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Hetta Lake Subsistence Sockeye Salmon Project: 2006 Annual Report and 2004–2006 Final Report

by

Jan M. Conitz

October 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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ADF&G Fishery Data Series was established in 1987 for the publication of Division of Sport Fish technically oriented results for a single project or group of closely related projects, and in 2004 became a joint divisional series with the Division of Commercial Fisheries. Fishery Data Series reports are intended for fishery and other technical professionals and 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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ABSTRACT

The sockeye salmon (*Oncorhynchus nerka*) run returning to Hetta Lake is a primary subsistence resource for the community of Hydaburg. This sockeye salmon run likely yielded annual harvests of around 100,000 fish in early commercial fisheries in the late 1800s–early 1900s, but in more recent years has shown signs of depletion. A program to assess the status of this stock was started in 2001. Mark-recapture estimates of sockeye salmon spawning populations in the lake between 2001 and 2004 indicated escapements as low as 1,000–3,000 fish. A weir count and mark-recapture estimate in 2005 likewise indicated an escapement of only about 3,000 fish. Subsistence harvests were extremely low in 2002 and 2004, and in 2005, only 350 sockeye salmon were counted in the harvest census from Hetta Cove. However in 2006, we were encouraged to see a much larger sockeye salmon return, with 17,930 adult sockeye salmon counted through the Hetta Creek weir and 9,800 sockeye salmon harvested in the Hetta Cove subsistence fishery. These were both the largest estimated escapement and the largest subsistence harvest observed since the assessment program began in 2001. In contrast, sockeye fry populations, estimated using hydroacoustic and trawl surveys, appear to have dropped drastically in 2005 and 2006 from former levels. As in several previous years, over one million small fish targets were estimated in the hydroacoustic survey, but in 2005 and 2006, almost all the fish caught in trawl samples to estimate species composition were threespine sticklebacks (*Gasterosteus aculeatus*). Zooplankton biomass per unit surface area in 2006 was lower than the already low level estimated in 2005, with a seasonal mean of only 32 $mg \cdot m^{-2}$, of which *Daphnia*, a preferred prey for both sockeye fry and sticklebacks, comprised only 1%.

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

INTRODUCTION

Sockeye salmon returning to Hetta Lake and a handful of others along Hetta Inlet have provided Hydaburg residents with a primary food resource since the founding of the village in the early 1900s (Betts et al. *In press*). Prior to that, Haida people moving into the area from the Queen Charlotte Islands in the late 1700s located seasonal camps and villages near these productive sockeye salmon streams, displacing Tlingit inhabitants who had also situated their camps and villages near these sockeye salmon runs (Langdon 1977). These same sockeye salmon runs were also targeted by commercial fishing interests that occupied the area beginning in the 1890s, with canneries in Hetta Inlet reporting total sockeye salmon harvests of 140,000 to 250,000 sockeye salmon (Moser 1899). Signs of depletion in the Hetta Lake stock and others became evident early in the commercial fishing era, when harvest methods sometimes included complete barricades across the mouths of the spawning streams. To compensate, attempts were made to supplement the Hetta Lake stock with hatchery production, which not only failed but removed large numbers fish from the natural spawning population to be used as broodstock (Roppel 1982). By 1918, annual escapements into Hetta Lake had fallen to less than 10,000 sockeye salmon (Roppel 1982; Rich and Ball 1933). Commercial fisheries were moved away from the marine terminal areas of these sockeye salmon streams in the late 1920s (Rich and Ball 1933), but continued farther offshore with the use of fish traps and purse seiners (Langdon 1977). No further escapement assessments of the Hetta Lake sockeye salmon run were conducted until 1967–1971, when a weir was installed and counts of some 15,000 to 24,000 sockeye salmon were recorded. A single year's weir count in 1982 was much smaller than those earlier counts (Table 1). Unfortunately, the absence of supporting information about the weir or other aspects of the sockeye salmon runs from this period prevents a more meaningful interpretation of typical escapement levels, and whether the 1982 count represented a long-term decline.

Table 1.–Historical sockeye salmon escapement counts from a weir located on the outlet stream of Hetta Lake.

Year	Sockeye count
1967	24,164
1968	17,599
1969	16,202
1970	20,542
1971	15,779
-	-
1982	5,387

In recent years, personnel from Alaska Department of Fish and Game (ADF&G) and the Hydaburg Cooperative Association (HCA) have cooperated on a sockeye salmon stock assessment program at Hetta Lake since 2001. In 2001–2004, mark-recapture studies were used in attempts to estimate the sockeye salmon spawning population in Hetta Lake. The resulting estimates ranged from a few hundred to about 3,000 fish (Conitz et al. 2007; Cartwright et al. 2005; Lewis and Cartwright 2004; McEwen et al. 2002), but most likely underestimated the true spawning population. One suspected deficit in these estimates was very late season spawners, for which we have anecdotal evidence (R. Sanderson, Hydaburg biologist and elder, personal communication 2002–2008), but no samples or surveys representing fish present after the end of October. Starting in 2005, a weir was used to obtain an annual escapement count, verified with a mark-recapture experiment (Host et al. 2008). In 2005, with the weir in place, we estimated an escapement of 3,300 fish, not much higher than the mark-recapture estimates of the previous four years.

Juvenile sockeye salmon population estimates in the lake have not reflected the observed pattern of adult escapements. Hydroacoustic estimates in Hetta Lake consistently indicated total populations of small fish of around one million annually in 2002–2005, and at the beginning of this period, trawl samples indicated that most of these targets were sockeye fry. These apparently large sockeye fry populations contrasted with the very small escapement estimates, and seemed to confirm suspicions that we had underestimated brood year spawning populations. However, the proportion of sockeye fry in the trawl samples dropped precipitously in 2005, when 98% of the fish sampled were sticklebacks (Host et al. 2008). Whether this apparent shift accurately reflects juvenile sockeye salmon population status, or resulted from bias inherent in trawl sampling methods is unknown. Zooplankton density and biomass estimates have been lower in Hetta Lake than in other sockeye salmon producing lakes in Southeast Alaska, indicating sockeye fry production may be limited by food availability (Cartwright et al. 2005).

The subsistence sockeye salmon fishery is a very important part of the cultural and economic life of the community of Hydaburg (Betts et al. *in press*). Residents fish at several sockeye salmon streams in the area of Hetta Inlet and Cordova Bay (Figure 1). Hetta Lake is generally the largest producer of sockeye salmon, and often supplies the largest share of the total subsistence sockeye salmon harvest by Hydaburg residents. However, in years when the sockeye salmon run to Hetta Lake is small, harvest from other streams becomes more important (Table 2; Conitz et al. 2007). Eek Lake stream is a favored fishing area because of its proximity to the community, and some people fish at other more distant streams such as those at Kasook and Hunter Bay. The community's total sockeye salmon harvest from all areas has been the highest in years when the

Hetta Lake run provided the largest share of the harvest (Table 2). These harvest figures indicate the community needs well over 3,000 sockeye salmon annually for subsistence, and that the Hetta Lake run was unable to supply this many fish in three out of five recent years.

Table 2.–Total subsistence harvest of sockeye salmon at Hetta Lake marine terminal area and other streams near the Hydaburg community, as determined by a direct census and interviews of participants after they completed fishing. The number of interviews is shown in parentheses. Each interview represents one fishing trip; some participants may have fished more than once, and at more than one location.

	Total sockeye harvest (and number of participants), Hydaburg area		
Year	**Hetta**	**Other streams**	**Total**
2001	4,416 (41)	NA	NA
2002	950 (28)	2,759 (53)	3,709
2003	5,770 (64)	1,930 (38)	7,700
2004	630 (20)	2,435 (29)	3,030
2005	350 (14)	468 (15)	818

The level of commercial harvest on the Hetta Lake sockeye salmon stock is unknown. Large numbers of sockeye salmon are harvested in commercial seine fisheries in Districts 103 and 104 on the outer coast of Prince of Wales Island and the islands off its outer coast. These are highly mixed-stock fisheries with many contributing stocks including those from large mainland rivers, and Hetta Lake sockeye salmon would be expected to comprise only a small fraction of the total harvest. Nevertheless, we cannot rule out the possibility of substantial commercial harvest in some years. Preliminary studies indicate that Hetta Lake sockeye salmon can be identified in mixture of stocks using rapidly advancing genetic stock identification technology (G. Oliver, ADF&G Div. of Commercial Fisheries, personal communication 2008). However, a comprehensive sampling program that would be needed to quantify this stock throughout all fisheries in the region does not yet exist.

Primary objectives for the Hetta Lake study in 2006, as in previous years, were to obtain a reliable and complete estimate of sockeye salmon escapement into the lake, and a complete subsistence sockeye salmon harvest census from all fishers in the Hydaburg community. The 2006 season was the second season of weir operation, again using a mark-recapture estimate to verify the weir count. We also collected auxiliary information as in the previous five years, including estimates of sockeye salmon age, sex, and length composition in the escapement. Zooplankton was sampled approximately every six weeks from May through October to estimate species composition, density, and biomass. A hydroacoustic and trawl survey was conducted in the fall, with particular attention given to the apparent decline in sockeye fry numbers relative to threespine sticklebacks.

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 (Figure 1). This dimictic oligotrophic lake has organically stained water, and a surface area of 207 ha, an elevation of 9.4 m, a mean depth of 48.0 m, and a maximum depth of 92.0 m (Figure 2). The volume of the lake is 99.4 million m^3, and the residence time is about 12.6 months. The Hetta Lake watershed is composed of 24 km^2

of steep spruce, cedar, and hemlock forest, much of which was logged in the 1950s. The main sockeye salmon spawning areas in Hetta Lake are Hetta Creek and the beach in front of Old Hatchery Creek. Sockeye salmon also spawn in small aggregations in other areas along the lake shoreline. The outlet stream, Outlet Creek, empties into Hetta Cove approximately 600 m from the lake. In addition to sockeye salmon, native fish species 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, and cottids (*Cottus* sp.).

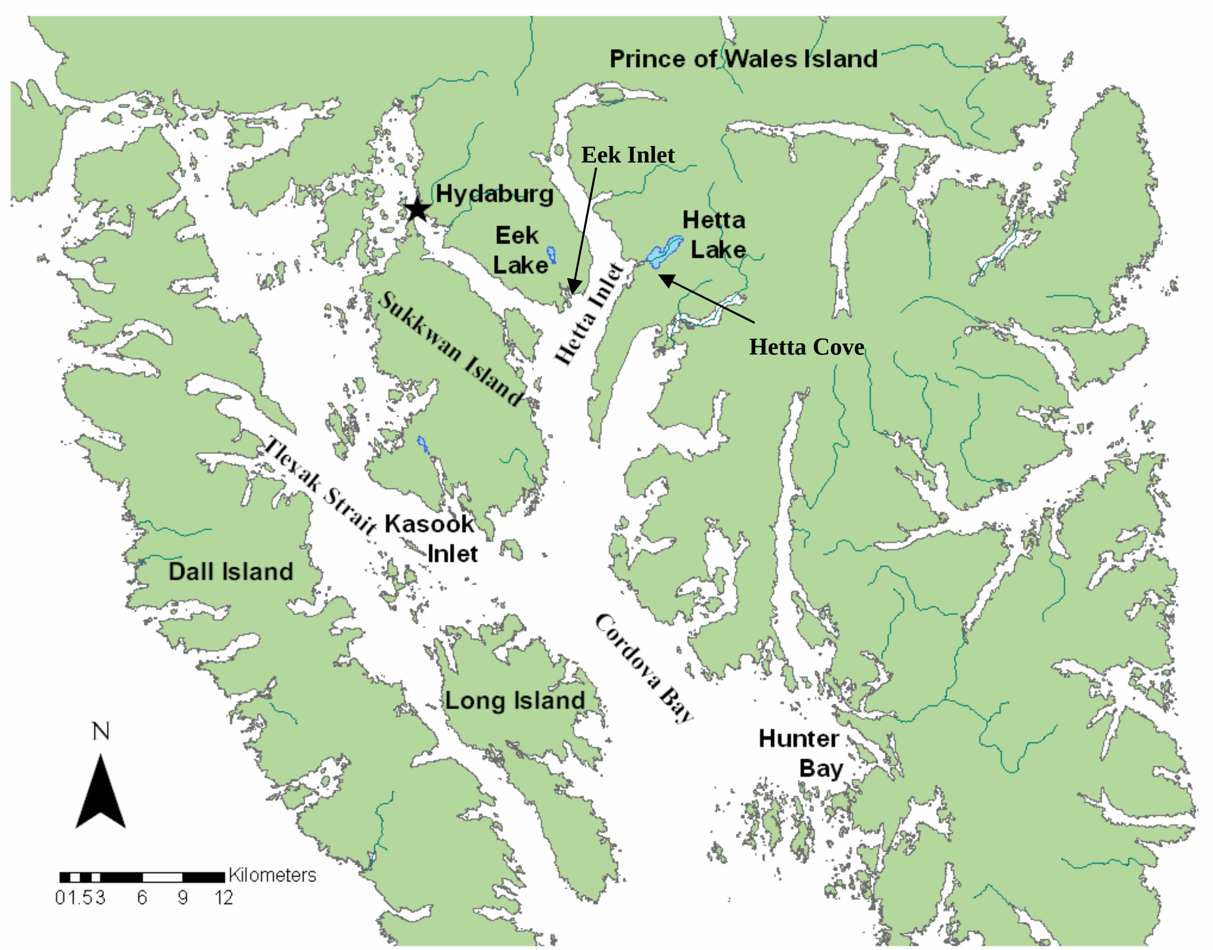

Figure 1.–The geographic location of Hetta Lake and subsistence fishing areas of Hetta Cove, Eek Inlet, Hunter Bay, and Kasook Inlet are shown in relationship to Hydaburg on southeast Prince of Wales Island.

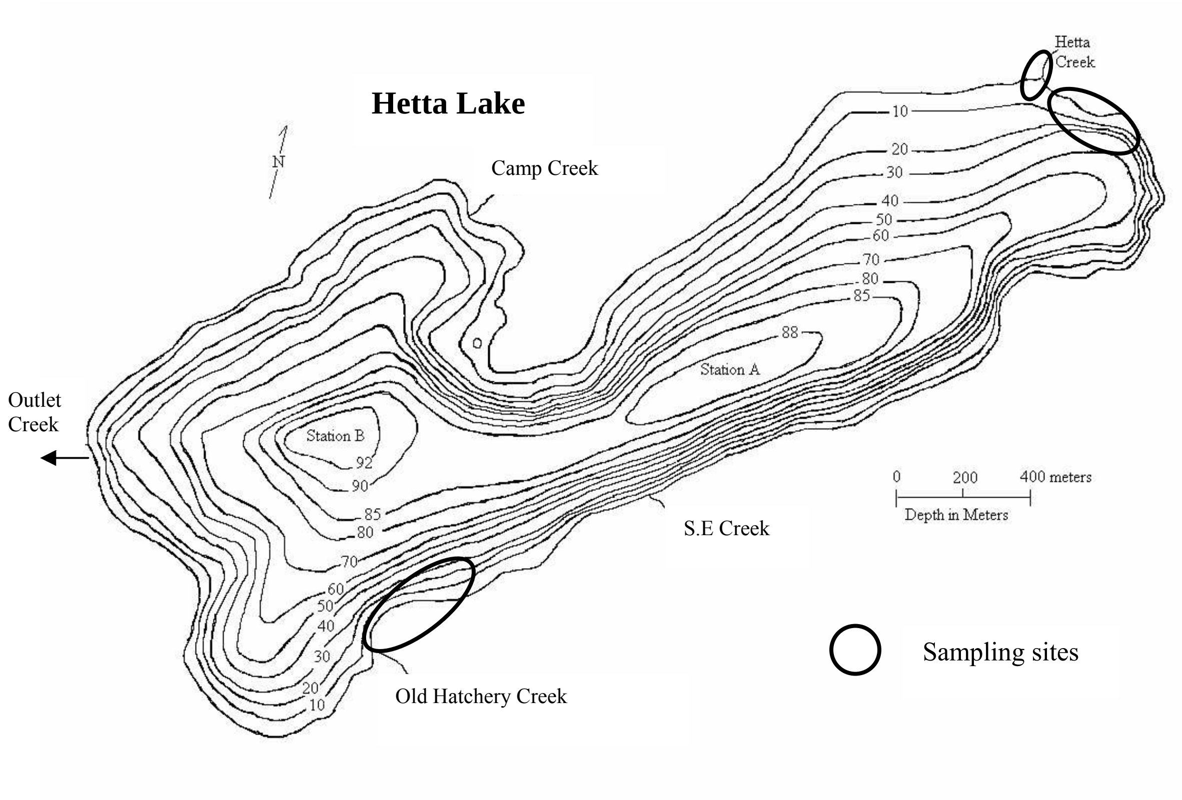

Figure 2.–Hetta Lake bathymetric map with locations of inlet and outlet streams, mark-recapture sampling sites, and limnological sampling stations (A and B).

OBJECTIVES

1. Count the number of sockeye salmon and other salmonid species entering Hetta Lake through a weir, and mark 30% of the sockeye salmon passing through the weir.
2. Estimate sockeye salmon escapement in Hetta Lake with a mark-recapture study on the spawning grounds, so that the coefficient of variation is less than 15%.
3. Estimate the age composition of the sockeye salmon escapement, so that the coefficient of variation is 10% or less for the two major age classes, and describe the size composition by age and sex.
4. Measure the subsistence harvest of sockeye salmon by Hydaburg residents at Hetta Cove and nearby streams using completed trip interviews with all participants on the fishing grounds or at the Hydaburg harbor (complete harvest census).
5. Estimate the number of sockeye fry in Hetta Lake using hydroacoustic and trawl survey methods, so that the sockeye fry population estimate has a coefficient of variation less than 15%.
6. Collect baseline data on sockeye fry habitat in Hetta Lake using established ADF&G limnological sampling procedures.

METHODS

SOCKEYE ESCAPEMENT ESTIMATE

Weir Count

The crew counted salmon daily, by species, through an aluminum bipod and picket weir on the outlet stream of Hetta Lake. The weir was 17 m wide with pickets spaced 4.48 cm apart on center. Fish passed through an opening in the weir into a 2.5 m x 1.25 m rectangular trap box constructed of aluminum channel and pickets. A field crew from the Hydaburg Cooperative Association operated the weir from 7 June to 21 September, 2006. All fish captured at the weir were enumerated by species and released above the weir. A portion of the sockeye salmon was sampled for age (using scale samples), sex, length, and marked with fin clips for the mark-recapture study.

Mark-Recapture Estimate

To test the integrity of the weir and provide an auxiliary estimate of sockeye salmon escapement into Hetta Lake, I estimated escapement using a closed, stratified, two-sample mark-recapture model (Arnason et al. 1996). The first sample, or marking phase of the study, consisted of fish marked at the weir. A constant marking rate of 30% of sockeye salmon passed through the weir, throughout the season, was set, and the primary mark was an adipose fin clip. The season was divided into three temporal strata, designated by secondary marks as follows: dorsal fin clip, 8 June–26 July; upper caudal fin clip, 27 July–23 August; and lower caudal fin clip, 24 August–20 September.

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 four sampling events: 30–31 August, 8–9 and 19–20 September, and 3–5 October. The crew sampled fish with a beach seine around the mouth of Hetta Creek and in other beach spawning areas around the lake and with dipnets in the channel of Hetta Creek. The crew sampled as many fish as possible on each sampling day or until the number of fish previously caught that day exceeded the number of new fish. All captured fish were examined for marks and then marked with an opercular punch to prevent duplicate sampling in future trips, to ensure sampling without replacement.

Visual Surveys

Crew members visually counted spawning sockeye salmon in all parts of the lake including Hetta Creek from 30 August to 26 October. Surveys of the lake perimeter were conducted by boat, and Hetta Creek was surveyed on foot, from the creek mouth to the barrier falls about 1 km upstream. The counts were completed before each mark-recapture sampling event.

Data Analysis

The two-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 the two-sample Petersen method over two or more sampling 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 their spawning streams (Arnason et al. 1996). Spawning migrations may last for a month or more, during which time there can be substantial variation in biological parameters such as 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). Briefly stated, the three assumptions of equal capture probability required by the Petersen model 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).

To test for consistency of capture probabilities in the marking and recapture strata, two chi-square tests are commonly used. 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 provided in the Stratified Population Analysis System (SPAS) software and labeled "equal proportions" and "complete mixing," respectively (Arnason et al. 1996; for details, refer to http://www.cs.umanitoba.ca/~popan/). I considered a test statistic with p-value ≤ 0.05 to be "significant." If neither test statistic, or only one test statistic, was significant, I concluded all marking and all recapture strata could be pooled without significant risk of bias and the simple Petersen ("pooled Petersen") estimator could be used. If both test statistics were significant, I concluded the pooled estimator had a significant risk of bias, and used the stratified Darroch estimator if it could be found. If the SPAS program was unable to converge to a solution for the Darroch estimator, I followed the guidelines and suggestions in Arnason et al. (1996) to search for a partial pooling scheme that would lead to a valid estimate. I also examined the data for any obvious deficiencies or discrepancies in sample sizes and recapture numbers, and considered events during the season, such as flooding or missed sampling dates, that may have led to inconsistencies.

If a valid estimate was found, 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, I 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 estimate was not found, the weir count was accepted as the best estimate, of at least minimum escapement.

Sockeye Escapement Age and Length Composition

The field crew sampled 605 sockeye salmon for scales, length, and sex at the Hetta Lake weir and on the spawning grounds to estimate the age, sex, and length composition of the spawning population. 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 two years in freshwater after hatching and three years in saltwater, and was six 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).

SUBSISTENCE HARVEST ESTIMATE

Subsistence fishers from Hydaburg were interviewed on the fishing grounds or in the harbor to determine fishing area, date, time, duration of fishing, gear, and total harvest by species, for each boat or group of participants. All participants were interviewed after they completed fishing for the day. I compiled data by area fished for Hetta Cove, Eek Inlet, Hunter Bay, and Kasook Inlet, and examined the harvest and effort by gear type. This survey was considered a census, because a technician interviewed every party that fished at each of these fishing grounds. Consequently, the total harvest in each area was simply the sum of individual harvests, with no variance.

SOCKEYE FRY 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 2006. To control year-to-year variation in our estimates, the acoustic survey in 2006 was conducted along the same fourteen transects that were randomly chosen in 2002 (two random transects from each of seven sampling sections of the lake) as permanent transects for this lake (Lewis and Cartwright 2004).

Hydroacoustic survey

During the acquisition of acoustic targets, each selected transect was surveyed from shore to shore, beginning and ending the sampling at the depth of 10 m. Sampling was conducted during the darkest part of the night. A constant boat speed of about 2.0 m sec^{-1} was attempted for all transects. The acoustic equipment used on the survey was the Biosonics DT-4000™ scientific echosounder (420 kHz, 6° single beam transducer); version 4.0.2 of the Biosonics Visual Acquisition© software was used to collect and record the data. The ping rate was set at 5 pings · sec^{-1} and the pulse width at 0.4 ms. Only target strengths ranging from –40 dB to –68 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 in conjunction with hydroacoustic surveys to determine species composition of pelagic fish and age distribution of sockeye fry. A 2 m x 2 m elongated beam-trawl net with a cod-end was used for trawl sampling. Trawl sampling was conducted in the area and depth of the lake with highest concentration of fish, identified during the hydroacoustic survey. Within this area, replicate tows were conducted at each depth. The second tow, at a given depth, was started at the termination point of the first tow. Direction of the second tow was selected so a different area from the first tow would be sampled. Trawl duration was 5–

20 minutes, starting in areas of highest target densities. If warranted, a second complete set of tows was conducted in a morphologically distinct section of the lake or in a second area of high fish density.

All adult fish caught in the midwater trawl were identified, counted, and released. All small fish from the trawl net were euthanized with MS 222. Fish were preserved with 90% alcohol. Samples from each tow were preserved in separate bottles. The bottle was labeled with the date, lake name, tow number, tow depth, time of tow, and initials of collectors.

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. Scales were collected from sockeye fry over 50 mm and mounted onto a microscope slide for age determination. Sockeye fry scales were examined through a Carton microscope with a video monitor and aged using methods outlined in Mosher (1968). Two trained technicians independently aged each sample. Results of each independent scale ageing were compared. In instances of discrepancy between the two age determinations, a third independent examination was conducted.

The proportion of each species caught in the trawls was used to allocate hydroacoustic targets estimates by species; the estimate of sockeye fry was further allocated according to proportion of sockeye fry in each age class. The process of capturing juvenile fish with a trawl was modeled with a hierarchical Bayesian model, assuming a separate random rate for each category of sonar target, with each trawl pass. Rates of sockeye salmon acquisition for each specific trawl pass were assumed to follow a Beta sampling distribution with a common set of parameters for the whole lake.

Data Analysis

Biosonics Visual Analyzer © version 4.0.2 software was used to analyze the sonar record. The lake was divided into seven sampling sections, with two transects per section. Echo integration was used to generate an estimate of target density (targets·m^{-2}) for each sample transect (MacLennan and Simmonds 1992). Mean target density for each section was estimated from the two random transects. The sample variance of each section estimate was estimated, with one degree of freedom. The mean target density for the whole lake was estimated as the average of the target-density estimates for each section, weighted by surface area of each section. The estimate of total targets in the lake was estimated as the sum of target 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 estimate of total targets was partitioned into two categories, sockeye fry and other small fish, by means of the trawl sampling. Commonly, researchers assume that the proportion of sockeye fry in such a sample follows a binomial distribution, an assumption of convenience but not necessarily a realistic assessment of the sampling conditions. Previous experience with many sockeye salmon-producing lakes has shown that the number of sockeye fry in a trawl sample can be much more variable than the usual binomial sampling model predicts. Thus, in practice, the confidence intervals based on binomial sampling assumptions can be biased and far too short.

A Bayesian procedure was developed to measure uncertainty in the estimated proportion of sockeye fry. Let T denote the actual value of the total targets in the lake, and let $\hat{T}$ denote the estimate of T, derived from the echo integration analysis of the sonar record. Conditioned on total number of fish caught in the i^{th} trawl sample, the number of sockeye fry in each trawl was assumed to follow a binomial sampling distribution. For the i^{th} trawl pass, trawl sample size was denoted as n_i and the number of sockeye fry in this sample was denoted as y_i. Parameter p_i denoted the unknown underlying proportion of sockeye fry in the i^{th} trawl sample, and p_i is assumed to be a key parameter in the sampling distribution of y_i. Each trawl sample was assumed to have its own sampling distribution, possibly different from any other in the lake. Next, suppose that p_i is itself drawn from a beta probability distribution with mean $p_\mu = \dfrac{\alpha}{\alpha + \beta}$.

In other words, let y_i be distributed as a binominal random variable with parameters p_i and n_i, and let p_i follow a beta probability distribution with parameters α and β. Again, α and β are the same for each transect in the lake at the occasion of trawl sampling. The hyperparameters α and β can be estimated through all of the trawl hauls.

A uniform distribution between 0 and 10 was chosen for both α and β hyperparameters after experimenting with this distribution and truncated normal distributions. This prior distribution limits influence of prior distributions on posterior distributions and ensures that the data have adequate influence if sample size is large. For example, for sample sizes less than 10, the posterior distribution will be almost entirely controlled by prior distribution. However, for sample sizes approaching 100, the prior distribution will have little influence on mean of the posterior distribution for each individual p_i. Note that if posterior probability were allowed to build up on larger and larger values of α and β, the posterior means of the p_i's would become more alike and the posterior variance of p_μ would decline unrealistically. Therefore, limiting maximum values of both α and β to 10 seemed to provide a compromise between allowing posterior means of individual p_i's to be either alike or unalike, and still allow data (likelihood) to dominate posterior distribution.

Let S denote the number of targets assigned to sockeye fry. To compare and combine an estimate of S and T in the same context as the Bayesian estimate of p_μ, the posterior distribution of T was assumed to be approximately normally distributed. At least 5,000 random draws were then generated from a normal distribution with the same mean and variance as the sample mean and sample variance for T. Previously 5,000 observations of the posterior distribution of p_μ were generated. Denoting each random draw with subscript j, a random draw from the posterior distribution of S was calculated as $S_j = p_j T_j$. Finally, the mean of the 5,000 simulated values of S was calculated and 95% credible intervals, the Bayesian counterpart to a 95% confidence interval, were established using the 2.5 and 97.5 percentiles of simulated posterior distributions of S. All analyses were performed with Winbugs software.

LIMNOLOGY

Sampling and measurements were taken in Hetta Lake on 14 June, 2 and 15 August, 9 September, and 3 October. Physical data were collected only at Station B (Figure 2); zooplankton samples were collected at both stations and the results were averaged.

Light and Temperature Profiles

Underwater light intensity was recorded at 0.5 m intervals from just below the surface to the depth where measured intensity was one percent of the surface light reading, using an electronic light sensor and 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 that depth at which light (photosynthetically available radiation, 400–700nm) was attenuated to one percent of the intensity just below the lake surface (Schindler 1971), and was calculated using 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 and probe. 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 five-meter intervals to 50 m.

Secondary Production

Sockeye fry typically feed on zooplankton, with a strong preference for *Daphnia* spp. when available (Scheuerell et al. 2005; Eggers 1982). 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 two 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

SOCKEYE ESCAPEMENT ESTIMATE

Weir Count

A total of 17,930 sockeye salmon was counted through the Hetta weir between 7 June and 21 September, 2006. Other fish counted during this weir operation period were 11,501 pink, 3,143 coho, and 668 chum salmon (Appendix A). Major peaks in sockeye salmon migration followed an approximately weekly cycle from late July through the beginning of September, and on 1 September 1,548 sockeye salmon were counted through the weir in the single largest peak daily migration. Water levels at the weir site remained low and stable through the summer season, and rose only moderately at the end of August (Figure 3).

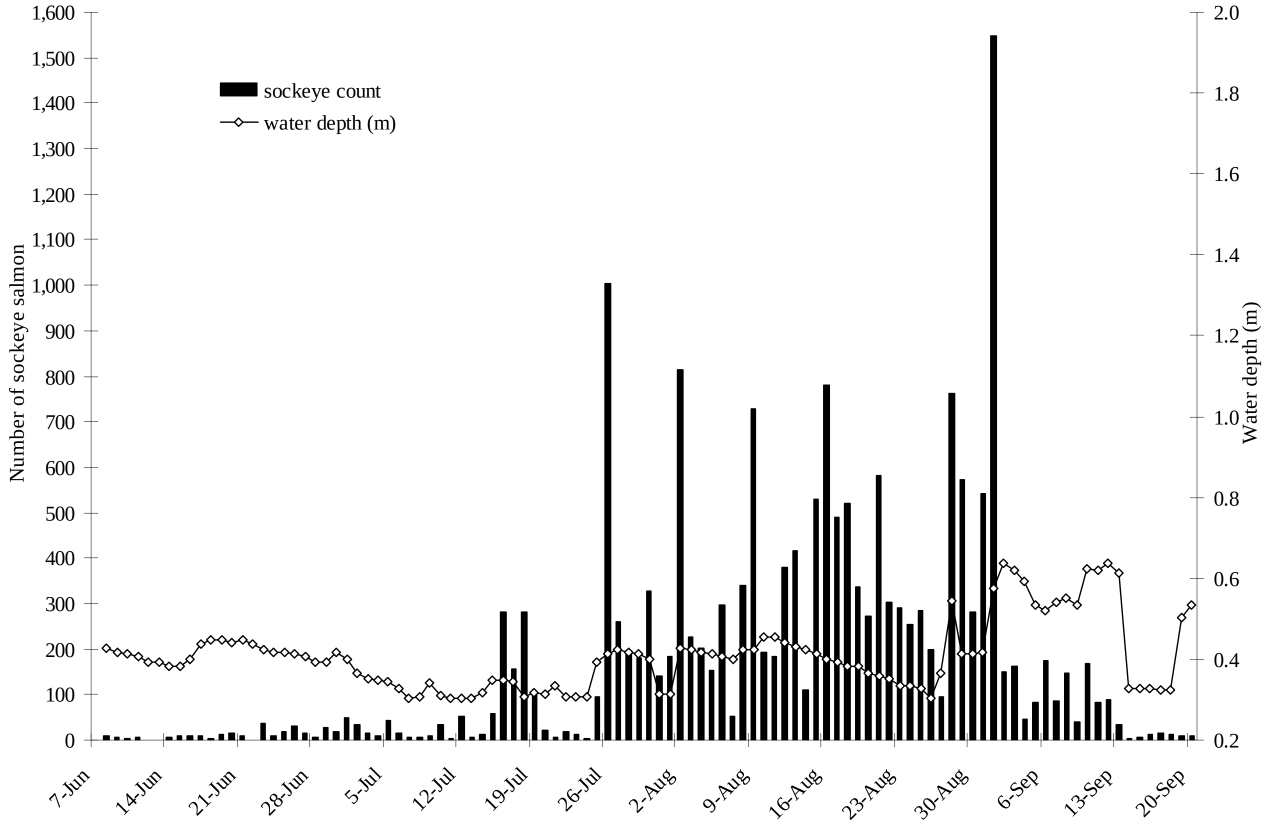

Figure 3.–Daily counts of sockeye salmon and water depth at the weir on Hetta Lake's outlet stream in 2006.

Mark-Recapture Estimate

The weir crew marked 5,693 sockeye salmon with fin clips during 2006 weir operations, representing an overall marking rate of 32% of the sockeye salmon passed through the weir (Table 3). About 30% of the marks from the first stratum were recovered, but less than 2% of the marks from the latter two strata were recovered. In the recapture samples overall, 45% of the fish sampled were found to have fin clips, which, compared with the 32% rate of marking at the weir, indicated that marked fish were over-represented in the samples. These inconsistencies in recapture rates provided evidence that capture probabilities among marking and recapture strata were unequal, and the two goodness-of-fit tests confirmed this ("equal proportions" $\chi^2 = 29$, 3 df, *p*-value<<0.01; "complete mixing" $\chi^2 = 1{,}093$, 2 df, *p*-value<<0.01). Therefore the pooled Petersen estimate was not considered. A Darroch estimate was found, using the SPAS program, and the weir count was included in the normal 95% confidence interval of 11,600–31,600 fish. Therefore the weir count (17,930 fish) was accepted.

Table 3.–Number of sockeye salmon marked at the weir in each marking stratum, and number of recoveries of marked fish, by recapture event and marking stratum, in Hetta Lake in 2006.

Stratum dates	Marking at weir		Marks recaptured on spawning grounds					Percent recaptured
	Count through weir	Number marked	30 Aug (stream)	8 Sep (stream)	19 Sep (stream)	3 Oct (beach)	Total recaps	
6/8–7/26	2,586	1,330	104	158	108	26	396	30%
7/27–8/23	9,474	2,590	2	7	20	20	49	2%
8/24–9/20	5,863	1,773	0	3	4	10	17	1%
Totals	17,923	5,693	106	168	132	56	462	20%
Total sampled in mark-recapture			201	319	310	187	1,021	
Percent marked fish in samples			58%	53%	43%	30%	45%	

Visual Surveys

Sockeye salmon spawners appeared in the inlet stream, Hetta Creek, during a well-defined period bracketed by the 30 August and 3 October surveys, with a maximum count in early September (Table 4). In contrast, large numbers of beach-spawning sockeye salmon appeared in the other areas of the lake, along the east, north, and south shores and around the mouth of Old Hatchery Creek, throughout October. Because essentially the same number of fish was counted on both 16 October and ten days later on 26 October, we cannot be certain that these counts in October represented a peak or maximum number of spawners. According to these visual counts, beach spawners dominated the 2006 escapement.

Table 4.–Number of sockeye spawners counted in visual surveys in 2006, by date and area. We assumed that fish counted in Hetta Creek were inlet stream spawners, and those counted in all other areas around the shoreline of Hetta Lake were beach spawners.

Date	Hetta Creek (stream spawners)	Other areas (beach spawners)	Total (all spawners)
30-Aug	27	0	27
8-Sep	293	76	369
20-Sep	220	n/a	220
3-Oct	39	1,164	1,203
16-Oct	0	1,304	1,304
26-Oct	0	1,298	1,298

SOCKEYE ESCAPEMENT AGE AND LENGTH COMPOSITION

Nearly all of the sockeye salmon that returned to Hetta Lake to spawn in 2006 were fish with one freshwater year, in age classes 1.2 and 1.3 (Table 5). Age-1.2 fish from the 2002 brood year made up the largest class. In the early weeks of the season, the age-1.3 class represented the largest percentage of each weekly sample, but starting with the week of 30 July, age-1.2 fish became the largest group in each weekly sample (Table 6). The average size difference between the two dominant age classes was over 50 mm, with age-1.2 fish averaging 492 mm in mid eye to fork length and age-1.3 fish averaging 549 mm (Table 7).

Table 5.–Age composition of sockeye salmon captured in the Hetta Lake weir by sex, brood year, and age class, sampled 8 June–21 September, 2006.

Brood year	**2002**	**2001**	**2000**	**1999**	
Age	**1.2**	**1.3**	**2.2**	**2.3**	**Total aged**
Male					
Sample size	164	146	14	0	324
Percent	27%	24%	2%	0%	54%
Standard error	1.8%	1.7%	0.6%	0.0	2.0
Female					
Sample size	156	115	8	1	280
Percent	26%	19%	1%	0%	46%
Standard error	1.8%	1.6%	0.5%	0.2%	2.0
All Fish					
Sample size	320	261	22	1	604
Percent	53%	43%	4%	0%	100%
Standard error	2.0%	2.0%	0.8%	0.2%	
Weighted percentages by age class, all fish					
	57%	39%	4%	0%	
Estimated number in escapement, by age class					
	10,132	6,933	799	6	

Table 6.–Sockeye age composition in the Hetta Lake escapement, by week, in 2006, based on number of fish sampled at the weir each week. The dotted line separates early weeks when the majority of fish sampled were age-1.3 and late weeks when the majority were age-1.2.

Week	**Percentage of sampled fish, by age class**				**Total**	**Total**
beginning	**1.2**	**1.3**	**2.2**	**2.3**	**sampled**	**passed**
4-Jun	50%	50%	0	0	2	17
11-Jun	-	-	-	-	0	36
18-Jun	10%	90%	0	0	29	87
25-Jun	41%	52%	4%	4%	27	166
2-Jul	50%	50%	0	0	8	128
9-Jul	21%	74%	5%	0	19	170
16-Jul	18%	82%	0	0	17	868
23-Jul	43%	54%	3%	0	112	1,744
30-Jul	63%	34%	3%	0	68	2,044
6-Aug	64%	31%	5%	0	59	2,174
13-Aug	65%	30%	5%	0	79	3,178
20-Aug	76%	21%	3%	0	58	2,186
27-Aug	49%	44%	7%	0	57	3,952
3-Sep	63%	34%	3%	0	35	739
10-Sep	60%	37%	3%	0	35	396
17-Sep	-	-	-	-	0	45

Table 7.–Mean fork length (mm) of sockeye salmon in Hetta Lake escapement by brood year, age class, and sex, sampled 8 June–21 September, 2006 at the Hetta Lake weir.

Brood year **Age**	**2002** **1.2**	**2001** **1.3**	**2001** **2.2**	**2000** **2.3**
Male				
Sample size	164	144	14	0
mean length	498	556	496	0
Standard error	1.6	2.1	4.2	0.0
Female				
Sample size	156	114	8	1
mean length	487	539	486	550
Standard error	1.6	2.0	5.7	0.0
All Fish				
Sample size	320	258	22	1
mean length	492	549	493	550
Standard error	1.2	1.5	3.4	0.0

SUBSISTENCE HARVEST ESTIMATE

Hydaburg residents fished primarily at Hetta Cove in 2006, with sockeye salmon far outnumbering other species harvested (Table 8). Interviews were conducted at the completion of 122 fishing trips, representing a total of 564 hours of fishing time, and participants harvested a total of 10,533 sockeye salmon from three fishing areas. Overall, 85% of the fishing trips and almost 91% of the fishing effort (hours fished) targeted Hetta Cove, and the harvest of 9,797 sockeye salmon from that location constituted 93% of the total subsistence harvest by Hydaburg residents. Most of the remaining effort and harvest targeted Eek Inlet, with only one participant reporting fishing in Hunter Bay.

Table 8.–Numbers of subsistence fishing interviews (completed trip) and summed responses for hours fished and salmon harvest by species. Interviews were conducted in the fishing areas or in Hydaburg, following fishing, and represent a complete census of all subsistence salmon fishing and effort in 2006.

Fishing location	**Number of interviews**	**Hours fished**	**Total harvest, by species**			
			Sockeye	**Coho**	**Chum**	**Pink**
Hetta Cove	104	512	9,797	0	2	31
Eek Inlet and Hunter Bay	18	52	736	20	0	0
All areas	122	564	10,533	20	2	31

Table 9.–Weekly fishing effort and harvest of sockeye salmon in the subsistence fishery at Hetta Cove in 2006. Data from two or more weeks at the beginning and end of the season were combined to protect confidentiality when two or fewer participants were interviewed per week.

				Weekly total sockeye harvest and rates		
Dates	**Gear**	**Interviews**	**Hours fished**	**Weekly total**	**Per hour**	**Per interview**
Hetta Cove						
27 Jun–8 Jul	Seine	9	39	786	20	87
9–15 Jul	Seine	14	65	1,524	24	109
16–22 Jul	Gillnet and Seine	22	127	1,865	15	85
23–29 Jul	Seine	10	41	507	13	51
30 Jul–5 Aug	Seine	28	156	3,261	21	116
6–12 Aug	Seine	14	61	1,355	22	97
13–31 Aug	Seine	7	24	499	21	71
Eek Inlet and Hunter Bay						
5–22 Jul	Gillnet and Seine	10	30	369	12	37
23–29 Jul	Gillnet and Seine	3	12	51	4	17
30 Jul–12 Aug	Seine	5	10	316	32	63

Subsistence fishing for sockeye salmon took place in Hetta Cove between 27 June and 31 August, and in Eek Inlet and Hunter Bay during a shorter period, between 5 July and 12 August (Table 9). Maximum harvest and rates of harvest per hour and per party interviewed occurred during mid July and early August, separated by a period of lower harvests in late July. Except during that week of 23–29 July, sockeye salmon harvests per fishing party interviewed averaged between 71 and 116 fish at Hetta Cove. In the other locations, the average harvests were smaller. Gillnets were used by only a small number of fishing parties; all others used seine gear.

SOCKEYE FRY ASSESSMENT

Hydroacoustic and mid-water trawl sampling were conducted on 15 September 2006. From the hydroacoustic survey data, we estimated a population of 1,024,000 (CV=7%) small fish targets. Apportionment of targets by species was based on species composition in a sample of 641 fish, collected during ten 10–15 minute tows. Only one percent of fish in the sample were sockeye fry, and the remainder were threespine sticklebacks (Table 10). All sockeye fry in the sample were age-0. Assuming that the actual proportion of sockeye fry in the Hetta Lake small fish assemblage was the same as that in the sample, we estimated the sockeye fry population in Hetta Lake was 25,500 age-0 fry in September 2006. The Bayesian posterior mean of the total number of targets was 1,020,000 fish, with a 97.5% credible interval of 880,000–1,160,000 fish. The Bayesian posterior mean of the proportion of targets that were sockeye salmon was 0.025, with a 97.5% credible interval of 0.015–0.038. From the product of the posterior means for $\hat{T}$ and $\hat{p}$, we estimated 25,000 sockeye fry, with a credible interval of 15,000–25,000 fry and a posterior standard deviation of 6,000 fry (CV=24%). Sockeye fry density was about 4 fry per 1,000 m^2 lake surface area, with a range of 2–7 fry per 1,000 m^2.

Table 10.–Summary of Hetta Lake trawl sampling results by tow, depth (m), time duration (min), and species in 2006.

Tow	**Depth (m)**	**Duration of tow (min)**	**Number of sockeye age-0**	**Number of stickleback**	**Percent age-0 sockeye fry**
1	12.5	15	0	9	0%
2	7.5	15	0	34	0%
3	2.5	15	1	98	1%
4	12.5	15	2	130	2%
5	7.5	10	1	51	2%
6	2.5	10	0	7	0%
7	12.5	10	3	32	9%
8	7.5	10	0	229	0%
9	2.5	10	0	30	0%
10	12.5	10	0	14	0%
		Totals	7	634	1%
		Total number of fish			641

The mean snout-fork length of the age-0 sockeye fry in the sample was 39 mm, with a range of 24–44 mm. The mean weight of age-0 fry was 0.6 g, with a range of 0.2–1.1g. The mean snout-fork length of the threespine sticklebacks in the sample was 38 mm with a range of 20–53 mm, and the mean weight of sticklebacks was 0.6 g, with a range of 0.1–1.4 g.

LIMNOLOGY

Light and Temperature Profiles

Light was only measured on two dates in 2006, 15 August and 9 September, and the estimated euphotic zone depths were 9.7 m and 13.0 m, respectively, averaging 11.4 m. Thermal stratification in the water column was evident by the date of the first measurement, 14 June, and had developed fully by the 2 August measurement date (Figure 4). The maximum measured lower depth of the thermocline was 11 m on 15 August, after which the stratification weakened.

Secondary Production

The cladoceran *Bosmina* sp. was the most abundant taxon in the Hetta Lake zooplankton assemblage in 2006, comprising over 70% (including ovigerous individuals) of total zooplankton by number (Table 11). *Bosmina* numbers fluctuated through the season, being highest on 3 October, but were the largest component of the zooplankton on all dates except 14 June, when *Cyclops* was dominant. After 14 June, *Cyclops* declined, increasing only slightly late in the season. Total zooplankton density declined from 14 June through 9 September, but increased to the maximum level for the season by 3 October, being largely determined by the levels of *Bosmina*. The zooplankton biomass was likewise dominated by *Bosmina*, even though the average length of individuals was very small (Table 12). Individual *Cyclops* and *Daphnia* were twice as large, on average, as *Bosmina*. *Cyclops* was the second largest component of biomass, contributing about 24%, but *Daphnia*, a preferred sockeye salmon prey, contributed only about 1%.

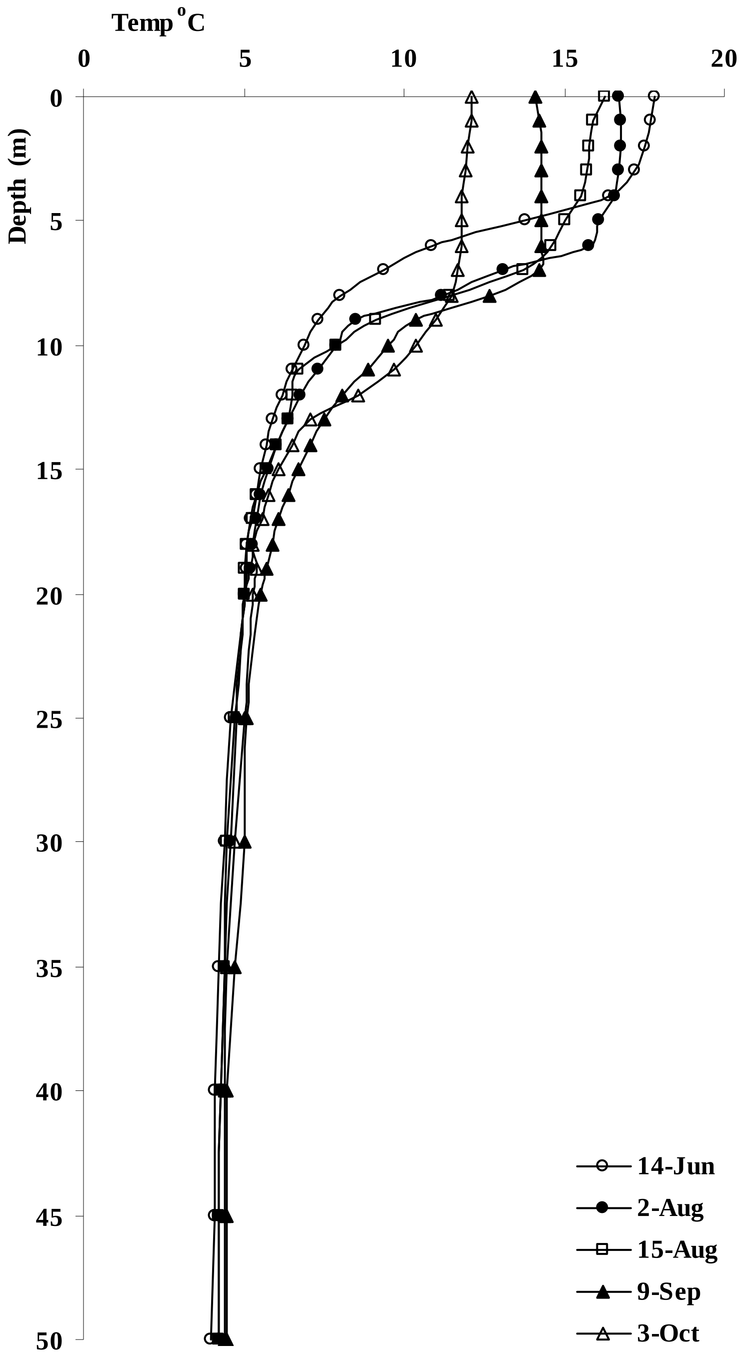

Figure 4.–Water column temperature profiles in Hetta Lake, 2006.

Table 11.–Estimated mean weighted density of zooplankton, by sampling date and taxon, in Hetta Lake in 2006. Density is the estimated number of organisms in the water column per unit of surface area, based on two vertical tows at each sampling date, with results averaged between stations A and B.

	Density (number per m^2), by date						
Taxon	**14-Jun**	**2-Aug**	**15-Aug**	**9-Sep**	**3-Oct**	**Seasonal mean**	**Percent of seasonal mean total**
Cyclops	25,854	5,222	573	658	1,783	6,818	16.6%
Copepod nauplii	13,160	1,062	170	213	2,887	3,498	8.5%
Harpaticus	0	85	0	0	0	17	0.0%
Bosmina	5,103	30,396	18,552	31,691	54,042	27,957	67.9%
Ovigerous *Bosmina*	365	3,397	1,316	701	1,062	1,368	3.3%
Daphnia longiremis	136	255	0	106	510	201	0.5%
Chydorinae	136	0	0	0	0	27	0.1%
Immature Cladocera	484	2,080	1,062	849	2,059	1,307	3.2%
Totals (rounded)	**45,200**	**42,500**	**21,700**	**34,200**	**62,300**	**41,200**	

Table 12.–Seasonal mean length (weighted by density at each sampling date), biomass, and percentage of total biomass, of zooplankton in Hetta Lake in 2006.

Taxon	**Mean length (mm)**	**Seasonal mean biomass (mg•m^{-2})**	**Percent of total biomass**
Cyclops	0.60	7.9	24.3%
Bosmina	0.30	23.1	71.2%
Ovig. Bosmina	0.30	1.0	3.1%
Daphnia longiremis	0.63	0.4	1.3%
		32.4	

DISCUSSION

Sockeye salmon escapement into Hetta Lake in 2006, as measured by the weir count, was the highest observed in the six most recent years of assessment (Table 13). Furthermore, the magnitude of the 2006 escapement was similar to escapements counted during a previous period of weir operation, 1967–1971 (Table 1). The 2006 subsistence harvest in Hetta Cove was also large compared with the previous five years' harvests (Table 13), nearly twice the size of the next-largest harvest during this period, in 2003 (Cartwright et al. 2005). Together, the escapement and subsistence harvest comprised a run of nearly 28,000 sockeye salmon returning to the marine terminal area at Hetta Cove, after passing through commercial fisheries which likely harvested some additional portion of the total run.

Table 13.–Subsistence sockeye harvests from Hetta Cove in 2001 through 2006, 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 2005 and 2006 escapements were estimated with a weir and backup mark-recapture study.

Year	Sockeye salmon harvested, Hetta Cove	Sockeye escapement, Hetta Lake
2001	4,500	NA (2,400)[a]
2002	950	NA (350)[1]
2003	5,770	3,100
2004	630	2,000
2005	350	3,300
2006	9,797	17,930

[a] Estimates of stream spawning population only in 2001 and 2002.

Although encouraging, the increased run size in 2006 cannot be assumed to represent a recovery of this stock, whose status remains in question. Limited historical evidence suggests that Hetta Lake once supported a much larger sockeye salmon run, although seemingly not within the past 50 years or more. Smaller escapements into the lake over a long period could have resulted in a change to a less productive state overall in this system.

Sockeye fry production in Hetta Lake has apparently declined drastically, from over 800,000 fry in 2002 to 25,000 or fewer fry in 2005 and 2006 (Lewis and Cartwright 2004; Host et al. 2008; Figure 5). The small fry populations in 2005 and 2006 followed low spawning populations in 2004 and 2005 (Conitz et al. 2007; Host et al. 2008; Table 13). However, the much larger fry populations in 2002 through 2004 also came from very low parent-year spawning populations in 2001 through 2003 (McEwen et al. 2002; Lewis and Cartwright 2004; Cartwright et al. 2005; Conitz et al. 2007; Figure 5; Table 13). Moreover, species composition estimates indicate a dramatic shift between 2002 and 2006, with a complete reversal in the respective numbers of sockeye fry and threespine sticklebacks (Figure 5). This dramatic shift cannot simply be attributed to inaccurate estimates, sampling error, or changes in protocol. Setting aside the estimate from 2001, which is likely too high to be credible, the estimates of about 750,000 to one million small fish "targets" from the hydroacoustic surveys appear to have remained stable from 2002 to 2006. Hydroacoustic survey methods were reviewed and improved in 2002, so we have more confidence in the accuracy of 2002–2006 estimates (D. Degan, Aquacoustics Inc., personal communication 2002). Trawl effort and sample sizes, on the other hand, did vary widely over the six-year period, but the change in species composition can nevertheless be clearly seen in the samples (Table 14). The basic methods, including gear, depth, and timing, remained the same over the six-year period, so we would expect well-known problems, such as net avoidance by larger and older fry, to have had a similar influence on samples in all years.

As mentioned above, the size of brood year escapements in 2001–2005 do not explain the striking pattern seen in the following years' fry populations. The apparent dramatic change between relative numbers of sticklebacks and sockeye fry could be a direct result of interspecific competition. The two fish species have overlapping diets and share a preference for cladoceran zooplankton such as *Daphnia*, but sticklebacks do not necessarily have a competitive advantage over sockeye fry (Hyatt et al. 2004; Beauchamp and Overman 2003; O'Neill and Hyatt 1987). Alternatively, we may be seeing a phenotypic response in the stickleback population, in which the very low recruitment of sockeye fry opened a niche opened that favored limnetic feeding behavior and morphology in sticklebacks (Schluter 1993; Day and McPhail 1996; Nosil and Reimchen 2005). Benthic feeding sticklebacks are normally out of range of detection of both hydroacoustic and mid-water trawl gear, whereas limnetic feeders would be potentially detectable to both types of gear. Thus, a shift from a predominantly benthic feeding population to one with a larger proportion of limnetic feeders would appear as an overall increase in stickleback numbers (A. Rosenburger, University of Alaska Fairbanks School of Fisheries and Ocean Science, personal communication 2007). If increased sockeye salmon escapements should result in increased recruitment of fry, interspecific competition may again drive the dynamics between stickleback and sockeye salmon populations, and perhaps close the niche to limnetic type sticklebacks. Stickleback population size, furthermore, can fluctuate cyclically or sporadically (Hyatt et al. 2004; O'Neill and Hyatt 1987).

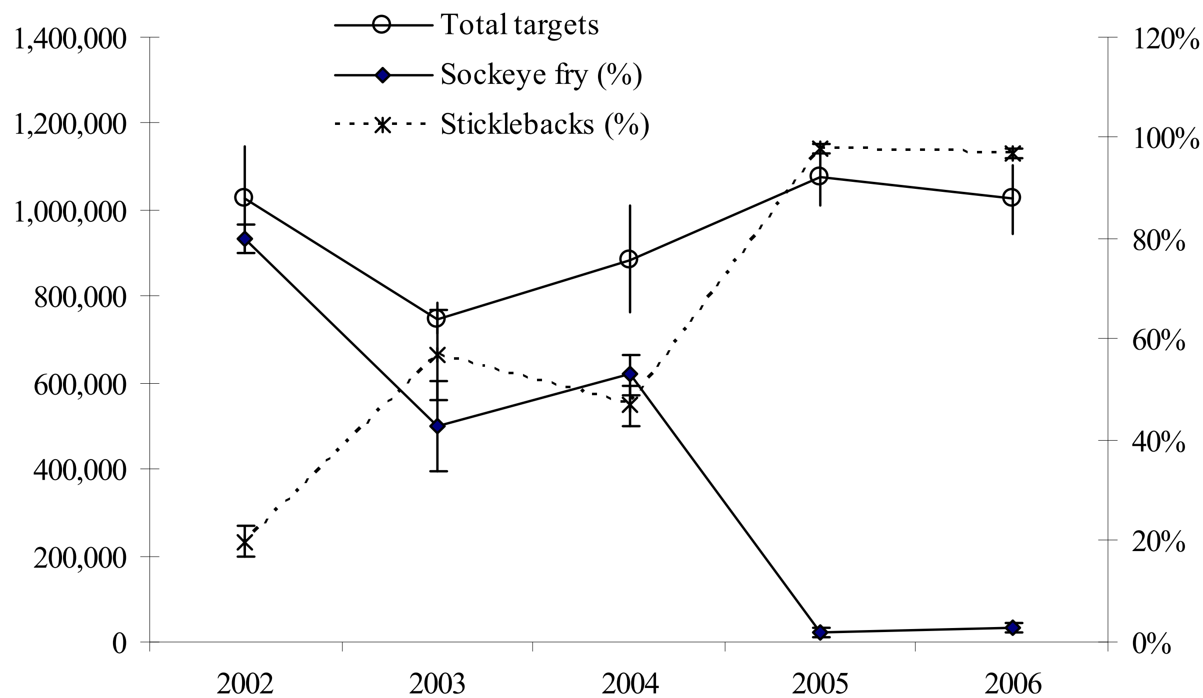

Figure 5.–Estimated numbers of small fish targets from hydroacoustic surveys and species composition estimates from mid-water trawl sampling in Hetta Lake, 2002–2006. The 2001 estimate was omitted because of questionable accuracy; new standards were implemented in 2002 following a review of methods. Standard error bars are shown for all estimates.

Table 14.–Summary of mid-water trawl survey results used to apportion small fish targets in the Hetta Lake hydroacoustic surveys in 2001–2006, showing number of tows, average tow times and average numbers of small fish per tow, by depth range.

Year	Depth range	Number of tows	Average tow duration (min)	Average number of fish per tow		
				All fish	Sockeye fry	Sticklebacks
2001	0–5 m	0	-	-	-	-
	6–10 m	1	10	127	120	7
	11–15 m	0	-	-	-	-
2002	0–5 m	1	15	6	1	5
	6–10 m	4	15	38	32	7
	11–15 m	0	-	-	-	-
2003	0–5 m	0	-	-	-	-
	6–10 m	4	15	24	11	14
	11–15 m	0	-	-	-	-
2004	0–5 m	8	12	166	62	104
	6–10 m	3	15	94	66	28
	11–15 m	9	9	55	34	21
2005	0–5 m	3	15	11	0	11
	6–10 m	4	16	147	2	145
	11–15 m	3	17	120	3	117
2006	0–5 m	3	12	45	0	45
	6–10 m	3	12	105	0	105
	11–15 m	4	13	48	1	46

Zooplankton levels in Hetta Lake were lower than in most other sockeye salmon lakes studied in Southeast Alaska during the 2001–2006 period. For example, the total zooplankton seasonal mean biomass in Hetta Lake in 2001–2003 was less than 50 $mg \cdot m^{-2}$, while Sitkoh Lake in 2001, Hoktaheen Lake in 2002, and Kutlaku Lake in 2003 had seasonal mean biomass values over 600 $mg \cdot m^{-2}$ (Appendix D1 in Cartwright et al. 2005). The zooplankton biomass estimate for Hetta Lake in 2006, 32 $mg \cdot m^{-2}$, was the lowest observed in the six-year study period. In a compilation of lake habitat data from 36 sockeye salmon lakes across Alaska, zooplankton biomass ranged from about 20 to 2,000 $mg \cdot m^{-2}$, although the zooplankton biomass in the Southeast Alaska lakes in this study had lower zooplankton biomass values than lakes elsewhere in Alaska (Edmundson and Mazumder 2001). These authors suggested that zooplankton biomass of 100 $mg \cdot m^{-2}$ represented a lower threshold for sockeye salmon growth. Zooplankton biomass in Hetta Lake clearly falls below this threshold and at the low end of the range of observed values. Furthermore, extremely small quantities (4 $mg \cdot m^{-2}$ or less) of *Daphnia*, a preferred prey for sockeye fry, have been found in Hetta Lake while high levels of *Daphnia* in other Southeast Alaska lakes have exceeded 100 $mg \cdot m^{-2}$, during this study period (Appendix D1 in Cartwright et al. 2005; Conitz et al. 2007; Host et al. 2008). The quantity of *Daphnia* in the total zooplankton assemblage provides an indicator of food quality for sockeye fry and may be a better predictor of sockeye salmon growth and survival than total zooplankton biomass (Mazumder and Edmundson 2002). Whether the very low levels of total zooplankton and *Daphnia* in Hetta Lake reflect heavy fish predation, possibly by both sockeye fry and sticklebacks, or some other condition such as nutrient limitation in the lake, is unknown. However, low zooplankton availability and quality clearly could limit sockeye salmon production from this lake in the future.

Assuming continuation of the monitoring project, the return of offspring from the very small brood year 2002–2005 spawning populations will be observed in the 2007 through 2011 escapements. Returns of adult sockeye salmon from the 2006 brood year, which had a substantially larger parent population, will not be seen until 2010–2012. The surprisingly large subsistence harvest and escapement in 2006 showed that we cannot expect to predict future run sizes based on escapement numbers and a limited amount of additional information on freshwater populations. Continued careful monitoring of this important subsistence stock will be necessary to gain a better understanding of factors controlling it, and to help determine when conservation measures may be needed.

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APPENDICES

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 2006.

Date	Sockeye salmon		Daily counts, other salmon			Water depth (m)	Water temperature (°C)
	Daily	Cumulative	Coho	Chum	Pink		
8-Jun	9	9	0	0	0	0.43	15
9-Jun	5	14	0	0	0	0.42	16
10-Jun	3	17	0	0	0	0.41	12
11-Jun	5	22	0	0	0	0.41	14
12-Jun	0	22	0	0	0	0.39	16
13-Jun	0	22	0	0	0	0.39	16
14-Jun	7	29	0	0	0	0.38	16
15-Jun	8	37	0	0	0	0.38	18
16-Jun	8	45	0	0	0	0.40	14
17-Jun	8	53	0	0	0	0.44	16
18-Jun	3	56	0	0	0	0.45	16
19-Jun	11	67	0	0	0	0.45	16
20-Jun	15	82	0	0	0	0.44	16
21-Jun	10	92	0	0	0	0.45	13
22-Jun	0	92	0	0	0	0.44	16
23-Jun	38	130	0	0	0	0.42	16
24-Jun	10	140	0	0	0	0.42	16
25-Jun	19	159	0	0	0	0.42	16
26-Jun	32	191	0	0	0	0.41	18
27-Jun	14	205	0	0	0	0.41	16
28-Jun	7	212	0	0	0	0.39	16
29-Jun	28	240	0	0	0	0.39	15
30-Jun	18	258	0	0	0	0.42	15
1-Jul	48	306	0	0	0	0.40	15
2-Jul	34	340	0	0	0	0.36	15
3-Jul	14	354	0	0	0	0.35	15
4-Jul	9	363	0	0	0	0.35	15
5-Jul	43	406	0	0	0	0.35	15
6-Jul	16	422	0	0	0	0.33	16
7-Jul	6	428	0	0	0	0.30	15
8-Jul	6	434	0	0	0	0.31	16
9-Jul	8	442	0	0	0	0.34	16
10-Jul	34	476	0	0	0	0.31	16
11-Jul	2	478	0	0	0	0.30	18
12-Jul	52	530	0	0	0	0.30	18
13-Jul	6	536	0	0	0	0.30	15
14-Jul	11	547	0	0	0	0.32	14
15-Jul	57	604	0	0	0	0.35	15
16-Jul	281	885	0	0	0	0.35	14
17-Jul	157	1,042	0	0	0	0.35	16
18-Jul	282	1,324	0	0	0	0.31	13
19-Jul	104	1,428	0	0	0	0.32	17
20-Jul	22	1,450	0	0	0	0.32	16

(Continued)

Appendix B–continued (page 2 of 3)

Date	Sockeye salmon		Daily counts, other salmon			Water depth (m)	Water temperature (^oC)
	Daily	Cumulative	Coho	Chum	Pink		
21-Jul	5	1,455	0	0	0	0.33	17
22-Jul	17	1,472	0	0	0	0.31	16
23-Jul	12	1,484	0	0	0	0.31	18
24-Jul	3	1,487	0	0	0	0.31	16
25-Jul	95	1,582	0	0	0	0.39	17
26-Jul	1,004	2,586	0	0	0	0.41	16
27-Jul	259	2,845	0	0	1	0.42	14
28-Jul	191	3,036	0	0	0	0.42	17
29-Jul	180	3,216	0	0	0	0.41	16
30-Jul	328	3,544	0	0	0	0.40	16
31-Jul	140	3,684	0	0	0	0.31	16
1-Aug	183	3,867	0	0	0	0.32	16
2-Aug	813	4,680	0	0	1	0.43	16
3-Aug	226	4,906	0	0	0	0.42	16
4-Aug	201	5,107	2	0	0	0.42	15
5-Aug	153	5,260	0	0	0	0.41	17
6-Aug	297	5,557	0	0	3	0.41	17
7-Aug	51	5,608	0	0	0	0.40	16
8-Aug	341	5,949	0	0	0	0.42	17
9-Aug	728	6,677	0	2	28	0.42	16
10-Aug	194	6,871	1	0	2	0.45	17
11-Aug	184	7,055	0	0	2	0.45	17
12-Aug	379	7,434	0	0	4	0.44	16
13-Aug	415	7,849	0	0	2	0.43	17
14-Aug	110	7,959	0	0	1	0.42	17
15-Aug	529	8,488	0	0	0	0.41	17
16-Aug	781	9,269	0	0	0	0.40	17
17-Aug	488	9,757	5	0	1	0.39	16
18-Aug	519	10,276	0	0	5	0.38	16
19-Aug	336	10,612	13	0	7	0.38	17
20-Aug	271	10,883	0	0	13	0.36	17
21-Aug	582	11,465	1	0	11	0.36	17
22-Aug	304	11,769	8	0	18	0.35	17
23-Aug	291	12,060	3	0	25	0.33	16
24-Aug	253	12,313	1	0	41	0.33	17
25-Aug	285	12,598	3	1	104	0.33	16
26-Aug	200	12,798	4	0	91	0.30	16
27-Aug	95	12,893	4	1	85	0.36	17
28-Aug	763	13,656	5	4	325	0.55	17
29-Aug	573	14,229	51	3	395	0.41	16
30-Aug	282	14,511	28	2	194	0.41	16
31-Aug	540	15,051	17	7	253	0.42	16

(Continued)

Appendix C–continued (page 3 of 3)

Date	Sockeye salmon		Daily counts, other salmon			Water depth (m)	Water temperature (°C)
	Daily	Cumulative	Coho	Chum	Pink		
1-Sep	1,548	16,599	50	42	1,859	0.58	16
2-Sep	151	16,750	58	23	758	0.64	15
3-Sep	163	16,913	61	48	736	0.62	15
4-Sep	46	16,959	79	21	352	0.59	16
5-Sep	82	17,041	70	18	639	0.53	16
6-Sep	173	17,214	83	27	776	0.52	15
7-Sep	86	17,300	211	10	301	0.54	15
8-Sep	148	17,448	78	40	714	0.55	15
9-Sep	41	17,489	248	18	445	0.53	15
10-Sep	167	17,656	178	124	1,495	0.62	15
11-Sep	82	17,738	340	72	614	0.62	15
12-Sep	90	17,828	352	70	526	0.64	15
13-Sep	33	17,861	291	37	210	0.61	15
14-Sep	4	17,865	235	3	21	0.33	15
15-Sep	7	17,872	4	24	107	0.33	15
16-Sep	13	17,885	139	27	105	0.33	15
17-Sep	16	17,901	212	15	62	0.32	15
18-Sep	12	17,913	107	9	69	0.32	15
19-Sep	9	17,922	92	7	45	0.50	14
20-Sep	8	17,930	45	13	55	0.53	14
Totals	17,930		3,079	668	11,501		