–12 Jul	20
29	13–19 Jul	20
30	20–26 Jul	40
31	27 Jul–2 Aug	60
32	3– 9 Aug	60
33	10–16 Aug	120
34	17–23 Aug	120
35	24–30 Aug	100
36	31 Aug–6 Sep	20
37	7–13 Sep	20
Total		620

Hydroacoustic Survey

Sampling was conducted at night, starting immediately after sunset. Acoustic targets were acquired by surveying each transect from shore to shore, beginning and ending where depth was approximately 10 m, at a constant boat speed of about 2.0 m/sec. A Biosonics DT-X™ scientific echosounder (430 kHz, 7.3° split-beam transducer) with Biosonics Visual Acquisition © version 5.0 software was used to collect the data. The ping rate was set at 5 pings/sec and the pulse width at 0.3 ms. Only target strengths ranging from –40 dB to –70 dB were recorded because this range represented fish within the size range of sockeye fry and other small pelagic fish.

Trawl Sampling

Midwater trawl sampling was conducted immediately following the hydroacoustic survey to estimate the species composition of the sonar fish count. Trawl sampling was started in the area and depth of the lake showing the highest concentration of fish on the hydroacoustic monitor, using a 2 m x 2 m elongated beam-trawl net with a cod-end. Subsequent tows were started at the termination point of the previous tow, in a direction such that a new area would be sampled. Tows were conducted at several depths between 2.5 and 12.5 m. The duration of each tow was approximately 20–30 minutes. The total sample size goal was at least 500 fish for estimation of species proportions.

All small fish from the trawl net were preserved in 90% alcohol. Samples from each tow were preserved in separate bottles, labeled with the date, time, tow number, tow depth, and tow duration. If adult fish were caught in the midwater trawl, they were identified and released. In the laboratory, fish were re-hydrated by soaking in tap water for 60 minutes prior to measurement. All fish were identified to species, and snout-fork length (to the nearest millimeter) and weight (to the nearest 0.1 gram) were measured on each fish. All sockeye fry under 50 mm were assumed to be age-0.

Data Analysis

Fish-target density (targets·m^2) was estimated using Biosonics software (User Guide, Visual Analyser™ 4.1, BioSonics, Inc.), using the echo integration technique as described in MacLennan and Simmonds (1992). For each of the 7 lake sections, the 2 transect densities were converted to population estimates by multiplying by the section area, and then the mean and variance of the 2 population estimates were calculated. The total population estimate for the lake was simply the sum of the mean population estimates for each section. Because each section was sampled independently from other sections, the sampling variance for the whole-lake target population estimate was estimated simply as the sum of the section variances.

The total fish population estimate was apportioned to species based on the species composition of the trawl sample. Commonly, researchers assume that the proportion of each species in such a sample follows a binomial distribution, an assumption of convenience but not necessarily a realistic reflection of actual sampling conditions. However, the hydroacoustic estimate provides a reasonably accurate assessment of the total planktivore population, and for the purpose of observing the dynamics between sockeye and stickleback populations in Hetta Lake over time, the binomial estimate was considered adequate.

LIMNOLOGY

Light and temperature were measured and zooplankton samples collected in Hetta Lake on 4, 19, and 30 June, 16 July, 13 August, and 12 September 2008. Physical data were collected only at Station B (Figure 2); zooplankton samples were collected at both stations and the results were averaged between stations.

Light and Temperature Profiles

Underwater light intensity was recorded at 0.5-m intervals from just below the surface to the depth of 1% of measured intensity of the light reading just below the surface using an electronic light meter (Li-Cor). The natural log (ln) of the ratio of light intensity just below the surface to light intensity at depth z, I_0/I_z, was calculated for each depth. The vertical light extinction coefficient (K_d) was estimated as the slope of $\ln(I_0/I_z)$ versus depth. The euphotic zone depth (EZD) was defined as the depth at which light (photosynthetically available radiation at 400–700 nm) was attenuated to one percent of the intensity just below the lake surface (Schindler 1971) and calculated with the equation EZD = 4.6205/ K_d (Kirk 1994).

Temperature, in degrees centigrade (ºC), was measured with a Yellow Springs Instruments (YSI) Model 58 meter. Measurements were made at one-meter intervals to the first 10 m or the lower boundary of the thermocline (defined as the depth at which the change in temperature decreased to less than 1ºC per meter). Below this depth, measurements were made at 5-m intervals to 50 m.

Secondary Production

To assess the quality of the prey base available to sockeye fry rearing in Hetta Lake, zooplankton density and biomass were estimated by species or genus. A zooplankton sample was collected at 2 stations using a 0.5 m diameter, 153 um mesh, 1:3 conical net. Vertical zooplankton tows were pulled from a maximum depth of 50 m, at a constant speed of 0.5 m/sec. The net was rinsed prior to removing the organisms, and all specimens were preserved in neutralized 10% formalin (Koenings et al. 1987). Each zooplankton tow was sub-sampled in the laboratory, and technicians identified to species or genus, counted, and measured organisms in the sub-samples

(Koenings et al. 1987). Density (individuals per m^2 of lake surface area) was extrapolated from counts by taxon in the sub-samples, and seasonal mean density was estimated by taking the simple average of densities across sampling dates. The seasonal mean length for each taxon, weighted by density at each sampling date, was estimated and used to calculate a seasonal mean biomass estimate (weight per m^2 surface area) based on known length-weight relationships (Koenings et al. 1987). Total seasonal mean zooplankton biomass and density were estimated by summing across all species.

RESULTS

SUBSISTENCE HARVEST

In 2008, Hydaburg residents successfully fished for sockeye and other salmon at Hetta Cove, Eek Inlet, and Klakas (Table 2). Hetta Cove saw 91% of the total effort (fishing time), provided 93% of the community's total sockeye harvest, and yielded the highest harvest per fishing trip, averaging about 53 fish per party interviewed. Subsistence fishing began at the end of June and continued through mid-August, with the highest effort and harvest in late July through early August. The total sockeye harvest from the Hetta Lake run was 3,585 fish (Table 2).

Table 2.–Total 2008 subsistence salmon harvest on fishing grounds around Hydaburg, determined from interviews of returning fishermen.

			Total subsistence salmon harvest			
Fishing location	**Interviews**	**Hours fished**	**Sockeye**	**Coho**	**Chum**	**Pink**
Hetta Cove	68	367	3,585	2	2	56
Eek Inlet	11	30	222	2	0	0
Klakas	1	6	42	0	0	0
Total	80	403	3,849	4	2	56

SOCKEYE ESCAPEMENT ESTIMATE

Weir Count

Totals of 4,883 sockeye salmon, 2,392 coho salmon, 31,350 pink salmon, 419 chum salmon, and 54 Dolly Varden char were counted at the Hetta weir between 30 May and 23 September 2008 (Appendix A). Sockeye migration had slowed to only one or 2 fish per day but coho, chum, and pink salmon were still migrating past the weir in somewhat larger numbers when the weir was removed for the season. Although the sockeye migration extended through some 4 months, by far the largest number of fish passed the weir during one month between the last week of July and the end of August, with a peak daily count on 13 August (Figure 3). The water level at the weir remained nearly constant during the 4 -month period of operation, varying by only about 0.3 m overall.

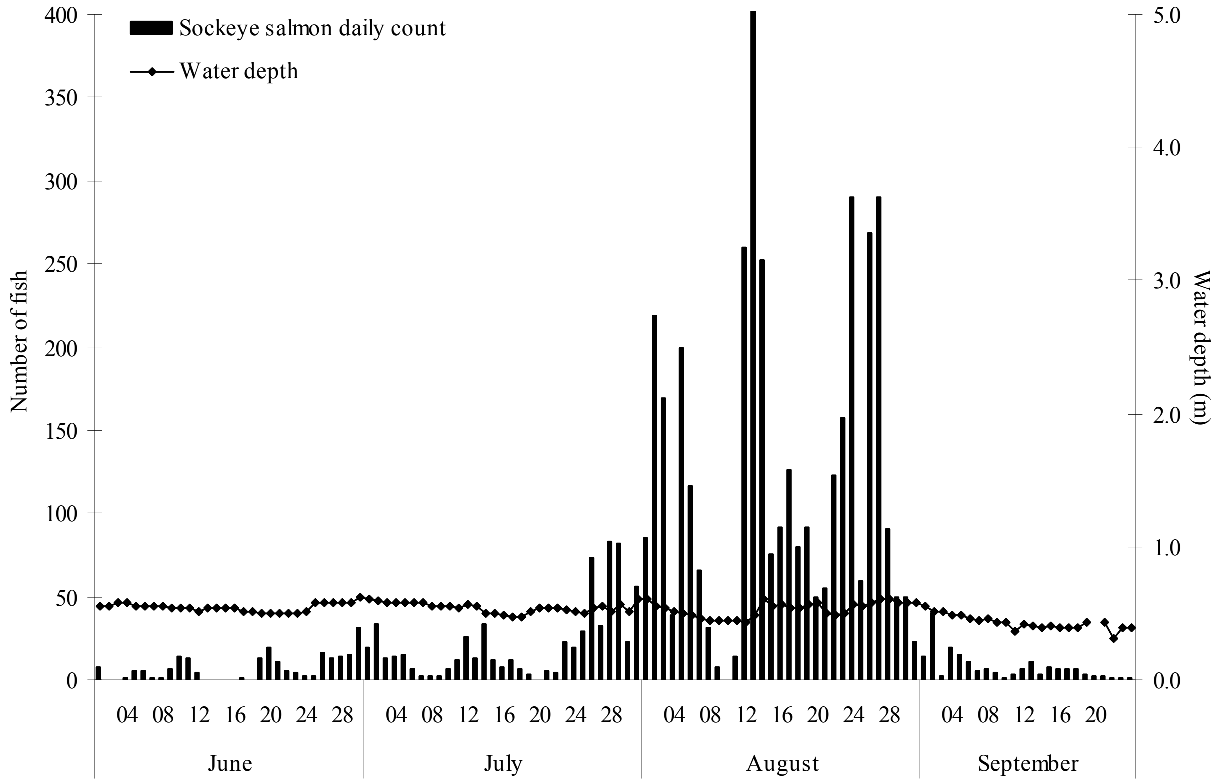

Figure 3.–Daily sockeye salmon escapement counts and water depth at the weir on the Hetta Lake outlet stream in 2008.

Visual Surveys

Unfortunately, the crew did not survey Hetta Creek in 2008, so we do not have a good indication of the number of early season stream spawners, other than counts of fish around the mouth of the stream, which were sporadic and low (Table 3). Beach spawner counts were also low, and as usual, beach spawners did not appear around the lake margins until late in the season, but maintained fairly steady numbers through the last trip to the lake on 4 November.

Mark-Recapture Estimate

A total of 1,462 sockeye salmon were marked at the weir in 2008 in 3 temporal strata (the first 2 marking strata were combined due to the small number of fish passed and marked in the first stratum; Table 4). The 30% marking goal was maintained throughout the season; however, the recovery of marked fish on the spawning grounds was uneven. About 6% of the fish marked in the early and late thirds of the run were recovered on the spawning grounds, but only about one percent of the fish marked during the peak of the run in August were recovered. Overall, only 56 fish, or 3.8% of all fish marked at the weir, were recovered in the mark-recapture sampling on the spawning grounds.

Table 3.–Visual counts of stream and beach sockeye salmon spawners around Hetta Lake in 2008. ("nd" indicates no data collected.)

	Stream spawners		Beach spawners		
Date	**Hetta Creek**	**Hetta Creek mouth**	**East lake shore**	**Old Hatchery Creek**	**Total**
26 Aug	nd	27	0	1	28
05 Sep	nd	0	0	0	0
16 Sep	nd	94	0	23	117
24 Sep	nd	8	79	50	137
08 Oct	nd	20	20	35	75
04 Nov	nd	0	51	20	71

Table 4.–Sockeye salmon marked and marked fish recovered by strata in the mark-recapture experiment at Hetta Lake in 2008. Only the beach spawners were recovered in the fish recapture phase.

Marking at weir				Recaptures by sampling date				All recoveries	
Stratum number	**Dates**	**Fish counted**	**Fish marked**	**26 Aug**	**5 Sep**	**16 Sep**	**8 Oct**	**Number**	**Percent of number marked**
1–2	30 May–5 Aug	1,583	470	1	28	0	0	29	6.2%
3	6 Aug–25 Aug	2,351	706	0	10	0	0	10	1.4%
4	26 Aug – 24 Sep	949	286	0	0	12	5	17	5.9%
Totals		4,883	1,462	1	38	12	5	56	3.8%
				Sample size and marked fish in samples by sampling date				**Totals for recapture samples**	
Number of fish in recapture samples				56	96	42	37	231	
Percent marked fish in recapture samples				2%	40%	29%	14%	24%	

Both chi-square tests were significant at *p*<0.05 ("complete mixing" χ^2=21.6, 2 df; "equal proportions χ^2=48.6, 3 df). Therefore the pooled-Petersen estimate was rejected. A maximum likelihood Darroch estimate of unpooled strata failed to converge. Therefore, no valid mark-recapture estimate was obtained, and the weir count was considered the best estimate of sockeye escapement for 2008.

SOCKEYE ESCAPEMENT AGE AND LENGTH COMPOSITION

The crew sampled 577 sockeye salmon for age, sex, and length composition and 562 were successfully aged. Fish returning from brood years from 2002 to 2005 were represented in the escapement. Most fish (86%) in the escapement were age 1.2 fish from brood year 2004 (Table 5). As expected, the mean lengths of fish corresponded with the time spent in the marine environment. Cohorts of ages 1.2 and 2.2 had similar mean lengths (502 mm and 496 mm), while age-1.3 and -1.4 fish were substantially larger (Table 6).

Table 5.–Age composition and proportion of sockeye salmon sampled in 2008 at the Hetta Lake weir, by sex, brood year, and age class.

	Brood Year, by Age Class					
	2005	2004	2003		2002	Total aged, by sex
Stratum	**1.1**	**1.2**	**1.3**	**2.2**	**1.4**	
Male						
Sample size	19	302	25	1	4	351
Proportion of all fish	3.4%	53.7%	4.4%	0.2%	0.7%	62.5%
SE	0.8%	2.1%	0.9%	—	0.4%	—
Female						
Sample size	3	181	16	2	9	211
Proportion of all fish	0.5%	32.2%	2.8%	0.4%	1.6%	37.5%
SE	0.3%	2.0%	0.7%	0.3%	0.5%	—
All Fish						
Sample size	22	483	41	3	13	562
Proportion of all fish	3.9%	85.9%	7.3%	0.5%	2.3%	100.0%
SE	0.8%	1.5%	1.1%	0.3%	0.6%	—

Table 6.–Length composition of sockeye salmon sampled in 2008 at the Hetta Lake weir, by sex, brood year, and age class.

	Brood Year, by Age Class				
	2005	2004	2003		2002
Stratum	**1.1**	**1.2**	**1.3**	**2.2**	**1.4**
Male					
Sample size	19	302	25	1	4
Mean length (mm)	353	510	581	495	573
SE (mm)	8.1	2.0	7.1	—	17.7
Female					
Sample size	3	181	16	2	9
Mean length (mm)	376	489	549	496	565
SE (mm)	16.8	2.2	7.3	20.6	9.7
All Fish					
Sample size	22	483	41	3	13
Mean length (mm)	357	502	569	496	567
SE (mm)	7.2	1.5	5.3	19.5	9.4

SOCKEYE FRY POPULATION ASSESSMENT

From hydroacoustic survey data, we estimated a total population of 737,000 small pelagic fish (CV=8.5%) in Hetta Lake on 25 September 2008. The species composition of the trawl samples (Table 7) indicated that 52%, or about 383,000 fish, were sockeye salmon fry and 48%, or about 354,000 fish, were sticklebacks.

Table 7.–Midwater trawl samples of small pelagic fish in Hetta Lake, 2008.

Tow number	Trawl depth (m)	All fish	Sockeye	Stickleback
1	12.5	120	33	87
2	7.5	79	55	24
3	2.5	13	5	8
4	12.5	55	38	17
5	7.5	73	32	41
6	12.5	80	47	33
7	2.5	55	37	18
Combined total		475	247	228
Percent (CV)			52% (4%)	48% (5%)

The mean snout-to-fork length of sockeye salmon fry in the samples was 36 mm (SD=4, n=252). The mean weight of fry was 0.32 g (SD=0.13, n=249). All fry were less than 50 mm long and assumed to be age-0.

LIMNOLOGY

Light and Temperature Profiles

The euphotic zone depth in Hetta Lake decreased from about 12 m early in the season to just under 8 m in September 2008, and averaged about 10 m for the season (Table 8). The thermocline was already developing when temperature was first measured on 4 June and reached maximum measured values on 13 August (Figure 4).

Table 8.–Euphotic zone depths at station B in Hetta Lake in 2008.

Date	Depth (m)
04 Jun	12.2
30 Jun	9.9
16 Jul	10.6
13 Aug	—
12 Sep	7.8
Seasonal mean	10.1

Secondary Production

The zooplankton assemblage in Hetta Lake was reduced to only 4 taxa identified in samples collected in 2008, comprising 2 copepod and 2 cladoceran genera plus unspecified immature forms from both groups (Table 9). Numerically, cladocerans and in particular, small-bodied *Bosmina* sp., dominated the Hetta Lake zooplantkon assemblage in 2008, comprising over 62% numerically and almost 75% of biomass (Table 10). Both *Cyclops* and *Bosmina* numbers increased rapidly during the summer months and *Cyclops* also increased in size while *Bosmina* did not. The total zoooplankton population, in terms of both density and biomass, was very low overall.

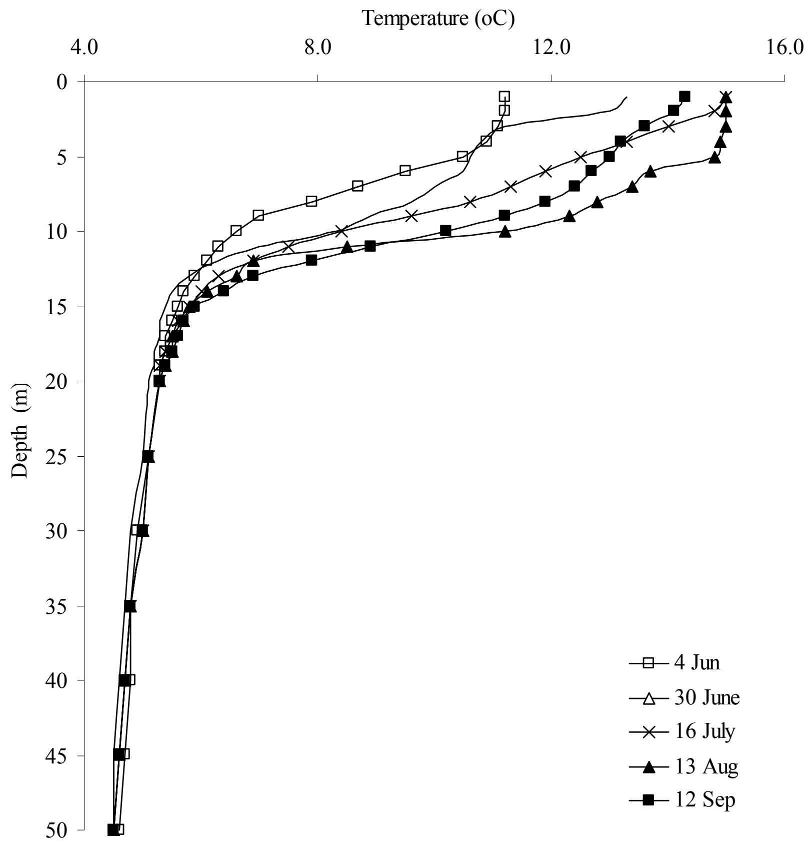

Figure 4.–Water temperature profiles at station B in Hetta Lake in 2008.

Table 9.–Mean numerical density of zooplankton per m2 of lake surface area, by sampling date and taxon, in Hetta Lake in 2008. Density estimates from station A and B samples were averaged.

	Macrozooplankton Density (number/m^2), by Sampling Date					Seasonal Mean Density	Percent of Seasonal Mean Density
Taxon	**4–19 Jun**[a]	**30 Jun**	**16 Jul**	**13 Aug**	**12 Sep**		
Cyclops sp.	382	594	3,354	2,229	85	1,329	9.6%
Harpaticus sp.	0	0	42	64	0	21	0.2%
Nauplii	297	425	764	2,643	2,250	1,276	9.2%
Bosmina sp.	849	5,455	8,788	18,498	9,424	8,603	62.0%
Daphnia longiremis	0	191	255	414	255	223	1.6%
Immature Cladocera	0	2,292	2,208	4,712	2,887	2,420	17.4%
Total	1,528	8,957	15,410	28,560	14,901	**13,871**	

[a]Actual sampling dates were 4 June at Station B and 19 June at Station A.

Table 10.–Seasonal mean length and biomass of zooplankton in Hetta Lake in 2008. Estimates are averages of stations A and B.

	Macrozooplankton Length (mm), by Sampling Date					Seasonal Means		Percent of Seasonal Mean Density
Taxon	**4–19 Jun**[a]	**30 Jun**	**16 Jul**	**13 Aug**	**12 Sep**	**Length, weighted (mm)**	**Biomass (mg/m^2)**	
Cyclops sp.	0.54	0.59	0.69	0.76	0.93	0.68	2.16	21.6%
Harpaticus sp.	—	—	0.58	0.53	—	0.56	0.02	0.2%
Bosmina sp.	0.33	0.30	0.33	0.30	0.33	0.31	7.45	74.5%
Daphnia longiremis	—	0.52	0.62	0.73	0.61	0.69	0.37	3.7%
Total							**10.0**	

[a]Actual sampling dates were 4 June at Station B and 19 June at Station A.

DISCUSSION

The weir count of 4,883 sockeye salmon will be used as the estimate of escapement at Hetta Lake in 2008. Weir counts are typically verified with a mark-recapture study; however, the field crew was unable to adequately sample the spawning population for mark-recapture information and we were unable to generate a valid mark-recapture estimate. Adequate mark-recovery samples can be obtained in Hetta Creek and adjacent areas in late August through September, but sample sizes from other areas of the lake later in the fall are often inadequate. The later, lake-spawning portion of the run represents a substantial percentage of the total spawning population, but is logistically difficult to sample and the lake-spawning period extends well past the season when our crews can safely travel to and from the lake for sampling. Hydaburg elders have long known of the late-season and spatially variable spawning patterns in the lake-spawning portions of the Hetta Lake sockeye run (R. Sanderson, technician, Hydaburg Cooperative Association, *personal communication,* 2001–2008). Past mark-recapture samples were probably not representative of the entire Hetta Lake sockeye spawning population. The addition of the weir in 2005 has helped to ensure more reliable estimates of escapement at Hetta Lake. Because of the difficulty of carrying out a mark-recapture study at Hetta Lake, it is extremely important that future weir operations be conducted as carefully as possible to ensure that the weir is fish tight through the season and that fish are counted accurately. In each of the 3 previous years, the stratified or pooled-Petersen estimate met the statistical criteria for reliability, suggesting an incomplete weir count in 2005 but confirming the weir count in 2006 and 2007. Despite the apparent difficulties with mark-recapture sampling, the independent estimates from the 3 previous years provide a measure of confidence in the effectiveness of the weir and weir counts. Confidence in fish counts at the weir can be extended to years such as 2008 when a mark-recapture verification is not obtained, provided that the weir configuration in the stream remains the same and weir and counting protocols are carefully followed.

The modest sockeye escapement and subsistence harvest numbers in 2008 followed 2 years that showed an encouraging increase in sockeye escapements and total sockeye salmon returns to the subsistence fishery and escapement at Hetta Lake (Table 11). The subsistence harvest was below the median, ranking fifth among 8 years, 2001–2008, but was substantially higher than the lowest 3 years' harvests. The size of recent subsistence harvests relative to the total number of sockeye salmon potentially available indicates that harvests of roughly 3,500–4,000 fish may fulfill the subsistence need in many years. In the most recent 3 years, Hetta Cove supplied between 86 and 93 percent of all sockeye salmon harvested by Hydaburg residents, and in each of those 3 years, the sockeye harvest from Hetta Cove exceeded 3,500 fish (Blikshteyn and Conitz 2009; Conitz 2008). Hydaburg residents tend to rely primarily on the Hetta sockeye run to fulfill their subsistence needs, seeking better fishing in other areas mostly in years when catches at Hetta Cove are very low (Conitz et al. 2007). The relatively small harvests from other sockeye runs in recent years suggest that harvests from Hetta Cove have been sufficient.

The 2008 escapement, and the combined subsistence harvest plus escapement, ranked third among the 4 years (2005–2008) for which we have reliable, weir-based escapement estimates (Table 11). Among the most recent 4 years, 2008 saw the largest subsistence harvest relative to escapement, at about 42% of the total combined terminal run. Overall, the pattern of subsistence harvests relative to escapements in the Hetta Lake sockeye run in recent years does not suggest a problem with over-harvesting. From 2004 on, the harvests have been considerably lower than escapements, and the years with low runs do not appear to be correlated with previous years of high harvest (Table 11). The more accurate subsistence harvest estimates, attributed to the cooperative effort and employment of local Hydaburg residents in conducting the surveys, provide additional assurance that the harvest is being maintained at sustainable levels.

Table 11.–Subsistence sockeye harvests from Hetta Cove in 2001 through 2008, and estimated sockeye escapements into Hetta Lake. Escapement estimates from 2001 through 2004 are less reliable, based on mark-recapture studies extrapolated to the whole lake using very rough visual survey estimates. The weir was used for escapement counts and estimation from 2005 through 2008.

Year	Subistence sockeye harvest in Hetta Cove	Sockeye escapement, Hetta Lake	Subsistence harvest + escapement	Escapement estimation method
2001	4,500	NA (2,400)[a]	NA	Mark-recapture, inlet stream only
2002	950	NA (350)[a]	NA	Mark-recapture, inlet stream only
2003	5,770	3,100[b]	8,870	Mark-recapture, stream and lake
2004	630	2,000[b]	2,630	Mark-recapture, stream and lake
2005	350	3,300	3,650	Weir-based mark-recapture
2006	9,797	17,930	27,727	Weir count
2007	3,689	12,860	16,549	Weir count
2008	3,585	4,883	8,468	Weir count

[a] Estimates of stream spawning population only in 2001 and 2002.
[b] Should be considered a rough, minimum estimate of escapement.

Little is known about the extent to which mixed-stock commercial fisheries operating around and offshore of Prince of Wales Island may intercept Hetta Lake sockeye salmon stocks. The Hetta Lake subsistence sockeye project has provided tissue samples for a genetic baseline of Southeast Alaska sockeye stocks. Preliminary studies indicate that Hetta Lake fish are separately identifiable in a mixture of samples that includes many other sockeye stocks from southern Southeast Alaska and northern British Columbia (G. Oliver, ADF&G Div. of Commercial Fisheries, Juneau, *personal communication* 2008). While this may mean the contribution of Hetta Lake sockeye salmon to Southeast Alaska commercial harvests could be determined, we don't know if these fish would be present in large enough proportions to be detectable in a mixed-stock fishery sample that contains many other, much larger stocks. Furthermore, sampling costs, feasibility, and other considerations make genetic stock identification of relatively small, incidentally harvested stocks very unlikely in the near future. Currently, ADF&G fisheries managers monitor harvest and escapement data in the Prince of Wales Island area and use time and area adjustments to protect stocks returning to the small sockeye systems in the area (S. Walker, ADF&G Div. of Commercial Fisheries biologist, Ketchikan, *personal communication* 2008).

Other important factors that can affect the size and productivity of the Hetta Lake sockeye salmon stock are those affecting fry survival in the lake, including the availability and quality of zooplankton and competition with other forage fish. In the 8 years this project has operated, Hetta Lake has been characterized by very low zooplankton populations, and a robust population of planktivores. In 2001–2004, large estimates of sockeye fry seemed inconsistent with the small spawning populations (McEwen et al. 2002; Lewis and Cartwright 2004; Cartwright et al. 2005; Conitz et al. 2007). Then in 2005 and 2006, the pelagic fish populations shifted to overwhelming dominance by threespine sticklebacks. Sockeye fry comprised only about 2% of the total fish assemblage in 2005 and 2006 (Host et al. 2008; Conitz 2008). These estimated population proportions depend completely on unbiased trawl samples, and unfortunately, the trawl sampling methods are subject to various potential sources of bias. Even though the absolute numbers of sockeye fry may be uncertain due to this potential bias, the presence of such large numbers of sticklebacks in the trawl samples in 2005 and 2006 clearly indicated a major population shift in the lake. Zooplankton biomass levels have been consistently low in Hetta Lake, compared with other sockeye producing lakes in the region (Cartwright et al. 2005). Under some circumstances, sticklebacks can be direct competitors with sockeye fry for zooplankton (Hyatt et al. 2004; Beauchamp and Overman 2003; O'Neill and Hyatt 1987). Alternatively, the stickleback population may have been manifesting a phenotypic response, or character release, exploiting the niche opened by extremely low sockeye recruitments. The niche opening would have favored limnetic feeding behavior and morphology in sticklebacks (Schluter 1993; Day and McPhail 1996; Nosil and Reimchen 2005), causing them, unlike their benthic feeding counterparts, to be detectable to the sampling gear. If larger sockeye salmon escapements in 2006 and 2007 resulted in increased fry recruitments the following years, we would expect the niche occupied by limnetic type sticklebacks to be closed. Unfortunately, a 2007 fry assessment could not be completed due to weather, but the 2008 survey was completed and the fry population appeared to reflect the increase expected from the larger number of parent-year spawners. Sticklebacks and sockeye fry were caught in the trawl samples in nearly equal proportions, yielding a sockeye population estimate fifteen times greater than in 2006 (Conitz 2008). The total number of pelagic fish estimated from the 2008 hydroacoustic survey, including both sockeye fry and sticklebacks, was somewhat lower than the 2005 and 2006 numbers, but still within the range of previous years' estimates (Figure 5). The most recent reversal in species composition suggests that the apparent proliferation of sticklebacks in 2005 and 2006 can be attributed to a phenotypic response or character release induced by greatly reduced numbers of sockeye competitors (Nosil and Reimchen 2005). In other words, larger spawning populations in 2006 and 2007 produced more sockeye fry, and these, having a competitive advantage over sticklebacks, once again closed the niche previously available to limnetic feeding sticklebacks.

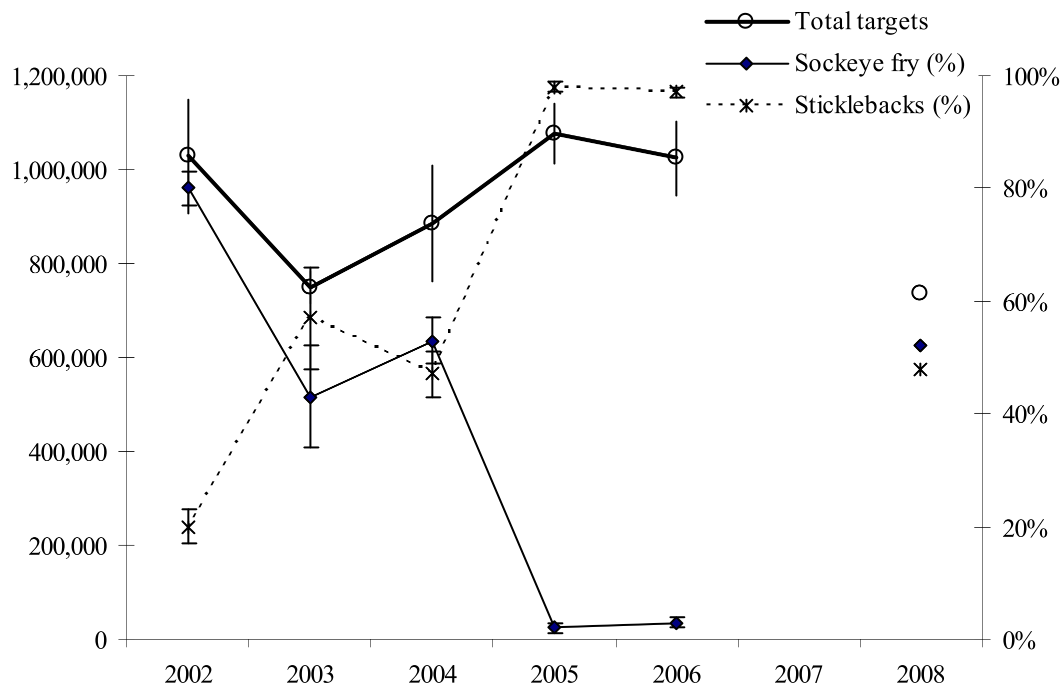

Figure 5.–Small fish population estimates from hydracoustic surveys of Hetta Lake, 2002–2008, and estimated species proportions of sockeye fry and sticklebacks. Standard error bars are shown.

Zooplankton populations in Hetta Lake have appeared to be very low throughout the 2001–2008 study period compared with other sockeye-producing lakes in Southeast Alaska (Appendix D in Cartwright et al. 2005). In the most recent 3 years, Hetta Lake zooplankton populations have dropped to only one-fourth (density) or one-fifth (biomass) of their highest observed levels (Figure 6). Observed species diversity, already low, has also declined during the study period. Whether zooplankton populations are kept at a low equilibrium by planktivore populations in Hetta Lake, or have been over-grazed in the last several years, or are affected by other factors in the environment is unknown. A direct relationship between the planktivore and zooplankton populations is not obvious from the 2001–2008 data, yet the much larger sockeye spawning populations in 2006 and 2007 should have resulted in more fry and thus more grazing the following summers. The effectiveness of grazing by large stickleback populations in 2005 and 2006 on zooplankton abundance and species composition is unknown but could have played a role in the decline. Another possibility is that replenishment of nutrients in the lake from the carcasses of salmon spawners was reduced when escapements were low in 2001–2005 and possibly many years prior to that. Evidently, Hetta Lake once produced much larger runs of sockeye salmon than those observed during the past half-century. The lake may have shifted to a less productive state, at least with respect to sockeye rearing capacity, after many years of low escapements.

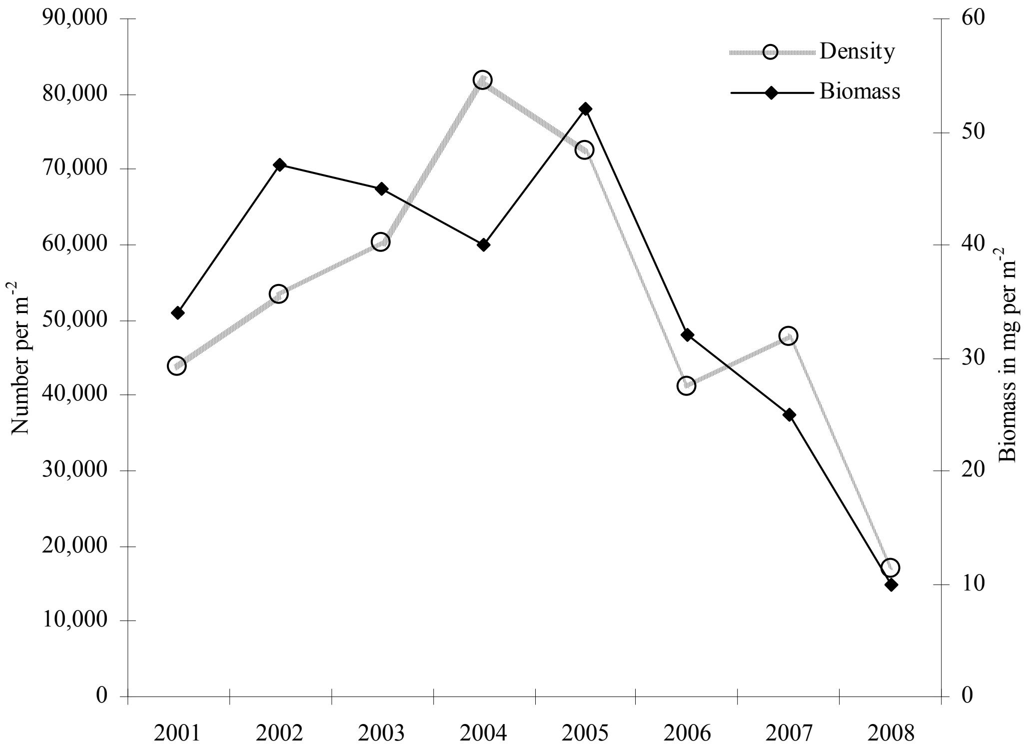

Figure 6.–Zooplankton population numerical and biomass densities in Hetta Lake, 2001–2008.

Nothing in the results from 2001 through 2008 suggests that recent subsistence harvest levels have adversely affected recent sockeye returns to Hetta Lake. However, since the run size has been very small in some years, careful monitoring and management continue to be necessary to protect the Hetta Lake sockeye stock. Additionally, further investigations into the dynamics of both freshwater and ocean sockeye populations may improve the understanding of this biologically and culturally important stock, so that its ecological and resource potential can hopefully once again be maximized.

ACKNOWLEDGMENTS

The Hydaburg Cooperative Association (HCA), under the leadership of natural resources director Anthony Christianson, was the principal cooperator on this project. HCA was responsible for the field project operation, including installation, maintenance, and removal in the fall of the Hetta weir. We thank the HCA crew members, Lee Charles, Jeff Peele, Troy Adams, and Tim Peele, and also HCA elder and retired biologist Robert Sanderson who supervised and conducted the subsistence harvest survey. Sue Domenowske served as the ADF&G field biologist overseeing data collection. ADF&G biologist Andy Piston organized and led the hydroacoustic and trawl surveys. Other ADF&G staff assisting with the project includes Iris Frank and Mark Olsen (who aged sockeye scale samples and compiled the age, sex, and length data) Steve Thomsen (who analyzed the zooplankton samples), ADF&G salmon research supervisor Doug Eggers, and publications staff Renate Riffe and Jim Craig.

REFERENCES CITED

Arnason, A. N., C. W. Kirby, C. J. Schwarz, and J. R. Irvine. 1996. Computer analysis of data from stratified mark-recovery experiments for estimators of salmon escapements and other populations. Fisheries and Oceans Canada. Canadian Technical Report of Fisheries and Aquatic Sciences No. 2106, Nanaimo, B.C., Canada.

Beauchamp, D. A. and N. C. Overman. 2003. Influence of fertilization on juvenile sockeye salmon growth and production in Redoubt Lake, Alaska. Washington Cooperative Fish and Wildlife Research Unit Report No. WACFWRU-03-03, Seattle.

Betts, M. F., M. Kookesh, R. F. Schroeder, T. F. Thornton, and A. M. Victor. *Unpublished report*. Subsistence resource use patterns in Southeast Alaska: summaries of 30 communities. Alaska Department of Fish and Game, Division of Subistence, Juneau.

Blikshteyn, M. A., and J. M. Conitz. 2009. Hetta Lake subsistence sockeye salmon project: 2007 annual report. Alaska Department of Fish and Game, Fishery Data Series No. 09-34, Anchorage.

Cartwright, M. A., J. M. Conitz, R. W. Bale, K. S. Reppert, and B. A. Lewis. 2005. Hetta Lake sockeye salmon (*Oncorhynchus nerka*) stock assessment project 2003 annual report and 2001–2003 final report. Alaska Department of Fish and Game. Fishery Data Series No. 05-33, Anchorage.

Conitz, J. M. 2008. Hetta Lake subsistence sockeye salmon project: 2006 Annual Report and 2004–2006 Final Report. Alaska Department of Fish and Game, Fishery Data Series No.08-52, Anchorage.

Conitz, J. M., J. P. Stahl, R. W. Bale, and M. A. Cartwright. 2007. Hetta and Eek lakes subsistence sockeye salmon project: 2004 annual report. Alaska Department of Fish and Game, Fishery Data Series No. 07-19, Anchorage.

Clutter, R., and L. Whitesel. 1956. Collection and interpretation of sockeye salmon scales. Bulletin of the International Pacific Salmon Fisheries Commission 9, New Westminister, B.C., Canada.

Day, T., and J. D. McPhail. 1996. The effect of behavioural and morphological plasticity on foraging efficiency in the threespine stickleback (*Gasterosteus* sp.). Oecologia 108:380–388.

Host, S. A., J. M. Conitz, and M. A. Cartwright. 2008. Hetta Lake subsistence sockeye salmon project: 2005 annual report. Alaska Department of Fish and Game, Fishery Data Series No. 08-09, Anchorage.

Hyatt, K. D., D. J. McQueen, K. S. Shortreed, and D. P. Rankin. 2004. Sockeye salmon (*Oncorhynchus nerka*) nursery lake fertilization: review and summary of results. Environmental Review 12:133–162.

INPFC (International North Pacific Fisheries Commission). 1963. Annual Report 1961. Vancouver, British Columbia, Canada.

Kirk, J. T. O. 1994. Light and photosynthesis in aquatic ecosystems. Cambridge University Press, England.

Koenings, J. P., G. B. Kyle, J. A. Edmundson, and J. E. Edmundson. 1987. Limnology field and laboratory manual: methods for assessing aquatic production. Alaska Department of Fish and Game, Division of Fisheries Rehabilitation, Enhancement, and Development, Report No. 71, Juneau.

Koo, T. S. Y. 1962. Age designation in Salmon. Pages 37–48 [*in*] Studies of Alaska red salmon. University of Washington Publications in Fisheries, New Series Volume 1, Seattle, W.A.

Langdon, S. J. 1977. Technology, ecology, and economy: fishing systems in Southeast Alaska. Doctoral dissertation, Stanford University.

Lewis, B. A., and M. A. Cartwright. 2004. Hetta Lake sockeye salmon (*Oncorhynchus nerka*) stock assessment project 2002 annual report. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 1J04-10, Juneau.

MacLennan, D. N., and E. J. Simmonds. 1992. Fisheries Acoustics. Van Nostrand-Reinhold, New York, NY.

McEwen, M., B. A. Lewis, and M. A. Cartwright. 2002. Hetta Lake sockeye salmon stock assessment project 2001 annual report. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J02-26, Juneau.

REFERENCES CITED (Continued)

Moser, J. F. 1899. The salmon and salmon fisheries of Alaska. Bulletin of the United States Fish Commission. U.S. Government Printing Office, Washington, D.C.

Nosil, P., and T. E. Reimchen. 2005. Ecological opportunity and levels of morphological variance within freshwater stickleback populations. Biological Journal of the Linnean Society 86:297–308.

O'Neill, S. M., and K. D. Hyatt. 1987. An experimental study of competition for food between sockeye salmon (*Oncorhynchus nerka*) and threespine sticklebacks (*Gasterosteus aculeatus*) in a British Columbia coastal lake. Pages 143–160 [*in*] H. D. Smith, L. Margolis, and C. C. Wood, *editors*. Sockeye salmon (*Oncorhynchus nerka*) population biology and future management. Canadian Special Publication of Fisheries and Aquatic Sciences No. 96.

Pollock, K. H, J. D. Nichols, C. Brownie, and J. E. James. 1990. Statistical inference for capture-recapture experiments. Wildlife Society Monographs 107.

Schindler, D. W. 1971. Light, temperature, and oxygen regimes of selected lakes in the experimental lakes area, northwestern Ontario. Journal of the Fisheries Research Board of Canada 28: 157–169.

Schluter, D. 1993. Adaptive radiation in sticklebacks: size, shape, and habitat use efficiency. Ecology 74:699–709.

Seber, G. A. F. 1982. The estimation of animal abundance, *2nd edition*. Griffin, London.

Thompson, S. K. 1992. Sampling. Wiley-Interscience, New York.

APPENDIX

Appendix A.–Daily and cumulative counts of sockeye salmon, daily counts of other salmon species, and water depth and temperature at the Hetta Creek weir in 2008.

Date	Sockeye salmon		Daily counts, other salmon			Water depth (m)	Water temperature (oC)
	Daily	Cumulative	Coho	Chum	Pink		
05/30	0	0	0	0	0	0.61	
05/31	0	0	0	0	0		
06/01	8	8	0	0	0	0.55	12.0
06/02	0	8	0	0	0	0.55	12.0
06/03	0	8	0	0	0	0.59	11.0
06/04	1	9	0	0	0	0.58	10.0
06/05	5	14	0	0	0	0.55	10.0
06/06	5	19	0	0	0	0.55	8.0
06/07	1	20	0	0	0	0.55	11.0
06/08	1	21	0	0	0	0.55	11.0
06/09	6	27	0	0	0	0.54	11.0
06/10	14	41	0	0	0	0.54	11.0
06/11	13	54	0	0	0	0.54	11.0
06/12	4	58	0	0	0	0.52	10.0
06/13	0	58	0	0	0	0.54	10.0
06/14	0	58	0	0	0	0.54	10.0
06/15	0	58	0	0	0	0.54	10.0
06/16	0	58	0	0	0	0.53	10.0
06/17	1	59	0	0	0	0.51	10.0
06/18	0	59	0	0	0	0.51	11.0
06/19	13	72	0	0	0	0.50	12.0
06/20	19	91	0	0	0	0.49	13.0
06/21	11	102	0	0	0	0.49	11.0
06/22	5	107	0	0	0	0.50	12.0
06/23	4	111	0	0	0	0.50	12.0
06/24	2	113	0	0	0	0.51	12.0
06/25	2	115	0	0	0	0.59	11.0
06/26	16	131	0	0	0	0.59	11.0
06/27	13	144	0	0	0	0.59	11.0
06/28	14	158	0	0	0	0.58	11.0
06/29	15	173	0	0	0	0.58	10.0
06/30	31	204	0	0	0	0.62	10.0

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Appendix A.–Page 2 of 3.

Date	Sockeye salmon		Daily counts, other salmon			Water depth (m)	Water temperature (oC)
	Daily	Cumulative	Coho	Chum	Pink		
07/01	19	223	0	0	0	0.61	14.0
07/02	33	256	0	0	0	0.60	13.0
07/03	13	269	0	0	0	0.59	14.0
07/04	14	283	0	0	0	0.59	14.0
07/05	15	298	0	0	0	0.58	15.0
07/06	7	305	0	0	0	0.58	14.0
07/07	2	307	0	0	0	0.58	14.0
07/08	2	309	0	0	0	0.55	14.0
07/09	2	311	0	0	0	0.55	14.0
07/10	6	317	0	0	0	0.55	13.0
07/11	12	329	0	0	0	0.54	13.0
07/12	26	355	0	0	0	0.56	13.0
07/13	13	368	0	0	0	0.55	13.0
07/14	33	401	0	0	0	0.50	14.0
07/15	12	413	0	0	0	0.50	15.0
07/16	8	421	0	0	0	0.49	14.0
07/17	12	433	0	0	0	0.48	15.0
07/18	6	439	0	0	0	0.47	12.0
07/19	3	442	0	0	0	0.52	14.0
07/20	0	442	0	0	0	0.54	13.0
07/21	5	447	0	0	0	0.54	13.0
07/22	4	451	0	0	0	0.54	13.0
07/23	23	474	0	0	0	0.53	14.0
07/24	19	493	0	0	0	0.51	14.0
07/25	29	522	0	0	0	0.50	14.0
07/26	73	595	0	0	0	0.54	14.0
07/27	32	627	0	0	0	0.55	14.0
07/28	83	710	0	0	0	0.52	13.0
07/29	82	792	0	0	0	0.57	12.0
07/30	23	815	0	0	0	0.52	13.0
07/31	56	871	0	0	0	0.60	13.0
08/01	85	956	0	0	0	0.60	12.0
08/02	219	1,175	0	0	1	0.55	12.0
08/03	169	1,344	0	0	2	0.54	14.0
08/04	39	1,383	0	0	0	0.51	15.0
08/05	200	1,583	0	0	0	0.49	15.0
08/06	116	1,699	0	0	2	0.48	17.0
08/07	66	1,765	0	0	0	0.46	16.0
08/08	31	1,796	0	0	0	0.45	16.0
08/09	8	1,804	0	0	0	0.45	15.0
08/10	0	1,804	0	0	2	0.45	15.0

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Appendix A.–Page 3 of 3.

Date	Sockeye salmon		Daily counts, other salmon			Water depth (m)	Water temperature (oC)
	Daily	Cumulative	Coho	Chum	Pink		
08/11	14	1,818	0	0	1	0.44	16.0
08/12	260	2,078	6	1	38	0.43	16.0
08/13	404	2,482	13	1	182	0.49	16.0
08/14	252	2,734	1	0	345	0.61	16.0
08/15	76	2,810	0	0	56	0.55	16.0
08/16	92	2,902	4	0	46	0.57	16.0
08/17	126	3,028	5	0	57	0.54	15.0
08/18	80	3,108	6	0	82	0.54	15.0
08/19	92	3,200	12	0	45	0.57	14.0
08/20	50	3,250	6	2	128	0.57	15.0
08/21	55	3,305	21	3	76	0.49	15.0
08/22	123	3,428	45	4	126	0.48	15.0
08/23	157	3,585	27	7	409	0.50	15.0
08/24	290	3,875	32	14	1,463	0.57	13.0
08/25	59	3,934	36	12	1,511	0.55	14.0
08/26	268	4,202	48	15	2,296	0.59	13.0
08/27	290	4,492	34	10	1,984	0.61	13.0
08/28	91	4,583	48	7	1,324	0.60	13.0
08/29	50	4,633	27	7	901	0.58	13.0
08/30	50	4,683	56	5	779	0.58	13.0
08/31	23	4,706	48	2	550	0.58	13.0
09/01	14	4,720	26	8	519	0.55	13.0
09/02	40	4,760	102	14	1,260	0.52	12.0
09/03	2	4,762	37	12	818	0.52	13.0
09/04	19	4,781	160	21	984	0.49	12.0
09/05	15	4,796	218	17	839	0.48	14.0
09/06	11	4,807	92	10	633	0.46	14.0
09/07	5	4,812	148	16	648	0.45	14.0
09/08	6	4,818	106	12	994	0.46	14.0
09/09	4	4,822	74	21	1,439	0.43	13.0
09/10	1	4,823	82	33	892	0.43	12.0
09/11	3	4,826	88	19	1,163	0.37	12.0
09/12	6	4,832	133	37	1,510	0.42	13.0
09/13	11	4,843	68	7	929	0.40	14.0
09/14	3	4,846	214	5	1,083	0.40	14.0
09/15	8	4,854	34	7	1,008	0.40	14.0
09/16	7	4,861	33	4	940	0.40	14.0
09/17	6	4,867	63	22	1,099	0.40	14.0
09/18	6	4,873	44	13	514	0.39	14.0
09/19	3	4,876	41	16	512	0.43	14.0
09/20	2	4,878	77	10	480	—	—
09/21	2	4,880	26	9	305	0.43	14.0
09/22	1	4,881	13	11	218	0.30	14.0
09/23	1	4,882	25	2	110	0.40	14.0
09/24	1	4,883	13	3	47	0.40	14.0