Fishery Data Series No. 09-62

Klawock Lake Subsistence Sockeye Salmon Project 2007 Annual Report

by

Jan M. Conitz

November 2009

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

Symbols and Abbreviations

The following symbols and abbreviations, and others approved for the Système International d'Unités (SI), are used without definition in the following reports by the Divisions of Sport Fish and of Commercial Fisheries: Fishery Manuscripts, Fishery Data Series Reports, Fishery Management Reports, and Special Publications. All others, including deviations from definitions listed below, are noted in the text at first mention, as well as in the titles or footnotes of tables, and in figure or figure captions.

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

A significant run of sockeye salmon (*Oncorhynchus nerka*) to Klawock Lake has supported human populations in and around the village of Klawock for centuries, or longer. The location of the original Tlingit settlement as well as subsequent commercial salmon processing plants are directly attributed to this salmon stock, which has been much diminished in recent years. A sockeye stock assessment project has been operated at Klawock Lake since 2001 to obtain direct estimates of escapement and subsistence harvest and study other factors contributing to the productivity of the sockeye salmon stock. In 2007, the seventh year of this ongoing project, the sockeye escapement of approximately 17,500 fish was somewhat larger than, but consistent with, escapements observed from 2001 through 2006. The 2007 estimate relied exclusively on mark-recapture sampling conducted in the three main spawning streams; the Klawock hatchery operated the weir but did not count sockeye salmon. A subsistence harvest of about 2,600 sockeye salmon was taken; the total run including escapement and subsistence harvest was about 20,000 sockeye salmon. Sockeye smolt were sampled at the lake outlet during late April through early June, with limited success. Over 98% of the 326 smolt that were aged were age-1. In contrast, the adult age composition showed 32% of returning spawners spent two years as juveniles in the lake, the same as the average for 2001–2007. Zooplankton populations were somewhat reduced in biomass and overall numbers from previous sizes estimated in 2001 through 2004. Limitations in the food supply for rearing sockeye juveniles may result in an older average age at smolting. Returning adult sockeye salmon in the escapement and subsistence fishery were sampled for the presence of hatchery otolith marks, which were found in only about 3% of the fish sampled.

Key words: Sockeye salmon, *Oncorhynchus nerka*, subsistence, Klawock, Klawock Lake, escapement, mark-recapture, age composition, smolt, zooplankton, hatchery, otolith

INTRODUCTION

The Klawock Lake watershed is an important sockeye salmon (*Oncorhynchus nerka*) rearing system. It has historically supported a permanent Tlingit settlement on Prince of Wales Island (Langdon 1977) and continues to be an important sockeye salmon resource for current residents of Klawock. Subsistence users harvest about 7,500 fish annually from nearby waters, including some 4,000–6,000 a year from the Klawock River estuary, making Klawock one of the largest subsistence fisheries in Southeast Alaska (Conitz et al. 2006).

Klawock Lake sockeye salmon also supported a commercial fishery for almost 150 years. At the end of the 19th Century, the sockeye salmon harvest in the Klawock River estuary averaged around 40,000 fish, with peaks of up to 70,000 fish (Moser 1899, Rich and Ball 1933). Attempts at hatchery supplementation and implementation of fishery regulations during the early commercial period acknowledged depletion of the stock due to over-exploitation (Rich and Ball 1933; Roppel 1982). Attempts to assess the size of sockeye salmon run returning to the lake to spawn date back to at least the 1930s. During that decade, a weir was operated on the Klawock River, with annual counts of sockeye salmon ranging from 7,000 to 65,000 fish (Orrell et at. 1963). Sockeye counts recorded at the Klawock River hatchery weir between 1968 and 2000 ranged from about 1,000 to 20,000 fish, but were notoriously unreliable (Lewis and Zadina 2001). Detailed reviews of available historical information on Klawock sockeye salmon can be found in the annual report series for the stock assessment program beginning in 2001 (Lewis and Zadina 2001; Lewis and Cartwright 2002; Cartwright and Lewis 2004; Cartwright and Conitz 2006; Conitz et al. 2006; Conitz and Cartwright 2007). The overall impression, both from available historical information and local ecological knowledge, is that abundance of Klawock Lake sockeye salmon was much greater in the past than in recent years (Ratner et al. 2005).

Logging, road-building, water withdrawals, and housing developments in the Klawock Lake watershed have compromised salmon habitat integrity, and the Klawock Watershed Council has recently undertaken several restoration projects. The Klawock hatchery began incubating sockeye eggs taken from wild broodstock in the 1980s, and released 250,000 and 900,000 emergent, mostly unfed sockeye fry annually between 1996 and 2005 (Appendix C in Prince of Wales Hatchery Association (POWHA) 2005 annual management plan). The results of this program were not evaluated until after POWHA began thermally marking sockeye otoliths in 1999 (Lewis and Zadina 2001). Juvenile and returning adult sockeye salmon were sampled starting in 2001 to determine the number and proportions of marked fish. Results for 2001–2006 showed marks present in only about one to four percent of the sampled juvenile and returning adult populations (ADF&G Thermal Mark Laboratory Mark Summary Report database, http://tagotoweb.adfg.state.ak.us/OTO/reports/MarkSummary.aspx; J. Conitz, ADF&G Division of Commercial Fisheries, unpublished memo to Scott Kelley, Regional Supervisor, 2007). The large additions of both sockeye and coho fry into the Klawock Lake environment could also have unintended effects on wild sockeye fry populations and their prey base (A. Mazumder, University of Victoria, unpublished review and report, 2006).

The recent subsistence sockeye monitoring project was started in 2001; its main goal has been to achieve reliable estimates of sockeye escapement and subsistence harvest in the Klawock Lake system to facilitate better management of the subsistence resource. Counts of sockeye salmon at the Klawock River weir were validated with mark-recapture studies in the primary spawning areas. After discovering discrepancies in the counts compared with the estimates, improvements were made to the weir in 2004. Mark-recapture sampling methods were also improved (Conitz et al. 2006). The escapement estimates between 2001 and 2006 were remarkably uniform, ranging from 13,000 to 15,000 fish, with a high of 21,000 fish in 2003. Similarly, subsistence harvest averaged 3,000 to 6,000 fish, with an exceptionally low harvest of 175 fish in 2005. Additional study objectives included measuring zooplankton abundance in the lake as the primary food source for sockeye fry and estimating sockeye fry and smolt populations.

The study in 2007 was similar to the 2001–2006 studies. The most important objectives were again to obtain a reliable and complete estimate of sockeye salmon escapement into the lake and a reliable estimate of the subsistence sockeye harvest. The escapement estimate in 2007 differed from previous years in that fish were not counted or marked at the weir; instead, an open-population mark-recapture study was conducted at each of the three main spawning streams, (Threemile, Halfmile, and Inlet creeks). Sockeye salmon were sampled for otoliths from the subsistence fishery and from carcasses in each spawning stream to determine hatchery contribution to the fishery and the escapement, by means of thermal marks. Sockeye salmon were sampled for age, sex, and length composition; most of these fish were sampled from those passed through the weir by hatchery staff. Sockeye smolt were sampled at the Klawock Lake outlet from late April through early June for age composition and size measurements. Zooplankton were sampled monthly at two stations in Klawock Lake for species composition, density, and biomass from mid-May through mid-September.

OBJECTIVES

1. Describe the age, sex, and size composition and run timing of sockeye salmon smolt migrating out of Klawock Lake.
2. Estimate the subsistence harvest of sockeye and other salmon in the subsistence fishery in Klawock Inlet and the Klawock River estuary.

3. Estimate the sockeye salmon spawning populations in Threemile, Halfmile and Inlet creeks using mark-recapture methods, so that the estimated coefficient of variation is less than 15%.
4. Estimate the age, length, and sex composition of the sockeye salmon in the escapement at Klawock Lake, so that the estimated coefficient of variation is less than or equal to 5% for the largest two age classes.
5. Estimate the proportion of hatchery-produced sockeye salmon in the escapement and subsistence fishery.
6. Measure water column temperature and light profiles and estimate zooplankton species composition, size, abundance, and biomass in Klawock Lake at monthly intervals through the season.

STUDY SITE

The Klawock River system (ADF&G stream number 103-60-047) is located on the west side of Prince of Wales Island (Figure 1), and drains into Klawock Inlet at the site of the village of Klawock (lat 55° 32.97'N, long 133° 02.60'W). Klawock Lake has two main basins and numerous tributaries, with four major tributaries providing most of the sockeye salmon spawning habitat in this system (Figure 2). At the head of the lake, Inlet Creek flows into basin B (maximum depth 49 m), draining a total area of 37.6 km^2. Hatchery Creek, Halfmile Creek, and Threemile Creek flow into basin A, the larger and shallower of the two basins (maximum depth 30 m), and drain a total watershed area of 76.1 km^2. The surface elevation of Klawock Lake is 9.1 m, and the lake has a total surface area of 11.9 km^2, mean depth of 17.7 m, maximum depth of 49.0 m, and volume of 209×10^6 m^3 (Figure 2). The lake is dimictic and organically stained, and its mean euphotic zone depth (EZD) is 4.2 m, based on limnological data collected in 1986–1988 and 2001 (Lewis and Cartwright 2002). Klawock Lake drains into the Klawock River, which is 2.85 km from the lake outlet to the estuary at the head of Klawock Inlet. The Prince of Wales hatchery and the weir are located on the Klawock River approximately 300 m below the lake. In addition to sockeye salmon, native fish species in Klawock Lake include coho (*O. kisutch*), pink (*O. gorbuscha*), and chum (*O. keta*) salmon, steelhead (*O. mykiss*) and cutthroat trout (*O. clarkii*), Dolly Varden char (*Salvelinus malma*), threespine stickleback (*Gasterosteus aculeatus*), and cottids (*Cottus* sp.). Mysid shrimp (*Neomysis mercedis*) are also present in the lake.

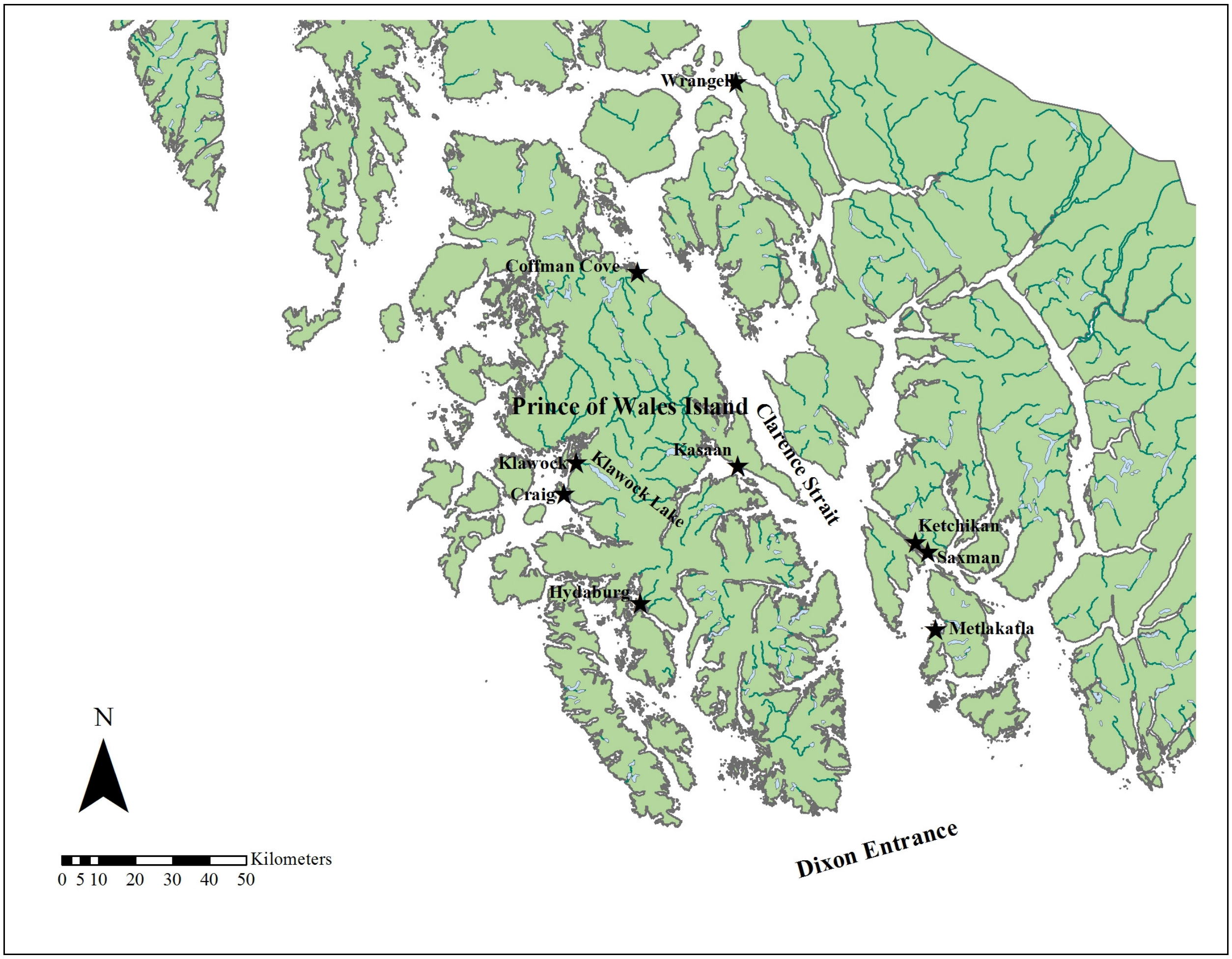

Figure 1.–Geographic location of Klawock Lake, in Southeast Alaska on Prince of Wales Island. The communities of Klawock and Craig, and other towns on and near Prince of Wales Island are shown.

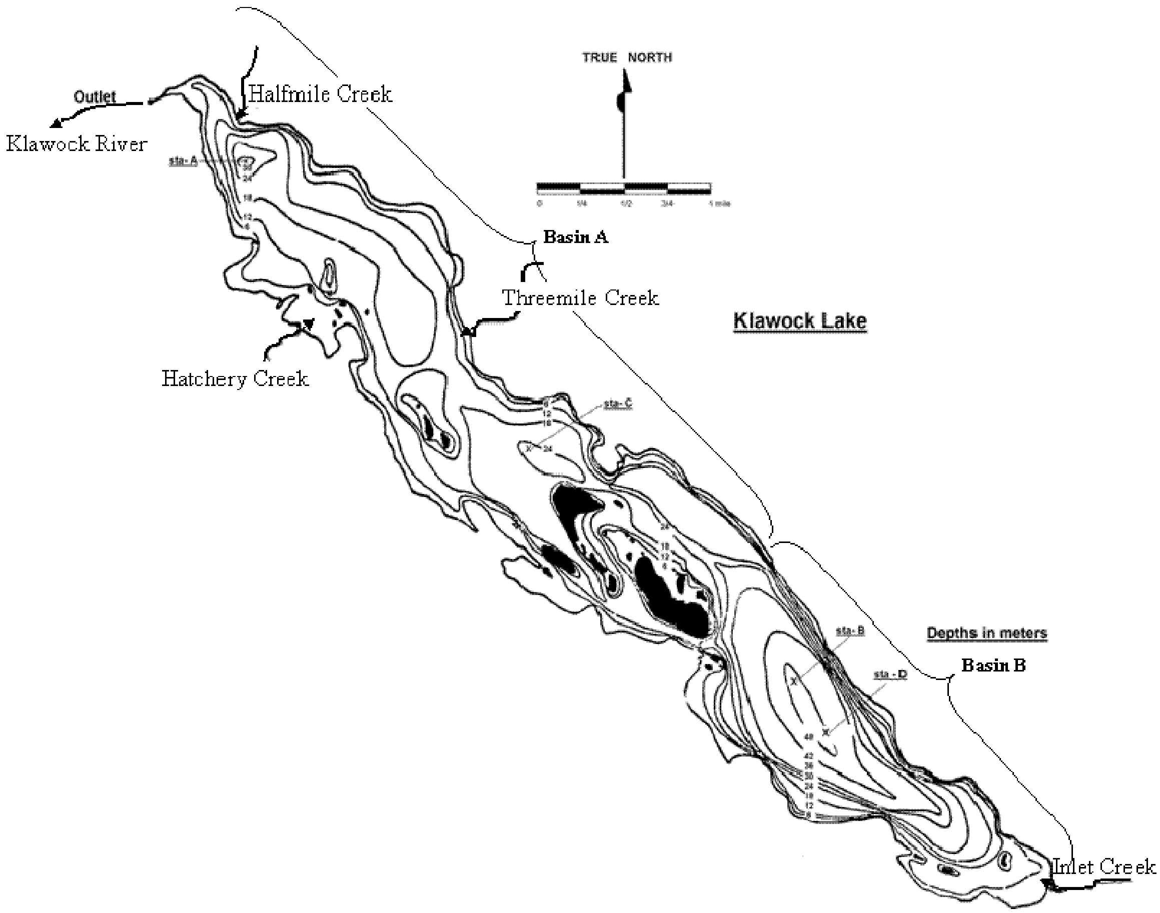

Figure 2.–Bathymetric map of Klawock Lake, showing the two main lake basins, four main inlet streams (Halfmile, Threemile, Inlet, Hatchery), and the outlet to Klawock River.

METHODS

SMOLT AGE, WEIGHT, AND LENGTH COMPOSITION

Sockeye smolt were sampled throughout their migration from Klawock Lake in the spring. Fish were captured live by means of a fyke net with a 1m x 1m opening, through which smolt were funneled into a floating live box trap for counting and sampling. The first fyke net was deployed between 25 April and 13 June 2007. A second fyke net was deployed starting 23 May and continuing through 13 June. For the first five weeks, the sampling schedule was two nights per week, beginning on Tuesdays and Saturdays and continuing into the early morning hours of the next day. During the sixth and seventh weeks of sampling, a third night was added to the schedule, and sampling began on Tuesday, Thursday, and Saturday evenings. The normal duration of the sampling period was six to eight hours starting at 6:00 pm, but the starting time was shifted to about 8:00 pm later in the season to more closely match the daily timing of the smolt migration. The consistent weekly schedule ensured that smolt were sampled for age, length, and weight composition roughly in proportion to numbers present throughout the emigration period. All sockeye smolt and other fish caught during each sampling period were counted. The trap was checked at one- to two-hour intervals throughout the sampling period, and up to 50% of the sockeye salmon smolt were retained for scale samples and length and weight measurements. The total sample size goal was 600 fish over the seven week sampling period, enough to distinguish proportions in two or three age classes to a precision of 95% (Thompson 1992).

Sockeye salmon smolt retained for sampling were anaesthetized with a clove oil solution (Anderson et al. 1997), weighed to the nearest 0.1 g, and measured to the nearest 1.0 mm. Scales were sampled by gently scraping a scalpel over the "preferred area" on the left side of the fish, above the lateral line and immediately posterior to the dorsal fin (INPFC 1963). Ages were determined by ADF&G personnel trained in salmon aging techniques.

SUBSISTENCE HARVEST ESTIMATE

By regulation, the subsistence fishery was open on weekdays from 08:00 on Mondays to 17:00 on Fridays, between 7 July and 31 July 2007. Three days out of each five-day week were randomly selected for observations and interviews with subsistence users. In 2007, week four had only two legal fishing days and both of these dates were sampled (Table 1). Sampling days ran from 06:00 to 22:00, with reduced hours on Monday and Friday. All subsistence fishing was conducted with small, hand-pulled seine nets, usually using two boats to deploy a single net. A net set was defined as a single net deployment and retrieval. A boat-party referred to all the people on one or two boats fishing the same net. Project technicians used binoculars and a motorized skiff to monitor the fishery so they could see all boat-parties fishing in Klawock Inlet. In addition to direct verbal interviews, direct observation and hand signals were used to communicate the size of the catch. To maintain the confidentiality of individual catch information, names of fishers were not recorded. Technicians attempted to interview all boat-parties after each set. However, in cases where technicians were unable to interview a boat-party after a set, the set was recorded as a "missed interview."

Table 1.–Dates selected for sampling in the Klawock Inlet subsistence fishery in 2007.

Week	Calendar dates	Sample dates
1	8–14 July	9, 11, 13 July
2	15–21 July	16, 19, 20 July
3	22–28 July	23, 24, 27 July
4	29–31 July	30, 31 July

The statistical population was designated to be the collection of net sets. Sets were organized into a day within a week. Sampling followed a two-stage design: a day within a week was selected at random (first stage), and then a set within a day (second stage) was selected if needed (Bernard et al. 1998; Thompson 1992). In the second stage estimation, the average harvest per net set for the day was assigned to any set with a "missed interview." In the first stage estimation, the average harvest per day, within a week, was expanded to estimate the harvest for the days not sampled each week. If the fishery was open for three or fewer days in a week, all days were sampled and no expansion was necessary.

We let h_{ijk} denote the harvest for set i on day j in week k, and m_{jk} denote the number of completed interviews on day j, in week k (i.e. the total number of sets for which interviews were obtained). Also, M_{jk} denoted the total number of net sets counted on day j in week k (i.e. the total number of sets observed, including any missed interviews), and d_k denoted the total number of days sampled out of D_k fishing days in week k. For a given species, the harvest for week k was estimated as,

$$\hat{H}_k = \frac{D_k}{d_k} \sum_{j=1}^{d_k} \frac{M_{jk}}{m_{jk}} \sum_{i=1}^{m_{jk}} h_{ijk} \ , \tag{1}$$

and the total harvest for the season was estimated as the sum of weekly harvests,

$$\hat{H} = \sum_{k=1}^{4} \hat{H}_k \ . \tag{2}$$

To estimate the variance of $\hat{H}$, we let $\bar{h}_{jk}$ denote the mean harvest per set, on day j in week k, and $\bar{h}_k$ denote the mean harvest for the week. We then estimated the variance for the estimated harvest in week k as,

$$\mathrm{var}(\hat{H}_k) = \frac{D_k}{d_k} \sum_{j=1}^{d_k} M_{jk}^{\ 2} \left(1 - \frac{m_{jk}}{M_{jk}} \right) \frac{\sum_{i=1}^{m_{jk}} (h_{ijk} - \bar{h}_{jk})^2}{m_{jk}(m_{jk} - 1)} + D_k^{\ 2} (1 - \frac{d_k}{D_k}) \frac{\sum_{j=1}^{d_k} (\bar{h}_{jk} - \bar{h}_k)^2}{d_k(d_k - 1)} \tag{3}$$

(Thompson 1992, p. 129). The overall variance for the season was estimated by summing the five weekly variance estimates,

$$\mathrm{var}(\hat{H}) = \sum_{k=1}^{4} \mathrm{var}(\hat{H}_k), \tag{4}$$

and the standard error was estimated by taking the square root of the seasonal variance estimate.

SOCKEYE ESCAPEMENT ESTIMATE

Sockeye spawning populations in the three main spawning tributaries of Klawock Lake (Threemile, Inlet, and Halfmile creeks; Figure 2) were estimated with mark-recapture studies. Marking of fish began when sockeye spawners started accumulating at the mouth of each stream, continuing at weekly intervals until the end of the spawning period.

During the first marking event at each stream, live sockeye salmon were captured at the mouth of the stream and marked with an opercular punch and a t-bar tag. During subsequent sampling events, all sockeye salmon were checked for opercular punches and tags. Any unmarked fish were tagged and marked with the specific opercular punch for that sampling event. When visual surveys revealed that sockeye spawners were migrating upstream to spawn, sampling was extended to the entire length of the spawning area in each stream. A tag number was recorded for each fish caught in a given sample, whether initial capture or recapture. The opercular punch served as a primary mark which would identify the fish to the sampling event in which it was captured and marked, even in the event of tag loss.

The tag number data were used to construct an individual capture history for each fish, by location and sampling event. Fish were sampled without replacement during a given sampling event, but a fish could be recaptured in multiple sampling events. A “1” denoted a sampling event in which a fish with a given tag number was captured, and a “0” denoted a sampling event in which the fish with that tag number was not captured (Pollock et al. 1990). In the event of tag loss, capture histories were reconstructed by means of the opercular punch mark(s) present.

The Jolly-Seber model for open populations (Pollock et al. 1990) extends the Schnabel method (Seber 1982, p. 130) to open populations. Schwarz et al. (1993) developed an adjustment for spawning salmon populations. Population size is estimated at the time of each sample, and the number of new animals entering the population is estimated between sampling events, for s sampling events. This model requires the following assumptions:

1. Every fish present in the population at time of the i^{th} sampling event (i=1, 2, …, s) has the same probability of capture (p_i);
2. Every fish (marked and unmarked) present in the population immediately after the i^{th} sampling event has the same probability of survival (ϕ_i) until the $(i+1)^{th}$ sampling event (i = 1, 2,…, s-1);
3. Marks are not lost or overlooked;
4. Sampling time is negligible.

The model incorporates the following parameters:

N = size of "super-population," or escapement;

M_i = number of marked fish in the population at time of the i^{th} sampling event (i=1, 2, …, s; $M_1 = 0$);

N_i = total number of fish in the population at time of the i^{th} sampling event (i=1, 2, …, s; N_1=B_0);

B_i= total number of new fish entering the population before the first event and between the i^{th} event and $(i+1)^{th}$ event, and still in the population at time of the $(i+1)^{th}$ event (i=1, …, s-1);

B_0 = the number of fish that entered the population before the first event and are still alive at the time of the first event; and

ϕ_i = survival probability for all fish between the i^{th} event and $(i+1)^{th}$ event (i=1, 2, …, s-1).

The following statistics were also used in the model:

m_i = number of marked fish captured in the i^{th} event (i=1, 2, …, s);

u_i = number of unmarked fish captured in the i^{th} event (i=1, 2, …, s);

$n_i = m_i + u_i$, total number of fish captured in the i^{th} event (i=1, 2, …, s);

R_i = number of the n_i fish that are released after the i^{th} event (i=1, 2, …, s-1; this may not be all of n_i fish due to losses on capture);

r_i = number of R_i fish released at i and captured again (i=1, 2, …, s-1); and

z_i = number of fish captured before i, not captured at i, and captured again later (i=1,2, …, s-1).

Seber (1982, page 204) recommended the following unbiased estimators:

$$\hat{M}_i = m_i + \frac{(R_i+1)z_i}{r_i+1};$$
$$\hat{N}_i = \frac{(n_i+1)\hat{M}_i}{m_i+1};$$
$$\hat{\phi}_i = \frac{\hat{M}_{i+1}}{\hat{M}_i - m_i + R_i}; \quad (5)$$
$$\hat{B}_i = \hat{N}_{i+1} - \hat{\phi}_i(\hat{N}_i - n_i + R_i).$$

Seber also recommended that m_i and r_i should be greater than 10 for satisfactory performance of these bias-adjusted estimators.

The interval between the last (s^{th}) sampling event and the next-to-last ($(s\text{-}1)^{th}$) sampling event was assumed to be so short that the number of fish entering the population during this interval was negligible. Furthermore, sampling was assumed to extend to a time when immigration had ended, and the number of fish entering the population after the last sample was negligible. In the Jolly-Seber model, the total population is usually estimated as the sum of $\hat{B}_i$, the estimated number of fish that entered the population between sampling events. However, $\hat{B}_i$ are estimates of the number of fish that entered the population after sampling event i and were alive at sampling event i+1. These estimates exclude those fish in the escapement that entered after sampling event i but died before sampling event i+1. Consequently, the sum of the Jolly-Seber estimates of B_i would underestimate the spawning recruitment, except when all fish are known to survive from their entry to the next sampling event. To account for those fish that entered the system after sampling event i, but died before sampling event i+1, $\hat{B}_i$ was adjusted before summing (Schwarz et al. 1993). Let B_i^* denote the total number of new fish entering the population between sampling events (including those that died before the next sampling event). When recruitment and mortality are assumed to occur uniformly between sampling events, the maximum likelihood estimator for B_i^* is,

$$\hat{B}_i^* = \hat{B}_i \frac{\log(\hat{\phi}_i)}{\hat{\phi}_i - 1}. \quad (6)$$

$\hat{B}_0$, $\hat{B}_1$, and $\hat{B}_{s-1}$ are confounded parameters and cannot be estimated without further assumptions (Schwarz et al. 1993). However, we assumed recruitment had virtually ended before the last sampling event, so we set $\hat{B}_{s-1}$ to zero. The number of fish alive in the population at the second sampling event, N_2, was estimated as,

$$\hat{N}_2 = \hat{B}_0\phi_1 + \hat{B}_1. \quad (7)$$

So a reasonable estimate (Schwarz et al. 1993) of the number of fish that entered the system before the first sampling event and between the first and second sampling events, including those that entered the system and died before and between these sampling events, is,

$$\hat{N}_2 \frac{\log(\hat{\phi}_1)}{\hat{\phi}_1 - 1}. \quad (8)$$

The super-population, or total escapement, is then the sum,

$$\hat{N} = \hat{N}_2 \frac{\log(\hat{\phi}_1)}{\hat{\phi}_1 - 1} + \sum_{i=2}^{k-1} \hat{B}_i^* \,. \tag{9}$$

We used a non-parametric bootstrap technique to estimate variance and form a confidence interval for N. A computer program to produce these estimates, written in S-Plus (Insightful Corp. 2001), is available from X. Zhang, ADF&G Division of Commercial Fisheries (xinxian.zhang@alaska.gov). The procedure works by resampling the observed experimental data to create a series of "pseudo-experiments," according to the following algorithm.

1. Analyze observed data using the Jolly-Seber method and Schwarz's adjustment described above to obtain the $\hat{N}$.
2. Sample with replacement from the observed n capture histories to generate a bootstrap sample of the same size n; analyze the bootstrap sample exactly as if it were the observed sample.
3. Repeat step (2) for 1,000 bootstrap samples to have 1,000 estimates of N from these bootstrap samples.
4. Calculate variance and standard error for N^* from the 1,000 bootstrap estimates of N.
5. Find the 95% confidence interval by taking the 0.025 and 0.975 quantiles of the 1,000 bootstrap estimates of N.

The three main spawning streams are well-separated from each other, and capture history data from previous years (Conitz 2008; Conitz and Cartwright 2007; Conitz et al. 2006) has shown very little evidence of spawner movement between streams. Therefore the three independent population estimates (one for each stream) were summed. This summed estimate was expected to be somewhat less than the total population of sockeye spawners in Klawock Lake because not all spawning areas were sampled. However, evidence from visual surveys indicate that a much smaller number of sockeye spawners use Hatchery Creek, and no other spawning areas have been observed in recent years (Lewis and Cartwright 2002; Cartwright and Lewis 2004; Conitz et al. 2006). Because the estimates for the three stream spawning groups were assumed to be independent, the standard error for the total spawning population estimate was simply the square root of the summed variance estimates for each stream spawning group. We reported the coefficient of variation as the standard error divided by the total population estimate.

ESCAPEMENT AGE, SEX, AND LENGTH COMPOSITION

Although sockeye escapement counting was not conducted at the Klawock River weir, about 600 adult sockeye salmon were sampled for length, sex, and scales (for age determination) from fish passed through the weir by hatchery personnel. Fish were selected systematically to prevent selection bias, and weekly sampling goals were set throughout the run based on average weekly escapements from previous years. Length of each fish was measured from mid eye to tail fork, to the nearest millimeter (mm). Sex of the fish was decided by length and shape of the kype or jaw. 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 by ADF&G salmon aging laboratory personnel in Douglas, Alaska. Age classes were designated by the European aging system where freshwater and saltwater years are separated by a period (e.g. 1.3

denotes a five-year-old fish with one freshwater and three ocean years; Koo 1962). The proportion in each age-sex group was estimated based on the number in each group compared with the total number sampled. Associated standard errors were estimated using standard statistical techniques for binomial proportions (e.g. Thompson 1992). The binomial standard error was expected to adequately approximate the standard error for a multinomial proportion. Mean lengths by age and sex and their standard errors were estimated as for simple random samples.

HATCHERY CONTRIBUTION

The proportion of hatchery-incubated sockeye salmon in the total population of sockeye salmon returning to the Klawock Lake system in 2007 was estimated from the proportion of marked otoliths in samples of fish from the subsistence harvest and escapement. The Klawock hatchery thermally marked incubating sockeye salmon in their facility from brood year 1999 through brood year 2004, after which the hatchery discontinued sockeye production. A thermal mark pattern template was assigned to each year of Klawock hatchery sockeye production by the ADF&G Mark, Tag, and Age Laboratory in Juneau. The laboratory checked a subsample of otoliths and the associated temperature log to verify the thermal mark pattern (John Bruns, Prince of Wales Hatchery Association manager, personal communication 2005). Adult sockeye salmon returning to the Klawock Lake system in 2007 could have been offspring from brood years 2000 through 2004, all of which included some hatchery sockeye production.

Adult sockeye salmon were sampled for otoliths in the Klawock Inlet subsistence fishery and on the spawning grounds in Klawock Lake. Heads from subsistence caught sockeye salmon were collected from fishers on a voluntary basis. Fishers dropped off heads in marked collection totes at either of the two public docks in Klawock village. The sample size goal was 200 fish from the subsistence harvest, distributed among weeks of the subsistence fishery roughly in proportion to weekly harvest. Heads were sampled randomly from those left in the collection totes, if numbers were greater than the weekly sampling goal. In the escapement, sockeye salmon carcasses were collected from each inlet stream during escapement surveys and mark-recapture sampling. Because most carcasses are removed by bears or washed back downstream, the crew attempted to sample most of the available carcasses. The sample size goal from the escapement was 300 fish, including 200 fish from Threemile Creek and 50 fish each from Inlet and Halfmile creeks, distributed roughly evenly among the last three to four weeks of the spawning period.

Otolith pairs were dissected from the sampled fish, cleaned, and sent to the ADF&G Mark, Tag, and Age Laboratory. Lab staff examined the otoliths under a microscope to determine the presence and identification (hatchery, brood year) of thermal marks. Results were reported in the Thermal Mark Laboratory Mark Summary Report database (http://tagotoweb.adfg.state.ak.us/OTO/reports/MarkSummary.aspx). Estimates of hatchery proportions in the subsistence harvest, escapement, and combined harvest plus escapement were calculated from the proportion of marked otoliths in the respective samples. We assumed that the proportion of hatchery fish in a sample followed a binomial distribution, and estimated the binomial standard error for the proportion.

LIMNOLOGY

Limnology sampling was conducted at two fixed stations, Station A (formerly Station C) in Basin A and Station B in Basin B, on Klawock Lake (Figure 2). Sampling dates were 25 June, 25

July, 17 August, and 7 September, 2007. Light intensity and temperature profiles were measured only at Station B; zooplankton samples were collected at both stations.

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 (Protomatic). 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.

Secondary Production

Zooplankton density and biomass were estimated by species, to roughly quantify the amount of prey available to sockeye fry rearing in Klawock Lake. One zooplankton sample was collected at each station on each sampling date using a vertical tow. A 0.5 m diameter, 153 um mesh, 1:3 conical net was pulled from a depth of 2 m above the lake bottom or a maximum depth of 50 m, at a constant speed of 0.5 m per 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 counted organisms in the sub-samples by species or genus (Koenings et al. 1987). Average counts by taxon in the sub-samples were expanded by the volume proportion of the sub-sample to estimate the number of individuals by taxon in the whole sample. The density of individuals in the water column under each m^2 of lake surface area was the estimated number in the sample divided by the area, in m^2, of the net opening. Body lengths of individuals in each taxon were measured and averaged. The mean length by taxon and sampling date, weighted by density of the taxon at each sampling date, was averaged for a seasonal mean body length. The seasonal mean biomass (weight per m^2 surface area) was estimated by converting the seasonal mean length to weight, based on known length-weight relationships for each taxon, and multiplying by the seasonal mean density (Koenings et al. 1987). Total seasonal mean zooplankton biomass and density were estimated by summing seasonal means across all species.

RESULTS

SMOLT AGE, WEIGHT, AND LENGTH COMPOSITION

Between 25 April and 13 June 2007, a total of 436 sockeye smolt were counted and passed through the fyke nets in Klawock River (Table 2). Additionally, 404 coho smolt, 11 juvenile pink salmon, 35 cutthroat trout, 2 Dolly Varden char, 7 threespine sticklebacks, and 21 sculpins were passed through the nets.

Table 2.–Summary of sockeye smolt sampling in the Klawock River in 2007.

Sampling start date and time[a]	Duration (hrs)[a]	Water temp (°C)	Number of sockeye smolt: Counted in trap	Number of sockeye smolt: Sampled (AWL)	Coho smolt counted in trap	Comments
25 Apr 3:00 pm	9.5		0	0	0	
28 Apr 7:00 pm	5.5	6.5	0	0	1	
2 May 6:55 pm	6.6	7.2	0	0	2	
5 May 6:15 pm	5.3	7.0	0	0	0	
9 May 6:50 pm	6.4	8.0	0	0	8	
12 May 6:30 pm	7.0	7.0	2	0	5	
16 May 6:15 pm	8.9	8.0	18	8	0	
19 May 8:05 pm	6.2	9.0	13	8	0	
23 May 7:45 pm	7.3	10.0	27	20	1	Added 2nd trap[b]
26 May 8:45 pm	7.0	10.5	120	84	14	
29 May 8:15 pm	7.3	10.0	116	84	37	
31 May 8:30 pm	7.0	10.0	26	20	12	Full moon, low water
2 Jun 9:00 pm	6.1	9.5	68	64	255	Hatchery coho release
5 Jun 8:40 pm	6.2	11.0	21	20	49	Hatchery coho
7 Jun 8:35 pm	4.3	11.0	11	8	11	Hatchery coho
9 Jun 8:40 pm	3.9	12.0	11	8	4	Hatchery coho
12 Jun 9:40 pm	3.8	12.0	3	2	5	Hatchery coho
Average sampling duration	6.4	**Fish totals**	436	326	404	

[a] Sampling was conducted only on dates listed, starting in the evening and continuing into the early morning hours of the following day.
[b] A single fyke net was used from 25 April through 19 May; a second net was added on 23 May.

A subsample of 326 sockeye smolt, distributed through the sampling period (Table 2) were sampled for age, weight, and length. Ages were determined for 324 sockeye smolt, and most (98.5%) were age-1 (Table 3). The few age-2 fish were on average 10 mm longer and weighed 1.4 g more than the age-1 fish.

Table 3.–Average weights and lengths of sockeye salmon smolt sampled in Klawock Lake in 2007.

Age	Number of smolt	Proportion of smolt	Average length, mm (SD)	Average weight, g (SD)
1	319	98.5%	80.1 (4.1)	4.4 (0.6)
2	5	1.5%	90.2 (8.8)	5.8 (1.5)

SUBSISTENCE HARVEST ESTIMATE

A total harvest of about 2,600 sockeye salmon (95% confidence interval 2,300–3,000 fish; CV = 7%) was estimated for the Klawock Inlet subsistence fishery in 2007. Out of the 18 days that the Klawock Inlet subsistence sockeye fishery was open, observation and interviews of the fishery were conducted during 11 days. During all sampling days except those during the second week of the fishery, interviews were conducted for every net set that was observed (Table 4). The maximum daily harvests occurred during the second week of the fishery, and the estimated harvest for the second week included over 50% of the total estimated harvest. Incidental harvests of other salmon species reported to the interviewers included 26 coho, 126 pink, and 10 chum salmon. Because these species are considered incidental, and because harvesting of these species could have continued after the sockeye season was closed, their totals were not estimated.

Table 4.–Summary of observations, interview data, and estimated sockeye harvest in the Klawock River subsistence fishery in 2007. The fishery was open every weekday (Monday through Friday) between 7 and 31 July, and sampling dates were selected at random for each week.

Week	Sampling date	Sets counted	Sets interviewed	Daily harvest reported in interviews	Estimated daily harvest	Estimated weekly harvest	Std error of weekly harvest
8–14 July	9-Jul	11	11	45	45	97	32
	11-Jul	6	6	2	2		
	13-Jul	7	7	11	11		
15–21 July	16-Jul	44	39	368	415	1,382	181
	19-Jul	36	34	236	250		
	20-Jul	19	17	147	164		
22–28 July	23-Jul	35	35	127	127	880	62
	24-Jul	26	26	190	190		
	27-Jul	33	33	211	211		
29–31 July[a]	30-Jul	34	34	195	195	286	0
	31-Jul	18	18	91	91		

[a] Fishery ended 31 July.

SOCKEYE ESCAPEMENT ESTIMATE

At Threemile Creek, 1,294 sockeye spawners were sampled (Table 5) during seven approximately weekly sampling events in 2007 (30 August; 5, 12, 20, 26 September; 4, 9 October). Numbers of recaptures were low, comprising only about 8% of all fish sampled. About half of the recaptured fish were caught in the next event after initial tagging, and the remainder were caught in a later event. Almost three-quarters of the recaptures were fish first caught and tagged in the first or second sampling event, indicating that stream survival rates dropped considerably as the spawning period progressed.

The Jolly-Seber estimate of the total number of sockeye salmon that spawned in Threemile Creek in 2007 was about 8,000 fish (95% confidence interval 5,400–14,900; CV=27%). The high coefficient of variation exceeded the objective (coefficient of variation less than 15%).

Table 5.–Summary of capture-recapture histories of sockeye salmon sampled on the spawning grounds at Threemile Creek in Klawock Lake, 2007.

Capture-recapture category	Capture history[a]	Number of fish[b]
Captured only once; tagged and released	1000000	284
	0100000	328
	0010000	363
	0001000	50
	0000100	65
	0000010	59
	0000001	40
Subtotal		**1,189**
Captured and released, then recaptured and released at next event	1100000	14
	0110000	21
	0001100	3
	0000110	7
	0000011	5
Subtotal		**50**
Captured and released, not captured in next event, but recaptured and released in a later event	1010000	28
	1000100	1
	0101000	3
	0100100	5
	0010100	2
	0010010	2
	0010001	1
	0001010	3
	0001001	1
	0000101	2
Subtotal		**48**
Recaptured and released more than once	1110000	2
	1000110	1
	0110100	1
	0010011	1
	0000111	2
Subtotal		**7**
Total sampled and released		**1,294**

[a] Capture histories show one digit for each of seven sampling events in chronological order: a "1" indicates a sampling event in which the fish was caught, and a "0" indicates a sampling event in which the fish was not caught.
[b] The number of fish with each observed capture history is shown.

At Inlet Creek, 922 sockeye spawners were sampled (Table 6) during five sampling events in 2007 (29 August; 4, 11, 18, 28 September). Recapture numbers were low, and recaptures comprised only about 5% of all fish sampled. Furthermore, most of the recaptures were fish initially sampled in the first or second sampling event, indicating very low stream survival after early September.

The Jolly-Seber estimate of the total number of sockeye salmon that spawned in Inlet Creek in 2007 was about 8,100 fish (95% confidence interval 5,200–16,900; CV=35%). The coefficient of variation was large and exceeded the objective (coefficient of variation less than 15%).

Table 6.–Summary of capture-recapture histories of sockeye salmon sampled on the spawning grounds at Inlet Creek in Klawock Lake, 2007.

Capture-recapture category	Capture history[a]	Number of fish[b]
Captured only once; tagged and released	10000	136
	01000	227
	00100	320
	00010	143
	00001	47
Subtotal		**873**
Captured and released, then recaptured and released at next event	11000	7
	01100	14
	00110	4
	00011	2
Subtotal		**27**
Captured and released, not captured in next event, but recaptured and released in a later event	10100	14
	01010	3
	01001	1
	00101	2
Subtotal		**20**
Recaptured and released more than once	11100	1
	11010	1
Subtotal		**2**
Total sampled and released		**922**

[a] Capture histories show one digit for each of five sampling events in chronological order: a "1" indicates a sampling event in which the fish was caught, and a "0" indicates a sampling event in which the fish was not caught.

[b] The number of fish with each observed capture history is shown.

At Halfmile Creek, fewer sockeye spawners were present than in Threemile and Inlet creeks, and only 330 fish were sampled (Table 7) in a total of six approximately weekly sampling events in 2007 (31 August; 6, 13, 20, 16 September; 1 October). A slightly higher percentage, about 12%, of the fish sampled at Halfmile Creek were recaptures, compared with Threemile and Inlet creeks, and recaptures were more evenly distributed across all sampling events.

The Jolly-Seber estimate of the total number of sockeye salmon that spawned in Halfmile Creek in 2007 was about 1,400 fish (95% confidence interval 1,000–2,300; CV=21%). The coefficient of variation, although closer than those of the estimates for Threemile and Inlet creeks, still exceeded the objective (coefficient of variation less than 15%).

Table 7.–Summary of capture-recapture histories of sockeye salmon sampled on the spawning grounds at Halfmile Creek in Klawock Lake, 2007.

Capture-recapture category	Capture history[a]	Number of fish[b]
Captured only once; tagged and released	100000	48
	010000	80
	001000	50
	000100	62
	000010	34
	000001	17
Subtotal		291
Captured and released, then recaptured and released at next event	110000	5
	011000	1
	001100	4
	000110	6
	000011	2
Subtotal		18
Captured and released, not captured in next event, but recaptured and released in a later event	101000	6
	100010	2
	010100	6
	010001	1
	000101	2
Subtotal		17
Recaptured and released more than once	111000	2
	001101	1
	001001	1
Subtotal		4
Total sampled and released		330

[a] Capture histories show one digit for each of six sampling events in chronological oreder: a "1" indicates a sampling event in which the fish was caught, and a "0" indicates a sampling event in which the fish was not caught.

[b] The number of fish with each observed capture history is shown.

The sum of the estimated sockeye spawning populations for Threemile, Inlet, and Halfmile creeks in 2007 was 17,500 fish (CV=22%). No sockeye count was available from the Prince of Wales Hatchery Association weir operation in 2007. Therefore, the summed spawning population estimate was considered to be a minimum estimate of sockeye escapement for Klawock Lake in 2007.

ESCAPEMENT AGE, SEX, AND LENGTH COMPOSITION

A total of 611 sockeye salmon was sampled for age, sex, and length composition. Of these, 517 fish were successfully aged and represented brood years 2001 to 2004. Five-year-old fish from the 2002 brood year (age classes 1.3 and 2.2) comprised an estimated 58% of the 2007 escapement, and four-year-old fish from the 2003 brood year (age classes 1.2 and 2.1) comprised an estimated 32% of escapement (Table 8). Age-1.1 jacks from the 2004 brood year and six-year-old fish from the 2001 brood year comprised the remainder of the escapement. About 68% of fish in the escapement had one freshwater year (age classes 1.1, 1.2, and 1.3), and the remaining 32% had two freshwater years (age classes 2.1, 2.2, and 2.3). As expected, the size of these sockeye salmon corresponded with the time spent in the marine environments; those with three ocean years had average lengths around 50 mm greater than those with two ocean years (Table 9). The large size, average 478 mm, of fish aged as 2.1 jacks, is characteristic of the Klawock Lake sockeye stock.

Table 8.–Age composition and proportion of sockeye salmon sampled in 2007 in Klawock Lake, by sex, brood year, and age class.

Brood year	2004	2003	2002	2003	2002	2001	All fish, by sex
Age class	1.1	1.2	1.3	2.1	2.2	2.3	
Male							
Number	12	89	85	12	34	23	255
Percentage	2%	17%	16%	2%	7%	4%	49%
Std. error	0.7%	1.7%	1.6%	0.7%	1.1%	0.9%	2.2%
Female							
Number	0	68	103	0	80	11	262
Percentage		13%	20%		15%	2%	51%
Std. error		1.5%	1.8%		1.6%	0.6%	2.2%
All fish							
Number	12	157	188	12	114	34	517
Percentage	2%	30%	36%	2%	22%	7%	
Std. error	0.7%	2.0%	2.1%	0.7%	1.8%	1.1%	

Table 9.–Length composition of sockeye salmon sampled in 2007 in Klawock Lake, by sex, brood year, and age class.

Brood year	2004	2003	2002	2003	2002	2001
Age class	1.1	1.2	1.3	2.1	2.2	2.3
Male						
Sample size	12	89	85	12	34	23
Mean length (mm)	375	521	582	478	538	589
Std. error (mm)	10	4	4	11	6	9
Female						
Sample size	0	68	103	0	80	11
Mean length (mm)		512	554		519	531
Std. error (mm)		4	4		4	14
All fish						
Sample size	12	157	188	12	114	34
Mean length (mm)	375	517	567	478	525	570
Std. error (mm)	10	3	3	11	3	8

HATCHERY CONTRIBUTION

A total of 382 sockeye salmon was sampled for otoliths from the subsistence fishery, exceeding the target sample size of 200, but the total of 129 carcasses sampled from the spawning streams fell short of the target of 300 fish. Distribution of samples among the three escapement sampling locations very roughly reflected spawner abundance in those streams: 55 samples from Threemile Creek, 70 samples from Inlet Creek, and 4 samples from Halfmile Creek. By date, samples were collected from Threemile Creek on 11 and 18 September and 1 October; from Inlet Creek on 11, 18, and 28 September and 8 October; and from Halfmile Creek on 11 September and 1 October. The combined sample comprised 511 otolith pairs, of which 506 pairs were analyzed (Table 10). Only 14 thermal marks were recovered from the entire combined sample, ten from the subsistence sample of 378 fish and four from the escapement sample of 128 fish (Table 10). Thus, the estimated contribution of hatchery-incubated sockeye salmon was just 2.6% (SE=0.8%) of the subsistence harvest, 3.1% (SE=1.5%) of the escapement, and 2.8% (SE=0.7%) of the total population of returning adults in 2007. Most of the marked otoliths were identified to brood year 2003 (four-year-old fish); only one marked otolith was identified to brood year 2002 (five-year-old fish); and three marked otoliths were identified to brood year 2004 (age-1.1 jacks). No marks from brood years 2001 or 2000 (six- or seven-year-old fish) were found in the sample. Eight sockeye otolith pairs with thermal marks identified to the Klawock hatchery were recovered in distant commercial fisheries (ADF&G Division of Commercial Fisheries Mark, Tag, and Age Laboratory online reports, http://tagotoweb.adfg.state.ak.us/OTO/reports/MarkSummary.aspx). Because these marked otoliths were recovered incidentally in other sampling programs targeting other stocks and fisheries, and miniscule in number compared with the total number of samples (over 20,000), they were ignored.

Table 10.–Summary of sockeye otolith sample sizes and numbers of hatchery-marked otoliths from the Klawock Inlet subsistence fishery and the Klawock Lake escapement in 2007.

Sample date	Number sampled	Number analyzed	Number not marked	Number marked by brood year			Total number marked
				2002	2003	2004	
12-Jul	19	19	19	0	0	0	0
17-Jul	130	128	125	0	3	0	3
23-Jul	185	183	178	0	3	2	5
30-Jul	48	48	46	0	1	1	2
11-Sep	56	55	55	0	0	0	0
18-Sep	40	40	40	0	0	0	0
28-Sep	14	14	14	0	0	0	0
1-Oct	17	17	13	1	3	0	4
8-Oct	2	2	2	0	0	0	0
Totals	511	506	492	1	10	3	14 (2.8%)
Subsistence subtotal	382	378	368	0	7	3	10 (2.6%)
Escapement subtotal	129	128	124	1	3	0	4 (3.1%)

LIMNOLOGY

Light and Temperature Profiles

Due to technical problems with the light meter, the euphotic zone depth was not estimated during the early season in 2007. The earliest valid measurements were obtained on 25 July, and valid measurements were also obtained on 17 August and 7 September. The estimated euphotic zone was between 7.6 and 7.7 m on all three measurement dates. Lake temperature profiles showed thermal stratification developing by the earliest sampling date, 25 June, with considerable warming of the water column above about 15 m. However even though the water temperature warmed to temperatures over 20°C, the maximum thermocline, observed on 17 August, reached only shallow depths between 3 and 7 m (Figure 3).

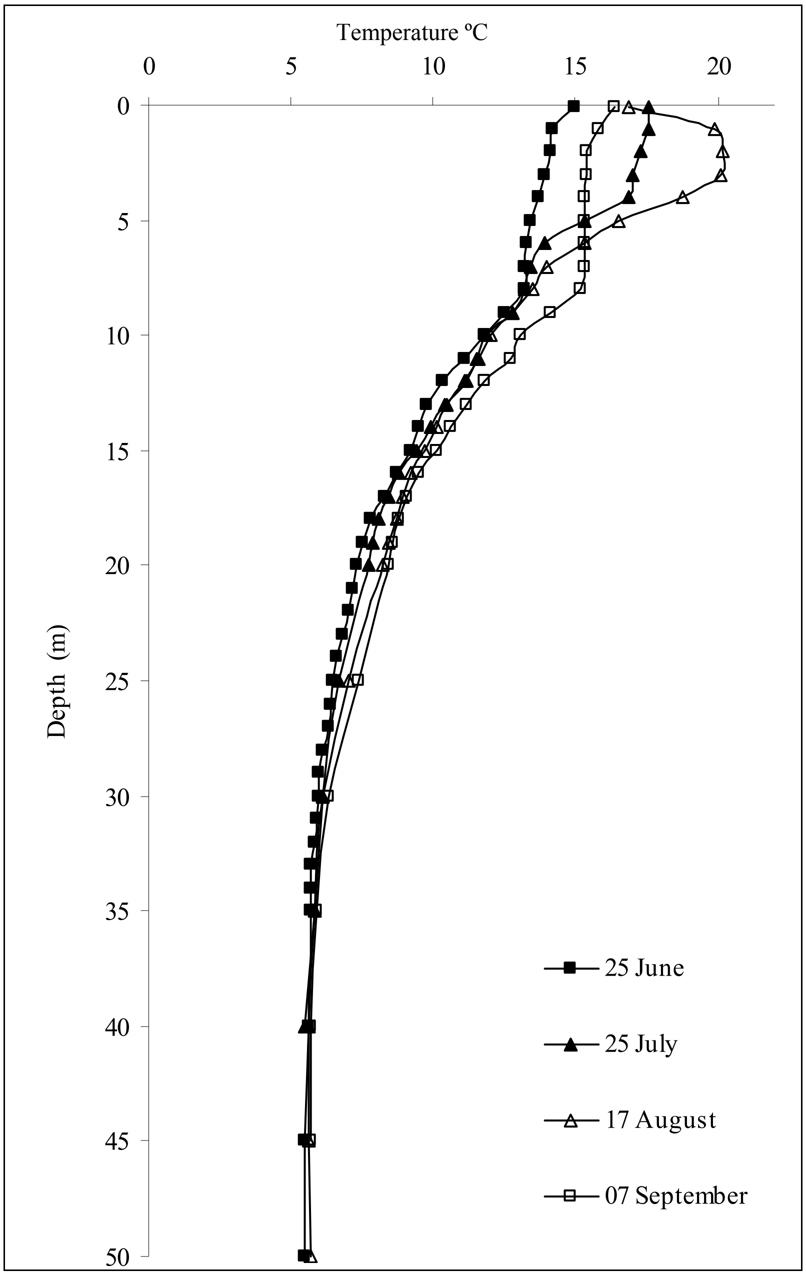

Figure 3.–Water temperature profiles of Klawock Lake in 2007.

Secondary Production

Cladocera dominated the zooplankton assemblage numerically in Klawock Lake in 2007. *Bosmina* sp. was the most numerous taxon comprising over 52% of the seasonal mean total density (Table 11). Because of its very small body size, *Bosmina* contributed far less, only about 21%, to the estimated seasonal mean biomass, while the larger-bodied cladocerans *Daphnia* and *Holopedium* each made up a greater share of the biomass than of the numerical assemblage. *Daphnia*, a genus preferred by foraging sockeye fry, comprised 2.9% of the total zooplankton density but 3.7% of total zooplankton biomass. On the whole, individual body size was larger in the copepoda, and they comprised over 50% of the total zooplankton biomass (Table 12).

Table 11.–Zooplankton density in Klawock Lake, 2007. Density estimates are averages of samples collected approximately monthly at stations A and B.

	Zooplankton density (numbers per m^2) by date[a]				Season	Percent
	6/25	7/25	8/17	9/7	mean	of total
Copepoda						
Epischura sp.	14,519	7,562	8,278	17,066	11,856	16.1%
Ovigerous *Epischura*	0	48	0	0	12	0.0%
Diaptomus sp.	85	0	0	0	21	0.0%
Ovigerous *Diaptomus*	0	0	0	0	0	0.0%
Cyclops sp.	24,113	8,151	4,903	25,217	15,596	21.2%
Ovigerous *Cyclops*	1,443	191	255	0	472	0.6%
Nauplii	764	1,289	2,929	891	1,469	2.0%
Cladocera						
Bosmina sp.	44,405	32,317	46,867	29,929	38,379	52.1%
Ovigerous *Bosmina*	0	0	318	0	80	0.1%
Daphnia sp.	594	621	1,592	5,094	1,975	2.7%
Ovigerous *Daphnia*	0	0	255	255	127	0.2%
Holopedium	5,943	0	0	0	1,486	2.0%
Ovig. *Holopedium*	1,104	0	0	0	276	0.4%
Immature Cladocera	3,990	1,465	1,337	1,146	1,985	2.7%
			Total zooplankton seasonal mean density		**73,734**	

[a] Density is the estimated number of individual zooplankters in the total water column, per square meter of surface area.

Table 12.–Seasonal mean length and biomass of zooplankton in Klawock Lake in 2007. Estimates are averages of stations A and B. Ovigorous and non-ovigorous stages were combined.

	Mean length (mm)	Seasonal mean biomass (mg·m^{-2})	Percent of total biomass
Copepoda			
Epischura sp.	1.12	72.1	41.2%
Ovigerous *Epischura*	1.61	0.4	0.2%
Diaptomus sp.	1.24	0.3	0.2%
Cyclops sp.	0.76	31.1	17.6%
Ovigerous *Cyclops*	1.00	1.7	0.9%
Cladocera			
Bosmina sp.	0.33	37.5	21.3%
Ovigerous *Bosmina*	0.38	0.2	0.1%
Daphnia sp.	0.77	5.1	2.9%
Ovigerous *Daphnia*	1.10	1.4	0.8%
Holopedium	0.85	22.8	12.9%
Ovig. *Holopedium*	1.11	3.1	1.8%
Total zooplankton seasonal mean biomass		**176.3**	

DISCUSSION

A similar or slightly higher number of adult sockeye salmon returned to Klawock Lake to spawn in 2007 as compared with the previous six years. Overall, the stability of this sockeye spawning population in recent years is noteworthy, and may allay concerns that this stock is currently in decline (Table 13; Conitz 2008; Conitz and Cartwright 2007; Conitz et al. 2006; Cartwright and Conitz 2006; Cartwright and Lewis 2004; Lewis and Cartwright 2002).

The estimate itself, based on an open-population model with sampling exclusively in the three main spawning streams, had more uncertainty than in previous years, when weir counts plus weir-based mark-recapture estimates were conducted (Table 13). The mark-recapture only program for escapement estimation was implemented in 2007 as a cost saving measure for the project. However, the estimate did not meet the objective for precision, and so overall, the objective of estimating escapement was only partially fulfilled by this method. Confidence in the escapement estimates produced by this project had increased after the weir was rebuilt in 2004 (Conitz et al. 2006). Nevertheless, a mark-recapture study was routinely included in the objectives for escapement estimation because fall flooding in the outlet stream can breach the weir (Cartwright and Conitz 2006). During the first three years of this study, in 2001–2003 and before the weir was rebuilt, the weir count was significantly lower than the mark-recapture estimate in two years (Table 13; Lewis and Cartwright 2002; Cartwright and Lewis 2004; Cartwright and Conitz 2006). With weir improvements in place, weir counts from 2004 to 2006 were consistent with the mark recapture estimates (Table 13). Since 2004, independent mark-recapture studies were also conducted in the three main spawning tributaries for comparison with the weir-based estimates (Conitz 2008; Conitz and Cartwright 2007; Conitz et al. 2006). The reasoning was that project costs might be lowered by using the spawning grounds estimate in lieu of the weir-based estimate if the results were comparable. In three years of comparisons, the independent mark-recapture estimates were lower than the weir-based estimates but not significantly so, given the limits of precision (Table 13). The open population Jolly-Seber estimators which were used can often be negatively biased (Pollock et al. 1990). The poor precision seen in the spawning grounds estimates can be expected given that sampling conditions in the streams are much less predictable than at the weir, and this also makes them a less reliable indicator of escapement in general. The spawning grounds estimates can still serve as a rough gauge of spawning population strength, if rigorously conducted. However, as long as the weir continues to be operated as it has been for hatchery operations, resuming in-season counting of sockeye salmon at the weir with a weir-based mark-recapture estimate seems sensible if the additional cost is not too great.

The estimated subsistence harvest of Klawock sockeye salmon was the second lowest for the 2001–2007 period (Table 14), but substantially better than the extreme low harvest in 2005, which was attributed in part to interference from very large pink salmon runs in that season (Conitz and Cartwright 2007). The combined 2007 sockeye run, including escapement and subsistence harvest but excluding any commercial harvest, was about 20,000 sockeye salmon, only slightly above the average run size for the recent seven-year period. Subsistence harvest during this period has comprised less than one-third of the total run in any one year and only about 22% on average (Table 14). Harvest at this level is unlikely to pose a threat to future populations (H. Geiger, retired fisheries biologist, ADF&G Division of Commercial Fisheries, personal communication 2007).

Table 13.–Comparison of weir counts and mark-recapture estimates of sockeye salmon spawning populations in Klawock Lake, 2001–2007.

Year	Weir Count	Weir-based mark-recapture estimate	95% confidence interval, weir-based estimate	Spawning grounds mark-recapture estimate (CV)	Best available estimate
2001	7,236	14,000	9,000–19,000	na	Weir-based mark-recapture
2002	13,631	13,000	11,500–15,000	na	Weir count
2003	6,276	21,300	na (CV=18%)	na (insufficient sampling)	Weir-based mark-recapture
2004	12,442	13,000	10,600–15,400	11,000 (23%)	Weir count
2005	14,840	13,700	12,400–15,200	10,500 (~30%)	Weir count
2006	14,757	13,600	12,500–14,800	11,000 (30%)	Weir count
2007	na	na	na	17,500 (22%)	Spawning grounds mark-recapture

Table 14.–Estimated subsistence sockeye salmon harvest, spawning escapement estimates, and total run size including escapement plus subsistence harvest for 2001 to 2007. Subsistence harvest reported on returned permits is also included for comparison with the direct, on-site estimates.

Year	Estimated subsistence harvest	Subsistence harvest reported on returned permits	Estimated escapement	Subsistence harvest + escapement
2001	6,400	4,433	14,000	20,400
2002	6,000	3,778	13,600	19,600
2003	6,000	3,195	21,300	27,300
2004	4,500	2,697	12,400	16,900
2005	175	238	14,800	14,975
2006	3,100	1,849	14,757	17,857
2007	2,600	2,042	17,500	20,100
Average, all yrs	4,363	2,605	15,480	19,590

The contribution of hatchery-produced sockeye salmon to the Klawock Inlet subsistence fishery and the Klawock Lake spawning population continued to be very low, less than 3% overall. The total number of hatchery-reared fish that returned to the Klawock Lake system likely failed to even replace the offspring that would have been produced naturally from those fish taken as broodstock, if they had been left in the wild. In other words, the hatchery-reared sockeye salmon from Klawock Lake appear to have had lower survival rates than those that were spawned and reared in the wild. Sockeye salmon in the 2007 escapement were the offspring of brood years 2001–2004. Those fish would have been rearing in Klawock Lake between 2002 and 2005, and during each of those years between 365,000 and 706,000 hatchery-incubated sockeye fry were released into Klawock Lake between early March and early May. In addition, between 2.2 and 4.6 million coho fry were reared annually in the lake in net pens during those years (http://tagotoweb.adfg.state.ak.us/CWT/reports/hatcheryrelease.asp).

Sockeye adult and smolt age compositions have been examined for evidence of change in growth and age at smolting. The age composition of sockeye salmon in the 2007 spawning population reflected the average age composition for the 2001–2007 period, with about 68% of fish having one freshwater year and about 32% having two freshwater years. This contrasts with average adult age compositions estimated in the 1980s and 1990s, when about 83% of sockeye spawners had one freshwater year and only 17% had two freshwater years (Appendix B in Conitz 2008). This change possibly reflects an increase, on average, in age at smolting for Klawock sockeye salmon; the additional time spent by the average sockeye fry in Klawock Lake would suggest slower growth and reduced food supply.

Results of direct smolt sampling and aging were inconclusive. Less than 2% of the sockeye smolt sampled in 2007 were age-2 fish, and in 2001 and 2002, age-2 smolt represented just 12% and 9% of fish sampled (Cartwright and Lewis 2004; Lewis and Cartwright 2002). However, smolt catches at the weir site in all three years were very low throughout the smolting period, indicating that the traps were inefficient in capturing sockeye smolt. Larger, older fish would be most able to avoid the traps, and therefore, the observed age compositions may not be representative of the true age compositions in these smolt populations.

Zooplankton evidence gathered so far suggests that the lake has adequate secondary production; however, the total zooplankton estimates for 2007 were somewhat lower than in previous years (Figure 4). Some of the differences shown in Figure 4 can probably be attributed to differences in personnel and other differences in the analyses in each of the three time periods (1986–1988, 2000–2004, and 2007), although the general methods did not change. Perhaps more significantly, in 2007 samples were sent for the first time to the ADF&G Near Island Laboratory in Kodiak for analysis, due to closure of the ADF&G limnology laboratory in Soldotna, where sample analyses had been performed in all preceding years. Changes in sampling stations in Klawock Lake could be another source of difference among samples from the different time periods. In 2000–2004, two sampling stations in each of the two main lake basins were used, but in the 1980s and in 2007, only one station was used in each basin.

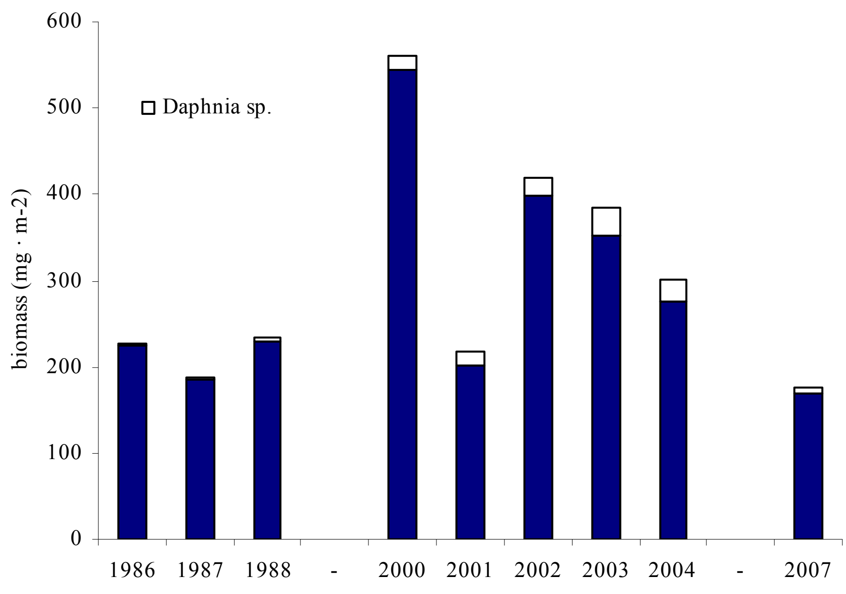

Figure 4.–Seasonal mean biomass of Klawock Lake zooplankton and contribution of *Daphnia* sp. in three time periods from 1986 through 2007.

In order to answer questions about relationships involving lake productivity and growth of sockeye fry in Klawock Lake, a more focused zooplankton sampling effort is needed in conjunction with a more intensive smolt sampling program. The observed changes in adult age composition show evidence that fry have been growing more slowly in more recent years, but the supporting evidence from juvenile life history and lake productivity studies to date is insufficient to explain the cause. The spawning and rearing environments for sockeye salmon in Klawock Lake have been compromised over many decades by logging, road building, water withdrawals, and hatchery operations. Attempts to understand current sockeye population dynamics must take these factors into consideration, although the exact nature of their effects remains unknown. Nevertheless, any efforts to rebuild to stock, including recent watershed restoration activities, cannot be expected to succeed unless the factors contributing to sockeye growth and survival in the lake are better understood. If the conditions which have allowed the adult sockeye runs to remain stable and provide a mostly adequate subsistence harvest during the most recent seven-year period continue to hold, the stock does not appear to be in immediate trouble. However, not knowing what factors contribute positively or negatively to the health of this stock leave it vulnerable to future, unexplainable declines, possibly similar to those that have already occurred in the past.

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