

Fishery Data Series No. 10-13

**Kanalku Lake Subsistence Sockeye Salmon Project:
2008 Annual Report**

by

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March 2010

Alaska Department of Fish and Game

Divisions of Sport Fish and Commercial Fisheries



Symbols and Abbreviations

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Weights and measures (metric)		General		Measures (fisheries)	
centimeter	cm	Alaska Administrative Code	AAC	fork length	FL
deciliter	dL			mid-eye to fork	MEF
gram	g	all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.	mid-eye to tail fork	METF
hectare	ha			standard length	SL
kilogram	kg	all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.	total length	TL
kilometer	km				
liter	L	at	@	Mathematics, statistics	
meter	m	compass directions:		<i>all standard mathematical signs, symbols and abbreviations</i>	
milliliter	mL	east	E	alternate hypothesis	H _A
millimeter	mm	north	N	base of natural logarithm	<i>e</i>
		south	S	catch per unit effort	CPUE
Weights and measures (English)		west	W	coefficient of variation	CV
cubic feet per second	ft ³ /s	copyright	©	common test statistics	(F, t, χ^2 , etc.)
foot	ft	corporate suffixes:		confidence interval	CI
gallon	gal	Company	Co.	correlation coefficient (multiple)	R
inch	in	Corporation	Corp.	correlation coefficient (simple)	r
mile	mi	Incorporated	Inc.	covariance	cov
nautical mile	nmi	Limited	Ltd.	degree (angular)	°
ounce	oz	District of Columbia	D.C.	degrees of freedom	df
pound	lb	et alii (and others)	et al.	expected value	<i>E</i>
quart	qt	et cetera (and so forth)	etc.	greater than	>
yard	yd	exempli gratia (for example)	e.g.	greater than or equal to	≥
		Federal Information Code	FIC	harvest per unit effort	HPUE
Time and temperature		id est (that is)	i.e.	less than	<
day	d	latitude or longitude	lat. or long.	less than or equal to	≤
degrees Celsius	°C	monetary symbols (U.S.)	\$, ¢	logarithm (natural)	ln
degrees Fahrenheit	°F	months (tables and figures): first three letters	Jan, ..., Dec	logarithm (base 10)	log
degrees kelvin	K	registered trademark	®	logarithm (specify base)	log ₂ , etc.
hour	h	trademark	™	minute (angular)	'
hour	h	United States (adjective)	U.S.	not significant	NS
minute	min	United States of America (noun)	USA	null hypothesis	H ₀
second	s	U.S.C.	United States Code	percent	%
		U.S. state	use two-letter abbreviations (e.g., AK, WA)	probability	P
Physics and chemistry				probability of a type I error (rejection of the null hypothesis when true)	α
all atomic symbols				probability of a type II error (acceptance of the null hypothesis when false)	β
alternating current	AC			second (angular)	"
ampere	A			standard deviation	SD
calorie	cal			standard error	SE
direct current	DC			variance	
hertz	Hz			population	Var
horsepower	hp			sample	var
hydrogen ion activity (negative log of)	pH				
parts per million	ppm				
parts per thousand	ppt, ‰				
volts	V				
watts	W				

FISHERY DATA SERIES NO. 10-13

**KANALKU LAKE SUBSISTENCE
SOCKEYE SALMON PROJECT: 2008 ANNUAL REPORT**

by

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ABSTRACT

For at least 1,000 years, the Kanalku Lake sockeye salmon (*Oncorhynchus nerka*) stock has provided for an important traditional Tlingit fishery for the residents of Angoon, Alaska. Due in part to its proximity to the village, residents have long depended on Kanalku Lake salmon runs, and it is their preferred source of subsistence sockeye salmon. Recent concerns about the sustainability of the stock prompted the establishment of an assessment program beginning in 2001. Mark-recapture studies were conducted to estimate the escapement in Kanalku Lake between 2001 and 2006, and a weir was implemented in 2007 to increase confidence in the estimates and observe the run timing. The weir count of 967 adult sockeye salmon in 2008 was lower than the weir-to-spawning-grounds mark-recapture estimate of 1,200 fish (95% confidence interval 1,000–1,500). The mark-recapture estimate was accepted as the best estimate of the total escapement into Kanalku Lake in 2008 because it met our pre-defined statistical criteria. In 2002, local residents and ADF&G agreed upon a voluntary reduction of subsistence harvest of sockeye salmon to help stocks rebuild. In 2006 and 2007, a traditional subsistence fishery for sockeye salmon in Kanalku Bay was opened under a shortened season. 2008 marked the return of traditional subsistence sockeye fishing at Kanalku Bay with a reported harvest of about 700 sockeye salmon by over 40 permit holders. In 2008, over 95% of the returning adults were estimated to be in a single age class, age 1.2. This result was indicative of a very weak return of age-1.3 fish from the 2003 brood year. Water temperature, euphotic zone depth, and zooplankton populations in Kanalku Lake appear to be adequate for good sockeye fry production in 2008.

Key words: sockeye salmon, *Oncorhynchus nerka*, subsistence, Kanalku Lake, escapement, weir, mark-recapture, age composition, limnology, zooplankton, Southeast Alaska.

INTRODUCTION

The Kanalku Lake system, located on the western side of Admiralty Island in Southeast Alaska, has traditionally been an important source of sockeye salmon (*Oncorhynchus nerka*) for Angoon residents. Several other fishing grounds in the vicinity are also used by the community, but the proximity and sheltered access of Kanalku Bay makes it the preferred harvest area (Conitz and Cartwright 2002). Remains of ancient weir structures at the mouth of Kanalku Creek, oral history, and other evidence, indicate uninterrupted use of this sockeye salmon resource for at least 1,000 years (de Laguna 1960; Moss 1989; Thornton 1990; Goldschmidt et al. 1998). Since 1985, subsistence harvests have been required to be reported on permits returned to ADF&G at the end of the fishing season. Although these self-reported harvest data should be considered minimum estimates of actual harvest (Conitz and Cartwright 2003; Lewis and Cartwright 2004; Lorrigan et al. 2004), reported harvests can show general patterns and trends. In the 1990s, annual total reported harvests of Kanalku Lake sockeye salmon were 2 to 3 times higher than typical harvest levels reported in the previous decade (Figure 1). During the same period, some Angoon fishermen observed a sharp decline in sockeye salmon runs at Kanalku Bay (Conitz and Burrell 2008). The long-term sustainability of the Kanalku sockeye salmon run and the traditional subsistence fishery had come under question over fears that overharvest had been a factor in the decline. Low escapement numbers prompted Alaska Department of Fish and Game (ADF&G) fisheries managers to consider an emergency closure at Kanalku Bay. Instead, Angoon residents agreed to voluntarily close subsistence fishing in Kanalku Bay from 2002 to 2005, although a limited harvest did occur during those years (Figure 1; Burrell and Conitz 2007). The decrease in available sockeye salmon for subsistence harvest concerned Angoon residents, as it was a major source of salmon for their cultural, traditional, and subsistence needs.

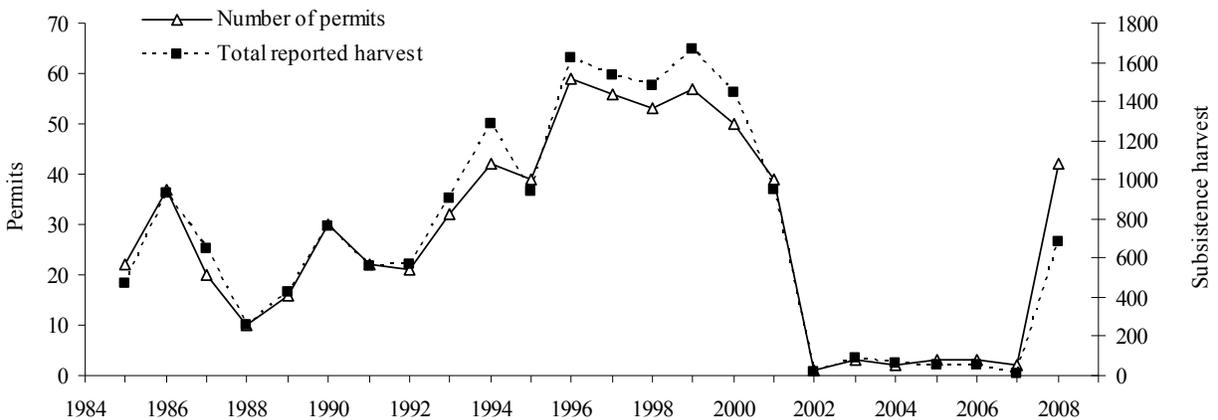


Figure 1.—Subsistence sockeye salmon permits returned and reported subsistence sockeye salmon harvest at Kanalku Bay, 1985–2008.

In 2006, after several years of confusion over the voluntary closure of subsistence fishing, ADF&G fisheries managers decided to resume the regular permitted subsistence fishery, but with a later fishing season, from 20 July to 15 August, and a smaller harvest limit of 15 fish per individual and household. Angoon residents were also allowed an increased harvest limit at both Sitkoh and Basket bays. In 2007 and 2008, the subsistence fishing season was shifted to an earlier season, from 1 June through 31 July, but the individual and household limits of 15 fish stayed in place. Harvest was minimal in 2007, but a sharp increase in subsistence harvest was observed in 2008 (Figure 1).

Due in part to concerns about declining run sizes, ADF&G implemented a sockeye salmon assessment program for the Kanalku Lake system in 2001. Escapements in 2001 and 2003 were estimated at less than 275 fish (Conitz and Cartwright 2005). In 2001, the subsistence harvest in Kanalku Bay exceeded the estimated escapement into Kanalku Lake. The escapement estimates from 2004 to 2006 were all greater than 1,000 sockeye salmon; however, the 2007 mark-recapture escapement estimate was only 630 fish (Vinzant et al. 2009).

Another impediment for the spawning sockeye salmon population in Kanalku Lake is the falls on the migration route up Kanalku Creek. In 2006, U.S. Forest Service personnel attempted to estimate the rate of natural mortality for sockeye salmon migrating past the falls by tracking radio-tagged fish; however, this effort was not successful (B. Van Alen, U.S. Forest Service, Juneau, *personal communication*, 2007). In 2007 and 2008, U.S. Forest Service biologists attempted a conventional mark-recapture program in a second attempt to estimate the natural mortality rate associated with migration over the falls.

Sockeye salmon escapement at Kanalku Lake may also be affected, to an unknown extent, by commercial fisheries in Chatham Strait, where they are harvested incidentally in purse seine fisheries targeting pink (*Oncorhynchus gorbuscha*) and chum (*Oncorhynchus keta*) salmon. The proportion of the total catch, if any, from Kanalku Lake stocks is unknown; however, the magnitude of these harvests is likely insignificant because of the early run timing of Kanalku Lake sockeye salmon relative to the opening date of the District 12 seine fishery (Geiger et al. 2007).

In 2008, our primary goal was to estimate the escapement of spawning sockeye salmon into Kanalku Lake. Continuation of the weir project near the outlet of Kanalku Lake allowed us to observe run timing, collect biological data, and estimate the total spawning population with a weir count and a weir-to-spawning-grounds mark-recapture estimate. Monitoring the Kanalku Lake sockeye salmon escapement will allow fisheries biologists and managers to consider escapement trends in developing subsistence fishing management strategies, with the goal of optimizing future runs and ensuring sustainable spawning escapements and harvest opportunities for this small and vulnerable run.

OBJECTIVES

1. Count all salmon species passed through a weir to Kanalku Lake for the duration of the sockeye salmon run, using conventional visual methods.
2. Estimate the escapement of sockeye salmon into Kanalku Lake with mark-recapture studies, marking fish at the weir and sampling for marked fish on the spawning grounds, so the estimated coefficient of variation is less than 15%.
3. Estimate the age, length, and sex composition of the Kanalku Lake sockeye salmon escapement.
4. Measure water column temperature and light profiles in Kanalku Lake through the season. Estimate zooplankton species composition, size, abundance, and biomass.

METHODS

STUDY SITE

Kanalku Lake (ADF&G stream no. 112-67-58/60; lat 57° 29.22'N long 134° 21.02'W) is about 20 km southeast of Angoon (Figure 2) and lies in a steep mountainous valley within the Hood-Gambier Bay carbonates ecological subsection (Nowacki et al. 2001). The U-shaped valley and rounded mountainsides are characterized by underlying carbonate bedrock and built up soil layers supporting a highly productive spruce forest, especially over major colluvial and alluvial fans. The watershed area is approximately 32 km², with one major inlet stream draining into the east end of the lake. The lake elevation is about 28 m. The lake surface area is about 113 hectares, with mean depth of 15 m, and maximum depth of 22 m (Figure 3). The outlet stream, Kanalku Creek, is 1.7 km long and drains into the east end of Kanalku Bay. In addition to sockeye salmon spawning in the lake, large numbers of pink salmon (*O. gorbuscha*) spawn in the lower part of the outlet creek and intertidal area. A few coho (*O. kisutch*) and chum (*O. keta*) salmon spawn in the Kanalku system, and resident populations of cutthroat trout (*O. clarkii*), Dolly Varden char (*Salvelinus malma*), and sculpin (*Cottus sp.*) are found in Kanalku Lake. A waterfall, approximately 8 to 10 m high and about 0.8 km upstream from the tidewater, forms a partial barrier to migrating sockeye salmon. In 1970, ADFG, working with the U.S. Forest Service, blasted resting pools and a small channel in the falls bedrock to assist the migrating salmon.

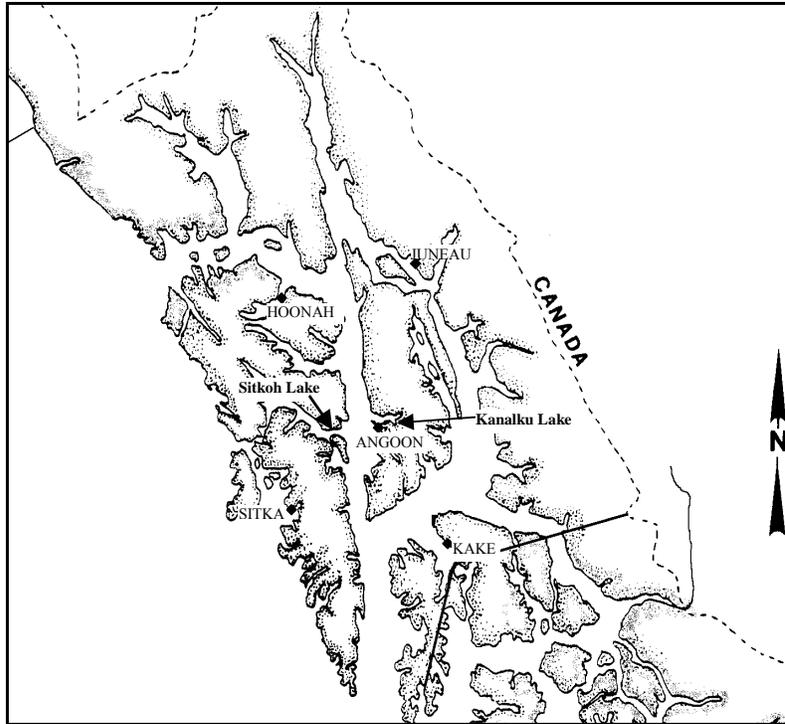


Figure 2.—Map of Southeast Alaska showing location of Kanalku Lake and the village of Angoon.

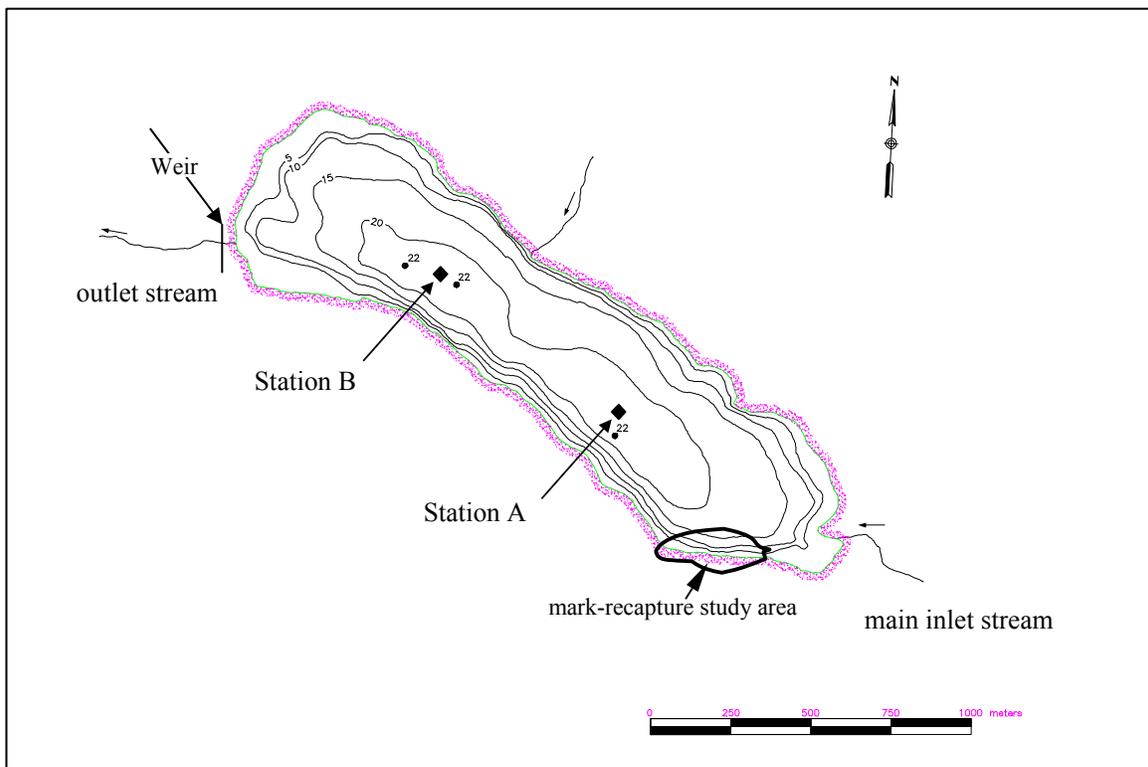


Figure 3.—Bathymetric map of Kanalku Lake, showing 5 m depth contours, the mark-recapture study area, and limnology sampling stations A and B. Arrows indicate direction of stream flow.

SOCKEYE SALMON ESCAPEMENT ESTIMATE

Weir Count

The Kanalku weir was located in Kanalku Creek, the outlet stream at the west side of the lake. The weir consisted of aluminum bipod supports anchored in the stream sediment. The supports were connected by rows of stringers that extended across the entire stream bed, with pickets inserted through regularly-spaced holes in the stringers into the stream bottom. Picket spacing was 1-3/4 inches (4.45 cm) on center of the pickets. Sandbags were placed across the stream along both sides of the weir to help stabilize the substrate and secure the pickets in place. A weir trap, sampling station, and catwalk were constructed and attached to the weir. Technicians inspected the weir daily for malfunction and breaches.

To minimize handling, fish were counted through the weir by pulling one or 2 pickets at the upstream side of the weir trap. We placed white sandbags on the bottom of the stream bed at this exit point to aid in fish identification. In addition to counting all fish by species, all sockeye salmon were categorized as jacks (fish less than 400 mm in length) or full-size adults. Water level at a marker near the weir was measured to the nearest millimeter (mm), and air and water temperature were measured in celsius degrees (°C), and recorded daily, along with observations of precipitation and weather. These observations were made at approximately the same time each morning. The weir was in operation from 29 June to 28 August. Observations before and after these dates, in 2008 and previous years, indicated that the weir was operated through the entire duration of the run.

Weir to Spawning Grounds Mark-Recapture Estimate

The total population of sockeye salmon was estimated with a stratified Petersen mark-recapture study. The mark-recapture study allowed us to determine if sockeye salmon passed through the weir undetected. Fish were marked at the weir with an adipose fin clip and a T-bar tag with a unique number that was used for post-season stratification of the marking sample. The adipose clip facilitated easy identification of marked fish and served as the primary mark in the event of tag loss. The T-bar tags were applied to the left side of the fish, inserted at the base of the leading dorsal fin rays. The tag number and date applied was recorded for each fish successfully tagged, and any fish marked only with the adipose clip was noted. To minimize handling of fish, only those sampled for age, sex, and length were tagged. The target sample size was 35% of the weekly sockeye salmon escapement. Sockeye salmon that appeared unhealthy were enumerated and released without marks. In addition, sockeye jacks were not marked and were not included in the mark-recapture study.

Fish were sampled for mark recovery with a beach seine in the only major spawning area along the eastern shore of Kanalku Lake, adjacent to the mouth of the inlet stream. No other spawning areas have been observed in Kanalku Lake (Conitz and Burril 2008). Sampling occurred on 28 August, 5 September, 12 September, and 19 September. An opercular punch was applied to all sockeye salmon in these samples to ensure sampling without replacement during that day or in later sampling events.

The 2-sample Petersen model provides a simple method for estimating population size, based on the number of animals marked in the first sample, the number of animals subsequently sampled for marks in the second sample, and the number of marks recovered in the second sample (Seber

1982, p. 59; Pollock et al. 1990). Stratified mark-recapture models extend the 2-sample Petersen method over 2 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). This assumption can be met by satisfying the following conditions: 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 conditions is met, the marking and recovery strata can generally be pooled, thereby providing the most precise estimate. However, if none of these conditions is 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, 2 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 that we used to analyze mark-recapture data and are labeled “equal proportions” and “complete mixing,” respectively (Arnason et al. 1996). We considered a test statistic with p -value ≤ 0.05 to be “significant.” If neither test statistic, or only one test statistic, was significant, we 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, we concluded the pooled estimator had a significant risk of bias, and used the stratified Darroch estimator if it could be calculated. If the SPAS program was unable to converge to a solution for the Darroch estimator, we followed the guidelines and suggestions in Arnason et al. (1996) to search for a partial pooling scheme that would lead to a valid estimate. We 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 Darroch estimate was generated, the 95% confidence interval bounds were used to judge the accuracy of the weir count. If the weir count fell within the 95% confidence interval bounds, it was considered accurate. If the weir count was below the lower 95% confidence interval bound, we considered the possibility that the weir count was inaccurate and some fish escaped into the lake 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 Darroch estimate could not be generated, the weir count was accepted as the best estimate of at least minimum escapement.

A parametric bootstrap procedure was used to estimate the standard error and construct the 95% confidence interval for a pooled-Petersen escapement estimate. We assumed that the number of marked fish recaptured in the second sample, m_2 , follows a hypergeometric probability distribution. Then we used the number of fish marked in the first sample, n_1 , the number of fish caught in the second sample, n_2 , and the Petersen estimate of escapement, \hat{N} , to generate 5,000 simulated recapture numbers based on the hypergeometric probability density function, $f(m_2 | n_1, n_2, \hat{N})$. From the bootstrap values of m_2 , we derived 5,000 Petersen escapement estimates, then calculated the standard error of these estimates and used the 0.025 and 0.975 quantiles to form the 95% confidence interval.

Visual Survey

A visual survey of the entire lake shore was conducted just before each sampling event. Using polarized sunglasses and hand counters, the crew counted sockeye salmon from a boat traveling slowly around the margin of the lake. The visual counts were not used in the estimation procedure because we assumed that each sockeye salmon throughout the entire spawning run was either counted or had an equal probability of being marked. The counts served only as an indicator of the number of fish available on the spawning grounds for sampling at each sampling event. The crew also surveyed up to 1 km of the inlet stream on foot to check for presence or absence of sockeye spawners.

ADULT POPULATION AGE AND SIZE COMPOSITION

To determine the age composition of the sockeye salmon escapement, length, sex, and scale samples were collected from 450 to 500 sockeye salmon at the weir. This sample size was expected to yield an adequate number of scales to estimate proportions of sockeye salmon in the major age classes (Thompson 1992). Expecting an escapement between 1,000 and 2,000 fish, we began the season with a daily sampling rate of 30 to 35%, and adjusted as needed to ensure that we reached our goal of 450 to 500 scale samples. If the escapement appeared to be very low, we kept the sampling rate at or below 50%, to minimize the number of fish handled. Length of each fish, to the nearest millimeter, was measured from mid-eye to tail fork. Fish sex was determined by length and shape of the kype or jaw. The sex and length data were paired by sample number with the scale 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-aging laboratory 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 5-year-old fish with one freshwater and 3 ocean years; Koo 1962). The proportion in each age-sex group was estimated along with its associated standard error, assuming a binominal distribution and using standard statistical techniques as described in common references (e.g., Thompson 1992).

LIMNOLOGY SAMPLING

Sampling technicians recorded underwater light intensity at 0.5 m intervals from just below the surface to the depth where measured intensity was one percent of the sub-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 , $\ln(I_0/I_z)$, 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) is defined as that depth at which light has attenuated to one percent of the intensity just below the lake surface (photosynthetically available radiation, 400–700nm) (Schindler 1971), and is calculated using the equation, $EZD = 4.6205 / K_d$ (Kirk 1994).

Temperature was measured in degrees centigrade (°C) 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 1°C per meter). Below this depth, measurements were made at 5-meter intervals.

Zooplankton samples were collected at 2 fixed stations using a 0.5 m diameter, 153 μm mesh, 1:3 conical net. Vertical zooplankton tows were pulled from a maximum depth of 2 meters from the bottom, at a constant speed of 0.5 m sec^{-1} . The net was rinsed prior to removing the organisms, and all specimens were preserved in neutralized 10% formalin (Koenings et al. 1987). Zooplankton samples were analyzed at the ADF&G limnology laboratory in Kodiak, Alaska. Zooplankton samples were sub-sampled in the laboratory and identified to species or genus, counted and measured (Koenings et al. 1987). Density (individuals per m^2 surface area) was extrapolated from counts by taxon and the seasonal mean density was estimated by averaging densities across the sampling dates. The seasonal mean length of each taxon, weighted by density at each sampling date, was also estimated and used to calculate an estimate of seasonal mean biomass (weight per m^2 surface area) based on known length-weight relationships (Koenings et al. 1987).

RESULTS

SOCKEYE SALMON ESCAPEMENT ESTIMATE

Weir Count

A total of 967 sockeye salmon was counted at the Kanalku outlet creek weir between 29 June and 28 August 2008. No other species of salmon were passed through the weir in that time interval, and no sockeye salmon jacks were observed. The peak period of sockeye salmon escapement occurred between 2 and 9 August, with the largest daily escapement of 184 fish on 6 August (Figure 4). Over the 2-month period, the water depth at the weir fluctuated between 0.28 and 0.59 m. Sockeye salmon migration through the weir was greatest during low-water periods. The weir remained intact through the entire season; we did not observe any obvious gaps or holes in the weir or any scouring below the weir which would have allowed fish to pass undetected.

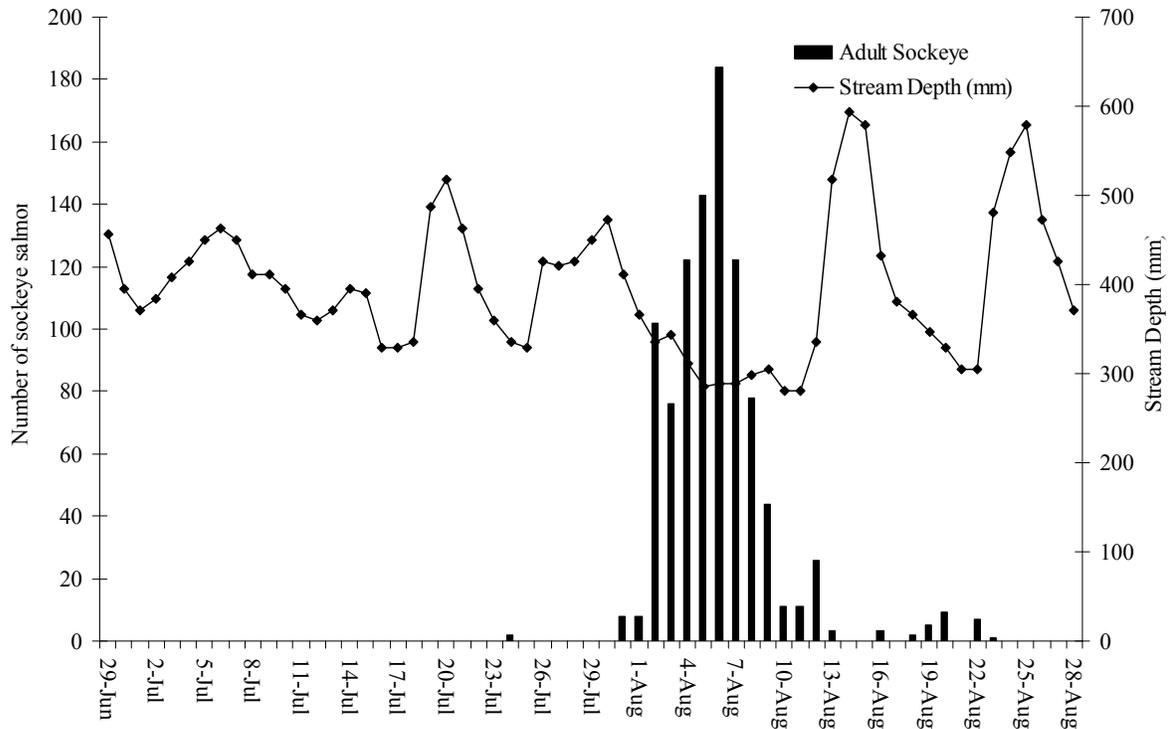


Figure 4.—Daily sockeye salmon counts and water depth levels at Kanalku Lake weir, 2008.

Weir to Spawning Grounds Mark-Recapture Estimate

A total of 434 adult sockeye salmon was captured and marked with uniquely numbered T-bar tags at the Kanalku weir in 2008. Four recapture events were conducted on the spawning beds in Kanalku Lake on 28 August, 5 September, 12 September, and 19 September, 2008. During the recapture efforts, a total of 185 sockeye salmon were captured in the study area. Of these captures, 66 fish were weir-tagged recaptures. Of the 66 marked fish recovered, 6 (9%) had shed their T-bar tag. Tag loss was generally quite easy to determine from the presence of the adipose fin clip (primary mark) and the residual tag hole. Since we could not determine which marking strata these fish were from, we assumed 9% of the total number of tagged sockeye salmon that we released had lost their tag. We then adjusted the marking strata accordingly (Table 1).

The recaptured sockeye salmon were stratified by tagging date (Table 1). Chi-square consistency tests were performed to determine the appropriateness of pooling strata. The test of complete mixing or equal probability of capture in the second event was significant ($X^2 = 21.99$, $df = 1$; $p < 0.05$); however, the test for the assumption of equal capture probability in the first event (i.e., that fish marked in a given stratum had equal probability of recovery in either recapture event) was not significant ($X^2 = 4.45$, $df = 3$, $p = 0.22$). A non-significant result for one of these diagnostic tests indicated the pooled estimator was appropriate for estimating abundance in this study. Therefore, we pooled the data and calculated a Petersen estimate of 1,200 (SE = 119 adult sockeye salmon, with a 95% confidence interval of approximately 1,000 to 1,500 fish and a coefficient of variation of 9.6%). The weir count of 967 sockeye salmon was lower than the lower confidence interval bound of the mark-recapture estimate (1,000 fish); therefore, we will use the mark-recapture estimate of 1,200 adult sockeye salmon as the best estimate of the escapement in 2008.

Table 1.—Number of sockeye salmon marked at weir, and recovery of marked fish at Kanalku Lake spawning area in 2008.

Marking stratum end date	Number marked	Count at weir	Marks recovered by sampling date				Total marks recovered	Proportion of marks recovered
			28-Aug	5-Sep	12-Sep	19-Sep		
5-Aug	180	318	11	20	13	0	44	0.24
23-Aug	215	649	2	5	7	2	16	0.07
Totals	395	967	13	25	20	2	60	
Number sampled			27	89	65	4	185	
Proportion marked in samples			0.48	0.28	0.31	0.5		

Visual Survey

Visual surveys were conducted prior to all recapture events in Kanalku Lake from 28 August to 19 September. The highest averaged count occurred on 5 September when 189 spawning sockeye salmon were observed. The visual counts of sockeye salmon spawners in the study area of Kanalku Lake accounted for the majority of fish observed (Table 2). Foot surveys of the inlet creek on 28 August and 12 September yielded no sightings of sockeye salmon.

Table 2.—Visual counts of sockeye salmon in a designated study area and the entire lake in 2008.

Date	Study area	Entire Lake	Percentage in study area
28 Aug	68	71	96%
05 Sep	184	189	97%
12 Sep	102	102	100%
19 Sep	15	15	100%

ADULT POPULATION AGE AND SIZE COMPOSITION

The crew sampled 431 sockeye salmon for age, sex, and length composition in 2008. Of those, 387 fish were successfully aged. The majority (96%) were age-1.2 from the 2004 brood year (Table 3). The mean lengths of fish corresponded with the time spent in the marine environment. Cohorts of age 1.3 had the highest mean length of 563 mm, while fish of age 1.2 had the smallest mean length of 496 mm (Table 4).

LIMNOLOGY SAMPLING

Light and Temperature Profiles

Light and temperature profiles were measured on 27 June, 31 July, and 28 August, 2008. The euphotic zone depth, the depth of 1% of measured intensity of the sub-surface light, varied from about 11.0 to 14.5 m at the sampling station in Kanalku Lake (Table 5). A pronounced thermocline was never present throughout the sampling period (Figure 5).

Table 3.—Age composition and proportion of sockeye salmon sampled in 2008 at the Kanalku Lake weir, by sex, brood year, and age class.

Stratum	Brood Year, by Age Class				Total aged, by sex
	2004	2003		2002	
	1.2	1.3	2.2	2.3	
Male					
Sample size	150	5	5	1	161
Proportion	38.8%	1.3%	1.3%	0.3%	41.6%
SE	2.5%	0.6%	0.6%	0.3%	2.5%
Female					
Sample size	220	1	5	0	226
Proportion	56.8%	0.3%	1.3%	0.0%	58.4%
SE	2.5%	0.3%	0.6%	0.0%	2.5%
All Fish					
Sample size	370	6	10	1	387
Proportion	95.6%	1.6%	2.6%	0.3%	
SE	1.0%	0.6%	0.8%	0.3%	

Table 4.—Length composition of sockeye salmon sampled in 2008 at the Kanalku Lake weir, by sex, brood year, and age class.

Stratum	Brood Year, by Age Class			
	2004	2003		2002
	1.2	1.3	2.2	2.3
Male				
Sample size	150	5	5	1
Mean length (mm)	500.0	564.0	514.0	530.0
SE (mm)	1.9	10.3	10.3	23.0
Female				
Sample size	220	1	5	0
Mean length (mm)	494.0	560.0	503.0	
SE (mm)	1.7	24.8	11.1	
All Fish				
Sample size	370	6	10	1
Mean length (mm)	496.0	563.0	509.0	530.0
SE (mm)	1.3	9.9	7.7	24.3

Table 5.—Euphotic zone depths at Kanalku Lake in 2008.

Date	Depth (m)
27-Jun	14.5
31-Jul	14.7
28-Aug	11.7
Seasonal mean	13.6

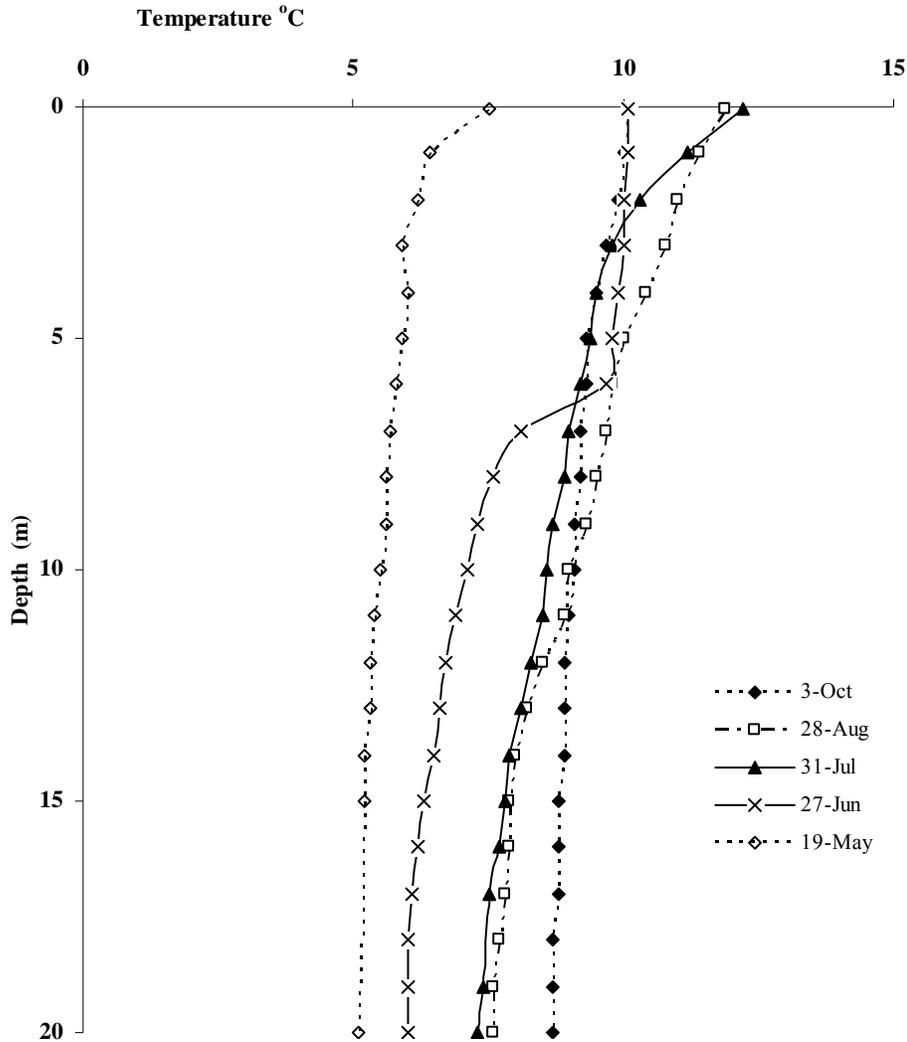


Figure 5.—Water temperature profiles in Kanalku Lake in 2008.

Secondary Production

The most abundant zooplankton taxa found at Kanalku Lake in 2008 were *Cyclops*, *Bosmina*, copepod nauplii, and *Daphnia longiremis* (Table 6). *Holopedium*, *Bosmina* and *Cyclops* each comprised about 25% of the total seasonal biomass at Kanalku Lake. *Daphnia longiremis* represented about 10% of the seasonal mean biomass. Although no clear pattern of zooplankton abundance was found throughout the season, the density of *Daphnia* generally increased throughout the sampling season with a peak abundance observed on 3 October.

DISCUSSION

The mark-recapture estimate of 1,200 adult sockeye salmon at Kanalku Lake was higher than the weir count of 967 fish, although the weir count was very close to the lower bound of the 95% confidence interval (1,000–1,500). Because it met the criteria in our methods, we have accepted the mark-recapture Petersen estimate as the best estimate of escapement in 2008. The difference

Table 6.—Zooplankton mean weighted densities, biomass, and lengths for Kanalku Lake, 2008.

Zooplankton	Density (number · m ⁻²) by date					Seasonal mean density		Seasonal weighted mean length (mm)	Seasonal weighted mean biomass	
	5-May	27-Jun	31-Jul	28-Aug	3-Oct	Number·m ⁻²	Percentage		mg·m ⁻²	Percentage
<i>Epischura</i>	4,160	3,120	1,231	2,016	2,292	2,564	2.5%	1.28	23.4	8.6%
<i>Cyclops</i>	44,320	20,504	6,495	1,358	50,433	24,622	23.7%	0.82	56.6	20.7%
Ovigerous <i>Cyclops</i>	0	9,743	1,656	531	0	2,386	2.3%	1.16	11.7	4.3%
Copepod nauplii	10,613	1,974	1,104	15,920	84,246	22,771	21.9%	—	—	—
<i>Diaptomus</i>	0	8,023	3,990	998	0	2,602	2.5%	1.12	15.3	5.6%
Ovigerous <i>Diaptomus</i>	0	0	425	0	0	85	0.1%	1.32	0.8	0.3%
<i>Bosmina</i>	9,000	40,053	24,198	19,528	25,790	23,714	22.8%	0.54	64.7	23.7%
Ovigerous <i>Bosmina</i>	42	382	0	0	191	123	0.1%	0.69	0.6	0.2%
<i>Daphnia longiremis</i>	637	3,248	2,208	6,177	29,419	8,338	8.0%	0.75	20.7	7.6%
Ovigerous <i>Daphnia l.</i>	0	637	552	552	2,674	883	0.9%	1.15	5.5	2.0%
<i>Holopedium</i>	10,401	33,431	7,472	0	0	10,261	9.9%	0.80	68.2	25.0%
Ovigerous <i>Holopedium</i>	0	509	934	0	0	289	0.3%	1.27	5.9	2.1%
<i>Immature Cladocera</i>	4,882	9,870	2,377	3,502	5,349	5,196	5.0%	—	—	—
Totals						103,833			273.31	

between the weir and the mark-recapture estimate could indicate that fish passed the weir uncounted or, conversely, that the weir-to-spawning-grounds mark-recapture estimate was biased high. Loss of tagged fish through mortality or change in behavior prior to reaching the spawning grounds (e.g., from handling effects incurred at the weir, injuries or stress related to ascending the partial barrier falls, or predation in the lake) would result in a mark-recapture estimate that is biased high (Seber 1982, Schwarz and Taylor 1998). We do not know if the mark-recapture estimate was biased by tagging mortality in 2008, but it is possible that either stresses or injuries incurred at the falls or the weir could have affected sockeye salmon survival prior to spawning. Also, adequate mark-recapture sample sizes can be difficult to obtain in the lake due to low numbers of fish, woody debris in the spawning area, and steep drop-offs (Vinzant et al. 2009). On the other hand, salmon weirs must be meticulously maintained to prevent fish from passing uncounted to avoid a weir count that is biased low. No problems with the weir structure were encountered in 2008, and we feel it is unlikely that 19% of the sockeye salmon escapement passed the weir undetected because daily escapements were low, no flooding events occurred, and misidentification was improbable as no other salmon species appeared able to ascend the falls during the duration of the field season (Appendix 1). There is no way to know with certainty if some fish did indeed escape through the weir undetected, and at the very least, the weir count of 967 adult sockeye salmon should be considered a minimum escapement in 2008. We note that it was only our second year operating the Kanalku Lake weir and there is still some uncertainty involved in both the weir and mark-recapture estimates. If the discrepancy between estimates continues in future years, we may need to reevaluate our methodology.

The sockeye salmon escapement into Kanalku Lake in 2008 was similar to the estimates obtained between 2004 and 2006, and was more than double the 2007 escapement (Figure 6). Since our stock assessment began at Kanalku Lake, our mark-recapture estimates have shown an average of 950 sockeye salmon from 2001 to 2008. Without any historical escapement data, however, we cannot establish what a “normal” escapement at Kanalku Lake should be.

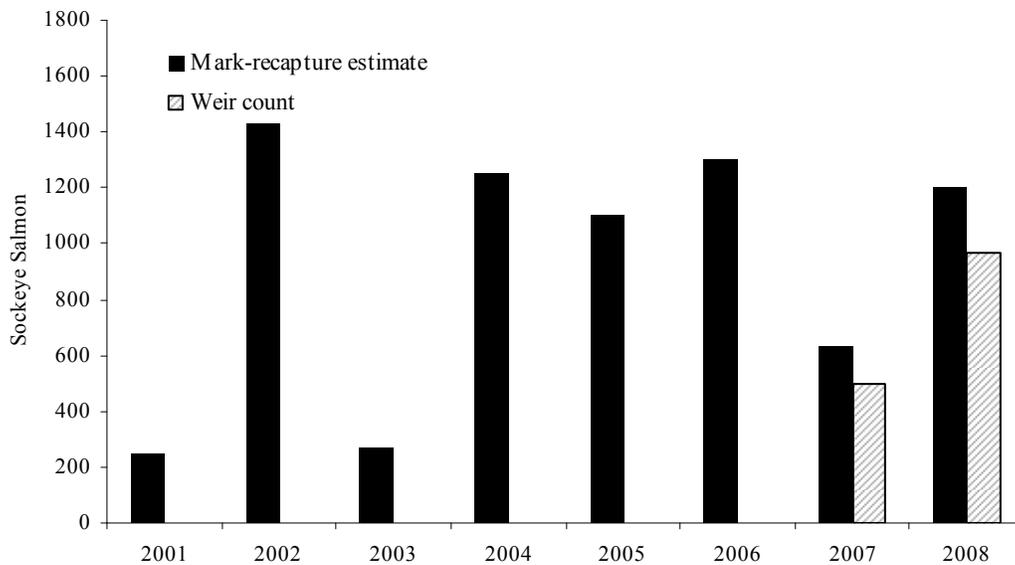


Figure 6.—Estimated sockeye salmon escapements into Kanalku Lake from 2001 to 2008.

The voluntary closure of subsistence fishing at Kanalku Bay effectively ended by 2008. Over 40 subsistence permits were issued and approximately 700 sockeye salmon were reported to have been harvested. The magnitude of harvest in 2008 fell roughly in the middle range of reported subsistence harvests from 1985 to 2001 (Figure 1). It was encouraging that Angoon residents were once again able to harvest sockeye salmon in Kanalku Bay, and still allow for a seemingly good-sized spawning escapement to reach the lake in 2008. Observations of large numbers of sockeye salmon below Kanalku falls strengthened the opinion that a surplus of fish was available for harvest, either by subsistence fishermen, or the many bears observed in the area.

The falls about midway up Kanalku Creek present a partial barrier to sockeye salmon migration and, as noted in the study site description, has been modified in the past by the U.S. Forest Service in cooperation with ADF&G. Sockeye salmon hold in the plunge pool at the base of the falls, which has been a traditional site for subsistence fishing, using gear such as baskets in former times, and dipnets more recently (M. Kookesh, ADF&G retired biologist and Angoon resident, *personal communication* 2002). Other predators, most notably brown bears, also frequent the falls area where sockeye salmon are relatively easy for them to catch. How stream level or water flow rate affects the ability of sockeye salmon to migrate over the falls is unclear, but sockeye salmon passage rates at the weir on the upper creek increased during periods of low water in 2008 (Figure 4; Appendix A). This suggests that lower flow levels at the falls may aid fish passage (Figure 4).

The U.S. Forest Service conducted a series of pilot studies from 2006 to 2008 in an attempt to estimate the rate of successful passage by sockeye salmon over the falls. In 2006, 35 fish captured below the falls were fitted with radio transmitters and only 4 of these fish (11%) were recovered in the lake. In 2007, 25 fish captured below the falls were tagged with numbered T-bar tags, and 8 tagged fish (23%) were recovered above the falls at the weir. In 2008, a total of 100 fish were captured and tagged below the falls and only 5 fish (5%) were recovered above the falls at the weir (B. Van Alen, U.S. Forest Service biologist, Juneau, *personal communication*). A significant problem with these studies is that stress due to handling could reduce the probability that tagged fish would successfully ascend the falls compared to unmarked fish. Additionally, sockeye salmon recovering from handling could have been more susceptible to subsistence harvest or bear predation at the base of the falls. Attempts were made to mitigate this problem by moving the sampling site downstream, but the section from tidewater to the falls is very short and migrating fish in this section are already undergoing the physiological stress of transitioning from saltwater to freshwater.

The U.S. Forest Service also deployed a weir system in 2008 to count the total number of fish entering the stream below the falls. This count, when compared with the escapement estimate from the lake, may give a more reliable estimate of the fish passage rate. About 2,460 sockeye salmon were counted through the weir system below the falls, but an estimated 1,000 fish had already entered the stream before the weir system was set up and the system was also breached several times during operation (B. Van Alen, U.S. Forest Service biologist, Juneau, *personal communication*). A conservative estimate of 3,000 to 4,000 sockeye salmon entering Kanalku Creek, compared with our mark-recapture estimate of 1,000 to 1,500 sockeye salmon subsequently reaching the lake, indicates that less than half sockeye salmon entering the lower stream succeeded in ascending the falls. The Kanalku Lake sockeye salmon population has obviously sustained significant and chronic mortality due to the partial barrier falls. The presence of the partial barrier may also make this sockeye salmon run more vulnerable to over-harvesting.

Passage for this sockeye run could possibly be improved by modifying or bypassing the partial barrier falls. A well-designed study is needed to better evaluate the impact of the partial barrier falls as well as possible passage improvements.

In 2008, a lack of age diversity was once again observed in the spawning population at Kanalku Lake. Roughly 96% of the adult sockeye salmon were found to be age-1.2 fish from the 2004 brood year. The near absence of age-1.3 and age-2.2 fish in 2008 is believed to be a direct consequence of the very small spawning population (275) found in 2003 (Conitz and Cartwright, 2005). In addition, returns of age-1.3 sockeye salmon were generally very poor throughout Southeast Alaska in 2008 (Eggers et al. 2008), indicating poor conditions for sockeye smolt that migrated to sea in 2005.

The spawning habitat available to sockeye salmon has also been an ongoing concern at Kanalku Lake. Weed growth in the lake has been encroaching upon the only known spawning area. Although no evidence for a cause-and-effect relationship between weed growth and low escapement exists, it may be a present or future limiting factor to recruitment of sockeye salmon in Kanalku Lake. We have observed that spawning activity has drastically declined in the easternmost section of the study area, which has become inundated with weeds within just the last 6 years (Conitz and Burril 2008). Although it is possible that larger spawning populations will simply brush away the aquatic weeds while digging their spawning redds, accumulation of sediments in this critical habitat is reason for future monitoring and concern. While a small number of sockeye salmon were observed spawning adjacent to the shoreline in this section of Kanalku Lake in 2008, we do not know how fully utilized this area was historically other than anecdotal reports from previous year's efforts. Attempts to capture these fish during the recapture efforts were prevented by deep sediment. Additionally, the lack of any spawning sockeye salmon in Kanalku Lake's major inlet stream is puzzling, as spawning habitat appears favorable.

The zooplankton samples taken from Kanalku Lake in 2008 provide evidence that sockeye fry have an abundance of prey. As shown in previous years, the lake is highly productive when compared to other sockeye rearing lakes in Southeast Alaska (Conitz and Cartwright 2005). Secondary production in Kanalku Lake is probably under-utilized and could likely support a larger population of rearing sockeye salmon fry.

Further monitoring Kanalku Lake's sockeye salmon escapement continues to be an important priority for the future management of Angoon area subsistence fisheries. With the return of traditional subsistence fishing in 2008, future monitoring of this vulnerable system remains essential to the long-term stability of the system. Continuing the stock assessment activities for Kanalku Lake sockeye salmon is paramount in establishing a sustainable balance between the spawning sockeye salmon population and subsistence fishery harvest. An improved study aimed at fully understanding the effects of the Kanalku Creek falls on the sockeye salmon population, including both natural mortality, harvest, and escapement, is recommended before undertaking any work to modify the falls.

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APPENDIX

Appendix A.–Daily and cumulative counts of sockeye salmon and water depth and temperature at Kanalku Lake in 2008. No other species were observed.

Date	Sockeye salmon		Water depth (m)	Water temperature (°C)	Air temperature (°C)
	Daily	Cumulative			
29-Jun	0	0	0.46	11.0	12.0
30-Jun	0	0	0.40	11.0	11.0
1-Jul	0	0	0.37	12.0	14.0
2-Jul	0	0	0.38	13.0	15.0
3-Jul	0	0	0.41	14.0	15.0
4-Jul	0	0	0.43	12.0	13.0
5-Jul	0	0	0.45	13.0	15.0
6-Jul	0	0	0.46	13.0	13.0
7-Jul	0	0	0.45	12.5	12.0
8-Jul	0	0	0.41	12.0	9.0
9-Jul	0	0	0.41	9.5	9.5
10-Jul	0	0	0.40	12.0	10.0
11-Jul	0	0	0.37	13.0	13.0
12-Jul	0	0	0.36	12.0	10.0
13-Jul	0	0	0.37	13.0	13.0
14-Jul	0	0	0.40	13.0	13.0
15-Jul	0	0	0.39	13.0	13.0
16-Jul	0	0	0.33	13.0	13.0
17-Jul	0	0	0.33	13.0	13.0
18-Jul	0	0	0.34	13.0	11.0
19-Jul	0	0	0.49	12.0	11.0
20-Jul	0	0	0.52	12.0	10.0
21-Jul	0	0	0.46	11.5	10.0
22-Jul	0	0	0.40	12.0	11.0
23-Jul	0	0	0.36	12.0	11.0
24-Jul	2	2	0.34	12.0	10.0
25-Jul	0	2	0.33	12.0	10.0
26-Jul	0	2	0.43	12.0	10.0
27-Jul	0	2	0.42	12.0	11.0
28-Jul	0	2	0.43	12.0	10.0
29-Jul	0	2	0.45	11.0	11.0
30-Jul	0	2	0.47	12.0	12.0
31-Jul	8	10	0.41	12.0	10.0
1-Aug	8	18	0.37	12.0	11.0
2-Aug	102	120	0.34	12.0	11.0
3-Aug	76	196	0.34	12.0	10.0
4-Aug	122	318	0.31	13.5	14.0
5-Aug	143	461	0.29	13.0	15.5
6-Aug	184	645	0.29	13.0	15.0
7-Aug	122	767	0.29	13.0	13.0
8-Aug	78	845	0.30	14.0	14.0
9-Aug	44	889	0.30	14.0	13.0
10-Aug	11	900	0.28	13.0	13.0

–continued–

Appendix A.–Page 2 of 2.

Date	Sockeye salmon		Water depth (m)	Water temperature (°C)	Air temperature (°C)
	Daily	Cumulative			
11-Aug	11	911	0.28	13.0	13.0
12-Aug	26	937	0.34	14.5	13.0
13-Aug	3	940	0.52	13.0	13.0
14-Aug	0	940	0.59	13.5	13.0
15-Aug	0	940	0.58	13.0	13.5
16-Aug	3	943	0.43	13.5	13.0
17-Aug	0	943	0.38	13.5	12.0
18-Aug	2	945	0.37	13.0	10.0
19-Aug	5	950	0.35	14.0	13.0
20-Aug	9	959	0.33	14.0	15.0
21-Aug	0	959	0.30	14.0	13.0
22-Aug	7	966	0.30	13.5	12.0
23-Aug	1	967	0.48	13.0	11.0
24-Aug	0	967	0.55	13.0	12.0
25-Aug	0	967	0.58	12.0	10.0
26-Aug	0	967	0.47	12.0	10.0
27-Aug	0	967	0.43	12.0	9.5
28-Aug	0	967	0.37	12.0	9.5
Season total		967			