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Kutlaku Lake Subsistence Sockeye Salmon Project: 2006 Annual and Final Report

by

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and

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

Symbols and Abbreviations

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Weights and measures (metric)	
centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

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

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

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

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

Measures (fisheries)	
fork length	FL
mideye to fork	MEF
mideye to tail fork	METF
standard length	SL
total length	TL

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

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The Federal Subsistence Board, managed by U.S. Fish and Wildlife Service Office of Subsistence Management, approved the Kutlaku Lake Subsistence Sockeye Salmon Project. The project was funded by the U.S. Forest Service, and was a cooperative project between the U.S. Forest Service (USFS), the Alaska Department of Fish and Game (ADF&G), and the Organized Village of Kake (OVK). This annual and final report fulfills contract obligations for Sikes Act Contracts AG-0109-P-06-0057 and AG-0109-P-06-0043.

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TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABSTRACT

Kutlaku Lake is a small lake on Kuiu Island in Southeast Alaska with a productive sockeye salmon (*Oncorhynchus nerka*) run and, in recent years, minimal fishing pressure in the marine terminal area. Due to recent changes in fishing regulations for this system, better information about the size and health of its sockeye salmon population was needed. In 2002–2005 the sockeye spawning population was estimated using mark-recapture studies in the lake and inlet stream. A weir was used in 2006 to count sockeye salmon entering the lake and provide a more reliable estimate of escapement and a benchmark for comparison with previous years' estimates. The count at the weir was 10,579 sockeye salmon and a Petersen mark-recapture estimate was 17,000 fish (95% confidence interval 11,000–26,000), compared with spawning grounds mark-recapture estimates in 2002–2005 of 8,500 to 12,000 sockeye salmon. To improve mark-recapture estimates over all four years, we used a hierarchical Bayesian model with common underlying parameters to estimate the number of spawners in the main inlet stream. We then expanded the inlet stream estimates to whole lake population estimates by the proportion of fish in the study area each year, determined by visual surveys with an area-under-the-curve method. The resulting spawning population estimate for 2006 was about 14,600 sockeye salmon, and adjusted estimates for the previous years ranged from about 10,000 to about 18,000 sockeye salmon. We concluded that the 2006 sockeye escapement estimate, aided by the weir, confirmed the magnitude of previous years' estimates, and 10,000 to 20,000 fish is a reasonable range for spawning population size. High levels of zooplankton, in particular *Daphnia*, indicate that Kutlaku Lake can support large rearing fry populations produced by these escapements, and adult age compositions show that most Kutlaku sockeye salmon spend only one year in freshwater.

Key words: Sockeye salmon, *Oncorhynchus nerka*, subsistence, Kutlaku Lake, Bay of Pillars, Kake, escapement, mark-recapture, hierarchical Bayesian, area-under-the-curve, age composition, zooplankton

INTRODUCTION

Kutlaku Lake and Creek (ADF&G stream number 109-52-935/035) on Kuiu Island is one of a handful of sockeye salmon producing systems which comprise a major element in the seasonal subsistence cycle of people from Kake. Traditionally, the harvest of sockeye salmon and other food resources was carried out in small, seasonal fish camps around the mouths of productive streams, including Kutlaku Creek, under the control and leadership of the various Kake clans (Goldschmidt et al. 1998). The traditional Kake territory included bays and shorelines on Kuiu, Kupreanof, Admiralty, and Baranof Islands and portions of the mainland (Goldschmidt et al. 1998; Firman and Bosworth 1990). By the early 1900s, U.S. government policies and commercial cannery interests had forced most of the Kake people to abandon these widely scattered fish camps and establish year-round homes in the centralized village of Kake. Seasonal harvesting and processing of fish by family groups was gradually replaced by commercial fishing and cash employment. Kake residents still engage in subsistence fishing based in part on clan affiliation and tradition, but they also take into consideration other factors such as non-fishing employment, size and type of boat owned, and current regulations and harvest limits. Through the 1980s Kake residents harvested subsistence sockeye salmon primarily from Gut Bay, on Baranof Island and at the mouth of Kutlaku Creek, in the Bay of Pillars (Firman and Bosworth 1990). In the 1990s, people gradually shifted their subsistence effort to Falls Creek, so that by 2000, reported harvests from Kutlaku and Falls Creeks had reversed in relative size (Appendix A in Conitz and Cartwright 2005).

Because of concerns about possible declines in subsistence salmon harvests, and increased effort by other user groups, the Organized Village of Kake proposed a regulation to exclude all but federally qualified subsistence users in the areas of Falls Lake, Gut Bay Lake, and Kutlaku Lake/Bay of Pillars. The Federal Subsistence Board passed the regulation in 2000, allowing non federally qualified users to be excluded from the parts of those areas under federal jurisdiction, which included waters above mean high tide, if a conservation concern existed. Since the State of Alaska has jurisdiction in waters below mean high tide, this regulation had no effect on harvest by non federally qualified fishers in marine waters.

Alaska Department of Fish and Game (ADF&G) submitted a Request for Reconsideration for the Kutlaku Lake system to the Federal Subsistence Board in December 2001, reasoning that information about sockeye runs into Kutlaku Lake was insufficient to determine whether a conservation concern existed. The Board did not reconsider their decision at the time, but an additional year of study on Kutlaku Lake was funded in 2003 through the federal subsistence program (Conitz and Cartwright 2005). In December 2004, ADF&G submitted a proposal to reverse the conservation concern status of Kutlaku Lake, based on the 2003 research results. The federal Interagency Staff Committee was split on their recommendation to the Federal Subsistence Board. The Federal Subsistence Board voted against this proposal in their January 2005 meeting, reaffirming its commitment to retaining the exclusion of other users in freshwater areas surrounding the Bay of Pillars. Clearly, having only one year of good information on this system left the results prone to different interpretations. Although funding was not provided to continue study at Kutlaku Lake in 2004, it was provided the following year and investigations resumed in 2005 (Conitz 2007).

Assessments of the Kutlaku Lake sockeye salmon spawning population in 2002, 2003, and 2005 indicated a moderately large run of sockeye in this system, relative to the size of the system and to other small sockeye salmon systems in Southeast Alaska. Escapement estimates, based on a combination of mark-recapture methods and visual surveys, ranged from 8,500 to 12,000 sockeye salmon (Conitz and Cartwright 2003, 2005; Conitz 2007). However, because of the spatial and temporal variations in sockeye spawning patterns and our inability to sample throughout all areas of the lake system, confidence in the accuracy of our estimates was low. ADF&G personnel who visited Kutlaku Lake in the 1980s and 1990s to sample sockeye salmon provided field notes and sketch maps which indicate the timing, rough abundance, and location of sockeye spawning populations in Kutlaku Lake over a 20-year time period. The lake has only one tributary of significant size, and sockeye spawners were consistently observed in and around the mouth of this stream, although for some years the stream was blocked by beaver dams, forcing spawners onto adjacent shoreline areas. Beach spawning aggregations were also noted in other parts of the lake. Our studies in 2002, 2003, and 2005 clearly showed a distinct temporal difference between sockeye salmon that spawned in the main tributary, or inlet stream, and those spawning in the shoreline areas. The inlet stream population begins schooling around the mouth of the stream in mid-August, entering the stream and beginning spawning by late August. In contrast, the beach spawning groups do not even approach their spawning areas until mid-September, and reach maximum abundance as late as mid-October, well after the stream spawning run has completely finished and died. Heavy fall rains in September often increase flow in the inlet stream so much that any remaining spawners are flushed out, while increasing water level in the lake provides more beach spawning habitat. Beach spawning habitat, being dependent to some extent upon lake water level, varies considerably from year to year. Because of the clear difference in timing between the stream spawning and beach spawning groups in Kutlaku Lake, mixing between the two populations is probably minimal.

Studies at Kutlaku Lake included sockeye salmon fry population estimates in 2001 and 2002, and zooplankton population estimates in 2001–2003 (Conitz and Cartwright 2003, 2005). Large fry populations and moderate abundance and high quality of zooplankton prey, relative to other small sockeye lakes in Southeast Alaska, were observed, suggesting a productive system not currently limited by rearing habitat (Conitz and Cartwright 2005). ADF&G field technicians sampled sockeye salmon from Kutlaku Lake in most years from 1982 through 2001 for age, sex, and length (ASL) information (Appendix A.2 in Conitz and Cartwright 2003), and our study continued ASL sampling in 2002–2005. Escapement age composition estimates from 1982 through 2005 consistently showed most sockeye salmon with only one freshwater year, indicating that fry attained sufficient growth in Kutlaku Lake during their first year to smolt in the following spring (Conitz and Cartwright 2003, 2005; Conitz 2007).

Although no formal subsistence harvest estimates have been performed for the Kutlaku Lake system, ADF&G Division of Commercial Fisheries maintains a record of subsistence harvest by fishing site, including Kutlaku Creek in the Bay of Pillars (Appendix A). Data are collected from returned fishing permits, on which permit holders are required to report harvest of salmon from all dates and locations fished. This self-reporting is not considered very accurate, but does give an indication of minimum harvest levels and trends. For example, the shift in relative effort and harvest between Kutlaku and Falls Creek can be clearly seen (Appendix A in Conitz and Cartwright 2005). At Kutlaku Creek, the average number of permits and the annual sockeye harvest have fallen dramatically since 2000 (Appendix A, this report). Between 2000 and 2006, the total annual sockeye harvest ranged from just 10 to about 550 fish, averaging 223 fish, reported on between one and 22 permits annually. Even considering possible under-reporting, the evidence suggests that subsistence harvest levels from Kutlaku Creek represent a very light exploitation rate, given the sockeye escapements estimated in 2002–2005.

Some Kutlaku Lake sockeye salmon are undoubtedly harvested in the commercial seine fisheries in Chatham Strait, but these are mixed stock fisheries with many contributing stocks and no program to estimate the contribution of any specific stock to the harvest. Summaries of recent commercial harvests in the fishing districts closest to the Bay of Pillars were provided in previous years' reports (Conitz and Cartwright 2003, 2005). Total commercial sockeye harvests in the major fishing districts in lower Chatham Strait reached record highs of 20,000–40,000 fish in the mid 1990s through the early 2000s but have since declined (Appendix B in Conitz and Cartwright 2005; ADF&G Division of Commercial Fisheries database 2008). Historically, directed sockeye fisheries in the Bay of Pillars produced annual harvests of 10,000 or more sockeye salmon during most of the 35-year period between 1890 and 1924 (Rich and Ball 1933).

The 2006 study included a weir to count sockeye salmon entering Kutlaku Lake to spawn, in addition to a mark-recapture study similar to those conducted in 2002, 2003, and 2005. The intention this dual assessment, in part, was to compare a single year's escapement count with the several years' mark-recapture based estimates to see how well the magnitude of the estimates corresponded with an actual escapement count. To improve the consistency of these estimates between years, and improve the overall estimates of annual spawning population, we developed a hierarchical Bayesian model which incorporated information from all four years in each year's estimate.

OBJECTIVES

1. Count sockeye salmon and other salmonid species entering Kutlaku Lake at a weir on the outlet stream below the lake. In addition, verify the sockeye salmon count with a mark-recapture estimate, marking fish at the weir and sampling for marked fish on the spawning grounds, so that the estimated coefficient of variation is less than 15%.

2. Estimate the size of the Kutlaku Lake sockeye salmon spawning population within a defined study area on spawning grounds, so that the estimated coefficient of variation is less than 15%. Using visual counts to determine the proportion of the total spawning population represented within the study area, expand the study area estimate to a rough population estimate for the whole lake and compare this estimate to the weir count.
3. Develop a comparison between the 2006 weir-based sockeye salmon escapement estimate, and mark-recapture estimates from the spawning grounds for 2002–2006, using a hierarchical Bayesian model, assuming a common underlying capture probability, with parameter estimates having an estimated coefficient of variation of less than 15%.
4. Estimate the age, length, and sex composition of the sockeye salmon escapement in Kutlaku Lake, based on a sample size of 600 fish, so that the estimated coefficient of variation for the two major age classes is 10% or less.
5. Measure light and temperature profiles and estimate zooplankton species composition, size, and abundance in Kutlaku Lake throughout the season using established ADF&G limnological sampling procedures.

METHODS

STUDY SITE

Kutlaku Lake (N 56°37.0', W 134°7.5') is located on the west side of Kuiu Island, about 45 km from Kake, and drains into the southeast arm at the head of Bay of Pillars (Figure 1). Kutlaku Lake and the Bay of Pillars are within the Rowan sediments subsection, characterized by rounded, heavily eroded mountains that were scoured by continental ice sheets. In some areas, deep residual silty or loamy soils have built up, supporting highly productive hemlock-spruce forests; in other areas, bogs and muskegs formed over glacial till with poorly drained organic soils (Nowacki et al. 2001). Kutlaku Lake is situated at an elevation of about 25 m, and lies in a steep-sided, heavily forested valley, with intermittent patches of windfall, muskeg, and beaver-dammed streams (Figure 2). The main inlet stream on the southeast side of the lake has been dammed repeatedly by beavers, forming a large delta area. The lake surface area is about 78 hectares, and the maximum depth is about 22 m. Over half the lake, on the southwest end, is less than 10 m in depth, with a shelf of less than 5 m depth extending out at least 100 m from the shore. The outlet stream exits the northeast corner of the lake through a shallow, marshy area, and flows over a uniform shallow gradient for about 0.7 km into the large intertidal zone at the head of the Bay of Pillars. The lake system and its outlet stream support populations of sockeye, coho (*O. kisutch*), pink (*O. gorbuscha*), and chum salmon (*O. keta*). Anadromous or resident Dolly Varden char (*Salvelinus malma*) and steelhead (*O. mykiss*) and cutthroat trout (*O. clarki*) are also present in the lake. Rough-skinned newts (*Taricha granulosa*) are common in the shallow water around the lake outlet. Coordinates for mark-recapture sampling study areas and limnology sampling stations are listed in Table 1.

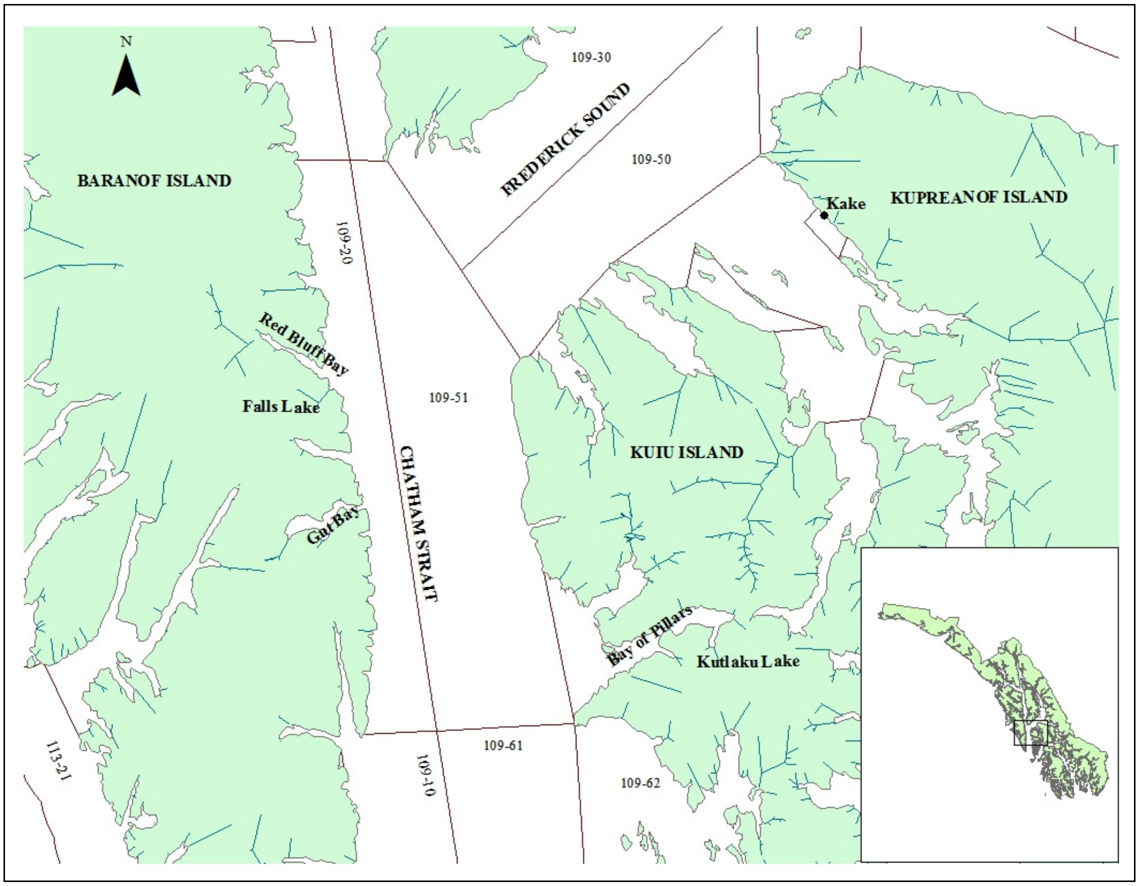

Figure 1.–Map showing the location of Kutlaku Lake on Kuiu Island, in Southeast Alaska (inset), in relation to the village of Kake and other subsistence sockeye systems traditionally used by the village (Gut Bay and Falls Lake). Commercial fishing districts in waters adjacent to the study sites are also shown.

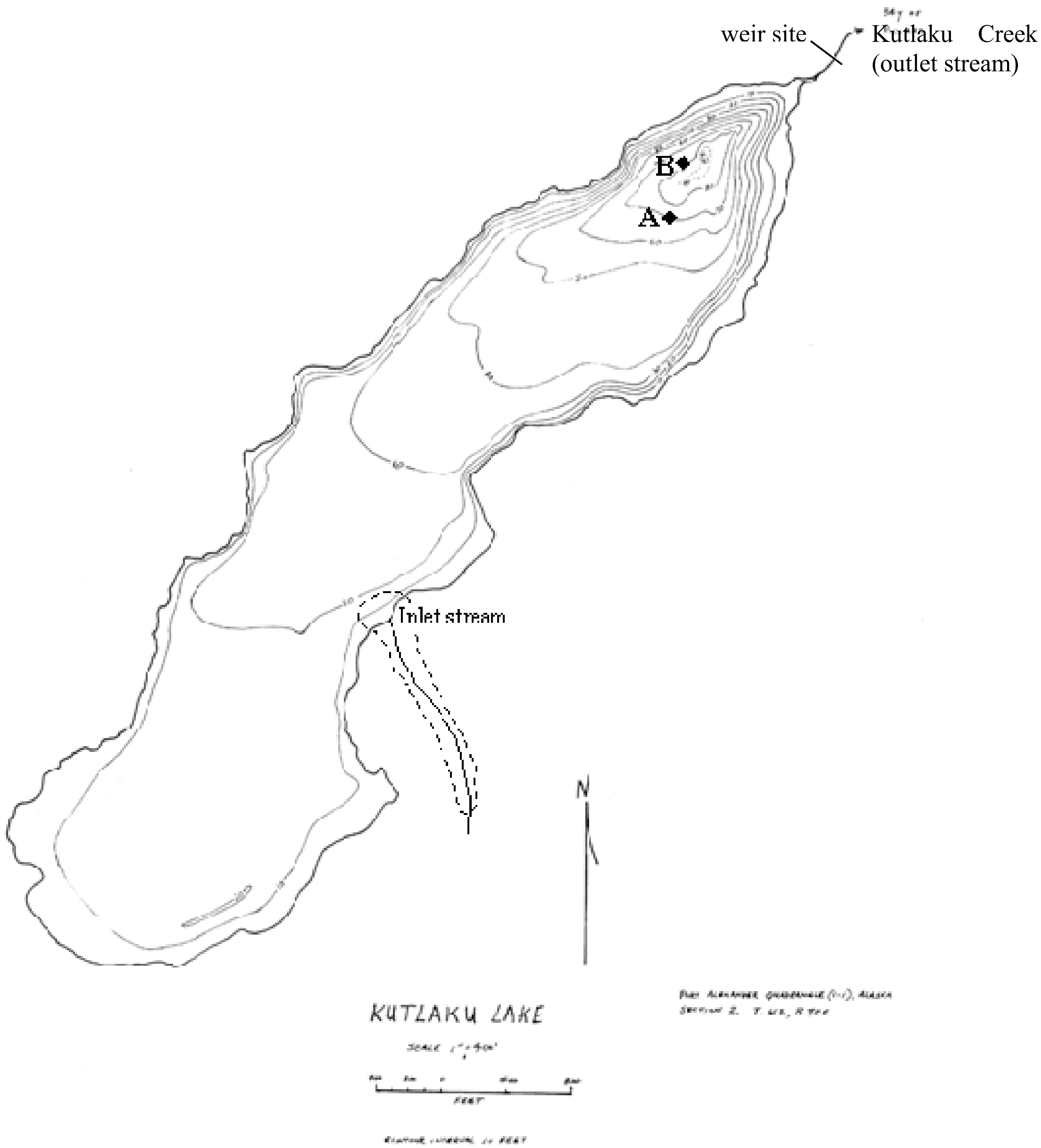

Figure 2.–Bathymetric map of Kutlaku Lake, showing the main inlet stream and limnology sampling stations (A and B). Depth contours are in intervals of 10 ft (approximately 3 m).

Table 1.–Latitude and longitude coordinates for mark-recapture study areas and limnology sampling stations in Kutlaku Lake, determined by Global Positioning System (GPS).

Waypoint ID	Description	Latitude	Longitude
KUT1	Study Area 1, mouth of inlet stream	56.608250	134.136900
B-2	Study Area 2 (new, 2005)	56.610267	134.145233
KUTA	Limnology Station A	56.614900	134.128167
KUTB	Limnology Station B	56.614183	134.129583

SOCKEYE ESCAPEMENT ESTIMATE

Weir Counts and Mark-Recapture Verification

A new weir was constructed across Kutlaku Creek, approximately 60 m below the lake outlet, in 2006. The normal water depth in mid-channel at the weir site was approximately 0.5 to 1.0 m. The weir, built on aluminum bipod supports spaced 2.5 m apart, spanned the creek channel width of about 17 m, and was anchored into each bank with additional 2.5 m sections. Aluminum pickets of diameter 19 mm, spaced 45 mm apart center to center, closed the entire weir to migrating salmonids, except for a small opening into a 1.25 m x 1.25 m x 2.5 m box frame trap, in which fish could be retained for sampling or simply counted and passed. Adjacent to the trap, an additional channel was constructed through which fish could be passed by pulling one or two pickets in the weir. An underwater video camera was positioned to capture images of fish as they swam through this channel, and the images were recorded onto a digital video recorder (DVR) for playback, counting, and identification later.

All migrating salmonids were counted through the weir, by species. A portion of the sockeye salmon were retained in the trap for sampling, and then passed manually; the remaining sockeye salmon and all other fish were counted visually as they swam through the small opening in the weir or trap. When the underwater video camera and DVR were in operation, the direct visual counts were compared with counts made later from the recording. Because the camera and recorder were being operated for the first time on a test basis, the visual and manual counts remained the primary data source.

To verify the accuracy of the weir count, a stratified, two-sample mark-recapture study was also conducted, marking fish in the first sample as they were passed through the weir (Arnason et al. 1996). The first sample was selected by passing a group of fish into the trap each morning and marking all sockeye salmon until the running average marking rate was approximately 30%. Sockeye salmon in the first sample were marked with an adipose fin clip, and a uniquely-numbered t-bar tag. The adipose clip was considered the primary mark, indicating presence of a tag, and allowing adjustment for tag loss in the analysis. The sample of marked fish was stratified post-season by time.

The second sample consisted of sockeye salmon captured on the spawning grounds at intervals throughout the spawning period and inspected for a primary mark and tag. Fish were sampled in the main spawning areas around the mouth and in the channel of the unnamed main inlet stream entering the lake from the southeast (Figure 2). Fish were also sampled in two main beach spawning areas where they were found concentrated, at the northeast and southwest ends of the lake. If a primary mark (adipose fin clip) was present, the tag number was recorded if present, and if not, the recapture was recorded as a lost tag. All previously unmarked fish were tagged, for an independent spawning grounds mark-recapture estimate (see below). All fish, whether previously marked or not, also received an opercular punch to identify the sampling event in which they were caught and to prevent re-sampling in that event. The date and location of capture were recorded along with tag numbers or marking status, and the data were stratified post-season by sampling event date or location. Although multiple captures of an individual fish were possible, tag numbers were sorted electronically post-season to eliminate all but the first capture or recapture of each fish.

Those fish with lost tags were included with other recaptures in each sampling stratum, but the initial tagging date, or first sample stratum, of such fish was unknown. Therefore recaptures of fish with lost tags were apportioned to initial capture strata based on proportions of all fish marked at the trap in each stratum.

The Stratified Population Analysis System (SPAS) software (Arnason et al. 1996; http://www.cs.umanitoba.ca/~popan/) was used to analyze the mark-recapture data. SPAS was designed for analysis of two-sample mark-recapture data where the first (marking) and second (mark-recovery) samples are collected over a number of strata. The maximum likelihood Darroch and pooled Petersen (Chapman's modified) estimates and their standard errors were calculated. The validity of full pooling of marking and mark-recovery data (pooled Petersen estimate) was evaluated using the first two chi-square tests provided in the output. These tests provide a reasonable indication of any serious violation of the basic mark-recapture assumptions by evaluating estimates of 1) complete mixing of marked and unmarked fish between release and recovery strata, and 2) equality of proportions of fish recovered from each marking stratum. A test statistic with p-value ≤ 0.05 was considered "significant." If neither test statistic, or only one of them, was significant, the pooled Petersen estimate was accepted. Otherwise, the stratified Darroch estimate was evaluated and we attempted to find a reasonable partial pooling scheme in order to reduce the number of parameters estimated. Two additional goodness-of-fit tests for the Darroch estimate provided in the SPAS software, along with the guidelines and suggestions in Arnason et al. (1996), were used in evaluating the estimate and any partial pooling schemes.

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 affected data collection. If a valid estimator could not be found, the weir count was accepted as the best estimate, of at least minimum escapement.

Spawning Population Mark-Recapture Estimate and Visual Survey

To provide a basis for comparison between the 2006 weir count and previous year's mark-recapture based spawning population estimates, we independently estimated the lake's spawning population using mark-recapture sampling and visual surveys in the spawning grounds. Although the crew sampled fish in two beach spawning areas as well as the main inlet stream in 2006, we confined the mark-recapture estimate to the stream spawning group. This spawning group appears to be distinct and separated by time and space from other sockeye spawners in the lake, and was consistently sampled with the same methods during all three previous years of study (Conitz and Cartwright 2003, 2005; Conitz 2007). Sampling began in late August when sockeye salmon were approaching the inlet stream area for spawning, and continued through September, during three more sampling events. Previously unmarked fish were tagged, and tag numbers and sampling locations were recorded for all recaptured and newly tagged fish. Each fish also had a primary mark (adipose clip or opercular punch) to identify the sampling event(s) in which it was caught, in case of tag loss. Records of these fish were selected electronically, using a location identifier, from the entire dataset of sockeye salmon marked at the weir and sampled from both beach and stream spawning locations in Kutlaku Lake. A stratified two-sample mark-recapture procedure, equivalent to that used for the weir count verification described above, was used to estimate the size of this stream spawning group. Fish sampled at the mouth of the stream during the first three sampling events comprised the first (marking) sample, and fish sampled within the main inlet stream during the second through the fourth sampling event comprised the second (recapture) sample. The data were analyzed, with the aid of the SPAS software, using consistency tests and procedures outlined in the previous section for the weir-based mark-recapture estimate.

In order to expand the sockeye spawning population estimates from the main inlet stream to the entire lake including areas not sampled, a visual survey of the lake and inlet stream were conducted at the time of each mark-recapture event. Crew members counted sockeye spawners from a boat around the perimeter of the lake, and on foot in the main inlet stream, and the counts of all observers (usually two to four) were averaged. Spawners in the main inlet stream, including the area around its mouth, were counted separately from those in beach spawning areas. The proportion of spawners in the inlet stream, compared to the total number of spawners in the lake system, was estimated for each survey. The proportion of spawners in the main inlet stream over the whole season was estimated as the average proportion among all surveys, weighted by total abundance (total count) at each survey.

Comparative Analysis of Escapement Estimates

In order to compare all four years' spawning population estimates with each other and with the 2006 weir count, we developed a hierarchical Bayesian model (Gelman et al. 2004) which incorporated information from all four years. This type of hierarchical model may improve the annual estimates by "borrowing strength" from other years. We modeled only the size of the group that spawned in the main, unnamed inlet stream using this method, because this spawning group had been more consistent with respect to timing, size, and sampling schedule over the study years than any beach spawning aggregation.

In the standard Petersen method for mark-recapture estimation (Seber 1982), the size of the first sample, n_1, is dependent on parameters p, the probability of capture, and N, the total population size, so that $n_1 = p \cdot N$. Thus, n_1 can be considered a random variable drawn from a binomial probability distribution with parameters N and p. Assuming that all n_1 fish are marked, released alive, and mix randomly with unmarked fish in the population, the number of marked fish m_2 in a second sample of size n_2 is dependent on p and n_2, so that $m_2 = p \cdot n_2$. Therefore, m_2 can also be considered a random variable from an underlying binomial probability distribution, whose parameters are n_2 and p. Let i be an index for year of sampling. We have binomial distributions for both n_{1i} and m_{2i} in year i:

$$n_{1i} \sim \text{Bin}(N_i, p_i),$$

$$m_{2i} \sim \text{Bin}(n_{2i}, p_i).$$

The probability of capture p is the fundamental parameter of the Petersen mark-recapture model. The p_i were assumed to be independent samples from a Beta distribution with two hyperprior parameters, α and β:

$$p_i \sim \text{Beta}(\alpha, \beta).$$

Accordingly, we sought hyperprior distributions for (α, β). We first reparameterized in terms of the means of capture probability and sample size from the four years' experiments. Let r denote the mean capture probability, and J denote the mean sample size so that we have $\alpha = J \cdot r$ and $\beta = J \cdot (1-r)$. We assumed r and J to follow beta and gamma distributions, respectively. Based on available capture-recapture information, we estimated r, for k years of sampling, as $\hat{r} = \frac{\sum_{i=1}^{k} m_{2i}}{\sum_{i=1}^{k} n_{2i}}$, and then multiplied $\hat{r}$ and $1-\hat{r}$ by an appropriate weighting factor to estimate the parameters in the beta distribution of r. Parameters in the Gamma distribution of J were estimated using the mean and variance of sample sizes from all the data. The statistical analysis was performed using WinBUGS software (Lunn et al. 2000). Posterior distributions for p_i and N_i were estimated over 10,000 iterations based on these priors and binomial sampling distributions for n_{1i} and m_{2i}, conditioned on the data. The median values and 2.5 and 97.5 quantiles of the 10,000 iterations for N_i formed the estimate and 95% credible interval for the new population estimate $\hat{N}_i$ for each year i.

The comparative abundance of sockeye salmon spawning in the main inlet stream in Kutlaku Lake over several years, however, had limited usefulness to fisheries managers and others who needed to know the size of the total sockeye spawning escapement. Our observations and those of ADF&G crews working in the 1980s and 1990s indicated that distribution of sockeye spawners between the inlet stream and other parts of the lake varied greatly from year to year, depending on environmental conditions such as water flow or presence of beaver dams. Therefore, the inlet stream population probably does not represent a constant proportion of the total spawning population from year to year. However, we did not have consistent mark-recapture estimates of the beach spawning populations because of inter-annual variation in their distribution around the lake.

Visual survey counts of the inlet stream population compared to the combined total sockeye spawning population (all beach and stream spawners) provided a rough expansion factor with which to estimate the total spawning population, as described in the previous section. Rather than simply use the point estimates of proportion of inlet stream spawners, however, we used the area-under-the-curve method (English et al. 1992 and Bue et al. 1998), essentially weighting the point estimates by the number of days between sampling events and integrating them over the season. For n visual surveys, designating the date of the j^{th} visual survey as t_j, and the fish count in the j^{th} survey as c_j, the total number of fish-days or area under the curve, auc, was estimated using a trapezoidal approximation,

$$auc = \sum_{j=0}^{n} 0.5 \cdot (t_{j+1} - t_j) \cdot (c_{j+1} + c_j) \, .$$

The starting date t_0 should be the day before the first sockeye salmon spawner appeared in the survey area, and the ending date t_{n+1} should likewise be the day after the last sockeye spawner died, so that both c_0 and c_{n+1} equal zero. In practice, however, some spawners were present in the survey area at the beginning and end of each annual series of surveys. We arbitrarily set c_0 and c_{n+1} to zero and assumed a residence time of 10 days prior to the first survey and following the last survey, based on survival estimates from our studies and typical residence times for sockeye spawners (Burgner 1991). To estimate population from auc, the average residence time of sockeye salmon in the spawning area and the observer efficiency, or detectability, must be known. However, we needed to know only the relationship between the size of inlet stream population and the total combined population of sockeye spawners in the Kutlaku Lake system. Therefore, assuming that average residence time and observer efficiency were equal for all areas of the Kutlaku Lake system, we used the ratio of auc, or fish-days, for the whole system to auc for the inlet stream as our annual expansion factor. For each year of study i, the mark-recapture estimate for the inlet stream population, $\hat{N}_i$, was multiplied by this expansion factor to approximate the total annual spawning population.

Adult Population Age and Size Distribution

Length, sex, and scale samples were collected from adult sockeye salmon at the Kutlaku Lake weir to estimate the size, sex, and age structure of the population. The total target sample size was 600 fish, and fish were sampled roughly in proportion to expected weekly escapement numbers, based on sockeye escapement timing in other Southeast Alaska runs (Table 2). Fish were sampled, on at least three days per week, by passing a group of fish into the trap and sampling all sockeye salmon in the trap, until the daily or weekly sampling goal was met. 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 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 five-year-old fish with one freshwater and three ocean years; Koo 1962). The proportion in each age-sex group, mean lengths by age-sex group, and associated standard errors were estimated using standard statistical techniques, assuming a binominal distribution for the age-sex group proportions (e.g. Thompson 1992).

Table 2.–Weekly sampling goals for numbers of sockeye salmon to be sampled for age (scales), sex, and length at the Kutlaku Lake weir in 2006.

Week dates	ASL weekly goal
25 June–1 July	-
2–8 July	40
9–15 July	40
16–22 July	80
23–29 July	160
30 July–5 August	120
6–12 August	80
13–19 August	60
20–26 August	20
27 August–2 September	-

LIMNOLOGY

Limnology sampling was conducted monthly in Kutlaku Lake from 4 July through 6 October 2006. Light and temperature measurements were taken only at Station A. Zooplankton samples were collected from both stations A and B (Figure 2) on each sampling date.

Light and Temperature Profiles

Underwater light intensity was recorded from just below the surface to the depth where measured intensity was one percent of the surface light reading, at 0.5 m intervals, 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 the depth at which light intensity was reduced to one percent of the value just below the surface [photosynthetically available radiation (400–700nm)] (Schindler 1971), and was calculated from 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[1]. 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 samples were collected at two stations using a 0.5 m diameter, 153 µm mesh, 1:3 conical net. Vertical zooplankton tows started two meters from the bottom, and were pulled at a constant speed of about 0.5 $m \cdot sec^{-1}$. The net was rinsed prior to removing the organisms, and all specimens were preserved in buffered 10% formalin (Koenings et al. 1987). Each zooplankton tow was sub-sampled in the laboratory, and technicians identified to species or genus, counted, and measured organisms in the sub-samples (Koenings et al. 1987). Zooplankton density in the water column (individuals per m^2 surface area) was extrapolated from counts by taxon in the sub-samples, and seasonal mean density was estimated by taking the simple average of densities across sampling dates. The seasonal mean length for each taxon, weighted by density at each sampling date, was estimated and used to calculate a seasonal mean biomass estimate (weight per m^2 surface area) based on known length-weight relationships (Koenings et al. 1987). Total seasonal mean zooplankton biomass and density were estimated by summing across all species.

RESULTS

SOCKEYE SALMON ESCAPEMENT ESTIMATES

Weir Counts and Mark-Recapture Verification

The weir on Kutlaku Creek was operated from 24 June to 20 September 2006, and the total count was 10,579 sockeye salmon, of which 27 were males under 400 mm, assumed to be jacks (Figure 3; Appendix A). Beginning in early August, a few salmon of other species were counted through the weir, including 246 coho salmon of which 113 were jacks, 70 pink salmon, one chum salmon, and 10 Chinook salmon. Also, beginning in late July, 68 Dolly Varden char and 90 cutthroat trout were counted. Because the purpose, design, and operating dates of the weir were intended to enumerate the entire sockeye spawning migration into Kutlaku Lake, but not necessarily that of other species, the counts of other species may be incomplete. Sockeye counts were very small during the first week of weir operation, but increased substantially beginning 1 July and fluctuated between tens and several hundred fish through 22 August. On three peak escapement days between 19 July and 12 August, daily counts of 600 or more sockeye salmon were recorded (Figure 3; Appendix A). Two smaller peak daily escapements were observed on 17 and 31 August. The 31 August peak preceded several days of flooding, during which the water level rose above the north bank of the stream. For the three days, 1–3 September, the weir was not operated due to the flooding, and migrating fish may have been able to pass around the weir over the flooded north bank. However, the weir structure itself was not damaged or breached and normal operation resumed on 4 September, with a count that day of nine sockeye salmon. Sockeye salmon counts remained low from then to the end of weir operation.

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[1] Product names are provided for scientific completeness, and does not constitute a product endorsement.

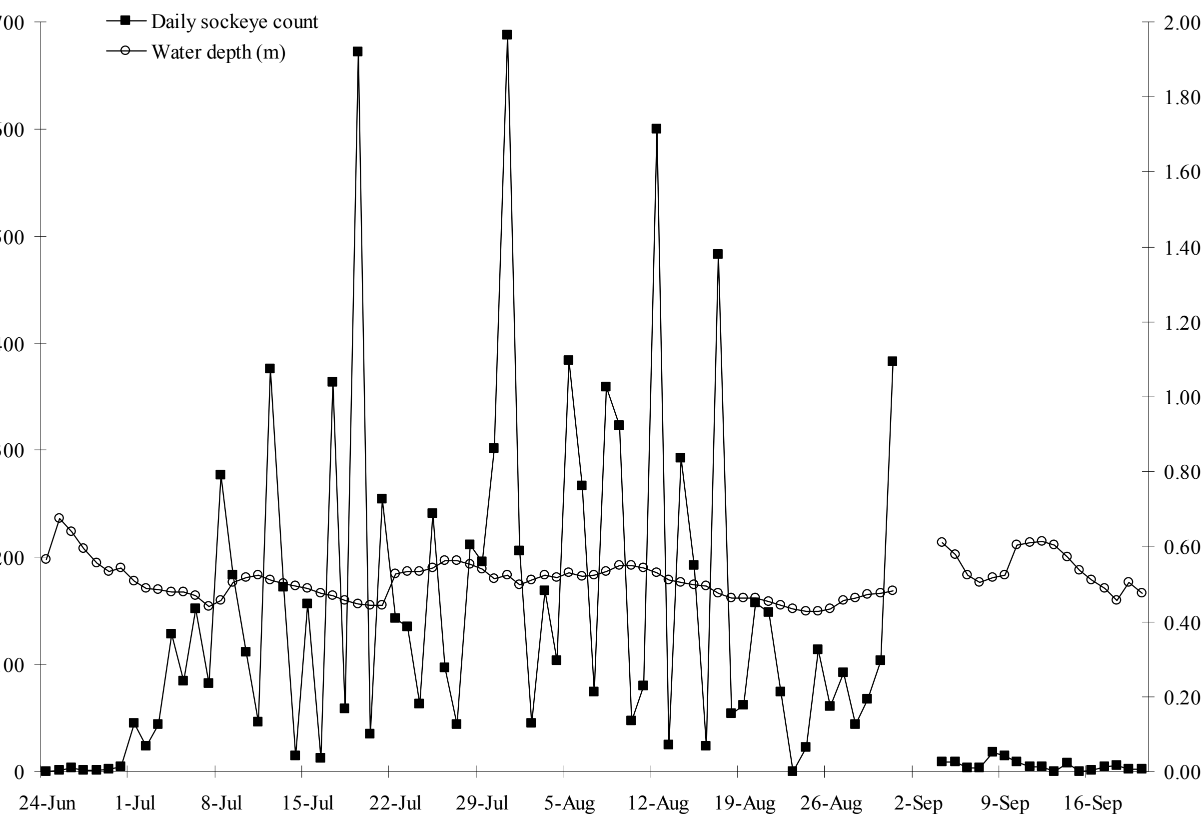

Figure 3.–Daily counts of sockeye salmon passed through weir and water depth at the Kutlaku Creek weir, 2006.

During the weir operation period, the crew marked 3,384 sockeye salmon with adipose fin clips and individually numbered tags. Marked fish were grouped into four marking strata post-season (Table 3). Sharp drops in sockeye counts the day following each of the three peak escapement days (19 July, 1 August, 12 August; Figure 3) provided natural breaks in the run; these dates were used to divide the marking samples into four strata, by date. Mark-recovery sampling was conducted on six dates between 26 August and 20 October (Table 3), and fish were sampled in and around the main inlet stream and in two beach spawning areas around the lake.

Table 3.–Numbers of sockeye salmon marked at the Kutlaku Lake weir, and numbers and proportions of marks recovered in mark-recapture sampling in Kutlaku Lake, 2006, with recapture samples stratified by sampling date.

Marking stratum end date	Number marked	Count at weir	Marks recovered by sampling date						Total marks recovered	Proportion of marks recovered
			26-Aug	4-Sep	9-Sep	26-Sep	6-Oct	20-Oct		
20-Jul	958	3,049	20	39	50	3	0	0	112	0.117
2-Aug	769	2,626	4	12	19	0	0	0	35	0.046
13-Aug	659	2,432	2	6	11	0	2	0	21	0.032
14-Sep	998	2,472	3	19	20	1	5	1	49	0.049
Totals	3,384	10,579							**Totals**	
Marks found in samples			29	76	100	4	7	1	217	
Number sampled			179	403	395	42	49	17	1,085	
Proportion marked in samples			0.162	0.189	0.253	0.095	0.143	0.059		

When recapture samples were stratified by sampling date (Table 3), significant lack of fit was evident in goodness-of-fit test results for “complete mixing” (X^2=64.1, 3 df, *p*-value<<0.01) and “equal proportions” (X^2=14.9, 5 df, *p*-value=0.01). Alternatively, when recapture samples were stratified by location (Table 4), the test statistic for “complete mixing” was still highly significant (X^2=62.9, 3 df, *p*-value<<0.01). However, a non-significant test statistic for “equal proportions” (X^2=1.76, 3 df, *p*-value=0.62) indicated the data could be pooled without serious risk of bias. The pooled Petersen estimate was about 17,000 fish (95% confidence interval 11,000–26,000; *CV*=27%). Although the weir count was much less than the estimate, the weir count was only slightly lower than the lower confidence interval bound. The wide estimated confidence interval and coefficient of variation of the estimate exceeded the objective of 15% indicated a great deal of uncertainty in the estimate. Some fish may have escaped uncounted through the weir, but the estimate could also be biased high. We concluded that the true escapement fell somewhere within the estimated 95% confidence interval.

Table 4.–Numbers of sockeye salmon marked at the Kutlaku Lake weir, and numbers and proportions of marks recovered in mark-recapture sampling in Kutlaku Lake, 2006, with recapture samples stratified by sampling location.

Marking stratum end date	Number marked	Count at weir	Marks recovered by location				Total marks recovered	Proportion of marks recovered
			Inlet stream		Beach spawning areas			
			Mouth	Channel	East	West		
20-Jul	958	3,049	68	23	0	21	112	0.117
2-Aug	769	2,626	24	5	0	6	35	0.046
13-Aug	659	2,432	18	0	2	1	21	0.032
14-Sep	998	2,472	21	10	5	13	49	0.049
Totals	3,384	10,579					**Totals**	
Marks found in samples			131	38	7	41	217	
Number sampled			639	196	53	197	1,085	
Proportion marked in samples			0.205	0.194	0.132	0.208		

Spawning Population Mark-Recapture Estimate and Visual Survey

Fish were caught in and around the mouth of the main inlet stream on four sampling dates: 26 August and 4, 9, and 26 September. We attempted to maintain a consistent schedule of seven to ten days between sampling events, but one sampling event that should have taken place between 9 and 26 September was missed due to bad weather. Recapture sample sizes were small, and very few marks were recovered; notably, on 26 September, when 17 days had elapsed since the previous sampling event, only one marked fish was recovered from a sample of 44 fish (Table 5). Overall, only about 2% of marked fish were recovered in the inlet stream, with fewer than 10 marked fish in each sample (Table 5). Goodness-of-fit test results were significant for “complete mixing” (X^2=21.6, 2 df, *p*-value<<0.01) but not significant for “equal proportions (X^2=4.0, 2 df, *p*-value=0.13), indicating the data could be pooled without an unacceptable risk of bias. The pooled Petersen estimate for the stream spawning group was 6,800 fish (95% confidence interval 4,500–10,900; *CV*=25%). The estimate did not meet the objective for precision (coefficient of variation less than 15%).

Table 5.–Numbers of sockeye spawners marked and numbers of fish sampled for marks and numbers of recaptures at the main inlet stream in Kutlaku Lake in 2006.

Marking date	Number marked	Marks recovered in stream by sampling date			Total marks recovered	Proportion of marks recovered
		4-Sep	9-Sep	26-Sep		
26-Aug	132	7	3	0	10	0.076
4-Sep	266	-	4	1	5	0.019
9-Sep	238	-	-	0	0	0
Total marked	636					
Marks found in samples		7	7	1	15	
Number sampled		50	76	44	170	
Proportion marked in samples		0.140	0.092	0.023		

Visual surveys showed the expected concentration of sockeye spawners around and in the main inlet stream early in the season, and larger numbers of spawners in other areas around the lake later in the season (Table 6). The maximum total count was on 9 September, and this was the peak date for both the stream count and the count of shoreline area spawners. Numbers of shoreline area spawners declined sharply after 9 September and then increased again in October, while stream spawners virtually disappeared after the end of September. Over the whole season, the visual count of stream spawners represented 35% of the total count of sockeye spawners throughout the lake and its small tributaries, weighted by abundance (total count) at each date.

Table 6.–Visual survey counts of sockeye spawners in Kutlaku Lake in 2006. Counts represent averages among two or three observers, counting from a boat around the margin of the lake and on foot in the main inlet stream. Fish at the mouth of the stream and in the stream channel were considered stream spawners, and fish in the remaining shoreline areas were considered beach spawners.

Survey date	Inlet stream		Remainder of lake shoreline	Total count[a]	Proportion of stream spawners[b]
	Mouth	Channel			
26-Aug	107	145	113	365	0.69
4-Sep	248	183	425	856	0.50
9-Sep	75	298	931	1,304	0.29
24-Sep	0	164	32	196	0.84
6-Oct	0	5	252	257	0.02
20-Oct	0	0	514	514	0.00

[a] Sum of counts for all areas, including spawners at the mouth of the inlet stream and in the inlet stream.

[b] Proportion of spawners counted in both parts of the inlet stream (mouth and channel), compared to the total count.

Comparative Analysis of Escapement Estimates

We estimated parameter values for prior distributions for J, sample size, and r, capture probability, in the hierarchical Bayesian model using the sample size and mean proportion of marked fish in recapture samples (Table 7). Posterior distributions for capture probability, p_i, and stream spawning population size, N_i, for each study year were estimated from these priors. Capture probability estimates ranged from 0.13 to 0.22 and population estimates ranged from 1,400 to 4,800 (Table 8). The year with the highest population estimate, 2006, also had the lowest estimated capture probability and the poorest precision, likely due to the small recapture sample size and very small number of recaptures (Table 7).

Table 7.–Mark and recapture sample sizes and parameter estimates for the prior distributions of sample size, J, and capture probability, r, in the hierarchical Bayesian model used to estimate the inlet stream population of sockeye spawners in Kutlaku Lake, based on four years of sampling between 2002 and 2006.

Year	Petersen sample sizes				
	Number marked in first sample (n_1)		**Number sampled in second sample (n_2)**	**Number recaptures in second sample (m_2)**	
2002	235		510	88	
2003	865		405	101	
2005	708		555	86	
2006	636		170	15	
	Mean sample size	511		**Mean proportion marked fish**	0.2
	Variance	55,054		**Weighting factor**	50
Probability distributions:					
	Sample size	J~dgamma(4.7, 0.01)		**Capture probability**	r~beta(10, 40)

Table 8.–Estimates of means, standard deviations, and quantiles of the posterior distributions for annual abundance, Ni, and capture probability, pi, of the inlet stream population in 2002–2006, produced by the hierarchical Bayesian model using the WinBUGS program. Parameter estimates were the median values and 95% credible interval bounds were the 2.5% and 97.5% quantiles of the posterior distribution.

Year	Estimator	Mean	Std. dev.	2.5%	Median	97.5%	CV
2002	p_1	0.17	0.015	0.14	**0.17**	0.20	9%
2003	p_2	0.22	0.019	0.19	**0.22**	0.26	8%
2005	p_3	0.16	0.014	0.13	**0.16**	0.19	9%
2006	p_4	0.13	0.022	0.09	**0.13**	0.17	16%
2002	N_1	1,400	150	1,100	**1,400**	1,700	11%
2003	N_2	3,900	350	3,300	**3,900**	4,700	9%
2005	N_3	4,500	430	3,700	**4,400**	5,400	10%
2006	N_4	4,900	920	3,600	**4,800**	7,200	19%

The Bayesian estimates of the inlet stream population, compared with the total spawning population by the area-under-the-curve method, indicated that the inlet stream population represented between 14% and 33% of the total (Table 9). The revised inlet stream population estimates differed very little from the original pooled Petersen estimates, except that the Bayesian model estimate for 2006 was lower than the original, making it more consistent with the other years' estimates. The revised expansion factors were also similar to the original ones. The overall effect of both revisions was to moderate the high estimates of the total spawning population; revised estimates ranged from 10,300 to 17,800 fish (Table 9). The total spawning population estimates presented in earlier reports (Cartwright and Conitz 2003, 2005; Conitz 2007) mostly fell within this range, and we note that they were lower in general than the simple expanded inlet stream population estimates (Table 9). With the exception of the 2002 estimate, these previously published estimates incorporated auxiliary information, such as mark-recapture estimates of other spawning groups in the lake.

Table 9.–Comparison of spawning population estimates for Kutlaku Lake between 2002 and 2006. The original Petersen estimates of the inlet stream population in Kutlaku Lake were expanded here to total spawning population estimates based on proportion of fish counted in the stream area. The revised estimates used the hierarchical Bayesian model (HBM) and an area-under-the-curve method to estimate the proportion represented by the inlet stream population. The total spawning population estimate presented in each year's annual report is also shown for comparison; in most years these estimates included other information about the spawning populations in Kutlaku Lake.

	Original estimates				Revised estimates		
Year	Petersen estimate main inlet stream	Old expansion factor[a]	Expanded Petersen estimate	Whole lake estimate from report[b]	HBM estimate main inlet stream	New expansion factor[c]	Expanded HBM estimate
2002	1,400	0.13	10,800	10,600	1,400	0.14	10,300
2003	3,500	0.18	19,400	8,500	3,900	0.22	17,800
2005	4,500	0.27	16,700	12,000	4,400	0.25	17,300
2006	6,800	0.35	19,400	17,000[d]	4,800	0.33	14,600
Averages			17,000	12,000			15,000

[a] Weighted average proportion of fish in stream area compared to total count for whole lake system.

[b] Estimates presented in annual report; some included additional study areas, different types of mark-recapture estimates, or other auxiliary information.

[c] Proportion of fish in stream area, estimated using area-under-the-curve method.

[d] Weir-based mark-recapture estimate.

Adult Population Age and Size Distribution

From a total sample of 613 fish, the scales of 553 sockeye salmon from the 2006 Kutlaku Lake escapement were analyzed for age (Table 10). Estimated as simple percentages of the total sample, the escapement was nearly evenly split between age-1.3 and age-1.2 fish, from brood years 2001 and 2002 respectively. When the estimated percentages in each age class were weighted by weekly escapement, the age-1.3 group was clearly the largest, with an estimated 52% of escapement. The two largest age classes represented all fish in the escapement with one freshwater year, and comprised 97% of the Kutlaku Lake sockeye escapement in 2006. No age-1.1 or -2.1 jacks were found in the sample that was aged. Weekly percentages of age-1.3 fish in the samples were higher than those of age-1.2 fish in all weeks except the last two weeks in July and the week of 13 August, but no obvious relationship between age class and timing appeared (Table 11). The estimated average length of sockeye spawners in all age classes and both sexes in the 2006 escapement, based on a sample of 553 fish, was 491 mm. Fish with three ocean years, both male and female with one or two freshwater years, were up to 50 mm longer, on average, than their counterparts with two ocean years (Table 12).

Table 10.–Age composition of the Kutlaku Lake sockeye spawning population by sex, 2006. Estimated numbers in each age class, based on a total escapement of 10,579 fish are also shown.

Brood year	**2002**	**2001**	**2001**	**2000**	
Age class	**1.2**	**1.3**	**2.2**	**2.3**	**All ages**
Male					
Number	116	103	0	4	223
Percentage	21.0%	18.6%	0.0%	0.7%	40.3%
Std. Error	1.7%	1.7%	0.0%	0.4%	2.1%
Female					
Number	148	171	3	8	330
Percentage	26.8%	30.9%	0.5%	1.4%	59.7%
Std. Error	1.9%	2.0%	0.3%	0.5%	2.1%
All fish					
Number	264	274	3	12	553
Percentage	47.7%	49.5%	0.5%	2.2%	100%
Std. Error	2.1%	2.1%	0.3%	0.6%	
Weighted percentages by age class, all fish					
	44.8%	52.0%	0.7%	2.5%	
Estimated number in escapement, by age class					
	4,743	5,503	70	263	

Table 11.–Weekly percentage age composition in the Kutlaku Lake sockeye spawning population, 2006, based on numbers of fish sampled at the weir each week.

	Percentage of total weekly sample, by age class					**Total**
Week beginning	**1.2**	**1.3**	**2.2**	**2.3**	**Total sampled**	**counted**
25 Jun	0.0%	100.0%	0.0%	0.0%	2	58
2 Jul	24.0%	68.0%	4.0%	4.0%	25	791
9 Jul	45.3%	53.5%	0.0%	1.2%	86	1,060
16 Jul	44.0%	53.3%	0.0%	2.7%	75	1,537
23 Jul	57.7%	39.4%	0.7%	2.2%	137	988
30 Jul	54.3%	43.5%	0.0%	2.2%	92	1,898
6 Aug	48.2%	50.0%	0.0%	1.8%	56	1,750
13 Aug	54.1%	43.2%	2.7%	0.0%	37	1,133
20 Aug	23.1%	76.9%	0.0%	0.0%	26	577
27 Aug	23.5%	64.7%	0.0%	11.8%	17	689
3 Sep	-	-	-	-	0	57
10 Sep	-	-	-	-	0	27
17 Sep	-	-	-	-	0	14

Table 12.–Average mideye to fork length (mm) of the Kutlaku Lake sockeye spawning population, by age class and sex, in 2006.

Brood year	2002	2001	2001	2000	
Age class	**1.2**	**1.3**	**2.2**	**2.3**	All ages
Male					
Mean length (mm)	474	525	-	510	498
Std. error	2.3	2.2	-	13.7	2.3
Sample size	116	103	0	4	223
Female					
Mean length (mm)	466	502	450	496	485
Std. error	1.8	1.8	16.1	6.4	1.6
Sample size	148	171	3	8	330
All fish					
Mean length (mm)	470	511	450	501	491
Std. error	1.5	1.5	16.1	6.2	1.4
Sample size	264	274	3	12	553

LIMNOLOGY

Light and Temperature Profiles

The euphotic zone depth in Kutlaku Lake was just over 8 m in the summer months and just over 4 m in the fall months in 2006 (Table 13). The sharp decrease in the euphotic zone depth in the fall was likely due to increased sediment input with fall rains and flooding.

Table 13. Estimated euphotic zone depths in m (EZD) for Kutlaku Lake in 2006. Light intensity was measured at station A.

Date	EZD
4-Jul	8.2
4-Aug	8.3
4-Sep	4.5
6-Oct	4.1
Season mean	**6.3**

A weak thermocline was present in Kutlaku Lake on the first sampling date in early July and was slightly more pronounced at the August sampling date (Figure 4). The temperature profiles from early September and October showed the water column gradually shifting back to isothermy.

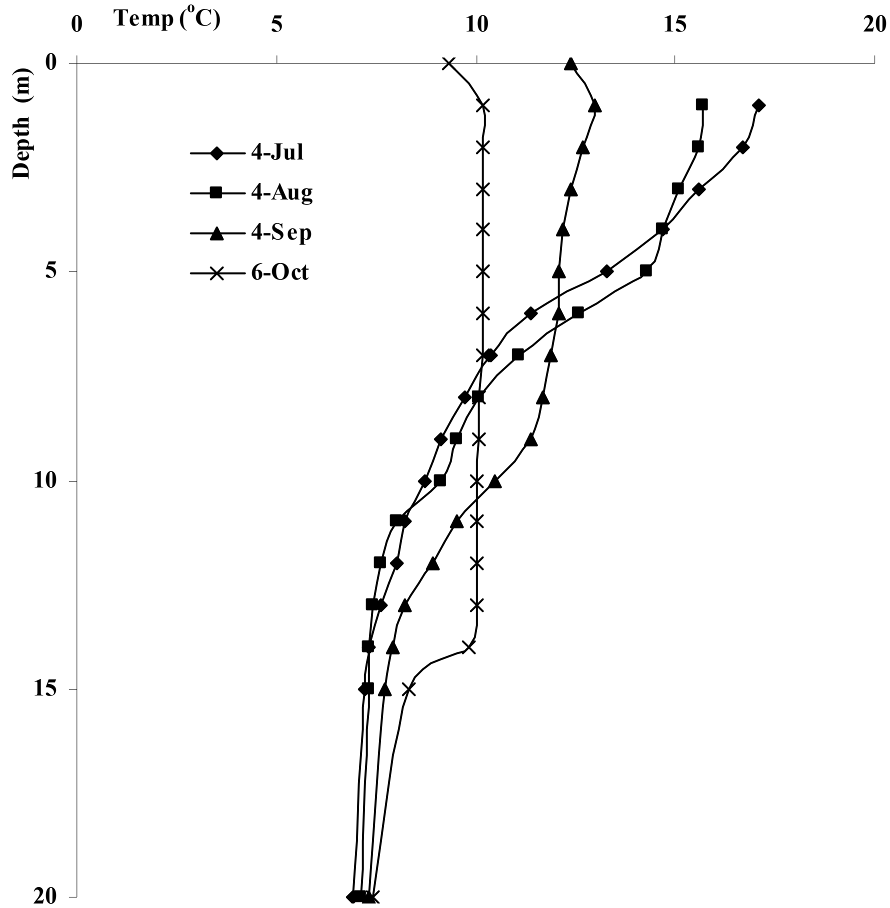

Figure 4.–Water column temperature profiles for Kutlaku Lake at four sampling dates between 4 July and 6 October 2006.

Secondary Production

The zooplankton assemblage in Kutlaku Lake was dominated by the cladocerans *Bosmina* and *Daphnia* in 2006, which comprised an estimated 47% and 30% of total zooplankton by number (Table 14). Because of its larger size, *Daphnia* comprised a larger percentage of the total biomass, about 41%. Numbers of *Bosmina* increased exponentially through the season, but for most other taxa, numbers declined through August and September and increased again by the last sampling date, 6 October. Because sampling did not begin until more than two months into the growing season (generally the ice-free period beginning in mid to late April), the seasonal means from Kutlaku Lake in 2006 may not accurately represent the actual zooplankton abundance and biomass.

Table 14.–Zooplankton species composition, numerical density, mean body length, and mean biomass in Kutlaku Lake in 2006. Density is average number of zooplankters in the water column, per square meter of surface area. Percentage composition of the total zooplankton assemblage by taxon is also shown. Seasonal mean body lengths are weighted by density. Seasonal mean biomass is a function of seasonal mean body size and density. Percentage composition of total zooplankton biomass by taxon is also shown. Ovigerous (egg-bearing) members of several taxa were counted and measured separately. Estimates shown are averages of two samples per sampling date, from Stations A and B.

	Density (number · m^{-2}) by date								
Taxon	**4 Jul**	**4 Aug**	**4 Sep**	**6 Oct**	**Season mean**	**Percent of total number**	**Weighted mean length (mm)**	**Season mean biomass (mg · m^{-2})**	**Percent of total biomass**
Cyclops	5,137	128	616	7,175	3,264	4.6%	0.58	3.7	5.9%
Harpaticus	255	85	0	340	170	0.2%	0.52	0.2	0.2%
Nauplii	17,788	1,401	4,033	5,476	7,174	10.1%			
Bosmina	1,231	4,415	14,795	62,956	20,849	29.5%	0.30	16.5	26.4%
Ovigerous *Bosmina*	0	43	8,278	41,221	12,385	17.5%	0.33	12.4	19.9%
Daphnia longiremis	44,193	3,863	8,448	22,033	19,634	27.7%	0.51	21.0	33.6%
Ovigerous *D. longiremis*	3,948	467	1,231	3,099	2,186	3.1%	0.70	4.6	7.5%
Holopedium	1,529	0	0	0	382	0.5%	0.85	2.9	4.7%
Ovigerous *Holopedium*	552	0	0	0	138	0.2%	0.88	1.1	1.8%
Chydorinae	0	43	0	85	32	0.1%	0.24	0.0	0.0%
Immature Cladocera	3,312	510	5,838	8,618	4,569	6.5%			
Season mean totals (all taxa)					**70,784**			**62.5**	

DISCUSSION

The one-season weir operation fulfilled the purpose of providing a benchmark estimate of sockeye escapement for Kutlaku Lake which can be compared to previous years' mark-recapture estimates. Although the weir count and the weir-based mark-recapture estimate differed, we can safely say that the weir count of 10,579 sockeye salmon represented a minimum escapement, with true escapement probably in the range of 11,000–26,000 fish. This provides evidence supporting the accuracy of previous years' estimates. Because of natural variation in the size of sockeye runs over time, we cannot expect one year's weir count to adequately characterize this stock; however, the count does confirm a minimum escapement the system is capable of producing. The difference between the weir count and the point mark-recapture estimate may not be as large as it appears. The uncertainty in the estimate was substantially greater than the objective, and the estimated sockeye escapement is only known within a wide range, of which the lower bound was very close to the weir count. In addition, the stratified Petersen estimate can be subject to positive bias especially when sampling is not strictly consistent among the various spatial and temporal strata (Arnason et al. 1996). However, despite careful monitoring for gaps and undercutting, and, with the exception of flooding near the end of the run, low and consistent stream flows, the possibility remains that substantial numbers of sockeye salmon did escape through the weir undetected. Spacing of the weir pickets was designed to retain all sockeye salmon including jacks (i.e. fish with only one ocean year and fork length less than 400 mm).

However, low count of fish identified as jacks and absence of any jacks in ASL samples could be an indicator that jacks were not retained. In previous years, age-1.1 jacks have been estimated to comprise up to 20–25% of escapement (Appendix A.2a in Conitz and Cartwright 2003).

Kutlaku Lake is a small, shallow, marshy lake subject to rapid fluctuations in water level and beaver dam building activity in its inlet and outlet streams, and its sockeye spawning population appears well adapted to frequent changes. These conditions, however, complicated the mark-recapture studies. The beach spawning areas varied between years, as did the relative proportions of the total spawning population that were inlet stream or beach spawners. Even when mark-recapture sampling was possible, small sample sizes and inconsistent timing contributed to an undesirably high level of sampling error. However, the hierarchical Bayesian model helped reduce uncertainty or sampling error. By assuming capture probability followed a common distribution across years, the model borrowed strength from years with larger, more consistent samples, helping to compensate for years in which small or inconsistent samples weakened the estimate. In particular, the inlet stream population estimate in 2006 was based on small sample sizes and very low recapture numbers, with large sampling error and the possibility of positive bias. The hierarchical Bayesian model provided an estimate for 2006 that was substantially smaller and had less uncertainty than the original Petersen estimate. This estimate, expanded to a total spawning population of about 14,000 fish, fell solidly within the confidence interval bounds as estimated by the weir mark-recapture study.

Unfortunately, we had to rely on visual counts to expand the estimate of the inlet stream population to the total spawning population, and we have no way to assess the uncertainty associated with these visual counts. The detectability of sockeye spawners is almost certainly different in a small stream than in the lake, but we did not have enough data across all four years to attempt to estimate that difference. Although use of the area-under-the-curve method was probably a small improvement, it still required the questionable assumption that observer efficiency and fish residence time were the same between the beach spawning and stream spawning groups. At best, we were able to capture some of the between-year variation in the size of the inlet stream population, which ranged from 1,400 to 4,800 fish, and observe that it consistently represented approximately 13–33% of the total spawning population. Based these estimates and other information such as the 2006 weir-based estimate, we concluded that estimates of total sockeye salmon escapement in the range of 10,000 to 20,000 fish appear to be reasonable. Our results further suggest that a mark-recapture estimate of the inlet stream population, with an expansion based on visual counts, may provide an adequate rough estimate when a full weir project cannot be operated.

In combination, the mark-recapture estimate, visual observations, and weir count for 2006 indicate a robust sockeye spawning population, similar in size to estimated spawning populations in recent years. Exploitation of the Kutlaku Lake sockeye run appears to be minimal, with reported subsistence harvests of only a few hundred fish throughout the 2002–2006 study period (Appendix A), and no directed commercial harvest. Although the incidental catch of Kutlaku Lake sockeye salmon in lower Chatham Strait commercial seine fisheries is unknown, it can only be a fraction of the total sockeye harvest in this area since these are highly mixed stock fisheries. The largest recorded sockeye harvest from all major lower Chatham Strait fishing districts, since Alaska statehood, was over 40,000 fish in 2001, but by 2006 and 2007, harvests had dropped to less than 5,000 fish (ADF&G Division of Commercial Fisheries database 2008). The directed sockeye salmon harvests of some 10,000 fish annually from inside the Bay of Pillars during the early commercial period (1890s to 1920s; Rich and Ball 1933) seems consistent with the information we have on harvest and escapement in the more recent period. Because little or no consideration was given to salmon escapement during the early commercial period, the fisheries may have harvested most of the returning fish in a given run. A harvest during that period of around 10,000 sockeye salmon plus an unknown, but probably small, escapement, represents a similar run size to one in recent years which comprised an escapement of around 10,000 fish and an unknown but probably small harvest.

Sockeye fry populations of about 100,000 fish were estimated in Kutlaku Lake in two recent years (Conitz and Cartwright 2003, 2005). Rearing fry populations in the lake appear to be supported by moderate secondary production, relative to other sockeye-producing lakes in Southeast Alaska. *Daphnia* represented a relatively high percentage of the total zooplankton, although individuals were small (Table 15; Appendix D in Conitz and Cartwright 2005). The small size could reflect selective predation by sockeye fry and other planktivores on larger individuals. Abundance, size, and biomass of *Daphnia* may be better indicators of the quality of the prey base for sockeye fry than measures of the total zooplankton community (Mazumder and Edmundson 2002). Sockeye fry show a strong dietary preference for *Daphnia* sp. when they are present in sufficient size and density (Scheuerell et al. 2005; Eggers 1982). Additionally, *Daphnia*, an efficient grazer, may facilitate the transfer of nutrients through the food web to sockeye fry (Mazumder and Edmundson 2002). Kutlaku Lake receives high levels of organic input from the surrounding old-growth forest, including many large trees falling directly into the lake, and large numbers of salmon carcasses relative to its volume. Its thick sediment layers and marshy outlet may help to retain nutrients. Consistent and relatively high proportions of *Daphnia* in the zooplankton community (Table 15), associated with consistent, moderately high sockeye production, suggest an efficient and balanced transfer of nutrients through the food web to the planktivore population in Kutlaku Lake.

Table 15.–Comparison of zooplankton estimates for four years sampled in Kutlaku Lake. Seasonal mean numerical density and biomass for all zooplankton are compared with density, biomass, and average body size (length) of *Daphnia* sp., a preferred prey for sockeye salmon fry.

		Density (number · m^{-2})			**Biomass (mg · m^{-2})**			
Year	**Date range[a]**	**All taxa**	***Daphnia***	**Percent *Daphnia***	**All taxa**	***Daphnia***	**Percent *Daphnia***	***Daphnia*[b] mean length (mm)**
2001	14 Jun–2 Oct	117,300	14,500	12%	177	31	17%	0.63
2002	30 May–29 Sep	81,000	26,700	33%	130	35	27%	0.59
2003	5 Jun–27 Sep	225,000	67,700	30%	619	80	13%	0.55
-	-	-	-	-	-	-	-	-
2006	4 Jul–6 Oct	70,800	21,800	31%	63	26	41%	0.54

[a] First to last sampling date for the season. In 2001 there were only two sampling dates; there were four sampling dates in the other years.

[b] Average of mean length for ovigerous and non-ovigerous groups, weighted by biomass of each group.

The strong dominance of fish with one freshwater annulus in Kutlaku Lake escapements also provides evidence that food is not limiting sockeye production in this lake. In general, sockeye salmon that attain sufficient growth during their first year in the lake will migrate to sea the following spring (Burgner 1991). In Kutlaku Lake, fish with one freshwater annulus comprised over 90% of the sockeye spawning population in all but a few of the last 25 years (Conitz and Cartwright 2003, 2005; Conitz 2007).

Spawning habitat could be limited in this small lake. For example, the main inlet stream provides spawning habitat for up to one-third of the total spawning population, but is vulnerable to low water levels and blockage by beaver dams. The water level in the lake can fluctuate by one meter or more during the spawning period, which may leave some shoreline spawning areas dry at times. We have observed certain shoreline or beach spawning areas that are used by sockeye salmon in one year, but not in the next. Although spawner density in recent years appears to have been high, without information about egg-to-fry survival, we have no basis on which to decide if it has been limiting.

At the time of writing, a restriction allowing only federally permitted subsistence fishing for sockeye salmon in the freshwater parts of the Kutlaku Lake system has been removed (Federal Subsistence Board 2007). We don't anticipate that this regulatory change will result in any significant change to the sockeye escapements in Kutlaku Lake in the near future. We do recommend periodic monitoring of sockeye salmon in this system, however, with attention to physical changes to the system that may affect sockeye spawning or rearing habitat. The Kutlaku Lake sockeye stock is a significant resource which, at the time of study, appeared to be robust and mostly unaffected by human activities.

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APPENDICES

Appendix A.–Subsistence harvest of sockeye salmon and number of permits fished at Bay of Pillars/Kutlaku Creek, as reported by permit holders who returned permits to ADF&G for years 1985 through 2006.

Year	Number of permits	Total sockeye harvest	Average sockeye harvest per permit	Total harvest of other salmon		
				Coho	**Pink**	**Chum**
1985	38	812	21	0	0	0
1986	32	750	23	0	0	0
1987	50	1312	26	0	0	0
1988	48	969	20	0	0	0
1989	36	784	22	8	20	25
1990	27	593	22	0	0	0
1991	37	813	22	0	0	0
1992	63	1375	22	0	80	0
1993	23	516	22	0	0	0
1994	24	629	26	5	14	1
1995	11	238	22	0	0	0
1996	33	842	26	0	6	2
1997	33	648	20	0	15	0
1998	33	791	24	0	1	1
1999	46	984	21	0	0	0
2000	15	200	13	0	2	28
2001	8	130	16	0	5	0
2002	8	194	24	0	0	0
2003	22	366	17	0	25	0
2004	16	548	34	0	8	8
2005	6	114	19	0	14	7
2006	1	0	12	0	0	0
			Averages			
All years	28	619	22	1	9	3
1985–1999	36	804	23	1	9	2
2000–2006	11	222	19	0	8	6

Appendix B.–Numbers of sockeye salmon counted and marked at the Kutlaku Lake weir, daily counts of other fish species passed through the weir, and daily temperatures and water levels at the weir site in 2006.

	Sockeye Salmon				Daily counts - other species[b,c]					Physical Data		
					Coho salmon						Temperature (°C)	
Date	Daily (all)[a]	Daily (jack)	Cumulative (all)[a]	Daily number marked	Full adults	Jacks	Pink salmon	Dolly Varden char	Cutthroat trout	Water level (mm)	Water	Air
24-Jun	0	0	0	0	0	0	0	0	0	0.57	15.0	
25-Jun	1	0	1	0	0	0	0	0	0	0.68	15.0	
26-Jun	3	0	4	3	0	0	0	0	0	0.64	13.0	12.0
27-Jun	1	0	5	0	0	0	0	0	0	0.59	12.0	11.0
28-Jun	1	0	6	0	0	0	0	0	0	0.55	12.0	11.0
29-Jun	2	0	8	0	0	0	0	0	0	0.53	12.0	10.0
30-Jun	5	0	13	1	0	0	0	0	0	0.54	14.0	12.0
1-Jul	45	0	58	12	0	0	0	0	0	0.51	14.0	13.0
2-Jul	24	0	82	9	0	0	0	0	0	0.49	15.0	14.0
3-Jul	44	0	126	13	0	0	0	0	0	0.48	16.5	14.0
4-Jul	128	1	254	52	0	0	0	0	0	0.48	17.5	10.0
5-Jul	84	0	338	41	0	0	0	0	0	0.48	17.0	11.0
6-Jul	152	0	490	30	0	0	0	0	0	0.47	19.0	12.0
7-Jul	82	0	572	30	0	0	0	0	0	0.44	18.0	12.0
8-Jul	277	2	849	7	0	0	0	0	0	0.46	17.5	10.0
9-Jul	184	0	1,033	88	0	0	0	0	0	0.51	17.0	11.0
10-Jul	111	1	1,144	17	0	0	0	0	0	0.52	17.0	11.0
11-Jul	46	0	1,190	0	0	0	0	0	0	0.52	19.0	17.0
12-Jul	376	0	1,566	37	0	0	0	0	0	0.51	17.5	12.0
13-Jul	172	0	1,738	126	0	0	0	0	0	0.50	17.0	10.0
14-Jul	15	0	1,753	15	0	0	0	0	0	0.49	17.0	14.0
15-Jul	156	0	1,909	30	0	0	0	0	0	0.49	17.0	12.0
16-Jul	12	0	1,921	5	0	0	0	0	0	0.48	18.0	15.0
17-Jul	363	0	2,284	58	0	0	0	0	0	0.47	19.0	13.0
18-Jul	58	0	2,342	52	0	0	0	0	0	0.46	19.0	12.0
19-Jul	672	0	3,014	295	0	0	0	0	0	0.45	18.0	9.0
20-Jul	35	0	3,049	0	0	0	0	0	0	0.45	18.0	13.0
21-Jul	254	0	3,303	75	0	0	0	0	0	0.45	17.0	12.0
22-Jul	143	2	3,446	55	0	0	0	0	0	0.53	17.0	14.0

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	Sockeye Salmon				Daily counts - other species[b,c]					Physical Data		
					Coho salmon						Temperature (°C)	
Date	Daily (all)[a]	Daily (jack)	Cumulative (all)[a]	Daily number marked	Full adults	Jacks	Pink salmon	Dolly Varden char	Cutthroat trout	Water level (mm)	Water	Air
23-Jul	135	6	3,581	19	0	0	0	0	0	0.53	17.0	16.0
24-Jul	63	0	3,644	31	0	0	0	0	0	0.53	18.0	13.0
25-Jul	241	2	3,885	66	0	0	0	0	0	0.54	17.5	13.0
26-Jul	97	3	3,982	41	0	0	0	0	0	0.56	17.0	12.0
27-Jul	44	2	4,026	0	0	0	0	0	0	0.56	17.0	11.0
28-Jul	212	0	4,238	46	0	0	0	0	0	0.55	16.5	11.0
29-Jul	196	1	4,434	100	0	0	0	3	0	0.54	16.5	10.0
30-Jul	302	1	4,736	76	0	0	0	3	0	0.52	18.0	12.0
31-Jul	688	0	5,424	207	0	0	0	4	0	0.52	17.0	12.0
1-Aug	206	0	5,630	66	0	0	0	0	0	0.50	16.5	9.0
2-Aug	45	0	5,675	12	0	0	0	0	0	0.51	16.0	10.0
3-Aug	169	0	5,844	86	1	0	0	16	1	0.52	16.0	10.0
4-Aug	104	0	5,948	80	2	0	0	6	0	0.52	16.0	10.0
5-Aug	384	0	6,332	71	2	0	0	2	0	0.53	15.5	10.5
6-Aug	267	0	6,599	47	0	0	0	3	0	0.52	16.0	12.0
7-Aug	74	0	6,673	33	0	0	0	0	0	0.52	16.0	11.0
8-Aug	359	0	7,032	120	0	0	0	0	0	0.53	15.0	12.0
9-Aug	323	0	7,355	120	5	0	2	10	0	0.55	16.0	11.0
10-Aug	47	2	7,402	0	1	0	0	5	0	0.55	15.5	11.0
11-Aug	80	0	7,482	0	0	0	0	0	0	0.54	15.0	9.0
12-Aug	600	0	8,082	78	6	0	3	2	0	0.53	16.0	12.0
13-Aug	25	0	8,107	24	0	0	0	0	0	0.51	16.0	11.0
14-Aug	293	0	8,400	173	0	0	0	1	0	0.51	15.0	9.0
15-Aug	192	0	8,592	69	1	0	1	0	0	0.50	15.5	10.0
16-Aug	24	0	8,616	0	0	0	0	0	0	0.49	16.5	11.0
17-Aug	483	2	9,099	90	1	0	1	0	0	0.48	16.0	12.0
18-Aug	54	0	9,153	0	0	0	0	0	0	0.46	16.0	12.0
19-Aug	62	0	9,215	34	0	0	0	0	0	0.46	16.0	15.0
20-Aug	158	0	9,373	53	0	0	0	0	0	0.46	17.0	15.0
21-Aug	148	0	9,521	130	0	0	0	0	0	0.45	17.0	13.0

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Appendix B.–Page 3 of 3.

Date	Sockeye Salmon				Daily counts - other species[b,c]					Physical Data		
	Daily (all)[a]	Daily (jack)	Cumulative (all)[a]	Daily number marked	Coho salmon: Full adults	Coho salmon: Jacks	Pink salmon	Dolly Varden char	Cutthroat trout	Water level (mm)	Temperature (°C): Water	Temperature (°C): Air
22-Aug	74	0	9,595	0	0	0	0	0	0	0.45	16.0	12.0
23-Aug	0	0	9,595	0	0	0	0	0	0	0.43	16.0	13.0
24-Aug	22	0	9,617	0	0	0	0	0	0	0.43	17.0	13.0
25-Aug	114	0	9,731	0	3	0	0	0	0	0.43	16.0	13.0
26-Aug	61	1	9,792	40	0	0	1	1	0	0.43	15.0	13.0
27-Aug	92	0	9,884	68	0	2	0	0	2	0.46	15.0	10.0
28-Aug	44	1	9,928	0	3	0	0	1	0	0.46	15.0	10.0
29-Aug	67	0	9,995	32	2	0	0	2	0	0.47	15.0	11.0
30-Aug	103	0	10,098	103	2	0	0	0	0	0.48	15.5	13.5
31-Aug	383	0	10,481	157	0	0	0	1	0	0.48	15.0	12.0
1-Sep	no counts		10,481			no counts due to flooding				flooding	-	-
2-Sep	-	-	10,481	0	-	-	-	-	-	-	-	-
3-Sep	-	-	10,481	0	-	-	-	-	-	-	-	-
4-Sep	9	0	10,490	1	1	0	2	0	0	0.61	14.0	11.0
5-Sep	9	0	10,499	9	5	5	0	0	0	0.58	13.0	9.0
6-Sep	3	0	10,502	3	6	5	1	0	9	0.52	14.0	11.0
7-Sep	3	0	10,505	3	7	1	3	0	14	0.51	14.0	12.0
8-Sep	18	0	10,523	0	8	5	4	0	4	0.52	14.0	11.0
9-Sep	15	0	10,538	12	6	16	4	0	1	0.52	14.0	11.0
10-Sep	9	0	10,547	8	9	14	7	0	0	0.60	13.0	10.0
11-Sep	5	0	10,552	5	18	16	7	0	0	0.61	13.0	10.0
12-Sep	4	0	10,556	4	14	16	9	0	0	0.61	13.0	10.0
13-Sep	0	0	10,556	0	8	7	2	0	0	0.60	13.0	8.0
14-Sep	8	0	10,564	6	10	14	0	3	0	0.57	13.0	8.0
15-Sep	0	0	10,564	0	0	0	0	0	0	0.54	13.5	9.5
16-Sep	1	0	10,565	0	3	3	3	1	9	0.51	13.5	14.0
17-Sep	4	0	10,569	0	1	1	3	0	5	0.49	13.0	10
18-Sep	6	0	10,575	0	5	2	6	2	19	0.46	14.0	11
19-Sep	2	0	10,577	0	0	1	6	0	9	0.51	13.0	9
20-Sep	2	0	10,579	0	3	5	5	2	18	0.48	13.0	10
Sum	10,579	27		3,374	133	113	70	68	91			

[a] Jack sockeye salmon are included in these counts.

[b] Counts of these species do not represent total or complete counts for this system due to differences in timing and size with respect to weir picket spacing.

[c] Ten Chinook salmon and one chum salmon were also counted between 16 August and 9 September.